RULES FOR BUILDING AND CLASSING

STEEL VESSELS 2009

PART 5C
SPECIFIC VESSEL TYPES (CHAPTERS 1-6)

American Bureau of Shipping
Incorporated by Act of Legislature of the State of New York 1862

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Foreword

In association with the introduction of the Common Structural Rules for Double Hull Oil Tankers and Bulk Carriers, respectively, on 1 April 2006, Part 5 of the *Rules for Building and Classing Steel Vessels*, 2007 was divided into three Sub-parts, 5A, 5B and 5C. The contents and application of each Part are as follows:

Contents

Part 5A:	Common Structural Rules for Double Hull Oil Tankers	
Part 5B:	Common Structural Rules for Bulk Carriers	
Part 5C:	This Part is divided into two separate booklets as follows:	
	Chapters 1 to 6:	Tankers not covered by Part 5A, Bulk Carriers not covered by Part 5B and Container Carriers
	Chapters 7 to 10:	Passenger Vessels, Liquefied Gas Carriers, Chemical Carriers and Vessels Intended to Carry Vehicles.

Application – Oil Tankers

The structural requirements in Part 5A of the Rules are applicable for double hull oil tankers of 150 m in length and upward, with structural arrangements as specified in Part 5A, Section 2.

For oil tankers with structural arrangements not covered by Part 5A, the requirements in Part 5C, Chapters 1 or 2, are to be complied with.

Application – Bulk Carriers

The structural requirements in Part 5B of the Rules are applicable for single side skin and double side skin bulk carriers of 90m in length and upward, with structural arrangements as specified in Part 5B, Chapter 1, Section 1.

For vessels intended to carry ore or bulk cargoes, other than the single side skin or double side skin bulk carriers of 90 m in length and upward with structural arrangements as specified in Part 5B, Chapter 1, Section 1, the requirements in Part 5C, Chapters 3 or 4 are to be complied with.

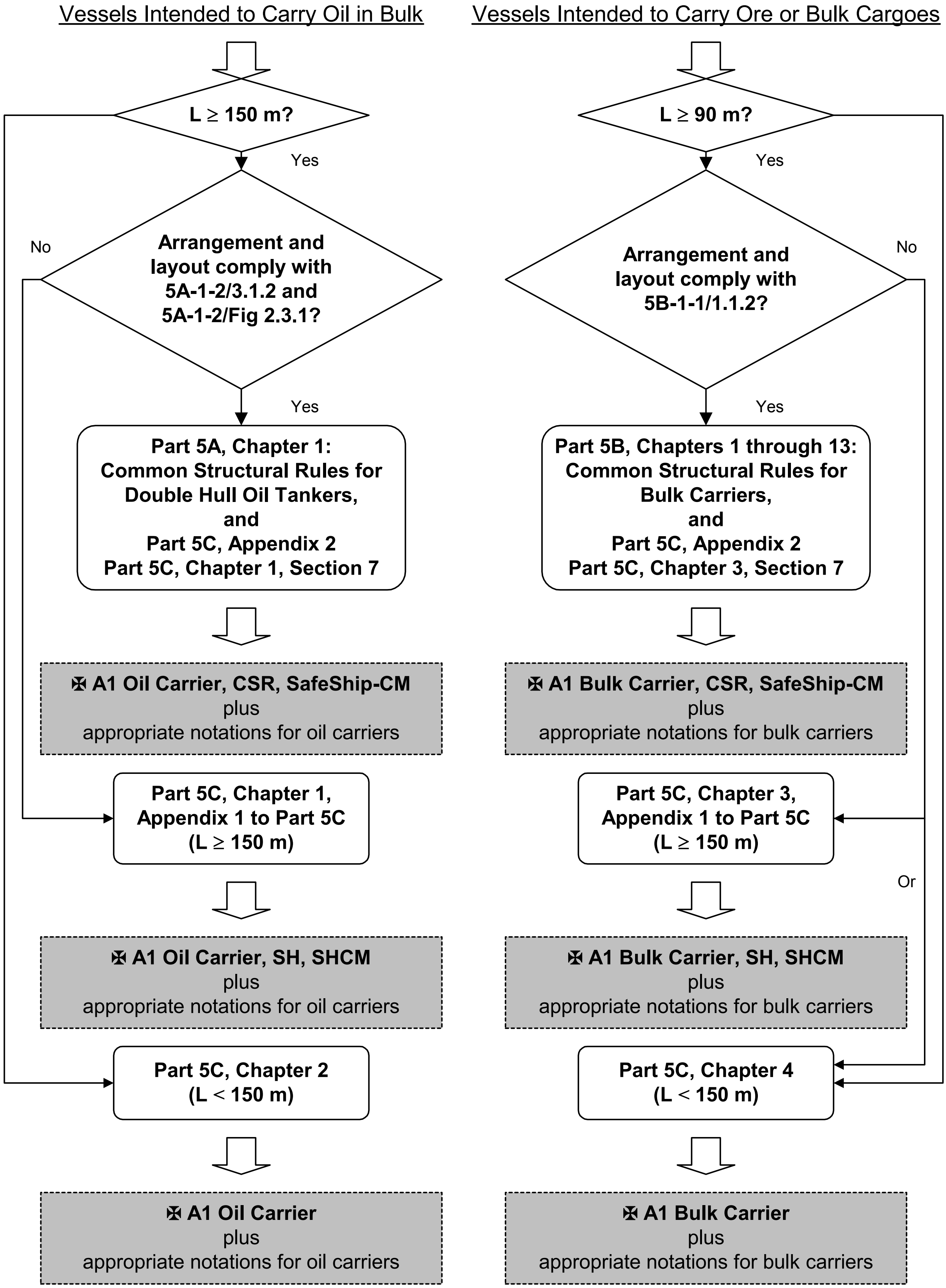
Application – SafeShip Construction Monitoring Program

These compulsory requirements for **CSR** notation are specified in Part 5C, Appendix 2.

Application – Onboard Systems for Oil Tankers and Bulk Carriers

The onboard systems for all tankers are to comply with the requirements of Part 5C, Chapter 1, Section 7, and for all bulk carriers are to comply with the requirements of Part 5C, Chapter 3, Section 7 of the Rules.

The following flow chart indicates the application of the Rules and typical Class Notations for tanker and bulk carrier vessels, of which arrangements and scantlings are in full compliance with the Rules:


Vessels Intended to Carry Oil in Bulk
Vessels Intended to Carry Ore or Bulk Cargoes
L ≥ 150 m?
Yes
No
Arrangement and layout comply with 5A-1-2/3.1.2 and 5A-1-2/Fig 2.3.1?
Yes
Part 5A, Chapter 1: Common Structural Rules for Double Hull Oil Tankers, and Part 5C, Appendix 2 Part 5C, Chapter 1, Section 7
✠ A1 Oil Carrier, CSR, SafeShip-CM plus appropriate notations for oil carriers
Part 5C, Chapter 1, Appendix 1 to Part 5C (L ≥ 150 m)
✠ A1 Oil Carrier, SH, SHCM plus appropriate notations for oil carriers
Part 5C, Chapter 2 (L < 150 m)
✠ A1 Oil Carrier plus appropriate notations for oil carriers
L ≥ 90 m?
Yes
No
Arrangement and layout comply with 5B-1-1/1.1.2?
Yes
Part 5B, Chapters 1 through 13: Common Structural Rules for Bulk Carriers, and Part 5C, Appendix 2 Part 5C, Chapter 3, Section 7
✠ A1 Bulk Carrier, CSR, SafeShip-CM plus appropriate notations for bulk carriers
Part 5C, Chapter 3, Appendix 1 to Part 5C (L ≥ 150 m)
Or
✠ A1 Bulk Carrier, SH, SHCM plus appropriate notations for bulk carriers
Part 5C, Chapter 4 (L < 150 m)
✠ A1 Bulk Carrier plus appropriate notations for bulk carriers

Rule Change Notice *(2009)*

The effective date of each technical change since 1993 is shown in parenthesis at the end of the subsection/paragraph titles within the text of each Part. Unless a particular date and month are shown, the years in parentheses refer to the following effective dates:

(2000) and after	1 January 2000 (and subsequent years)	*(1996)*	9 May 1996
(1999)	12 May 1999	*(1995)*	15 May 1995
(1998)	13 May 1998	*(1994)*	9 May 1994
(1997)	19 May 1997	*(1993)*	11 May 1993

Listing by Effective Dates of Changes from the 2008 Rules

Notice No. 1 (effective on 1 July 2008) to the 2008 Rules, which is incorporated in the 2009 Rules, is summarized below.

EFFECTIVE DATE 1 July 2008 – shown as *(1 July 2008)*
(based on the contract date for new construction between builder and Owner)

Part/Para. No.	*Title/Subject*	*Status/Remarks*
5C-1-1/1.5.1	Section Properties of Structural Members	To be consistent with the adjustment to the section modulus of inclined sections, the effective shear area is adjusted according to angle θ. (Incorporates Notice No. 1)
5C-1-3/Figure 15	Definition of Bow Geometry	To include the effects of flare angles less than 35° and to introduce the normal body plane angle, β_{ij}. (Incorporates Notice No. 1)
5C-1-3/13.5	Bowflare Slamming	To include the effects of flare angles less than 35° and to introduce the normal body plane angle, β_{ij}. (Incorporates Notice No. 1)
5C-1-3/13.5.1	Nominal Bowflare Slamming	To include the effects of flare angles less than 35° and to introduce the normal body plane angle, β_{ij}. (Incorporates Notice No. 1)
5C-1-6/7.3.3	Side Transverses and Side Stringers	To remove reduction factor of 0.85. (Incorporates Notice No. 1)
5C-3-1/1.7	Section Properties of Structural Members	To be consistent with the adjustment to the section modulus of inclined sections, the effective shear area is adjusted according to angle θ. (Incorporates Notice No. 1)
5C-3-3/Figure 7	Definition of Bow Geometry	To include the effects of flare angles less than 35° and to introduce the normal body plane angle, β_{ij}. (Incorporates Notice No. 1)
5C-3-3/11.3.1	Nominal Bowflare Slamming	To include the effects of flare angles less than 35° and to introduce the normal body plane angle, β_{ij}. (Incorporates Notice No. 1)
5C-3-6/13.5.3	Side Transverses and Side Stringers	To remove reduction factor of 0.85. (Incorporates Notice No. 1)
5C-5-1/3	Section Properties of Structural Members	To be consistent with the adjustment to the section modulus of inclined sections, the effective shear area is adjusted according to angle θ. (Incorporates Notice No. 1)
5C-5-3/Figure 11	Definition of Bow Geometry	To include the effects of flare angles less than 35° and to introduce the normal body plane angle, β_{ij}. (Incorporates Notice No. 1)
5C-5-3/11.3.1	Nominal Bowflare Slamming	To include the effects of flare angles less than 35° and to introduce the normal body plane angle, β_{ij}. (Incorporates Notice No. 1)
5C-5-4/1.5	Structural Details	To reflect service experience. (Incorporates Notice No. 1)
5C-5-6/23.3.3	Side Transverses and Side Stringers	To remove reduction factor of 0.85. (Incorporates Notice No. 1)
5C-5-6/ 23.3.3(a)i)	Longitudinally Framed Side Shell	To remove reduction factor of 0.85. (Incorporates Notice No. 1)
5C-5-6/Table 1	Coefficient c_2	To remove reduction factor of 0.85. (Incorporates Notice No. 1)
5C-5-6/Table 2	Coefficient c_3	To remove reduction factor of 0.85. (Incorporates Notice No. 1)

Part/Para. No.	*Title/Subject*	*Status/Remarks*
5C-5-6/ 23.3.3(a)ii)	Transversely Framed Side Shell	To remove reduction factor of 0.85. (Incorporates Notice No. 1)
5C-5-6/ 23.3.3(b)i)	Longitudinally Framed Side Shell	To remove reduction factor of 0.85. (Incorporates Notice No. 1)
5C-5-6/Table 4	Coefficient c_1	To remove reduction factor of 0.85. (Incorporates Notice No. 1)
5C-5-6/ 23.3.3(b)ii)	Transversely Framed Side Shell	To remove reduction factor of 0.85. (Incorporates Notice No. 1)

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PART

5C

Specific Vessel Types

CONTENTS

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PART

5C

CHAPTER 1 Vessels Intended to Carry Oil in Bulk (150 meters (492 feet) or more in Length)

CONTENTS

PART

5C

CHAPTER 1 Vessels Intended to Carry Oil in Bulk (150 meters (492 feet) or more in Length)

SECTION 1 Introduction

1 General

1.1 Classification *(1 July 2001)*

In accordance with 1-1-3/3 and 1-1-3/25, the classification notation ✠ **A1 Oil Carrier, SH, SHCM** is to be assigned to vessels designed for the carriage of oil cargoes in bulk, and built to the requirements of this Chapter and other relevant sections of the Rules. As used in the Rules, the term ''oil'' refers to petroleum products having flash points at or below 60°C (140°F), closed cup test, and specific gravity of not over 1.05. Vessels intended to carry fuel oil having a flash point above 60°C (140°F), closed cup test, and to receive classification ✠ **A1 Fuel Oil Carrier, SH, SHCM** are to comply with the requirements of this Chapter and other relevant sections of the Rules, with the exception that the requirements for cofferdams, gastight bulkheads and aluminum paint may be modified.

1.2 Optional Class Notation for Design Fatigue Life *(2003)*

Vessels designed and built to the requirements in this Chapter are intended to have a structural fatigue life of not less than 20 years. Where a vessel's design calls for a fatigue life in excess of the minimum design fatigue life of 20 years, the optional class notation **FL (year)** will be assigned at the request of the applicant. This optional notation is eligible, provided the excess design fatigue life is verified to be in compliance with the criteria in Appendix 1 of this Chapter, "Guide for Fatigue Strength Assessment of Tankers." Only one design fatigue life value is published for the entire structural system. Where differing design fatigue life values are intended for different structural elements within the vessel, the **(year)** refers to the least of the varying target lives. The 'design fatigue life' refers to the target value set by the applicant, not the value calculated in the analysis.

The notation **FL (year)** denotes that the design fatigue life assessed according to Appendix 1 of this Chapter is greater than the minimum design fatigue life of 20 years. The **(year)** refers to the fatigue life equal to 25 years or more (in 5-year increments) as specified by the applicant. The fatigue life will be identified in the *Record* by the notation **FL (year)**; e.g., **FL(30)** if the minimum design fatigue life assessed is 30 years.

1.3 Application

1.3.1 Size and Proportion *(1997)*

The requirements contained in this Chapter are applicable to double hull tankers intended for unrestricted service, having lengths of 150 meters (492 feet) or more, and having parameters within the range as specified in 3-2-1/1.

1.3.2 Vessel Types

The equations and formulae for determining design load and strength requirements, as specified in Section 5C-1-3 and Section 5C-1-4, are applicable to double hull tankers. For mid-deck or single hull tankers, the parameters used in the equations are to be adjusted according to the structural configurations and loading patterns outlined in Appendix 5C-1-A3 or Appendix 5C-1-A4. The strength assessment procedures and the failure criteria, as specified in Section 5C-1-5, are applicable to all types of tankers.

Double hull tanker is a tank vessel having full depth wing water ballast tanks or other non-cargo spaces, and full breadth double bottom water ballast tanks or other non-cargo spaces throughout the cargo area, intended to prevent or at least reduce the liquid cargo outflow in an accidental stranding or collision. The size and capacity of these wing/double bottom tanks or spaces are to comply with MARPOL 73/78 and national Regulations, as applicable.

Mid-deck tanker: Refer to 5C-1-A4/1.1, "Design Concepts".

Single hull tanker is a tank vessel that does not fit the above definitions of *Double hull tanker or Mid-deck tanker*.

1.3.3 Direct Calculations

Direct calculations with respect to the determination of design loads and the establishment of alternative strength criteria based on first principles will be accepted for consideration, provided that all the supporting data, analysis procedures and calculated results are fully documented and submitted for review. In this regard, due consideration is to be given to the environmental conditions, probability of occurrence, uncertainties in load and response predictions and reliability of the structure in service. For long term prediction of wave loads, realistic wave spectra covering the North Atlantic Ocean and a probability level of 10^{-8} are to be employed.

1.3.4 SafeHull Construction Monitoring Program *(1 July 2001)*

For the class notation **SH, SHCM,** a Construction Monitoring Plan for critical areas, prepared in accordance with the requirements of Part 5C, Appendix 1, is to be submitted for approval prior to commencement of fabrication. See Part 5C, Appendix 1 "Guide for SafeHull Construction Monitoring Program."

1.5 Internal Members *(2002)*

1.5.1 Section Properties of Structural Members *(1 July 2008)*

The geometric properties of structural members may be calculated directly from the dimensions of the section and the associated effective plating (see 3-1-2/13.3 or 5C-1-4/Figure 6, as applicable). For structural member with angle θ (see 5C-1-1/Figure 1) between web and associated plating not less than 75 degrees, the section modulus, web sectional area and moment of inertia of the "standard" (θ = 90 degrees) section may be used without modification. Where the angle θ is less than 75 degrees, the sectional properties are to be directly calculated about an axis parallel to the associated plating (see 5C-1-1/Figure 1).

For longitudinals, frames and stiffeners, the section modulus may be obtained by the following equation:

$$SM = \alpha_\theta SM_{90}$$

where

α_θ = $1.45 - 40.5/\theta$

SM_{90} = the section modulus at θ = 90 degrees

The effective section area may be obtained from the following equation:

$$A = A_{90} \sin\theta$$

where

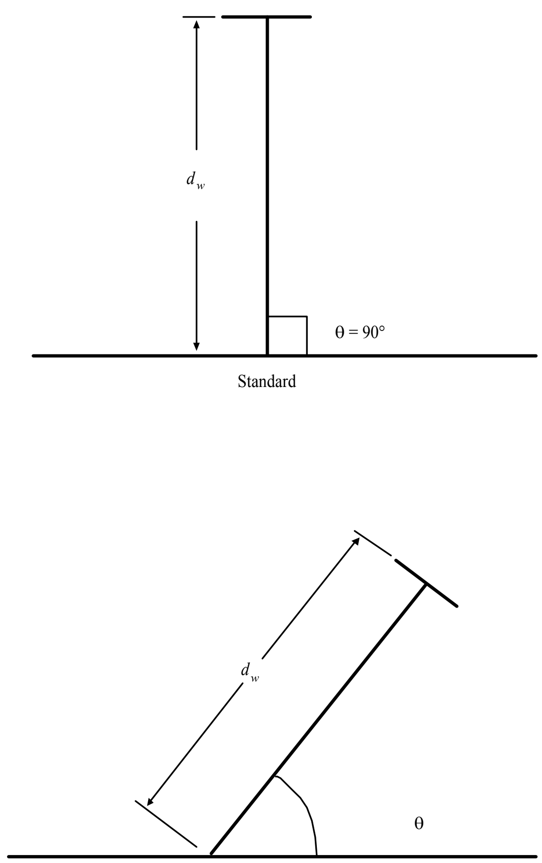
A_{90} = effective shear area at θ = 90 degrees

1.5.2 Detailed Design

The detailed design of internals is to follow the guidance given in 3-1-2/15 and 5C-1-4/1.5.

See also Appendix 5C-1-A1 "Guide for Fatigue Strength Assessment of Tankers".

FIGURE 1



1.7 Breaks

Special care is to be taken to provide against local stresses at the ends of the cargo oil spaces, superstructures, etc., and throughout the structure in general. The main longitudinal bulkheads are to be suitably tapered at their ends, and effective longitudinal bulkheads in the poop are to be located such as to provide effective continuity between the structure in way of and beyond the main cargo spaces. Where the break of a superstructure lies within the midship $0.5L$, the required shell and deck scantlings for the amidship $0.4L$ may be required to be extended to effect a gradual taper of the structure, and the deck stringer plate and sheer strake are to be increased. See 5C-1-4/9.1 and 5C-1-4/9.3. Where the breaks of the forecastle or poop are appreciably beyond the amidship $0.5L$, the requirements for the deck stringer plate and sheer strake, as specified in 5C-1-4/9.1 and 5C-1-4/9.3, may be modified.

1.9 Variations

Tankers of a special type or design, differing from those described in these Rules, will be specially considered on the basis of equivalent strength.

1.11 Loading Guidance *(1997)*

Loading guidance is to be as required by 3-2-1/7, except that 5C-1-4/5 will apply for allowable shear stresses.

1.13 Pressure-Vacuum Valve Setting *(1993)*

Where pressure-vacuum valves of cargo oil tanks are set at a pressure in excess of the pressure appropriate to the length of the vessel (see 5C-1-7/11.11.2), the tank scantlings will be specially considered.

Particular attention is to be given to a higher pressure setting of pressure-vacuum valves as may be required for the efficient operation of cargo vapor emission control systems, where installed.

1.15 Protection of Structure

For the protection of structure, see 3-2-18/5.

1.17 Aluminum Paint

Paint containing aluminum is not to be used in cargo tanks, on tank decks in way of cargo tanks, and in pump rooms and cofferdams, nor in any other area where cargo vapor may accumulate, unless it has been shown by appropriate tests that the paint to be used does not increase the fire hazard.

3 Special Requirements for Deep Loading

3.1 General *(2003)*

Where a vessel is intended to operate at the minimum freeboard allowed by the International Convention on Load Lines, 1966 for Type-A vessels, the conditions in 5C-1-1/3.3 through 5C-1-1/3.11 are to be complied with.

3.3 Machinery Casings

Machinery casings are normally to be protected by an enclosed poop or bridge, or by a deckhouse of equivalent strength. The height of such structure is to be not less than 2.3 m (7.5 ft). The bulkheads at the forward ends of these structures are to have scantlings not less than required for bridge-front bulkheads (See 3-2-11/3). Machinery casings may be exposed, provided that they are specially stiffened and there are no openings giving direct access from the freeboard deck to the machinery space. A door complying with the requirements of 3-2-11/5.3 may, however, be permitted in the exposed machinery casing, provided that it leads to a space or passageway which is as strongly constructed as the casing and is separated from the engine room by a second door complying with 3-2-11/5.3. The sill of the exterior door is not to be less than 600 mm (23.5 in.), and the sill of the second door is not to be less than 230 mm (9 in.).

3.5 Access *(1998)*

Satisfactory arrangements are to be provided to safeguard the crew in reaching all areas used in the necessary work of the vessel. See 3-2-17/3.

3.7 Hatchways

Exposed hatchways on the freeboard and forecastle decks or on the tops of expansion trunks are to be provided with efficient steel watertight covers. The use of material other than steel will be subject to special consideration.

3.9 Freeing Arrangements

Tankers with bulwarks are to have open rails fitted for at least half the length of the exposed parts of the freeboard and superstructure decks, or other effective freeing arrangements are to be provided. The upper edge of the sheer strake is to be kept as low as practicable. Where superstructures are connected by trunks, open rails are to be fitted for the entire length of the exposed parts of the freeboard deck.

3.11 Flooding *(2003)*

Attention is called to the requirement of the International Convention on Load Lines, 1966, that tankers over 150 m (492 ft) in freeboard length (see 3-1-1/3.3), to which freeboards less than those based solely on Table B are assigned, must be able to withstand the flooding of certain compartments.

3.13 Ventilators *(2003)*

Ventilators to spaces below the freeboard deck are to be specially stiffened or protected by superstructures or other efficient means. See also 3-2-17/9.

5 Arrangement *(1994)*

5.1 General

The arrangements of the vessel are to comply with the requirements in Annex 1 to the International Convention for the Prevention of Pollution from Ships with regard to segregated ballast tanks (Regulation 13), their protective locations (Regulation 13E – where the option in Regulation 13F (4) or (5) is exercised), collision or stranding considerations (Regulation 13F), hypothetical outflow of oil (Regulation 23), limitations of size and arrangement of cargo tanks (Regulation 24) and slop tanks [Regulation 15 (2) (c)]. A valid International Oil Pollution Prevention Certificate issued by the flag administration may be accepted as evidence of compliance with these requirements.

5.3 Subdivision

The length of tanks, the location of expansion trunks and the position of longitudinal bulkheads are to be arranged to avoid excessive dynamic stresses in the hull structure.

5.5 Cofferdams

Cofferdams, thoroughly oiltight and vented, and having widths as required for ready access, are to be provided in order to separate all cargo tanks from galleys and living quarters, general cargo spaces which are below the uppermost continuous deck, boiler rooms and spaces containing propulsion machinery or other machinery where sources of ignition are normally present. Pump rooms, compartments arranged solely for ballast and fuel oil tanks may be considered as cofferdams for the purpose of this requirement.

5.7 Gastight Bulkheads

Gastight bulkheads are to be provided in order to isolate all cargo pumps and piping from spaces containing stoves, boilers, propelling machinery, electric apparatus or machinery where sources of ignition are normally present. These bulkheads are to comply with the requirements of Section 3-2-9.

5.9 Cathodic Protection *(1996)*

5.9.1 Anode Installation Plan

Where sacrificial anodes are fitted in cargo or adjacent ballast tanks, their material, their disposition and details of their attachment are to be submitted for approval.

5.9.2 Magnesium and Magnesium Alloy Anodes

Magnesium and magnesium alloy anodes are not to be used.

5.9.3 Aluminum Anodes *(2006)*

Aluminum anodes may be used in the cargo tanks and tanks adjacent to the cargo tanks of tankers in locations where the potential energy does not exceed 275 N-m (28 kgf-m, 200 ft-lb). The height of the anode is to be measured from the bottom of the tank to the center of the anode, and the weight is to be taken as the weight of the anode as fitted, including the fitting devices and inserts.

Where aluminum anodes are located on horizontal surfaces, such as bulkhead girders and stringers, which are not less than 1 m (39 in.) wide and fitted with an upstanding flange or face flat projecting not less than 75 mm (3 in.) above the horizontal surface, the height of the anode may be measured from this surface.

Aluminum anodes are not to be located under tank hatches or Butterworth openings unless protected from falling metal objects by adjacent tank structure.

5.9.4 Zinc Anodes *(2006)*

There is no restriction on the positioning of zinc anodes.

5.9.5 Anode Attachment

Anodes are to have steel cores sufficiently rigid to avoid resonance in the anode support, and the cores are to be designed to retain the anode even when it is wasted.

The steel cores are to be attached to the structure by means of continuous welds at least 75 mm (3 in.) in length. Alternatively, they may be attached to separate supports by bolting. A minimum of two bolts with locknuts is to be used.

The supports at each end of an anode are not to be attached to items of structure that are likely to move independently.

Anode inserts and supports welded directly to the structure are to be arranged so that the welds are clear of stress raisers.

5.11 Ports in Pump Room Bulkheads

Where fixed ports are fitted in the bulkheads between a pump room and the machinery or other safe space, they are to maintain the gastight and watertight integrity of the bulkhead. The ports are to be effectively protected against the possibility of mechanical damage and are to be fire resistant. Hinged port covers of steel, having non-corrosive hinge pins and secured from the safe space side, are to be provided. The covers are to provide strength and integrity equivalent to the unpierced bulkhead. Except where it may interfere with the function of the ports, the covers are to be secured in the closed position. The use of material other than steel for the covers will be subject to special consideration. Lighting fixtures providing strength and integrity equivalent to that of the port covers will be accepted as an alternative.

5.13 Location of Cargo Oil Tank Openings

Cargo oil tank openings, including those for tank cleaning, which are not intended to be secured gastight at all times during the normal operation of the vessel, are not to be located in enclosed spaces. For the purpose of this requirement, spaces open on one side only are to be considered enclosed. See also 5C-1-1/5.23.

5.15 Structural Fire Protection

The applicable requirements of Section 3-4-1 are to be complied with.

5.17 Allocation of Spaces *(1994)*

5.17.1 Tanks Forward of the Collision Bulkhead

Tanks forward of the collision bulkhead are not to be arranged for the carriage of oil or other liquid substances that are flammable.

5.17.2 Double Bottom Spaces and Wing Tank Spaces

For vessels of 5000 metric tons (4921 long tons) deadweight and above, double bottom spaces or wing tanks adjacent to cargo oil tanks are to be allocated for water ballast or spaces other than cargo and fuel oil tanks.

5.19 Access to Upper Parts of Ballast Tanks on Double Hull Tankers *(1993)*

Where the structural configuration within ballast tanks is such that it will prevent access to upper parts of the tanks for required close-up examination (see 7-3-2/5.13.4) by conventional means, such as a raft on partly filled tank, permanent means of safe access is to be provided. Details of the access are to be submitted for review.

Where horizontal girders or diaphragm plates are fitted, they may be considered as forming part of a permanent access. Alternative arrangements to the above may be considered upon submission.

5.21 Access to All Spaces in the Cargo Area *(1 October 1994)*

Access to cofferdams, ballast tanks, cargo tanks and other spaces in the cargo area is to be direct and from the open deck. Access to double bottom spaces may be through a cargo pump room, deep cofferdam, pipe tunnel or similar space, provided ventilation is suitable.

For access through horizontal openings, hatches or manholes, the access is to be of a size such as to allow a person wearing a self-contained, air-breathing apparatus and protective equipment (see 4-7-3/15.5) to ascend or descend any ladder without obstruction and also to provide a clear opening to facilitate the hoisting of an injured person from the bottom of the space. In general, the minimum clear opening is not to be less than 600 mm (24 in.) by 600 mm (24 in.).

For access through vertical openings or manholes providing passage through the length and breadth of the space, the minimum clear opening is not to be less than 600 mm (24 in.) by 800 mm (32 in.) at a height of not more than 600 mm (24 in.) from the bottom shell plating unless gratings or other footholds are provided.

5.23 Duct Keels or Pipe Tunnels in Double Bottom *(2000)*

Duct keels or pipe tunnels are not to pass into machinery spaces. Provision is to be made for at least two exits to the open deck, arranged at a maximum distance from each other. One of these exits may lead to the cargo pump room, provided that it is watertight and fitted with a watertight door complying with the requirements of 3-2-9/9.1 and in addition complying with the following:

i) In addition to bridge operation, the watertight door is to be capable of being closed from outside the main pump room entrance; and

ii) A notice is to be affixed at each operating position to the effect that the watertight door is to be kept closed during normal operations of the vessel, except when access to the pipe tunnel is required.

For the requirements of ventilation and gas detection in duct keels or pipe tunnels, see 5C-1-7/31.17.1.

5.25 Ventilation *(1996)*

Holes are to be cut in every part of the structure where otherwise there might be a chance of gases being "pocketed". Special attention is to be paid to the effective ventilation of pump rooms and other working spaces adjacent to oil tanks. In general, floor plating is to be of an open type not to restrict the flow of air, see 5C-1-7/17.1 and 5C-1-7/17.5. Efficient means are to be provided for clearing the oil spaces of dangerous vapors by means of artificial ventilation or steam. For cargo tank venting, see 5C-1-7/11 and 5C-1-7/21.

5.27 Pumping Arrangements

See applicable requirements in Section 5C-1-7.

5.29 Electrical Equipment

See 5C-1-7/31.

5.31 Testing

Requirements for testing are contained in Part 3, Chapter 7.

5.33 Machinery Spaces

Machinery spaces aft are to be specially stiffened transversely. Longitudinal material at the break is also to be specially considered to reduce concentrated stresses in this region. Longitudinal wing bulkheads are to be incorporated with the machinery casings or with substantial accommodation bulkheads in the tween decks and within the poop.

PART

5C

CHAPTER 1 **Vessels Intended to Carry Oil in Bulk (150 meters (492 feet) or more in Length)**

SECTION 2 **Design Considerations and General Requirements**

1 General Requirements *(1995)*

1.1 General *(1995)*

The strength requirements specified in this Chapter are based on a "net" ship approach. In determining the required scantlings and performing structural analyses and strength assessments, the nominal design corrosion values given in 5C-1-2/Table 1 are to be deducted.

1.3 Initial Scantling Requirements *(1995)*

The initial thickness of plating, the section modulus of longitudinals/stiffeners, and the scantlings of the main supporting structures are to be determined in accordance with Section 5C-1-4 for the "net" ship. These "net" ship values are to be used for further assessment as required in the following paragraph. The relevant nominal design corrosion values are then added to obtain the full scantling requirements.

1.5 Strength Assessment – Failure Modes *(1995)*

A total assessment of the structures, determined on the basis of the initial strength criteria in Section 5C-1-4 is to be carried out against the following three failure modes.

1.5.1 Material Yielding

The calculated stress intensities are not to be greater than the yielding state limit given in 5C-1-5/3.1 for all load cases specified in 5C-1-3/9.

1.5.2 Buckling and Ultimate Strength

For each individual member, plate or stiffened panel, the buckling and ultimate strength is to be in compliance with the requirements specified in 5C-1-5/5. In addition, the hull girder ultimate strength is to be in accordance with 5C-1-5/5.11.

1.5.3 Fatigue

The fatigue strength of structural details and welded joints in highly stressed regions is to be analyzed in accordance with 5C-1-5/7.

1.7 Structural Redundancy and Residual Strength *(1995)*

Consideration should be given to structural redundancy and hull girder residual strength in the early design stages.

In addition to other requirements of these Rules, vessels which have been built in accordance with the procedure and criteria for calculating and evaluating the residual strength of hull structures, as outlined in the ABS *Guide for Assessing Hull Girder Residual Strength*, will be classed and distinguished in the *Record* by the symbol **RES** placed after the appropriate hull classification notation.

3 Nominal Design Corrosion Values (NDCV) *(1995)*

3.1 General

As indicated in 5C-1-2/1.1, the strength criteria specified in this Chapter are based on a “net” ship approach, wherein the nominal design corrosion values are deducted.

The “net” thickness or scantlings correspond to the minimum strength requirements acceptable for classification, regardless of the design service life of the vessel. In addition to the coating protection specified in the Rules for all ballast tanks, minimum corrosion values for plating and structural members as given in 5C-1-2/Table 1 and 5C-1-2/Figure 1 are to be applied. These minimum values are being introduced solely for the above purpose, and are not to be construed as renewal standards.

In view of the anticipated higher corrosion rates for structural members in some regions, such as highly stressed areas, additional design margins should be considered for the primary and critical structural members to minimize repairs and maintenance costs. The beneficial effects of these design margins on reduction of stresses and increase of the effective hull girder section modulus can be appropriately accounted for in the design evaluation.

FIGURE 1
Nominal Design Corrosion Values (NDCV) *(1995)*

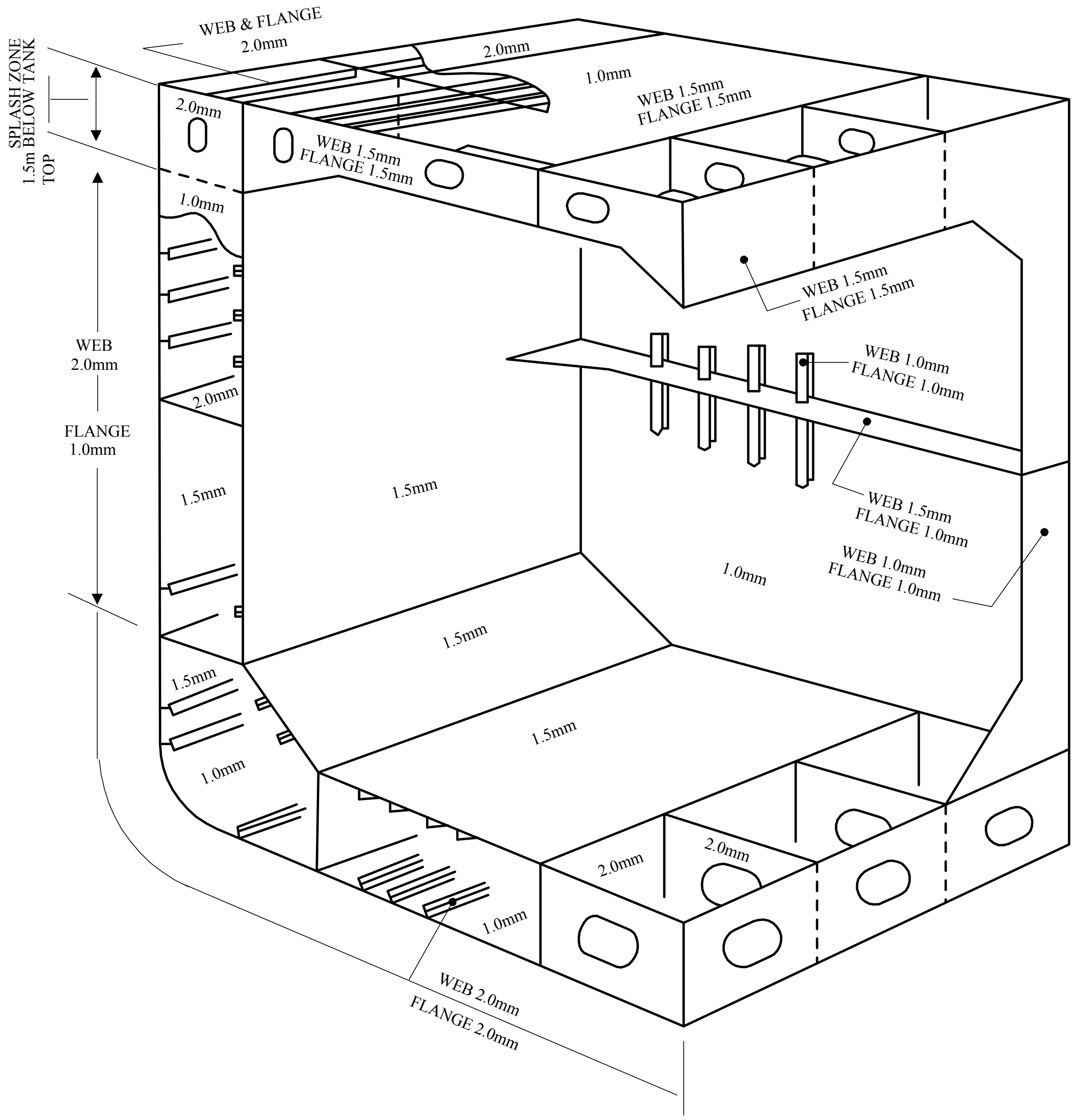


TABLE 1
Nominal Design Corrosion Values (NDCV) *(1995)*

Structural Element/Location		*Nominal Design Corrosion Values in mm (in.)* — *Cargo Tank*	*Nominal Design Corrosion Values in mm (in.)* — *Ballast Tank Effectively Coated*
Deck Plating		1.0 (0.04)	2.0 (0.08)
Side Shell Plating		NA	1.5 (0.06)
Bottom Plating		NA	1.0 (0.04)
Inner Bottom Plating		1.5 (0.06)	
Longitudinal Bulkhead Plating	Between cargo tanks	1.0 (0.04)	N.A.
	Other Plating	1.5 (0.06)	
Transverse Bulkhead Plating	Between cargo tanks	1.0 (0.04)	N.A.
	Other Plating	1.5 (0.06)	
Transverse & Longitudinal Deck Supporting Members		1.5 (0.06)	2.0 (0.08)
Double Bottom Tanks Internals (Stiffeners, Floors and Girders)		N.A.	2.0 (0.08)
Vertical Stiffeners and Supporting Members Elsewhere		1.0 (0.04)	1.0 (0.04)
Non-vertical Longitudinals/Stiffeners and Supporting Members Elsewhere		1.5 (0.06)	2.0 (0.08)

Notes

1. It is recognized that corrosion depends on many factors including coating properties, cargo composition, inert gas properties and temperature of carriage, and that actual wastage rates observed may be appreciably different from those given here.
2. Pitting and grooving are regarded as localized phenomena and are not covered in this table.
3. For nominal design corrosion values for single hull and mid-deck type tankers, see Appendix 5C-1-A3 and Appendix 5C-1-A4.

PART

5C

CHAPTER 1 Vessels Intended to Carry Oil in Bulk (150 meters (492 feet) or more in Length)

SECTION 3 Load Criteria

1 General

1.1 Load Components *(1995)*

In the design of the hull structure of tankers, all load components with respect to the hull girder and local structure as specified in this Chapter and Section 3-2-1 are to be taken into account. These include static loads in still water, wave-induced motions and loads, sloshing, slamming, dynamic, thermal and ice loads, where applicable.

3 Static Loads *(1995)*

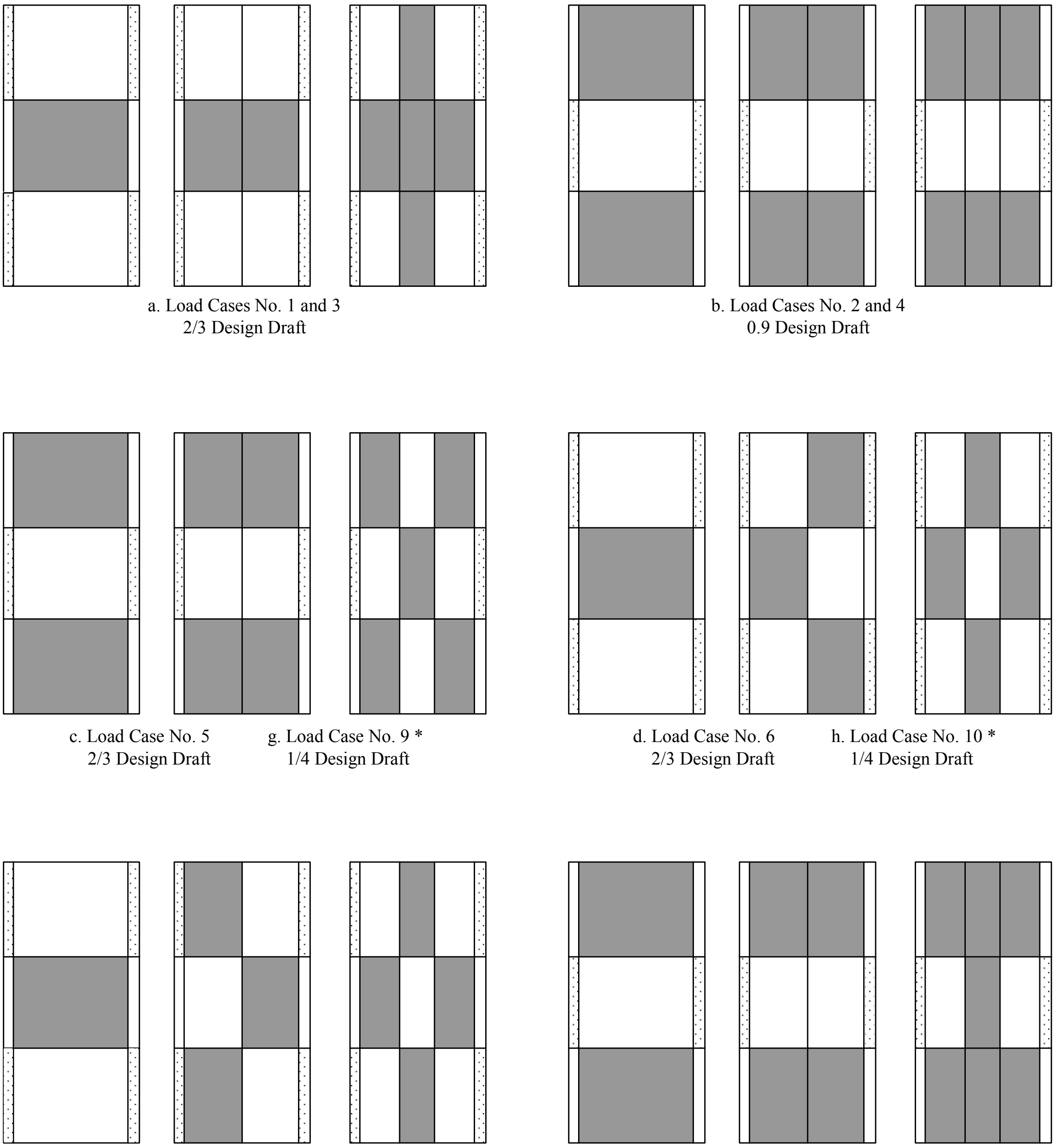
3.1 Still-water Bending Moment

For still-water bending moment calculations, see 3-2-1/3.3.

When a direct calculation of wave-induced loads [i.e., longitudinal bending moments and shear forces, hydrodynamic pressures (external) and inertial forces and added pressure heads (internal)] is not submitted, envelope curves of the still-water bending moments (hogging and sagging) and shear forces (positive and negative) are to be provided.

Except for special loading cases, the loading patterns shown in 5C-1-3/Figure 1 are to be considered in determining local static loads.

FIGURE 1
Loading Pattern *(1 July 2005)*



a. Load Cases No. 1 and 3
2/3 Design Draft

b. Load Cases No. 2 and 4
0.9 Design Draft

c. Load Case No. 5
2/3 Design Draft

g. Load Case No. 9 *
1/4 Design Draft

d. Load Case No. 6
2/3 Design Draft

h. Load Case No. 10 *
1/4 Design Draft

e. Load Case No. 7
2/3 Design Draft

f. Load Case No. 8
Design Draft

For detailed loading information see 5C-1-3/Table 1A and 5C-1-3/Table 1B.

* For L.C. 9 and 10, where static conditions, such as tank testing, that have the same load pattern as the center row of tanks resulting in a draft less than 1/4 Design Draft, the actual static condition draft is to be used. For vessels with two outer longitudinal bulkheads only (inner skin), the minimum actual static condition or tank test draft is to be used. The value of k_s = 1.0 is to be used in all tanks. The tanks are to be loaded considering the actual height of the overflow pipe, which is not to be taken less than 2.44 m (8 feet) above the deck at side.

(1 July 2005) For a hull structure with the main supporting members that are asymmetric forward and after the mid-tank transverse bulkheads, the above load cases are to be evaluated by turning the finite element model by 180 degrees with respect to the vertical axis.

(1 July 2005) For a hull structure that is asymmetric with respect to the centerline plane, the additional load cases mirroring the above asymmetric load case are to be evaluated.

5 Wave-induced Loads *(1995)*

5.1 General

Where a direct calculation of the wave-induced loads is not available, the approximation equations given below and specified in 3-2-1/3.5 may be used to calculate the design loads.

When a direct calculation of the wave-induced loads is performed, envelope curves of the combined wave and still-water bending moments and shear forces, covering all the anticipated loading conditions, are to be submitted for review.

5.3 Horizontal Wave Bending Moment and Shear Force *(1995)*

5.3.1 Horizontal Wave Bending Moment

The horizontal wave bending moment, positive (tension port) or negative (tension starboard), may be obtained from the following equation:

$$M_H = \pm\, m_h K_3 C_1 L^2 D C_b \times 10^{-3} \qquad \text{kN-m (tf-m, Ltf-ft)}$$

where

m_h = distribution factor, as given by 5C-1-3/Figure 2

K_3 = 180 (18.34, 1.68)

D = depth of vessel, as defined in 3-1-1/7, in m (ft)

C_1, L, and C_b are as given in 3-2-1/3.5.

5.3.2 Horizontal Wave Shear Force

The envelope of horizontal wave shearing force, F_H, positive (toward port forward) or negative (toward starboard aft), may be obtained from the following equation:

$$F_H = \pm f_h\, k C_1 L D (C_b + 0.7) \times 10^{-2} \qquad \text{kN (tf, Ltf)}$$

where

f_h = distribution factor, as given in 5C-1-3/Figure 3

k = 36 (3.67, 0.34)

C_1, L, D and C_b are as defined in 5C-1-3/5.3.1 above.

5.5 External Pressures

5.5.1 Pressure Distribution

The external pressures, p_e, (positive toward inboard), imposed on the hull in seaways can be expressed by the following equation at a given location:

$$p_e = \rho g (h_s + k_u h_{de}) \geq 0 \quad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

ρg = specific weight of sea water

= 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf/in^2-ft)

h_s = hydrostatic pressure head in still water, in m (ft)

k_u = load factor, and may be taken as unity unless otherwise specified.

h_{de} = hydrodynamic pressure head induced by the wave, in m (ft), may be calculated as follows:

= $k_c h_{di}$

where

k_c = correlation factor for a specific combined load case, as given in 5C-1-3/7.1 and 5C-1-3/9

h_{di} = hydrodynamic pressure head, in m (ft), at location i (i =1, 2, 3, 4 or 5; see 5C-1-3/Figure 4)

= $k_\ell \alpha_i h_{do}$ in m (ft)

k_ℓ = distribution factor along the length of the vessel

= $1 + (k_{\ell o} - 1) \cos \mu$, $k_{\ell o}$ is as given in 5C-1-3/Figure 5

= 1.0 amidships

h_{do} = $1.36\, kC_1$ in m (ft)

C_1 = as defined in 3-2-1/3.5

k = 1 (1, 3.281)

α_i = distribution factor around the girth of vessel at location i.

= $1.00 - 0.25 \cos \mu$ for $i = 1$, at WL, starboard

= $0.40 - 0.10 \cos \mu$ for $i = 2$, at bilge, starboard

= $0.30 - 0.20 \sin \mu$ for $i = 3$, at bottom centerline

= $2\alpha_3 - \alpha_2$ for $i = 4$, at bilge, port

= $0.75 - 1.25 \sin \mu$ for $i = 5$, at WL, port

α_i at intermediate locations of i may be obtained by linear interpolation.

μ = wave heading angle, to be taken from 0° to 90° (0° for head sea, 90° for beam sea for wave coming from starboard)

The distribution of the total external pressure including static and hydrodynamic pressure is illustrated in 5C-1-3/Figure 6.

5.5.2 Extreme Pressures

In determining the required scantlings of local structural members, the extreme external pressure, p_e, to be used, is as defined in 5C-1-3/5.5.1 with k_u as given in 5C-1-3/7 and 5C-1-3/9.

5.5.3 Simultaneous Pressures

When performing 3D structural analysis, the simultaneous pressure along any portion of the hull girder may be obtained from:

$$p_{es} = \rho g(h_s + k_f k_u h_{de}) \geq 0 \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

k_f is a factor denoting the phase relationship between the reference station and adjacent stations considered along the vessel's length, and may be determined as follows:

$$k_f = k_{fo} \{ 1 - [1 - \cos \frac{2\pi(x - x_o)}{L}] \cos \mu \}$$

where

x = distance from A.P. to the station considered, in m (ft)

x_o = distance from A.P. to the reference station*, in m (ft).

L = the vessel length, as defined in 3-1-1/3, in m (ft)

μ = the wave heading angle, to be taken from 0° to 90°

k_{fo} = ±1.0, as specified in 5C-1-3/Table 1.

* The reference station is the point along the vessel's length where the wave trough or crest is located and may be taken as the mid-point of the mid-hold of the three hold model.

The simultaneous pressure distribution around the girth of the vessel is to be determined based on the wave heading angles specified in 5C-1-3/7 and 5C-1-3/9.

5.7 Internal Pressures – Inertia Forces and Added Pressure Heads *(1995)*

5.7.1 Ship Motions and Accelerations

To determine the inertial forces and added pressure heads for a completely filled cargo or ballast tank, the dominating ship motions, pitch and roll, and the resultant accelerations induced by the wave are required. When a direct calculation is not available, the equations given below may be used.

5.7.1(a) Pitch (1 July 2005). The pitch amplitude: (positive bow up)

$\phi = k_1(V/C_b)^{1/4}/L$, in deg., but need not to be taken more than 10 deg.

The pitch natural period:

T_p = $k_2 \sqrt{C_b\, d_i}$ seconds.

where

k_1 = 1030 (3378) for L in m (ft)

k_2 = 3.5 (1.932) for d_i in m (ft)

V = 75% of the design speed V_d, in knots for the purpose of calculating pitch and roll amplitudes for both strength and fatigue strength formulation. V is not to be taken less than 10 knots. V_d is defined in 3-2-14/3.

d_i = draft amidships for the relevant loading conditions.

L and C_b are defined in 3-1-1/3.1 and 3-1-1/11.3, respectively.

5.7.1(b) Roll (1 July 2005). The roll amplitude: (positive starboard down)

$\theta = C_R (35 - k_\theta C_{di} \Delta/1000)$ if $T_r > 20$ seconds.

$\theta = C_R (35 - k_\theta C_{di} \Delta/1000)(1.5375 - 0.027T_r)$ if $12.5 \le T_r \le 20$ seconds

$\theta = C_R (35 - k_\theta C_{di} \Delta/1000)(0.8625 + 0.027T_r)$ if $T_r \le 12.5$ seconds

where

θ is in degrees, but need not to be taken greater than 30°.

k_θ = 0.005 (0.05, 0.051)

C_R = $1.3 - 0.025V$

C_{di} = $1.06\,(d_i/d_f) - 0.06$

d_i = draft amidships for the relevant loading conditions, m (ft)

d_f = draft, as defined in 3-1-1/9, m (ft)

Δ = $k_d LBd_f C_b$ kN (tf, Ltf)

k_d = 10.05 (1.025, 0.0286)

L and *B* are as defined in Section 3-1-1.

The roll natural motion period:

$T_r = k_4\, k_r / GM^{1/2}$ seconds

where

k_4 = 2 (1.104) for k_r, *GM* in m (ft)

k_r = roll radius of gyration, in m (ft), and may be taken as $0.35B$ for full load conditions and $0.45B$ for ballast conditions.

GM = metacentric height, to be taken as:

= *GM* (full) for full draft

= 1.1 *GM* (full) for 9/10 d_f

= 1.5 *GM* (full) for 2/3 d_f

= 2.0 *GM* (full) for 1/2 d_f

GM (full) = metacentric height for fully loaded condition

If *GM* (full) is not available, *GM* (full) may be taken as $0.12B$ for the purpose of estimation.

5.7.1(c) Accelerations (1 July 2005). The vertical, longitudinal and transverse accelerations of tank contents (cargo or ballast), a_v, a_ℓ and a_t may be obtained from the following formulae:

$a_v = C_v\, k_v\, a_o\, g$ m/sec² (ft/sec²) positive downward

$a_\ell = C_\ell\, k_\ell\, a_o\, g$ m/sec² (ft/sec²) positive forward

$a_t = C_t\, k_t\, a_o\, g$ m/sec² (ft/sec²) positive starboard

where

a_o = $k_o\,(2.4/L^{1/2} + 34/L - 600/L^2)$ for *L* in m

= $k_o\,(4.347/L^{1/2} + 111.55/L - 6458/L^2)$ for *L* in ft

k_o = $1.3 - 0.47C_b$ for strength formulation and assessment of local structural elements and members in Section 5C-1-4, 5C-1-5/1, 5C-1-3/3 and 5C-1-5/5.

= $0.86 + 0.048V - 0.47C_b$ for fatigue strength formulation in 5C-1-5/7 and Appendix 5C-1-A1

C_v = $\cos\mu + (1 + 2.4\,z/B)\,(\sin\mu)/k_v$

μ = wave heading angle in degrees, 0° for head sea, and 90° for beam sea for wave coming from starboard

k_v = $[1 + 0.65(5.3 - 45/L)^2\ (x/L - 0.45)^2]^{1/2}$ for L in m

= $[1 + 0.65(5.3 - 147.6/L)^2\ (x/L - 0.45)^2]^{1/2}$ for L in ft

C_ℓ = $0.35 - 0.0005(L - 200)$ for L in m

= $0.35 - 0.00015\ (L - 656)$ for L in ft

k_ℓ = $0.5 + 8y/L$

C_t = $1.27[1 + 1.52(x/L - 0.45)^2]^{1/2}$

k_t = $0.35 + y/B$

L and B are the length and breadth of the vessel respectively, as defined in Section 3-1-1, in m (ft).

x = longitudinal distance from the A.P. to the station considered, in m (ft)

y = vertical distance from the waterline to the point considered, in m (ft), positive upward

z = transverse distance from the centerline to the point considered, in m (ft), positive starboard

g = acceleration of gravity = 9.8 m/sec^2 (32.2 ft/sec^2)

5.7.2 Internal Pressures

5.7.2(a) Distribution of Internal Pressures. (1 July 2000) The internal pressure, P_i (positive toward tank boundaries), for a completely filled tank may be obtained from the following formula:

p_i = $k_s \rho g(\eta + k_u h_d) + p_o \geq 0$ in N/cm^2 (kgf/cm^2, lbf/in^2)

p_o = $(p_{vp} - p_n) \geq 0$ in N/cm^2 (kgf/cm^2, lbf/in^2)

where

p_{vp} = pressure setting on pressure/vacuum relief valve ≤ 6.90 N/cm^2 (0.71 kgf/cm^2, 10.00 lbf/in^2) for integral-gravity tanks

p_n = 2.06 N/cm^2 (0.21 kgf/cm^2, 3.00 lbf/in^2)

ρg = specific weight of the liquid, not to be taken less than 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf/in^2-ft)

η = local coordinate in vertical direction for tank boundaries measuring from the top of the tanks, as shown 5C-1-3/Figure 7, in m (ft)

For lower ballast tanks, a distance equivalent to $^2/_3$ of the distance from the top of the tank to the top of the overflow [minimum 760 mm (30 in.) above deck] is to be added to η.

k_s = load factor – see also 5C-1-3/5.7.2(c)

= 1.0 for structural members 1 through 10 in 5C-1-3/Table 3, and for all loads from ballast tanks

= 0.878 for ρg of 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf/in^2-ft) and 1.0 for ρg of 1.118 N/cm^2-m (0.114 kgf/cm^2-m, 0.4942 lbf/in^2-ft) and above for structural members 11 through 17 in 5C-1-3/Table 3

For cargo ρg between 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf/in^2-ft) and 1.118 N/cm^2-m (0.114 kgf/cm^2-m, 0.4942 lbf/in^2-ft), the factor k_s may be determined by interpolation

k_u = load factor and may be taken as unity unless otherwise specified

h_d = wave-induced internal pressure head, including inertial force and added pressure head.

= $k_c(\eta\, a_i/g + \Delta h_i)$, in m (ft)

k_c = correlation factor and may be taken as unity unless otherwise specified

a_i = effective resultant acceleration, in m/sec^2 (ft/sec^2), at the point considered and may be approximated by

a_i = $0.71C_{dp}[w_v a_v + w_\ell(\ell/h)a_\ell + w_t(b/h)a_t]$

C_{dp} is as specified in 5C-1-3/5.7.2(d).

a_v, a_ℓ and a_t are as given in 5C-1-3/5.7.1(c).

w_v, w_ℓ and w_t are weighted coefficients, showing directions, as specified in 5C-1-3/Table 1 and 5C-1-3/Table 3.

Δh_i = added pressure head due to pitch and roll motions at the point considered, in m (ft), may be calculated as follows

i) for bow down and starboard down ($\phi_e < 0$, $\theta_e > 0$)

Δh_i = $\xi \sin(-\phi_e) + C_{ru}(\zeta_e \sin\theta_e \cos\phi_e + \eta_e \cos\theta_e \cos\phi_e - \eta)$

ζ_e = $b - \zeta$

η_e = η

ii) for bow up and starboard up ($\phi_e > 0$, $\theta_e < 0$)

Δh_i = $(\ell - \xi)\sin\phi_e + C_{ru}(\zeta_e \sin(-\theta_e)\cos\phi_e + \eta_e\cos\theta_e\cos\phi_e - \eta)$

ζ_e = $\zeta - \delta_b$

η_e = $\eta - \delta_h$

ξ, ζ, η are the local coordinates, in m (ft), for the point considered with respect to the origin in 5C-1-3/Figure 7.

C_{ru} is as specified in 5C-1-3/5.7.2(d).

δ_b and δ_h are local coordinates adjustments, in m (ft), for the point considered with respect to the origin shown in 5C-1-3/Figure 7.

where

θ_e = $0.71\ C_\theta\ \theta$

ϕ_e = $0.71\ C_\phi\ \phi$

ℓ = length of the tank, in m (ft)

h = depth of the tank, in m (ft)

b = breadth of the tank considered, in m (ft)

ϕ and θ are pitch and roll amplitudes, as given in 5C-1-3/5.7.1(a) and 5C-1-3/5.7.1(b)

C_ϕ and C_θ are weighted coefficients, showing directions as given in 5C-1-3/Table 1 and 5C-1-3/Table 3

Where pressure-vacuum valves of cargo tanks are set at greater than 2.06 N/cm^2 (0.21 kgf/cm^2, 3 lbf/in^2), the value of P_i is to be increased appropriately.

5.7.2(b) Extreme Internal Pressure. For assessing local structures at a tank boundary, the extreme internal pressure with k_u, as specified in 5C-1-3/7, is to be considered.

5.7.2(c) Simultaneous Internal Pressures (1 July 2000). In performing a 3D structural analysis, the internal pressures may be calculated in accordance with 5C-1-3/5.7.2(a) and 5C-1-3/5.7.2(b) above for tanks in the mid-body. For tanks in the fore or aft body, the pressures should be determined based on linear distributions of accelerations and ship motions along the length of the vessel.

Note: In performing a 3D structural analysis, k_s in 5C-1-3/5.7.2(a) is to be taken as:

k_s = 1.0 for all loads from ballast tanks

= 0.878 for ρg of 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf/in^2-ft) and 1.0 for ρg of 1.118 N/cm^2-m (0.114 kgf/cm^2-m, 0.4942 lbf/in^2-ft) and above for all loads from cargo tanks

For cargo ρg between 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf/in^2-ft) and 1.118 N/cm^2-m (0.114 kgf/cm^2-m, 0.4942 lbf/in^2-ft), the factor k_s may be determined by interpolation

5.7.2(d) Definition of Tank Shape and Associated Coefficients

i) J-shaped Tank

A tank having the following configurations is considered as a "J-shaped" tank.

$b/b_1 \geq 5.0$ and $h/h_1 \geq 5.0$

where

b = extreme breadth at the tank top of the tank considered

b_1 = least breadth of wing tank part of the tank considered

h = extreme height of the tank considered

h_1 = least height of double bottom part of the tank considered

as shown in 5C-1-3/Figure 7.

The coefficients C_{dp} and C_{ru} are as follows:

$C_{dp} = 0.7$

$C_{ru} = 1.0$

ii) *Rectangular Tank*

The following tank is considered as a rectangular tank:

$b/b_1 \leq 3.0$ or $h/h_1 \leq 3.0$

The coefficients C_{dp} and C_{ru} of the tank are as follows:

$C_{dp} = 1.0$

$C_{ru} = 1.0$

iii) *U-shaped Tank*

A half of a "U-shaped" tank, divided at the centerline, should satisfy the condition of a "J-shaped" tank.

The coefficients C_{dp} and C_{ru} are as follows:

$C_{dp} = 0.5$

$C_{ru} = 0.7$

iv) In a case where the minimum tank ratio of b/b_1 or h/h_1 whichever is lesser, is greater than 3.0 but less than 5.0, the coefficients C_{dp} and C_{ru} of the tank are to be determined by the following interpolation:

J-shaped Tank in head and non-head seas, U-shaped Tank in head seas:

$C_{dp} = 1.0 - 0.3$ (the min. tank ratio - 3.0) / 2.0

U-shaped Tank in non-head seas:

$C_{dp} = 1.0 - 0.5$ (the min. tank ratio - 3.0) / 2.0

U-shaped Tank:

$C_{ru} = 1.0 - 0.3$ (the min. tank ratio - 3.0) / 2.0

v) For non-prismatic tanks mentioned above, b_1, h and h_1 are to be determined based on the extreme section.

FIGURE 2
Distribution Factor m_h *(1995)*

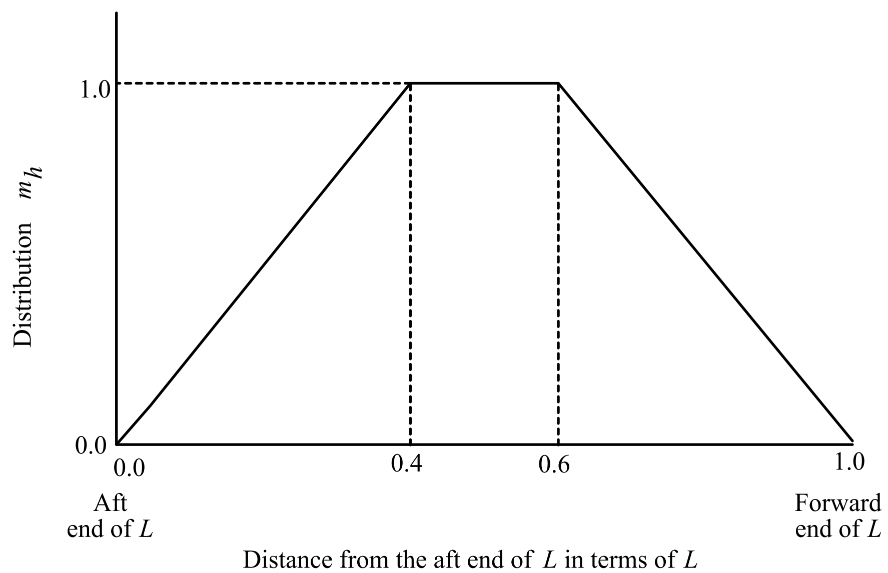


FIGURE 3
Distribution Factor f_h (1995)

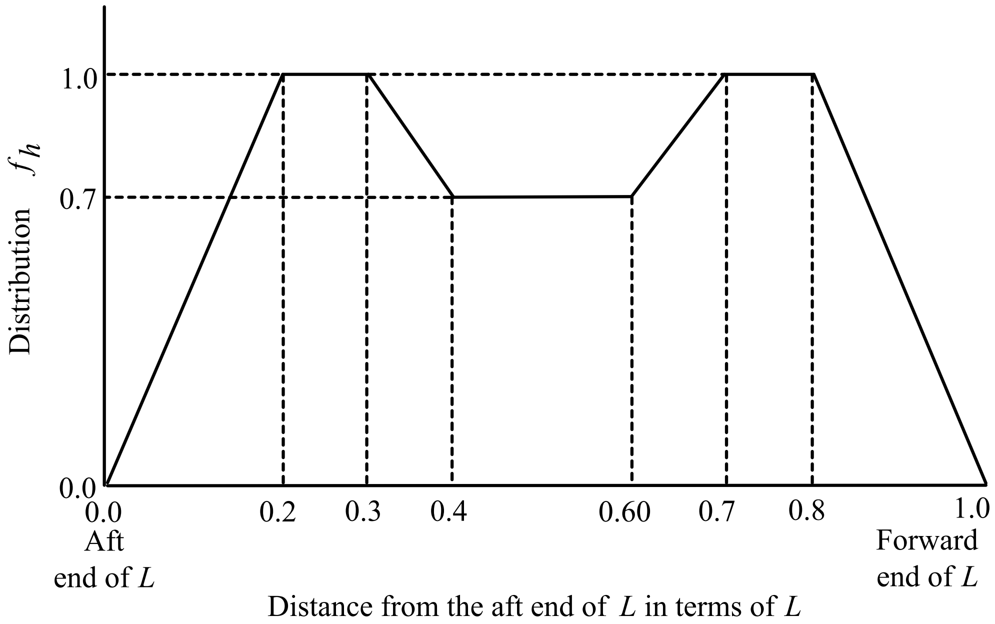
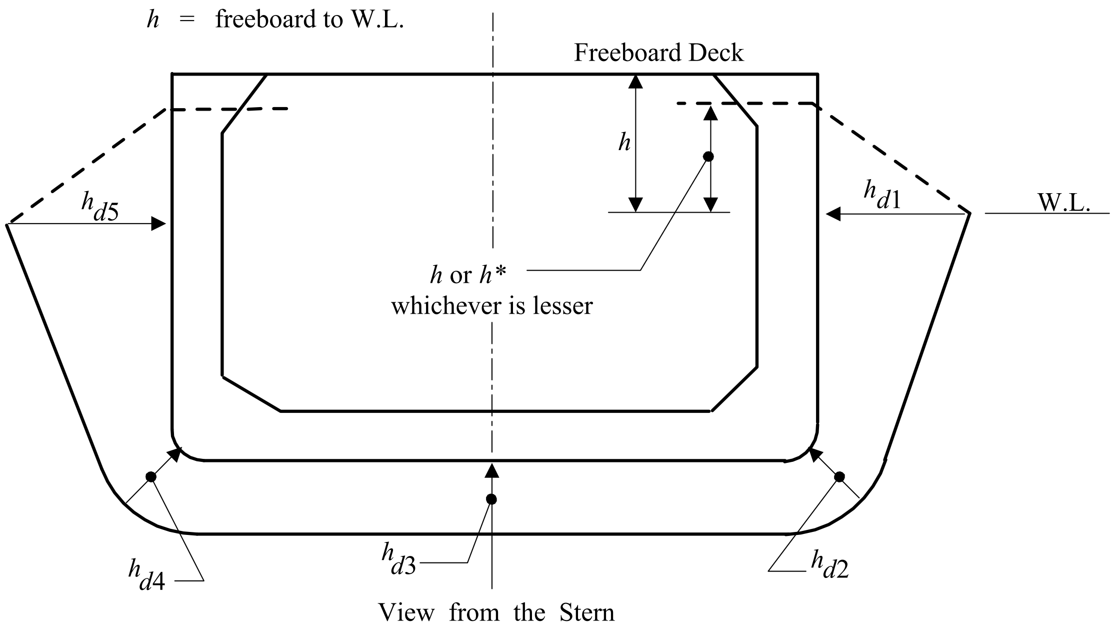


FIGURE 4
Distribution of h_{di} (1995)



Note: $h^* = k_u k_c h_{d1}$ for nominal pressure
$h^* = k_f k_u h_{d1}$ for simultaneous pressure

FIGURE 5
Pressure Distribution Function $k_{\ell o}$ *(1995)*

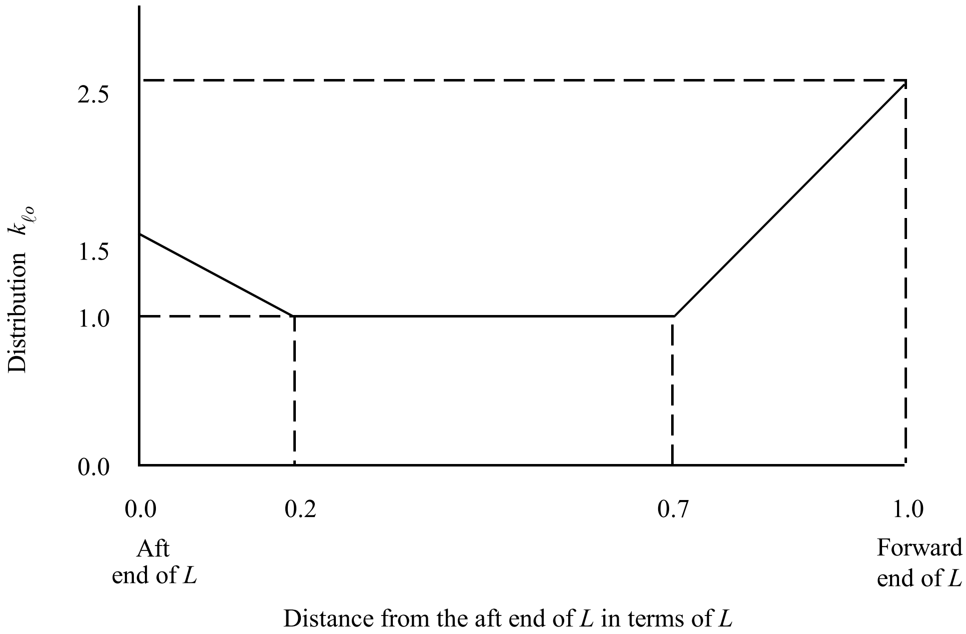
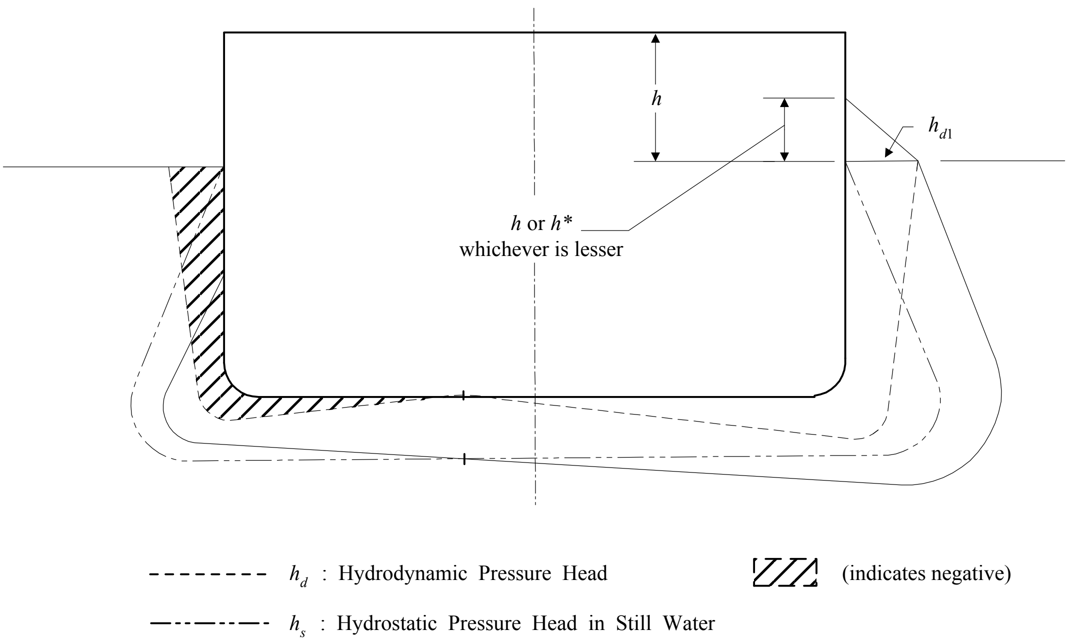
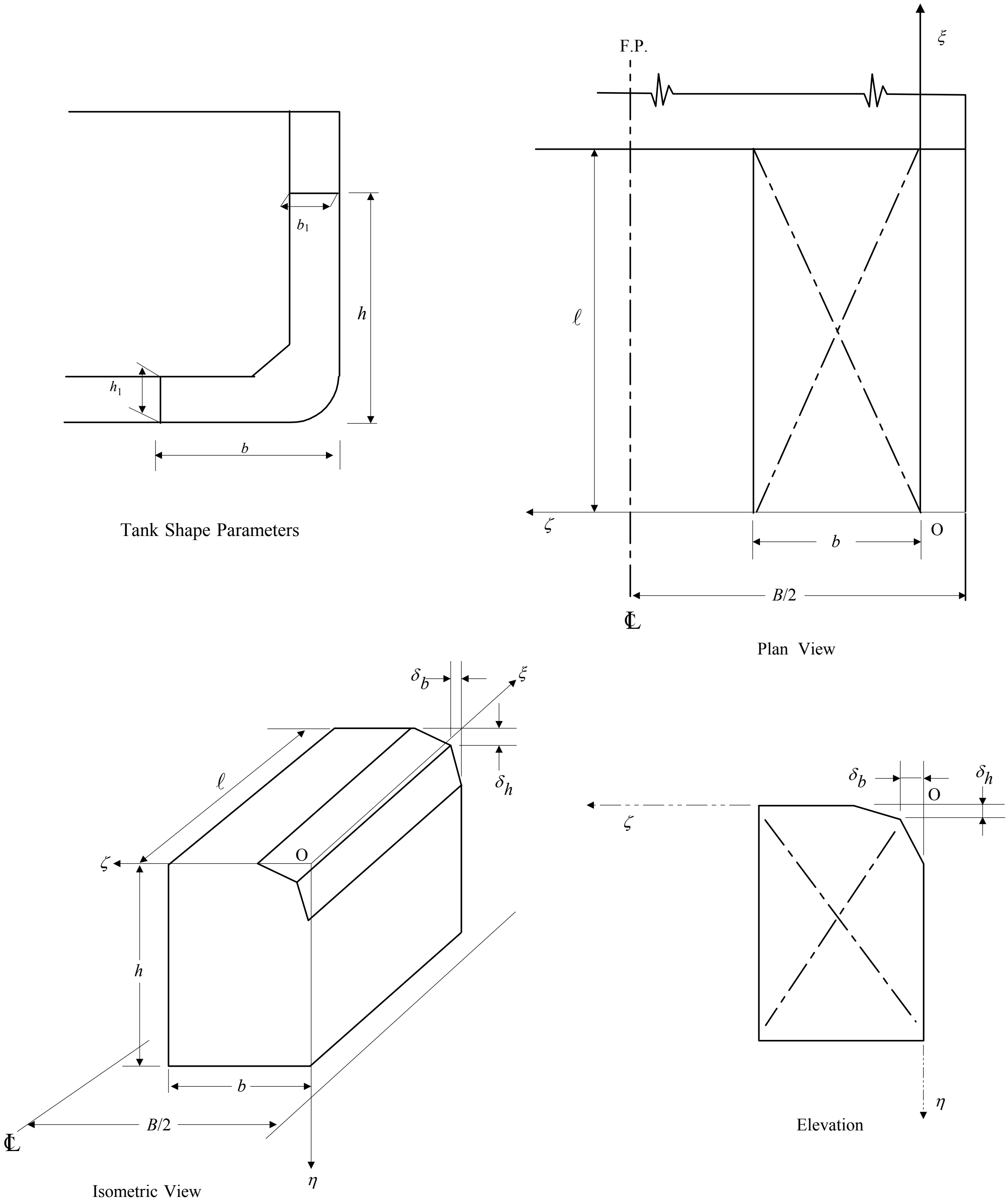


FIGURE 6
Illustration of Determining Total External Pressure *(1997)*



Note: $h^* = k_u k_c h_{d1}$ for nominal pressure
$h^* = k_f k_u h_{d1}$ for simultaneous pressure

FIGURE 7
Definition of Tank Geometry *(1995)*



For lower ballast tanks, η is to be measured from a point located at $^2/_3$ the distance from the top of the tank to the top of the overflow (minimum 760 mm above deck).

FIGURE 8
Location of Tank for Nominal Pressure Calculation *(1997)*

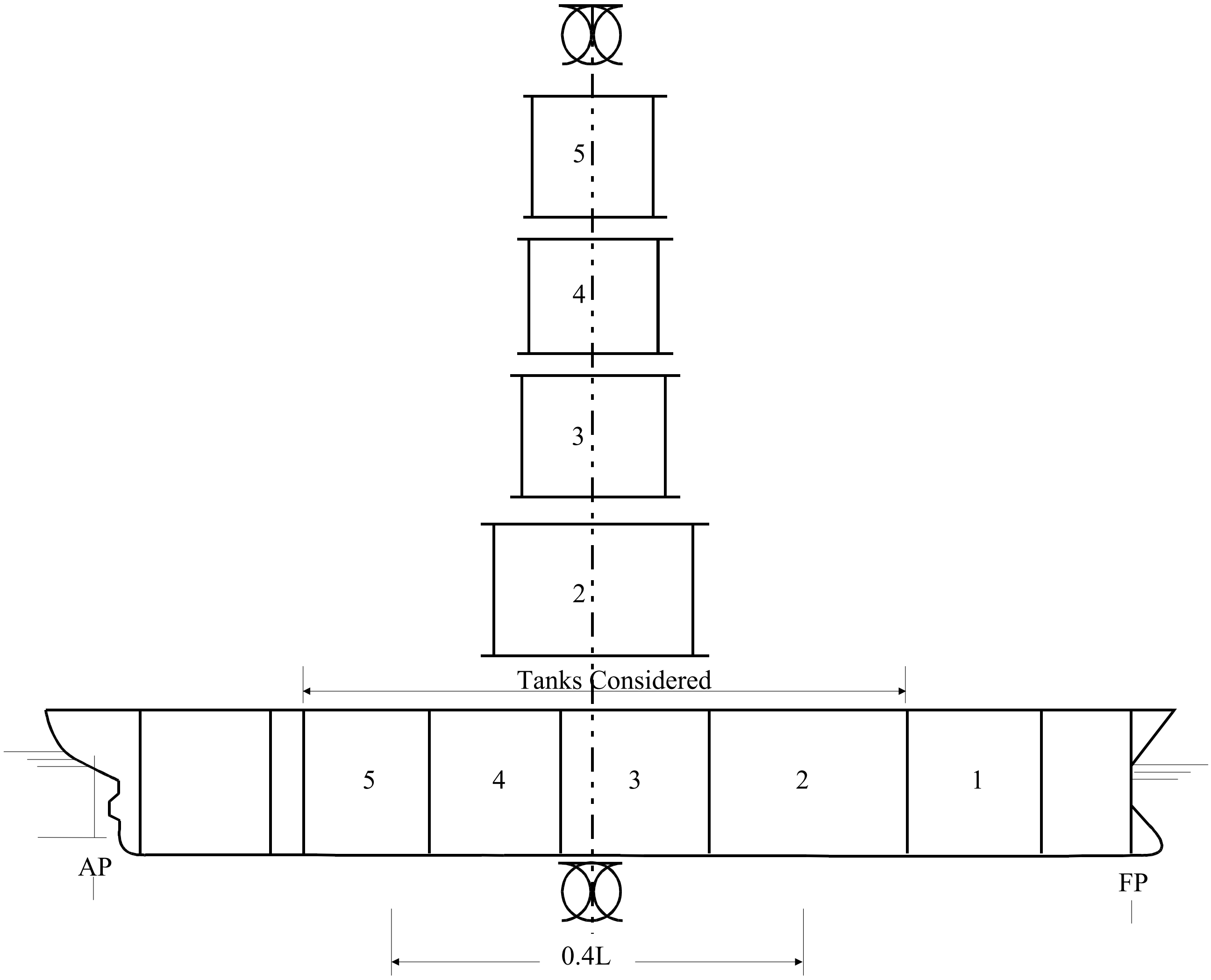


TABLE 1A
Combined Load Cases for Yielding and Buckling Strength Formulation (1)
(1 July 2005)

	L.C. 1	*L.C. 2*	*L.C. 3* (3)	*L.C. 4* (3)	*L.C. 5*	*L.C. 6*	*L.C. 7*	*L.C. 8*	*L.C. 9*	*L.C. 10*
A. Hull Girder Loads (See 5C-1-3/5)										
Vertical B.M.	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)	—	—
k_c	1.0	1.0	0.7	0.7	0.3	0.3	0.4	0.4	0.0	0.0
Vertical S.F. (2)	(+)	(–)	(+)	(–)	(+)	(–)	(+)	(–)	—	—
k_c	0.5	0.5	1.0	1.0	0.3	0.3	0.4	0.4	0.0	0.0
Horizontal B.M.					(–)	(+)	(–)	(+)		
k_c	0.0	0.0	0.0	0.0	0.3	0.3	1.0	1.0	0.0	0.0
Horizontal S.F.					(+)	(–)	(+)	(–)		
k_c	0.0	0.0	0.0	0.0	0.3	0.3	0.5	0.5	0.0	0.0
B. External Pressure (See 5C-1-3/5.5)										
k_c	0.5	0.5	0.5	1.0	0.5	1.0	0.5	1.0	0.0	0.0
k_{f0}	-1.0	1.0	-1.0	1.0	-1.0	1.0	-1.0	1.0	0.0	0.0
C. Internal Tank Pressure (See 5C-1-3/5.7)										
k_c	0.4	0.4	1.0	0.5	1.0	0.5	1.0	0.5	0.0	0.0
w_v	0.75	-0.75	0.75	-0.75	0.25	-0.25	0.4	-0.4	0.0	0.0
w_ℓ	Fwd Bhd 0.25	Fwd Bhd -0.25	Fwd Bhd 0.25	Fwd Bhd -0.25	—	—	Fwd Bhd 0.2	Fwd Bhd -0.2	—	—
	Aft Bhd -0.25	Aft Bhd 0.25	Aft Bhd -0.25	Aft Bhd 0.25	—	—	Aft Bhd -0.2	Aft Bhd 0.2	—	—
w_t	—	—	—	—	Port Bhd -0.75	Port Bhd 0.75	Port Bhd -0.4	Port Bhd 0.4	—	—
	—	—	—	—	Stbd Bhd 0.75	Stbd Bhd -0.75	Stbd Bhd 0.4	Stbd Bhd -0.4	—	—
c_ϕ, Pitch	-0.35	0.35	-0.7	0.7	0.0	0.0	-0.3	0.3	0.0	0.0
c_θ, Roll	0.0	0.0	0.0	0.0	1.0	-1.0	0.3	-0.3	0.0	0.0
D. Reference Wave Heading and Motion of Vessel										
Heading Angle	0	0	0	0	90	90	60	60	—	—
Heave	Down	Up	Down	Up	Down	Up	Down	Up	—	—
Pitch	Bow Down	Bow Up	Bow Down	Bow Up	—	—	Bow Down	Bow Up	—	—
Roll	—	—	—	—	Stbd Down	Stbd Up	Stbd Down	Stbd Up	—	—

Notes:

1 k_u = 1.0 for all load components.

2 *(1 July 2005)* The sign convention for the shear force corresponds to the forward end of the middle hold.

3 *(1 July 2005)* Load cases 3 & 4 are to be analyzed for the structural model that is fully balanced under the boundary forces to achieve the specified hull girder vertical bending moment at the middle of the model. These load cases are also to be analyzed for the structural model that is fully balanced under the boundary forces to achieve the specified hull girder vertical shear force s at the mid-tank transverse bulkheads.

TABLE 1B
Combined Load Cases for Fatigue Strength Formulation (1) *(1 July 2005)*

	L.C. 1	*L.C. 2*	*L.C. 3*	*L.C. 4*	*L.C. 5*	*L.C. 6*	*L.C. 7*	*L.C. 8*	*L.C. 9*	*L.C. 10*
A. Hull Girder Loads (See 5C-1-3/5)										
Vertical B.M.	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)	—	—
k_c	1.0	1.0	0.7	0.7	0.3	0.3	0.4	0.4	0.0	0.0
Vertical S.F. (2)	(+)	(–)	(+)	(–)	(+)	(–)	(+)	(–)	—	—
k_c	0.5	0.5	1.0	1.0	0.3	0.3	0.4	0.4	0.0	0.0
Horizontal B.M.					(–)	(+)	(–)	(+)		
k_c	0.0	0.0	0.0	0.0	0.3	0.3	1.0	1.0	0.0	0.0
Horizontal S.F.					(+)	(–)	(+)	(–)		
k_c	0.0	0.0	0.0	0.0	0.3	0.3	0.5	0.5	0.0	0.0
B. External Pressure (See 5C-1-3/5.5)										
k_c	0.5	0.5	0.5	1.0	0.5	1.0	0.5	1.0	0.0	0.0
k_{f0}	-1.0	1.0	-1.0	1.0	-1.0	1.0	-1.0	1.0	0.0	0.0
C. Internal Tank Pressure (See 5C-1-3/5.7)										
k_c	0.4	0.4	1.0	0.5	1.0	0.5	1.0	0.5	0.0	0.0
w_v	0.75	-0.75	0.75	-0.75	0.25	-0.25	0.4	-0.4	0.0	0.0
w_ℓ	Fwd Bhd 0.25	Fwd Bhd -0.25	Fwd Bhd 0.25	Fwd Bhd -0.25	—	—	Fwd Bhd 0.2	Fwd Bhd -0.2	—	—
	Aft Bhd -0.25	Aft Bhd 0.25	Aft Bhd -0.25	Aft Bhd 0.25	—	—	Aft Bhd -0.2	Aft Bhd 0.2	—	—
w_t	—	—	—	—	Port Bhd -0.75	Port Bhd 0.75	Port Bhd -0.4	Port Bhd 0.4	—	—
	—	—	—	—	Stbd Bhd 0.75	Stbd Bhd -0.75	Stbd Bhd 0.4	Stbd Bhd -0.4	—	—
c_ϕ, Pitch	-1.0	1.0	-1.0	1.0	0.0	0.0	-0.7	0.7	0.0	0.0
c_θ, Roll	0.0	0.0	0.0	0.0	1.0	-1.0	0.7	-0.7	0.0	0.0
D. Reference Wave Heading and Motion of Vessel										
Heading Angle	0	0	0	0	90	90	60	60	—	—
Heave	Down	Up	Down	Up	Down	Up	Down	Up	—	—
Pitch	Bow Down	Bow Up	Bow Down	Bow Up	—	—	Bow Down	Bow Up	—	—
Roll	—	—	—	—	Stbd Down	Stbd Up	Stbd Down	Stbd Up	—	—

Notes:

1. k_u = 1.0 for all load components.
2. The sign convention for the shear force corresponds to the forward end of the middle hold.

TABLE 2
Load Cases for Sloshing *(1 July 2005)*

Type A: For Horizontal Girder on the Aft Side of Transverse Bulkhead

	Hull girder Loads [(1)]				*External Pressures*			*Sloshing Pressures* [(2)]		*Reference Wave Heading and Motions*			
	V.B.M. [*H.B.M.*	*V.S.F.* *H.S.F.*	k_w k_w	k_c k_c]	k_u	k_c	k_{fo}	k_u	k_c	*Heading Angle*	*Heave*	*Pitch*	*Roll*
LC S - 1	(–)	(+)	1.0	0.4	1.0	0.5	-1.0	1.0	1.0	60°	Down	Bow Down	Stbd Down
	[(–)	(+)	1.0	0.7]								-0.9	0.9
LC S - 2	(+)	(–)	1.0	0.4	1.0	1.0	1.0	1.0	1.0	60°	Up	Bow Up	Stbd Up
	[(+)	(–)	1.0	0.7]								0.9	-0.9

Type B: For Horizontal Girder on the Forward Side of Transverse Bulkhead

	Hull girder Loads [(1)]				*External Pressures*			*Sloshing Pressures* [(2)]		*Reference Wave Heading and Motions*			
	V.B.M. [*H.B.M.*	*V.S.F.* *H.S.F.*	k_w k_w	k_c k_c]	k_u	k_c	k_{fo}	k_u	k_c	*Heading Angle*	*Heave*	*Pitch*	*Roll*
LC S - 1	(–)	(+)	1.0	0.4	1.0	0.5	1.0	1.0	1.0	60°	Up	Bow Up	Stbd Up
	[(–)	(+)	1.0	0.7]								0.9	-0.9
LC S - 2	(+)	(–)	1.0	0.4	1.0	1.0	-1.0	1.0	1.0	60°	Down	Bow Down	Stbd Down
	[(+)	(–)	1.0	0.7]								-0.9	0.9

Notes:

1 For determining the total vertical bending moment for the above two load cases, 70% of the maximum designed still water bending moment may be used at the specified wave vertical bending moment station.

where:

V.B.M. is vertical wave bending moment

V.S.F. is vertical wave shear force

H.B.M. is horizontal wave bending moment

H.S.F. is horizontal wave shear force

2 The vertical distribution of the sloshing pressure P_{is} is shown in 5C-1-3/Figure 9.

TABLE 3
Design Pressure for Local and Supporting Members

A. Plating & Longitudinals/Stiffeners. *(1997)*
The nominal pressure, $p = |p_i - p_e|$, is to be determined from load cases "a" & "b" below, whichever is greater, with $k_u = 1.10$ and $k_c = 1.0$ unless otherwise specified in the table

	Case "a" – At fwd end of the tank				*Case "b" – At mid tank/fwd end of tank*			
			Coefficients				*Coefficients*	
Structural Members/ Components	*Draft/Wave Heading Angle*	*Location and Loading Pattern*	p_i	p_e	*Draft/Wave Heading Angle*	*Location and Loading Pattern*	p_i	p_e
1. Bottom Plating & Long'l	2/3 design draft/0°	Full ballast tank	A_i	A_e	design draft/0°	Midtank of empty ballast tanks	—	B_e
2. Inner Bottom Plating & Long'l	2/3 design draft/0°	Full ballast tank, cargo tanks empty	A_i	—	design draft/0°	Fwd end of full cargo tank, ballast tanks empty	A_i	—
3. Side Shell Plating & Long'l	2/3 design draft/60°	Starboard side of full ballast tank	B_i	A_e	design draft/60°	Midtank of empty ballast tanks	—	B_e
4. * Deck Plating & Long'l (Cargo Tank)	design draft/0°	Full cargo tank	D_i	—				
5. Deck Plating & Long'l (Ballast Tank)	2/3 design draft/0°	Full ballast tank	D_i	—				
6. * Inner Skin Long'l Bhd. Plating & Long'l	design draft/ 60°	Starboard side of full cargo tank, ballast tank empty	B_i	—	2/3 design draft/60°	Fwd. end and starboard side of full ballast tank, cargo tank empty	B_i	—
7. * Centerline Long'l Bhd. Plating & Long'l	design draft/ 60°	Full starboard cargo and ballast tanks, adjacent tank empty	E_i	—				
8. * Other Long'l Bhd. Plating & Long'l	design draft/ 60°	Starboard side of full inward cargo tanks, adjacent tank empty	B_i	—	design draft/60° *(1997)*	Fwd. end and starboard side of full outboard cargo tanks, adjacent tank empty	B_i	—
9. * Trans. Bhd. Plating & Stiffener (Cargo Tank)	design draft/0°	Fwd. bhd. of full cargo tank, adjacent tanks empty	A_i	—				
10. * Trans. Bhd. Plating & Stiffener (Ballast Tank)	2/3 design draft/0°	Fwd. bhd. of full ballast tank, adjacent tanks empty	A_i	—				

* See note 4

TABLE 3 (continued)
Design Pressure for Local and Supporting Members

B. Main Supporting Members

The nominal pressure, $p = |p_i - p_e|$, is to be determined at the mid-span of the structural member at starboard side of vessel from load cases "a" & "b" below, whichever is greater, with k_u = 1.0 and k_c = 1.0 unless otherwise specified in the table

	Case "a" – Mid-tank for Transverses				*Case "b" – Mid-tank for Transverses*			
Structural Members/ Components	*Draft/Wave Heading Angle*	*Location and Loading Pattern*	*Coefficients* p_i	*Coefficients* p_e	*Draft/Wave Heading Angle*	*Location and Loading Pattern*	*Coefficients* p_i	*Coefficients* p_e
11. Double Bottom Floor & Girder	2/3 design draft/0°	Full cargo tank, ballast tanks empty	A_i	A_e	design draft/0°	Mid-tank, cargo and ballast tanks empty	—	B_e
12. Side Transverse	2/3 design draft/60°	Wing cargo tanks full	B_i	—	design draft/60°	Center cargo tank full, wing cargo tanks empty	—	B_e
13. Transverse on Long'l. Bhd.:								
Tanker with C.L. Long'l, Bhd., without cross ties, (5C-1-4/ Figure 2A-b, 5C-1-4/Figure 2A-c):	2/3 design draft/60°	Starboard cargo tank full, port-empty	F_i	—				
Tanker with four Long'l. Bhds. with cross ties:								
Cross Ties in wing cargo tanks (5C-1-4/ Figure 2A-d)	2/3 design draft/90°	Center cargo tank full, wing cargo tanks empty	C_i	—	2/3 design draft/90°	Center cargo tank empty, wing cargo tanks full	G_i	—
Cross Tie in center cargo tank, (5C-1-4/ Figure 2A-e)	2/3 design draft/60°	Wing cargo tanks full, center cargo tank empty	F_i	—	2/3 design draft/60°	Center cargo tank full, wing cargo tanks empty	B_i	—
Tanker with four Long'l. Bhds. without cross ties, (5C-1-4/ Figure 2A-f)	2/3 design draft/60°	Wing cargo tanks full, center cargo tank empty	F_i	—	2/3 design draft/60°	Center cargo tank full, wing cargo tanks empty	C_i	—
14. Horizontal Girder and Vertical Web on Transverse Bulkhead	2/3 design draft/60°	Fwd Bhd. of full cargo tank, adjacent tanks empty	B_i	—				
15. Cross Ties: Cross Ties in wing cargo tanks (5C-1-4/Figure 2A-d)	2/3 design draft/90°	Center cargo tank full, wing cargo tanks empty	C_i	—	design draft/60°	Wing cargo tanks empty, center cargo tank full (starboard)	—	B_e
Cross tie in center cargo tank (5C-1-4/Figure 2A-e)	2/3 design draft/60°	Wing cargo tanks full, center cargo tank empty	F_i	—				

TABLE 3 (continued)
Design Pressure for Local and Supporting Members

B. Main Supporting Members

The nominal pressure, $p = |p_i - p_e|$, is to be determined at the mid-span of the structural member at starboard side of vessel from load cases "a" & "b" below, whichever is greater, with k_u = 1.0 and k_c = 1.0 unless otherwise specified in the table

	Case "a" – Mid-tank for Transverses				*Case "b" – Mid-tank for Transverses*			
Structural Members/ Components	*Draft/Wave Heading Angle*	*Location and Loading Pattern*	*Coefficients*		*Draft/Wave Heading Angle*	*Location and Loading Pattern*	*Coefficients*	
			p_i	p_e			p_i	p_e
16. Deck Transverses: Tanker without cross ties (5C-1-4/Figure 2A-a, 5C-1-4/ Figure 2A-b, 5C-1-4/Figure 2A-c & 5C-1-4/ Figure 2A-f) and, tankers with cross tie in center cargo tanks, (5C-1-4/ Figure 2A-e)	2/3 design draft/60°	Cargo tank full, adjacent tanks empty	B_i	—				
Tanker with cross ties in wing cargo tanks (5C-1-4/ Figure 2A-d)	2/3 design draft/90°	Cargo tank full, adjacent tanks empty	C_i	—				
17. Deck girders	2/3 design draft/0°	Cargo tank full, adjacent tanks empty	A_i	—	2/3 design draft/60°	Cargo tank full, adjacent tanks empty	B_i	—

TABLE 3 (continued)
Design Pressure for Local and Supporting Members *(2001)*

Notes

1 *(1 July 2005)* For calculating p_i and p_e, the necessary coefficients are to be determined based on the following designated groups:

a) For p_i

A_i: $w_v = 0.75$, w_ℓ(fwd bhd) = 0.25, w_ℓ(aft bhd) = –0.25, $w_t = 0.0$, $c_\phi = -0.35$, $c_\theta = 0.0$

B_i: $w_v = 0.4$, w_ℓ(fwd bhd) = 0.2, w_ℓ(aft bhd) = –0.2, w_t (starboard) = 0.4, w_t (port) = –0.4, $c_\phi = -0.3$, $c_\theta = 0.3$

C_i: $w_v = 0.25$, $w_\ell = 0$, w_t (starboard) = 0.75, w_t (port) = –0.75, $c_\phi = 0.0$, $c_\theta = 1.0$

D_i: $w_v = -0.75$, w_ℓ (fwd bhd) = 0.25, $w_t = 0.0$, $c_\phi = -0.35$, $c_\theta = 0.0$

E_i: $w_v = 0.4$, w_ℓ (fwd bhd) = 0.2, w_t (centerline) = 0.4, $c_\phi = -0.3$, $c_\theta = -0.3$

F_i: $w_v = 0.4$, w_ℓ (fwd bhd) = 0.2, w_ℓ (aft bhd) = –0.2, w_t (starboard) = –0.4, w_t (port) = 0.4, $c_\phi = -0.3$, $c_\theta = -0.3$

G_i: $w_v = 0.25$, $w_\ell = 0$, w_t (starboard) = –0.75, w_t (port) = 0.75, $c_\phi = 0.0$, $c_\theta = -1.0$

b) For p_e

A_e: $k_{\ell o} = 1.0$, $k_u = 1.0$, $k_c = -0.5$

B_e: $k_{\ell o} = 1.0$

2 *(1997)* For structures within 0.4L amidships, the nominal pressure is to be calculated for a tank located amidships. Each cargo tank or ballast tank in the region should be considered as located amidships, as shown in 5C-1-3/Figure 8.

3 *(1 July 2000)* In calculation of the nominal pressure, $\rho\, g$ of the fluid cargoes is not to be taken less than 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf/in^2-ft).

4 For structural members 4 and 6 to 10, sloshing pressures are to be considered in accordance with 5C-1-3/11.3. For calculation of sloshing pressures, refer to 5C-1-3/11.5 with $\rho\, g$ not less than 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf/in^2-ft).

7 Nominal Design Loads *(1995)*

7.1 General

The nominal design loads specified below are to be used for determining the required scantlings of hull structures in conjunction with the specified permissible stresses given in Section 5C-1-4.

7.3 Hull Girder Loads – Longitudinal Bending Moments and Shear Forces *(1995)*

7.3.1 Total Vertical Bending Moment and Shear Force

The total longitudinal vertical bending moments and shear forces may be obtained from the following equations:

$$M_t = M_{sw} + k_u k_c M_w \quad \text{kN-m (tf-m, Ltf-ft)}$$

$$F_t = F_{sw} + k_u k_c F_w \quad \text{kN (tf, Ltf)}$$

where

M_{sw} and M_w are the still-water bending moment and wave-induced bending moment, respectively, as specified in 3-2-1/3.7 for either hogging or sagging conditions.

F_{sw} and F_w are the still-water and wave-induced shear forces, respectively, as specified in 3-2-1/3.9 for either positive or negative shears.

k_u is a load factor and may be taken as unity unless otherwise specified

k_c is a correlation factor and may be taken as unity unless otherwise specified.

For determining the hull girder section modulus for 0.4L amidships, as specified in 5C-1-4/3, the maximum still-water bending moments, either hogging or sagging, are to be added to the hogging or sagging wave bending moments, respectively. Elsewhere, the total bending moment may be directly obtained based on the envelope curves, as specified in 5C-1-3/3.1 and 5C-1-3/5.1.

For this purpose, k_u = 1.0, and k_c = 1.0

7.3.2 Horizontal Wave Bending Moment and Shear Force

For non-head sea conditions, the horizontal wave bending moment and the horizontal shear force, as specified in 5C-1-3/5.3, are to be considered as additional hull girder loads, especially for the design of the side shell and inner skin structures. The effective horizontal bending moment and shear force, M_{HE} and F_{HE}, may be determined by the following equations:

$$M_{HE} = k_u k_c M_H \quad \text{kN-m (tf-m, Ltf-ft)}$$

$$F_{HE} = k_u k_c F_H \quad \text{kN (tf, Ltf)}$$

where k_u and k_c are a load factor and a correlation factor, respectively, which may be taken as unity unless otherwise specified.

7.5 Local Loads for Design of Supporting Structures *(1 July 2000)*

In determining the required scantlings of the main supporting structures, such as girders, transverses, stringers, floors and deep webs, the nominal loads induced by the liquid pressures distributed over both sides of the structural panel within the tank boundaries should be considered for the worst possible load combinations. In general, considerations should be given to the following two loading cases accounting for the worst effects of the dynamic load components.

i) Maximum internal pressures for a fully filled tank with the adjacent tanks empty and minimum external pressures, where applicable.

ii) Empty tank with the surrounding tanks full and maximum external pressures, where applicable.

Taking the side shell supporting structure as an example, the nominal loads may be determined from either:

i) $p_i = k_s \rho g (\eta + k_u h_d)$ max. and

$p_e = \rho g (h_s + k_u h_{de})$ min.

ii) $p_i = 0$ and

$p_e = \rho g (h_s + k_u h_{de})$ max.

where

$k_u = 1.0$

ρg, η, h_d, h_s, h_{de}, k_s are as defined in 5C-1-3/5.5 and 5C-1-3/5.7.

Specific information required for calculating the nominal loads are given in 5C-1-3/Table 3 for various structural members and configurations.

7.7 Local Pressures for Design of Plating and Longitudinals *(1995)*

In calculating the required scantlings of plating, longitudinals and stiffeners, the nominal pressures should be considered for the two load cases given in 5C-1-3/7.5, using $k_u = 1.1$ for p_i and p_e instead of $k_u = 1.0$ as shown above.

The necessary details for calculating p_i and p_e are given in 5C-1-3/Table 3.

9 Combined Load Cases

9.1 Combined Load Cases for Structural Analysis *(2001)*

For assessing the strength of the hull girder structure and in performing a structural analysis as outlined in Section 5C-1-5, the eight combined load cases specified in 5C-1-3/Table 1 are to be considered. Additional combined load cases may be required as warranted. The loading patterns are shown in 5C-1-3/Figure 1 for three cargo tank lengths. The necessary correlation factors and relevant coefficients for the loaded tanks are also given in 5C-1-3/Table 1. The total external pressure distribution including static and hydrodynamic pressure is illustrated in 5C-1-3/Figure 6.

9.3 Combined Load Cases for Failure Assessment *(1995)*

For assessing the failure modes with respect to material yielding, buckling and ultimate strength, the following combined load cases shall be considered.

9.3.1 Ultimate Strength of Hull Girder

For assessing ultimate strength of the hull girder, the combined effects of the following primary and local loads are to be considered.

9.3.1(a) Primary Loads, Longitudinal Bending Moments in Head Sea Conditions. ($M_H = 0$, $F_H = 0$)

$M_t = M_s + k_u k_c M_w$, $k_u = 1.15$, $k_c = 1.0$ hogging and sagging

$F_t = F_s + k_u k_c F_w$, $k_u = 1.15$, $k_c = 1.0$ positive and negative

9.3.1(b) Local Loads for Large Stiffened Panels. Internal and external pressure loads as given for L.C. No. 1 and L.C. No. 2 in 5C-1-3/Table 1.

9.3.2 Yielding, Buckling and Ultimate Strength of Local Structures

For assessing the yielding, buckling and ultimate strength of local structures, the eight combined load cases as given in 5C-1-3/Table 1 are to be considered.

9.3.3 Fatigue Strength

For assessing the fatigue strength of structural joints, the eight combined load cases given in 5C-1-3/9.1 are to be used for a first level fatigue strength assessment as outlined in Appendix 5C-1-A1 "Guide for the Fatigue Assessment of Tankers."

11 Sloshing Loads

11.1 General *(1995)*

11.1.1 *(2002)*

Except for tanks that are situated wholly within the double side or double bottom, the natural periods of liquid motions and sloshing loads are to be examined in assessing the strength of boundary structures for all cargo or ballast tanks which will be partially filled between 20% and 90% of tank capacity. The sloshing pressure heads given in this subsection may be used for determining the strength requirements for the tank structures. Alternatively, sloshing loads may be determined by model experiments or by numerical simulation using three dimensional flow analysis. Methodology and procedures of tests and measurements or analysis methods are to be fully documented and referenced. They are to be submitted for review.

11.1.2

The effects of impulsive sloshing pressures on the design of the main supporting structures of tank transverse and longitudinal bulkheads will be subject to special consideration.

11.3 Strength Assessment of Tank Boundary Structures

11.3.1 Tank Length and Pitch Induced Sloshing Loads *(2002)*

Tanks of length 54 m (177 ft) or greater are to satisfy requirements of either of the preventative measures given in 5C-1-3/11.3.3 or 5C-1-3/11.3.4. Where the tank has smooth surfaces, one or more swash bulkheads are to be fitted. Structural reinforcement is to be provided to the tank ends, when the calculated pressure is higher than the pressure, p_i, as specified in 5C-1-4/13.

Tanks of length 54 m (177 ft) or greater that have ring webs are to have a partial non-tight bulkhead (i.e. non-full depth swash bulkhead) to eliminate the possibility of resonance at all filling levels. The partial non-tight bulkhead may be waived if it can be demonstrated through the application of model experiments or numerical simulation using three-dimensional flow analysis that sloshing impacts do not occur. The height of the swash bulkhead is to be determined on the basis of calculation using three-dimensional flow analysis as described in 5C-1-3/11.1.1

Where the tank length is less than 54 m (177 ft), and if either of the preventative measures given in 5C-1-3/11.3.3 or 5C-1-3/11.3.4 is not satisfied, the tank boundary structures are to be designed in accordance with 5C-1-4/13 to withstand the sloshing pressures specified in 5C-1-3/11.5.

11.3.2 Roll Induced Sloshing Loads *(2002)*

Tanks that do not satisfy either of the preventative measures given in 5C-1-3/11.3.3 or 5C-1-3/11.3.4, with respect of roll resonance, are to have their tank boundary structures designed in accordance with 5C-1-4/13 to withstand the sloshing pressures specified in 5C-1-3/11.5.

11.3.3 *(1997)*

For long or wide cargo tanks, non-tight bulkheads or ring webs or both are to be designed and fitted to eliminate the possibility of resonance at all filling levels.

Long tanks have length, ℓ, exceeding $0.1L$. Wide tanks have width, b, exceeding $0.6B$.

11.3.4

For each of the anticipated loading conditions, the "critical" filling levels of the tank should be avoided so that the natural periods of fluid motions in the longitudinal and transverse directions will not synchronize with the natural periods of the vessel's pitch and roll motions, respectively. It is further recommended that the natural periods of the fluid motions in the tank, for each of the anticipated filling levels, be at least 20% greater or smaller than that of the relevant ship's motion.

The natural period of the fluid motion, in seconds, may be approximated by the following equations:

$T_x = (\beta_T \ell_e)^{1/2}/k$ in the longitudinal direction

$T_y = (\beta_L b_e)^{1/2}/k$ in the transverse direction

where

ℓ_e = effective length of the tank, as defined in 5C-1-3/11.5.1, in m (ft)

b_e = effective breadth of the tank, as defined in 5C-1-3/11.5.1 in m (ft)

$k = [(\tanh H_1)/(4\pi/g)]^{1/2}$

$H_1 = \pi d_\ell/\ell_e$ or $\pi d_b/b_e$

β_T, β_L, d_ℓ and d_b are as defined in 5C-1-3/11.5.1. The natural periods given in 5C-1-3/5.7 for pitch and roll of the vessel, T_p and T_r, using the actual GM value, if available, may be used for this purpose.

11.5 Sloshing Pressures *(1995)*

11.5.1 Nominal Sloshing Pressure *(1 July 2005)*

For cargo tanks with filling levels within the critical range specified in 5C-1-3/11.3.2, the internal pressures p_{is}, including static and sloshing pressures, positive toward tank boundaries, may be expressed in terms of equivalent liquid pressure head, h_e, as given below:

$p_{is} = k_s \rho g h_e \geq 0$ in N/cm^2 (kgf/cm^2, lbf/in^2)

where

k_s = load factor as defined in 5C-1-3/5.7.2(a)

$h_e = c_m h_m + k_u h_c$ for y below filling level d_m ($c_m h_m$ need not exceed h and h_e need not exceed h_e calculated at $y = 0.15$ for y below $0.15h$)

$= k_u[h_c + (h_t - h_c)(y - d_m)/(h - d_m)]$ for y above d_m

c_m = coefficient in accordance with 5C-1-3/Figure 10

h_m = static head, taken as the vertical distance, in m (ft), measured from the filling level, d_m, down to the point considered. d_m, the filling level for maximum h_c calculated with $C_{\phi s}$ and $C_{\theta s}$ equal to 1.0, should not be taken less than 0.55h.

d_m = filling level, in m (ft), as shown in 5C-1-3/Figure 9

k_u = load factor, and may be taken as unity unless otherwise specified.

h_c = maximum average sloshing pressure heads, in m (ft), to be obtained from calculations as specified below for at least two filling levels, 0.55h and the one closest to the resonant period of ship's motions, between 0.2h and 0.9h. h_c may be taken as constant over the tank depth, h (See 5C-1-3/Figure 9)

h_t = sloshing pressure heads for upper bulkhead, in m (ft), to be obtained from calculation below

h = depth of tank, in m (ft)

y = distance, in m (ft), measured from the tank bottom to the point considered

ρg is as defined in 5C-1-3/5.7.2.

The values of h_c and h_t may be obtained from the following equations:

$$h_c = k_c\,(C_{\phi s}\, h_\ell^2 + C_{\theta s}\, h_b^2)^{1/2} \qquad \text{in m (ft)}$$

$$h_t = k_c\,(C_{\phi s}\, h_{t\ell}^2 + C_{\theta s}\, h_{tb}^2)^{1/2} \qquad \text{in m (ft)}$$

where

k_c = correlation factor for combined load cases, and may be taken as unity unless otherwise specified.

h_ℓ = $\phi_{es}\ell_e C_{t\ell}\beta_T[0.018 + C_{f\ell}(1.0 - d_\ell/H_\ell)/\phi_{es}]d_\ell/H_\ell$ m (ft)

h_b = $\theta_{es}b_e C_{tb}\beta_L[0.016 + C_{fb}(1.0 - d_b/H_b)/\theta_{es}]d_b/H_b$ m (ft)

$C_{\phi s}$ and $C_{\theta s}$ are the weighted coefficients as given in 5C-1-3/Figure 10.

where

β_T represents β for transverse bulkheads and β_L represents β for the longitudinal bulkheads.

ϕ_{es} = $0.71\, c_\phi\, \phi$

θ_{es} = $0.71\, c_\theta\, \theta$

ϕ and θ are as defined in 5C-1-3/5.7.1.

ℓ_e = effective tank length that accounts for the effect of deep ring-web frames, in m (ft)

= $\beta_T^{*2}\,\ell$

b_e = effective tank width that accounts for the effect of deep ring-web frames, in m (ft)

= $\beta_L^{*2}\,b$

β^* = 1.0 for tanks without deep ring webs,

= $0.25[4.0 - (1 - \alpha^*) - (1 - \alpha^*)^2]$ for α^* to be determined at d_o,

β_T^* represents β^* for transverse bulkheads.

β_L^* represents β^* for longitudinal bulkheads.

β = $(\beta_o)(\beta_s) \geq 0.5$

β_T represents β for transverse bulkheads.

β_L represents β for longitudinal bulkheads.

β_o = 1.0 for tanks without a swash bulkhead

= $0.25[4.0 - (1 - \alpha_o) - (1 - \alpha_o)^2]$ for tanks with a swash bulkhead

β_s = 1.0 for boundary bulkheads that:

i) do not contain any deep horizontal girder; or

ii) do contain deep horizontal girders but with an opening ratio, α_s, less than 0.2 or greater than 0.4

= $0.25[4.0 - (1 - \alpha_s) - (1 - \alpha_s)^2]$ for bulkheads with deep horizontal girders having an opening ratio, α_s, between 0.2 and 0.4

α = opening ratio (see 5C-1-3/Figure 11)

For α_o 5C-1-3/Figure 12(1), opening ratios of swash bulkheads, shall be used for all filling levels considered. Also, 5C-1-3/Figure 12(2), local opening ratio for $d_o = 0.7h$, bounded by the range between $0.6h$ and $0.9h$, shall be considered for openings within the range. The smaller of the two opening ratios calculated, based on 5C-1-3/Figure 12(1) and 5C-1-3/Figure 12(2) for this filling level, shall be used as the opening ratio.

For α^*, 5C-1-3/Figure 12(3), opening ratio of deep ring-webs, filling level d_o shall be used.

For α_s, 5C-1-3/Figure 12(4), opening ratio of a deep horizontal girder on a boundary bulkhead, is applicable to a filling level just above the horizontal girder in the zones illustrated in the figure. Not to be considered for $d_o = 0.7h$, unless a sizable girder is installed between $0.7h$ and h. Also not to be considered if opening area in the girder is less than 20% or greater than 40% of the area of the girder (i.e., $\alpha_s = 1$)

$C_{f\ell}$ = $0.792[d_\ell/(\beta_T \ell_e)]^{1/2} + 1.98$

C_{fb} = $0.704[d_b/(\beta_L b_e)]^{1/2} + 1.76$

$C_{t\ell}$ = $0.9\, x_{o1}/[1 + 9(1 - x_o)^2] \geq 0.25$

x_o = T_x/T_p

x_{o1} = x_o if $x_o \leq 1.0$

= $1/x_o$ if $x_o > 1.0$

C_{tb} = $0.9\, y_{o1}/[1 + 9(1 - y_o)^2] \geq 0.25$

y_o = T_y/T_r. If roll radius of gyration is not known, $0.39B$ may be used in the calculation of T_r

y_{o1} = y_o if $y_o \leq 1.0$

= $1/y_o$ if $y_o > 1.0$

T_x and T_y are as defined in 5C-1-3/11.3.4.

T_p and T_r are as defined in 5C-1-3/5.7.

d_o = filling depth, in m (ft)

d_ℓ = $d_o - d_{\ell 1}[(n/(n+4)]^{1/2} - 0.45 d_{\ell 2}$, and ≥ 0.0

d_b = $d_o - d_{b1}[m/(m+4)]^{1/2} - 0.45 d_{b2}$, and ≥ 0.0

H_ℓ = $h - d_{\ell 1}[n/(n+4)]^{1/2} - 0.45 d_{\ell 2}$

H_b = $h - d_{b1}[m/(m+4)]^{1/2} - 0.45 d_{b2}$

$d_{\ell 1}$ = height of deep bottom transverses measured from the tank bottom, (5C-1-3/Figure 13), in m (ft)

$d_{\ell 2}$ = bottom height of the lowest openings in non-tight transverse bulkhead measured above the tank bottom or top of bottom transverses (5C-1-3/Figure 13), in m (ft)

n = number of deep bottom transverses in the tank

d_{b1} = height of deep bottom longitudinal girders measured from the tank bottom (5C-1-3/Figure 13), in m (ft)

d_{b2} = bottom height of the lowest openings in non-tight longitudinal bulkhead measured above the tank bottom, or top of bottom longitudinal girders (5C-1-3/Figure 13), in m (ft)

m = number of deep bottom longitudinal girders in the tank

ℓ_s (b_s) shall be used in place of ℓ_e (b_e) for a filling level below the completely solid portion of the nontight bulkhead, i.e., the region below the lowest opening, (5C-1-3/Figure 13), where ℓ_s (b_s) is taken as the distance bounded by the solid portion of the nontight bulkhead below the lowest opening and the tight bulkhead. d_ℓ, H_ℓ and d_b, H_b need not consider the effect of $d_{\ell 2}$ and d_{b2}, respectively.

$$h_{tl} = 0.0068\, \beta'_T\, \ell_e\, C'_{t\ell}\, (\phi_{es} + 40)\, (\phi_{es})^{1/2} \qquad \text{m (ft)}$$

$$h_{tb} = 0.0055\, \beta'_L\, b_e\, C'_{tb}\, (\theta_{es} + 35)\, (\theta_{es})^{1/2} \qquad \text{m (ft)}$$

where

$C'_{t\ell}$ and C'_{tb} are $C_{t\ell}$ and C_{tb} for $h_m = 0.70h$; β'_T and β'_L correspond to β for $d_o = 0.7h$; ϕ_{es} and θ_{es} are as defined previously.

$C_{\phi s}$ and $C_{\theta s}$ are weighted coefficients, as given in 5C-1-3/Figure 10.

h_{tl} shall not be less than h_p; h_{tb} shall not be less than h_r

h_p = $\ell \sin(\phi_{es})$

h_r = $b \sin(\theta_{es})$

11.5.2 Sloshing Loads for Assessing Strength of Structures at Tank Boundaries

11.5.2(a) In assessing the strength of tank boundary supporting structures, the two combined load cases with loading pattern shown in 5C-1-3/Figure 14, with the specified sloshing loads shown in 5C-1-3/Table 2 for the respective side on which the horizontal girder is located, are to be considered when performing a 3D structural analysis.

11.5.2(b) In assessing the strength of plating and stiffeners at tank boundaries, local bending of the plating and stiffeners with respect to the local sloshing pressures for structural members/elements is to be considered in addition to the nominal loadings specified for the 3D analysis in 5C-1-3/11.5.2(a) above. In this regard, k_u should be taken as 1.15 instead of 1.0, shown in 5C-1-3/11.5.2(a) above for the combined load cases, to account for the maximum pressures due to possible non-uniform distribution.

11.5.3 Sloshing Loads Normal to the Web Plates of Horizontal and Vertical Girders

In addition to the sloshing loads acting on the bulkhead plating, the sloshing loads normal to the web plates of horizontal and vertical girders are to be also considered for assessing the strength of the girders. The magnitude of the normal sloshing loads may be approximated by taking 25% of h_c or h_t for k_u = 1.0, whichever is greater, at the location considered.

FIGURE 9
Vertical Distribution of Equivalent Slosh Pressure Head, h_e *(1995)*

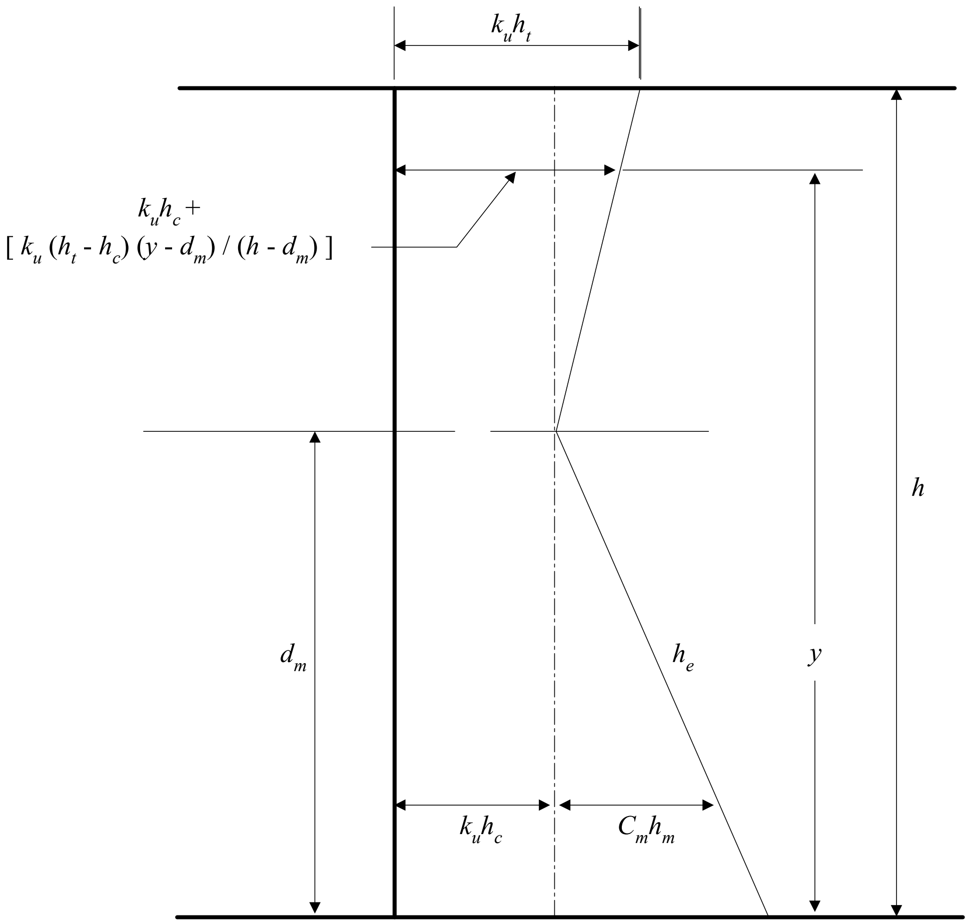
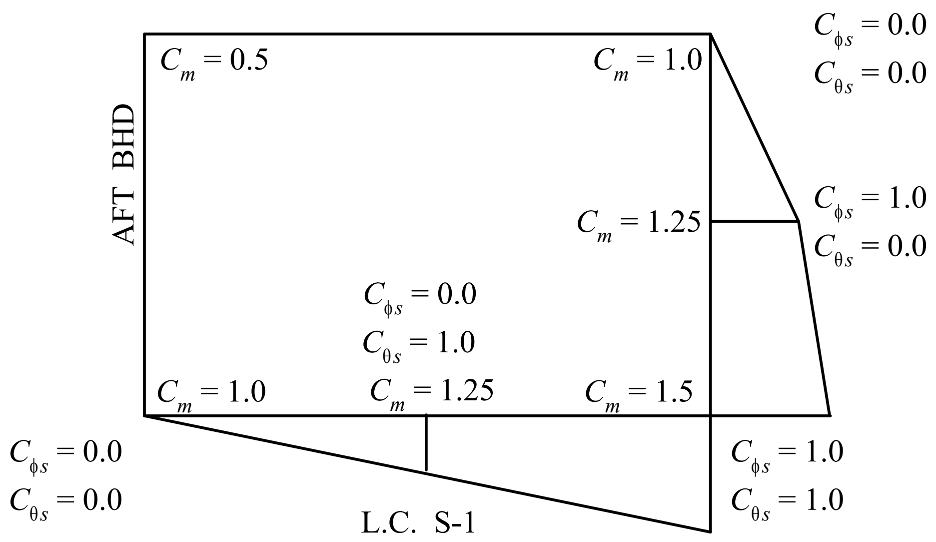
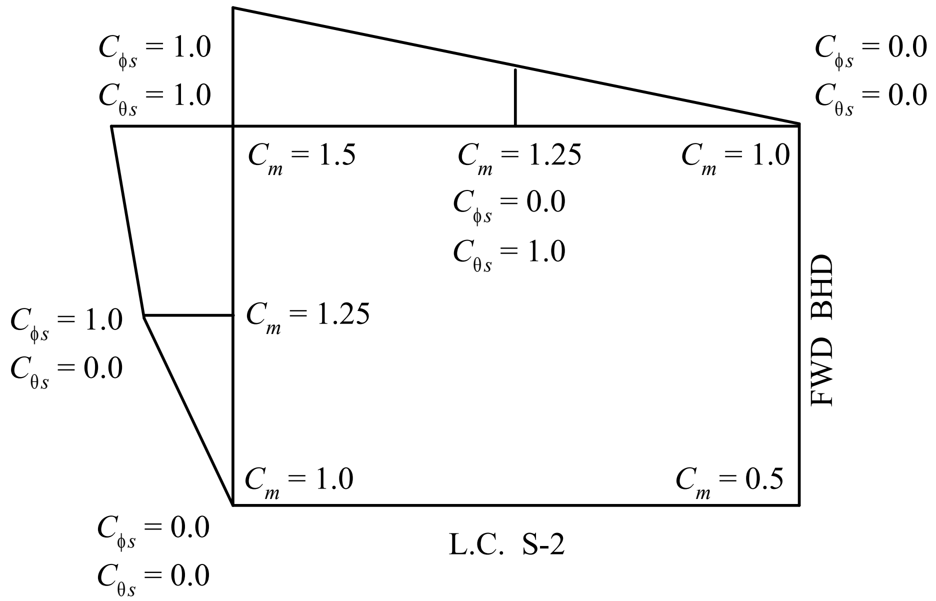


FIGURE 10
Horizontal Distribution of Simultaneous Slosh Pressure Heads, h_c (ϕ_s θ_s) or h_t (ϕ_s θ_s) *(1995)*





Note: h_c may be taken as zero for the deck and inner bottom

FIGURE 11
Definitions for Opening Ratio, α *(1995)*

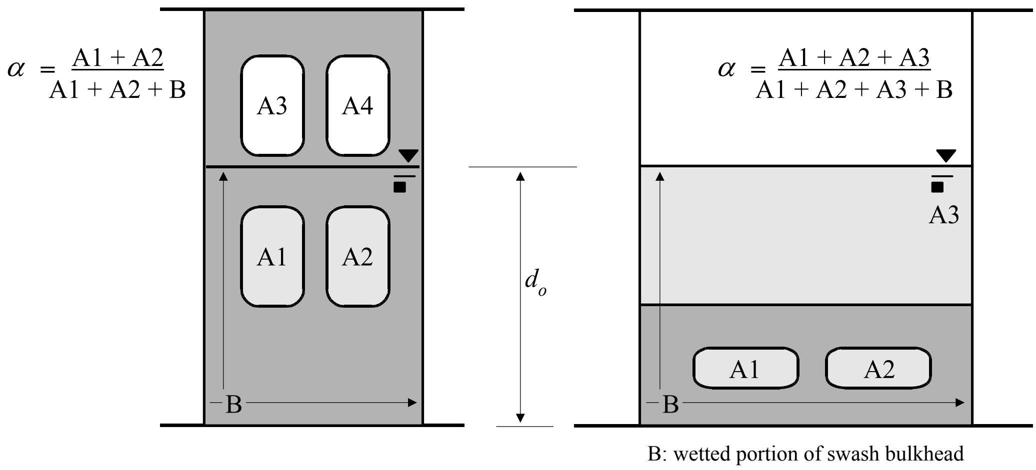
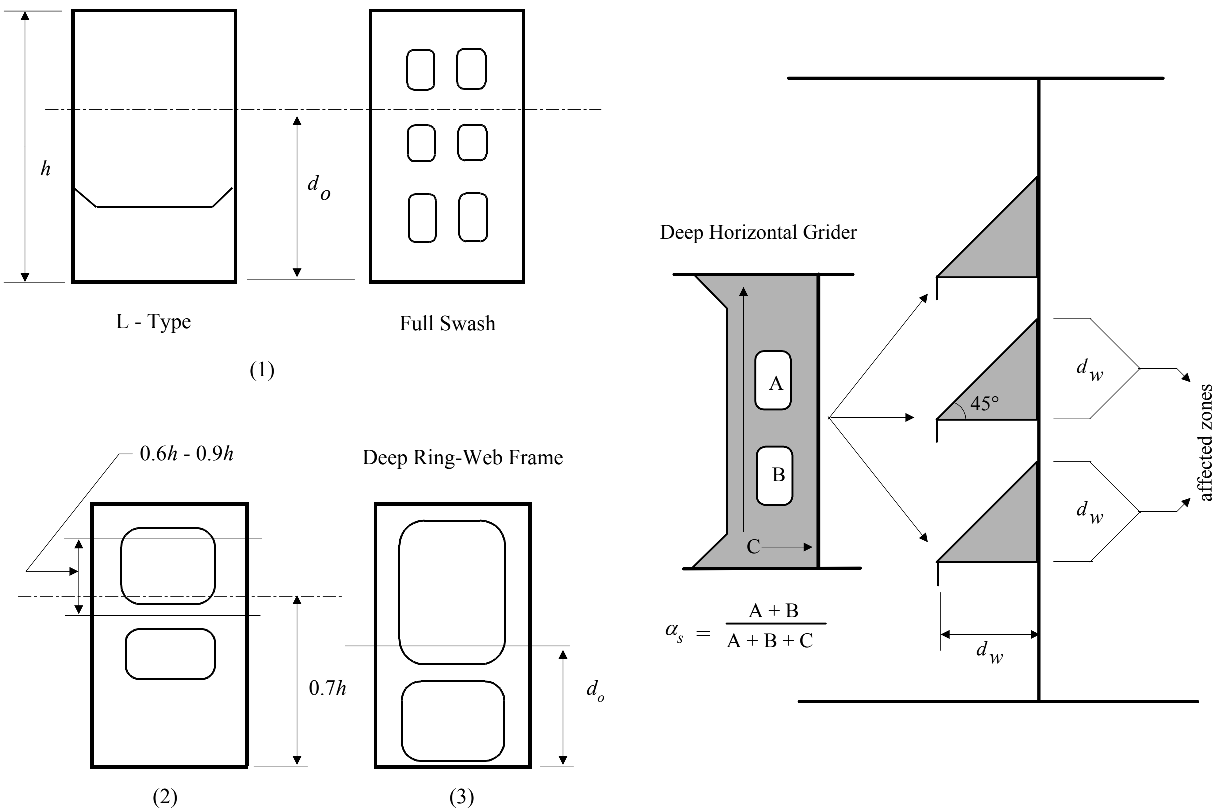


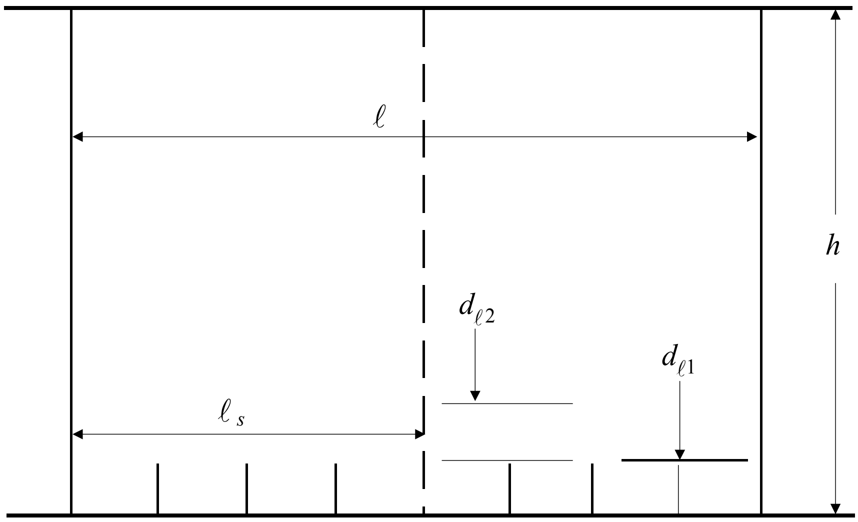
FIGURE 12
Opening Ratios *(1995)*



(1) – (3) Opening Ratios of Nontight Bulkheads and Deep Ring-Webs

(4) Opening Ratio of Deep Horizontal Girders Boundary Bulkheads

FIGURE 13
Dimensions of Internal Structures *(1995)*



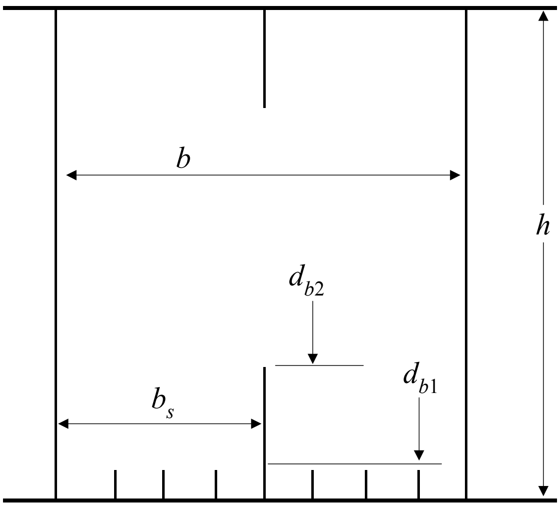
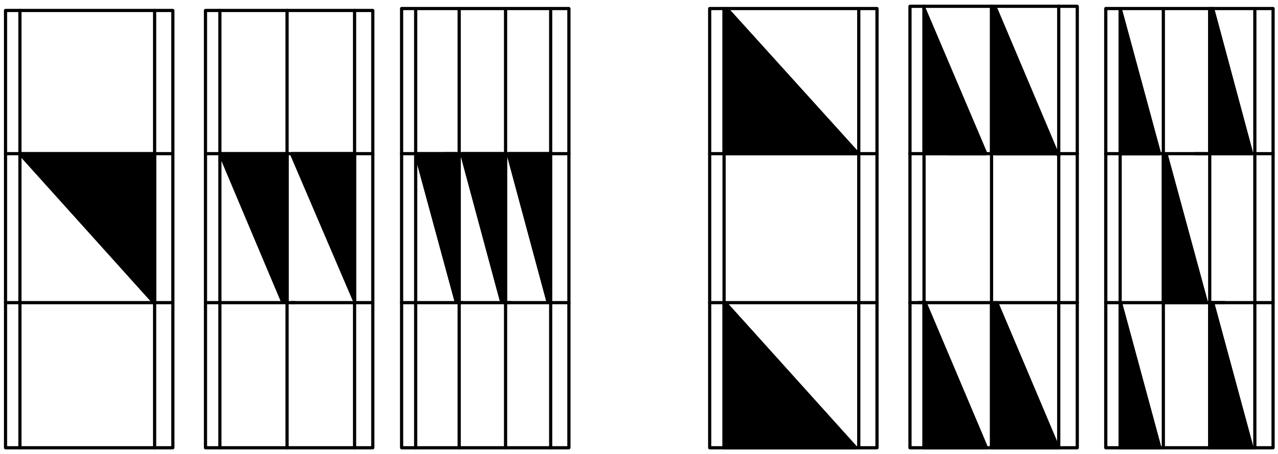


FIGURE 14
Loading Patterns for Sloshing Loads Cases *(1997)*

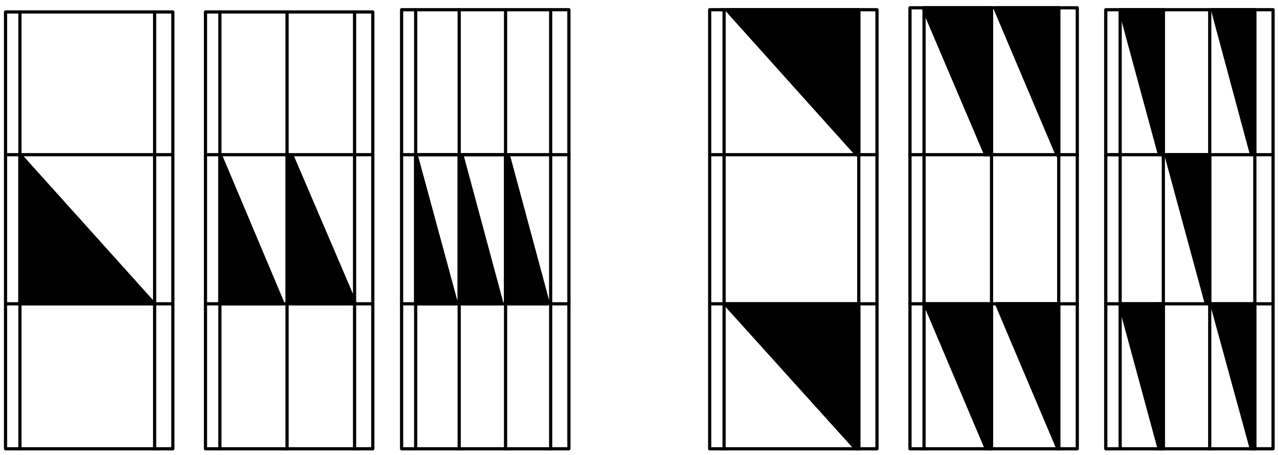
Type A: Where the Horizontal Girder is on the Aft Side of Transverse Bulkhead



a. Load Case S-1; 1/2 Design Draft

b. Load Case S-2; 1/2 Design Draft

Type B: Where the Horizontal Girder is on the Forward Side of Transverse Bulkhead



a. Load Case S-1; 1/2 Design Draft

b. Load Case S-2; 1/2 Design Draft

13 Impact Loads *(2000)*

13.1 Impact Loads on Bow *(2000)*

For tankers possessing significant bowflare or with a heavy ballast draft forward less than 0.04L, the bowflare and/or bottom slamming loads are to be considered for assessing the strength of the side and bottom plating and associated stiffening system in the forebody region.

13.1.1 Bow Pressure

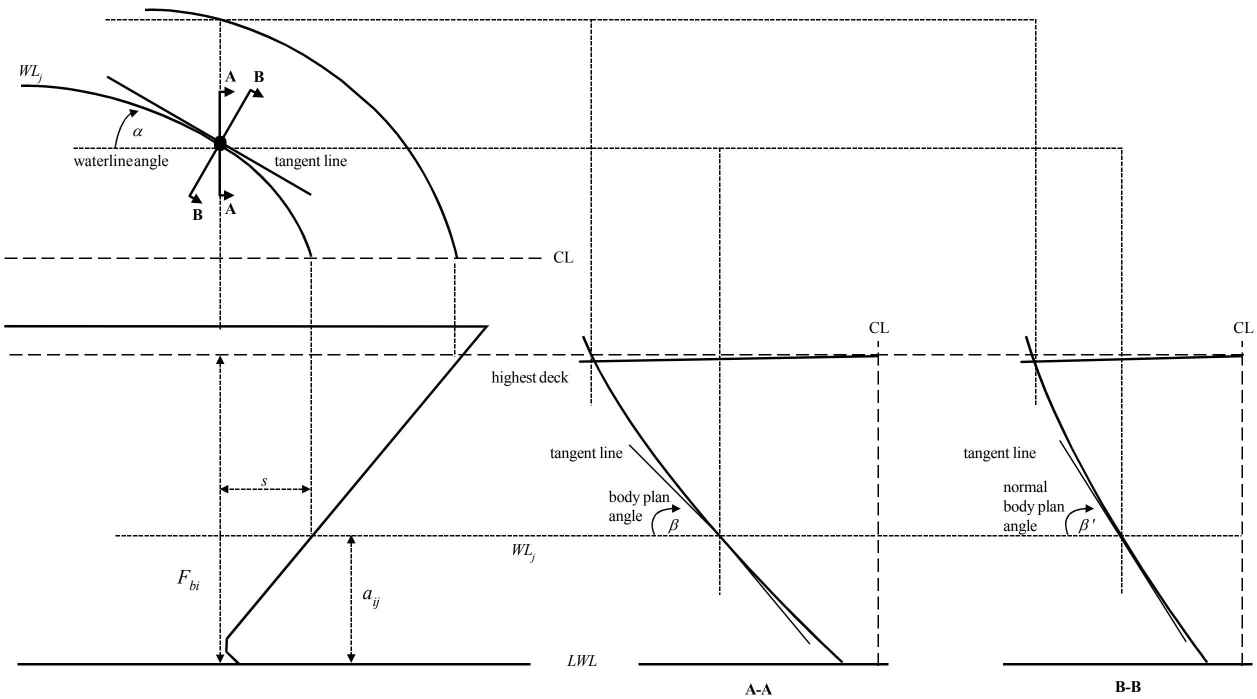
When experimental data or direct calculation are not available, nominal wave-induced bow pressures above LWL in the region from the forward end to the collision bulkhead may be obtained from the following equation:

$$P_{bij} = kC_k C_{ij} V_{ij}^2 \sin \gamma_{ij} \quad \text{kN/m}^2 \text{ (tf/m}^2\text{, Ltf/ft}^2\text{)}$$

where

k	=	1.025 (0.1045, 0.000888)
C_{ij}	=	$\{1 + \cos^2 [90(F_{bi} - 2a_{ij})/F_{bi}]\}^{1/2}$
V_{ij}	=	$\omega_1 V \sin \alpha_{ij} + \omega_2 (L)^{1/2}$
ω_1	=	0.515 (1.68) for m (ft)
ω_2	=	1.0 (1.8)
V	=	75% of the design speed, V_d, in knots. V is not to be taken less than 10 knots. V_d is defined in 3-2-14/3.1.
γ_{ij}	=	local bow angle measured from the horizontal, not to be taken less than 50°
	=	$\tan^{-1} (\tan \beta_{ij}/\cos \alpha_{ij})$
α_{ij}	=	local waterline angle measured from the centerline, see 5C-1-3/Figure 15, not to be taken less than 35°
β_{ij}	=	local body plan angle measure from the horizontal, see 5C-1-3/Figure 15, not to be taken less than 35°
F_{bi}	=	freeboard from the highest deck at side to the load waterline (LWL) at station i, see 5C-1-3/Figure 15
a_{ij}	=	vertical distance from the LWL to WL_j, see 5C-1-3/Figure 15
C_k	=	0.7 at collision bulkhead and 0.9 at 0.0125L, linear interpolation for in between
	=	0.9 between 0.0125L and the FP
	=	1.0 at and forward of the FP
i, j	=	station and waterline, to be taken to correspond to the locations as required by 5C-1-6/3.1.1

FIGURE 15
Definition of Bow Geometry *(1 July 2008)*



13.3 Bottom Slamming *(2002)*

For tankers with heavy ballast draft forward less than $0.04L$ but greater than $0.025L$, bottom slamming loads are to be considered for assessing strength of the flat of bottom plating forward and the associated stiffening system in the fore body region. For this assessment, the heavy ballast draft forward is to be determined by using segregated ballast tanks only.

13.3.1 Bottom Slamming Pressure

The equivalent bottom slamming pressure for strength formulation and assessment should be determined based on well-documented experimental data or analytical studies. When these direct calculations are not available, nominal bottom slamming pressures may be determined by the following equations:

$$P_{si} = kk_i [v_o^2 + M_{Vi}E_{ni}]E_f \qquad \text{kN/m}^2 \text{ (tf/m}^2\text{, Ltf/ft}^2\text{)}$$

where

P_{si} = equivalent bottom slamming pressure for section i

k = 1.025 (0.1045, 0.000888)

k_i = $2.2\, b^*/d_o + \alpha \leq 40$

b^* = half width of flat of bottom at the i-th ship station, see 5C-1-3/Figure 16

d_o = $^1/_{10}$ of the section draft at the heavy ballast condition, see 5C-1-3/Figure 16

α = a constant as given in 5C-1-3/Table 4

E_f = $f_1\, \omega_1\, (L)^{1/2}$

f_1 = 0.004 (0.0022) for m (ft)

where b represents the half breadth at the $^1/_{10}$ draft of the section, see 5C-1-3/Figure 16. Linear interpolation may be used for intermediate values.

V = 75% of the design speed V_d in knots. V is not to be taken less than 10 knots

v_o = $c_o(L)^{1/2}$, in m/s (ft/s)

c_o = 0.29 (0.525) for m (ft)

L = vessel's length as defined in 3-1-1/3.1

M_{Ri} = $c_1 A_i(VL/C_b)^{1/2}$

c_1 = 0.44 (2.615) for m (ft)

M_{Vi} = $B_i M_{Ri}$

A_i and B_i are as given in 5C-1-3/Table 5.

G_{ei} = $e^{[-(v_o^2 / M_{Vi} + d_i^2 / M_{Ri})]}$

d_i = local section draft, in m (ft)

E_{ni} = natural log of n_i

n_i = $5730(M_{Vi}/M_{Ri})^{1/2}\, G_{ei}$, if $n_i < 1$ then $P_{si} = 0$

ω_1 = natural angular frequency of the hull girder 2-node vertical vibration of the vessel in the wet mode and the heavy ballast draft condition, in rad/second. If not known, the following equation may be used:

= $\mu\, [B\, D^3/(\varDelta_S\, C_b^3\, L^3)]^{1/2} + c_o \quad \geq 3.7$

where

μ = 23400 (7475, 4094)

$\varDelta_S$ = $\varDelta_b[1.2 + B/(3d_b)]$

$\varDelta_b$ = vessel displacement at the heavy ballast condition, in kN (tf, Ltf)

d_b = mean draft of vessel at the heavy ballast condition, in m (ft)

c_o = 1.0 for heavy ballast draft

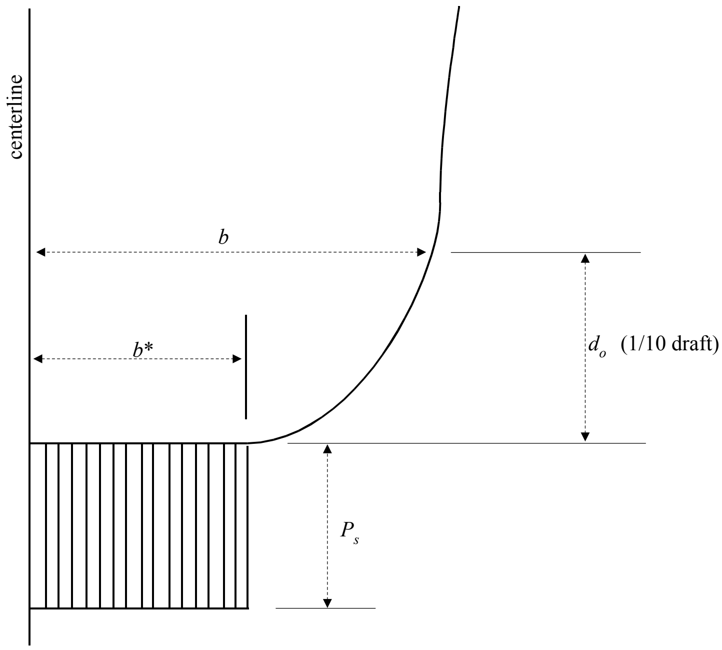
L, B and D are as defined in Section 3-1-1.

C_b is as defined in 3-2-1/3.5.

TABLE 4
Values of α *(2000)*

b/d_o	α	b/d_o	α
1.00	0.00	4.00	20.25
1.50	9.00	5.00	22.00
2.00	11.75	6.00	23.75
2.50	14.25	7.00	24.50
3.00	16.50	7.50	24.75
3.50	18.50	25.0	24.75

FIGURE 16
Distribution of Bottom Slamming Pressure Along the Section Girth *(2000)*



13.5 Bowflare Slamming *(2000)*

For vessels possessing bowflare and having a shape parameter A_r greater than 21 m (68.9 ft), in the forebody region, bowflare slamming loads are to be considered for assessing the strength of the side plating and the associated stiffening system in the forebody region of the vessel at its scantling draft.

A_r = the maximum value of A_{ri} in the forebody region

A_{ri} = bowflare shape parameter at a station i forward of the quarter length, up to the FP of the vessel, to be determined between the load waterline (LWL) and the upper deck/forecastle, as follows:

= $(b_T/H)^2 \ \sum b_j[1 + (s_j/b_j)^2]^{1/2}, \quad j = 1, n; \ n \geq 3$

where

n = number of segments

b_T = $\sum b_j$

H = $\sum s_j$

b_j = local change (increase) in beam for the j-th segment at station i (see 5C-1-3/Figure 17)

s_j = local change (increase) in freeboard up to the highest deck for the j-th segment at station i forward (see 5C-1-3/Figure 17).

13.5.1 Nominal Bowflare Slamming *(1 July 2008)*

When experimental data or direct calculation is not available, nominal bowflare slamming pressures may be determined by the following equations:

$P_{ij} = P_{oij}$ or P_{bij} as defined below, whichever is greater

$P_{oij} = k_1(9M_{Ri} - h_{ij}^2)^{1/2}$ kN/m² (tf/m², Ltf/ft²)

$P_{bij} = k_2\, k_3\, [C_2 + K_{ij}M_{Vi}(1 + E_{ni})]$ kN/m² (tf/m², Ltf/ft²)

where

k_1 = 9.807 (1, 0.0278)

k_2 = 1.025 (0.1045, 0.000888)

k_3 = 1 for $h_{ij} \le h_b^*$

= $1 + (h_{ij}/h_b^* - 1)^2$ for $h_b^* < h_{ij} < 2h_b^*$

= 2 for $h_{ij} \ge 2h_b^*$

h_{ij} = vertical distance measured from the load waterline (LWL) at station i to WL_j on the bowflare. The value of h_{ij} is not to be taken less than h_b^*. P_{bij} at a location between LWL and h_b^* above LWL need not be taken greater than p_{bij}^*.

h_b^* = $0.005(L - 130) + 3.0$ (m) for $L < 230$ m

= $0.005(L - 426.4) + 9.84$ (ft) for $L < 754$ ft

= $7.143 \times 10^{-3}(L - 230) + 3.5$ (m) for $230 \text{ m} \le L < 300$ m

= $7.143 \times 10^{-3}(L - 754.4) + 11.48$ (ft) for $754 \text{ ft} \le L < 984$ ft

= 4.0 m (13.12 ft) for $L \ge 300$ m (984 ft)

p_{bij}^* = $P_{bi}^* \sqrt{\beta_i^* / \beta'_{ij}}$

P_{bi}^* = P_{bij} at h_b^* above LWL

C_2 = 39.2 m (422.46 ft)

E_{ni} = natural log of n_{ij}

n_{ij} = $5730(M_{Vi}/M_{Ri})^{1/2}\, G_{ij} \ge 1.0$

G_{ij} = $e^{\left(-h_{ij}^2 / M_{Ri}\right)}$

M_{Vi} = $B_i M_{Ri}$, where B_i is given in 5C-1-3/Table 5.

M_{Ri} = $c_1\, A_i\, (VL/C_b)^{1/2}$, where A_i is given in 5C-1-3/Table 5, if $9M_{Ri} < h_{ij}^2$, then $P_{oij} = 0$

c_1 = 0.44 (2.615) for m (ft)

V = as defined in 5C-5-3/11.1

L = as defined in 3-1-1/3.1, in m (ft)

C_b = as defined in 3-2-1/3.5.1 and not to be less than 0.6

K_{ij} = $f_{ij}\, [r_j/(bb_{ij} + 0.5h_{ij})]^{3/2}\, [\ell_{ij}/r_j]\, [1.09 + 0.029V - 0.47C_b]^2$

f_{ij} = $[90/\beta'_{ij} - 1]^2\, [\tan^2(\beta'_{ij})/9.86] \cos\gamma$

β'_{ij} = normal local body plan angle

β_{ij} = local body plan angle measured from the horizontal, in degrees, need not be taken greater than 75 degrees, see 5C-1-3/Figure 15

β_i^* = β'_{ij} at h_b^* above LWL

r_j = $(M_{Ri})^{1/2}$

bb_{ij} = $b_{ij} - b_{i0} > 2.0$ m (6.56 ft)

b_{ij} = local half beam of location j at station i

b_{i0} = load waterline half beam at station i

ℓ_{ij} = longitudinal distance of WL_j at station i measured from amidships, based on the scantling length

γ = ship stem angle at the centerline measured from the horizontal, 5C-1-3/Figure 18, in degrees, not to be taken greater than 75 degrees

TABLE 5
Values of A_i and B_i * *(2000)*

	A_i	B_i
-0.05L	1.25	0.3600
FP	1.00	0.4000
0.05L	0.80	0.4375
0.10L	0.62	0.4838
0.15L	0.47	0.5532
0.20L	0.33	0.6666
0.25L	0.22	0.8182
0.30L	0.22	0.8182

* Linear interpolation may be used for intermediate values.

FIGURE 17
Definition of Bowflare Geometry for Bowflare Shape Parameter *(2000)*

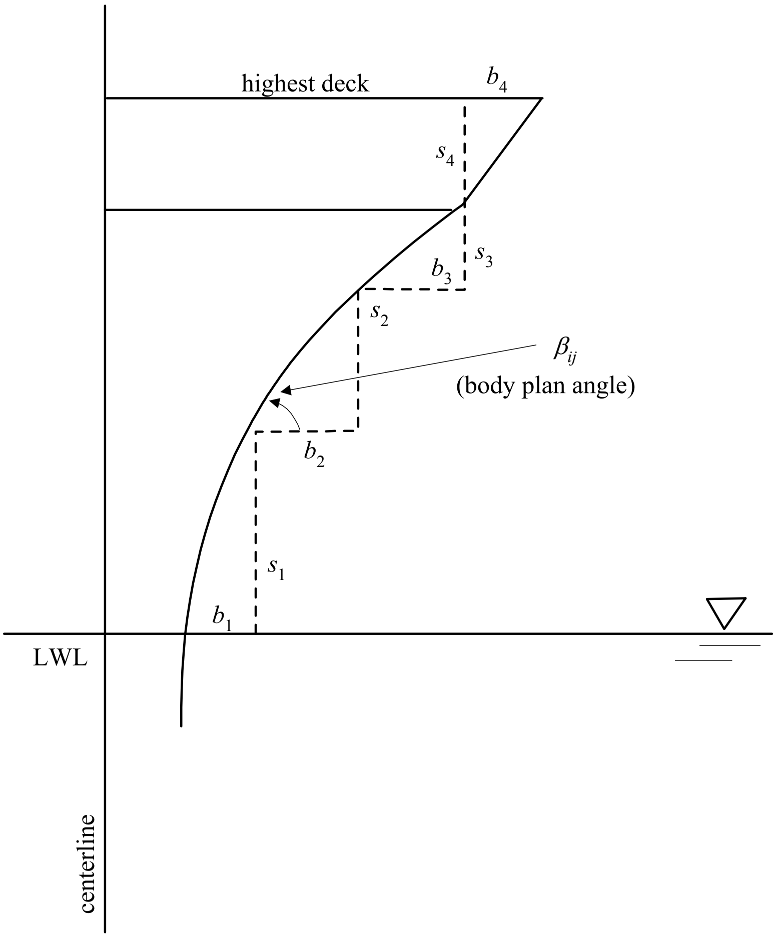
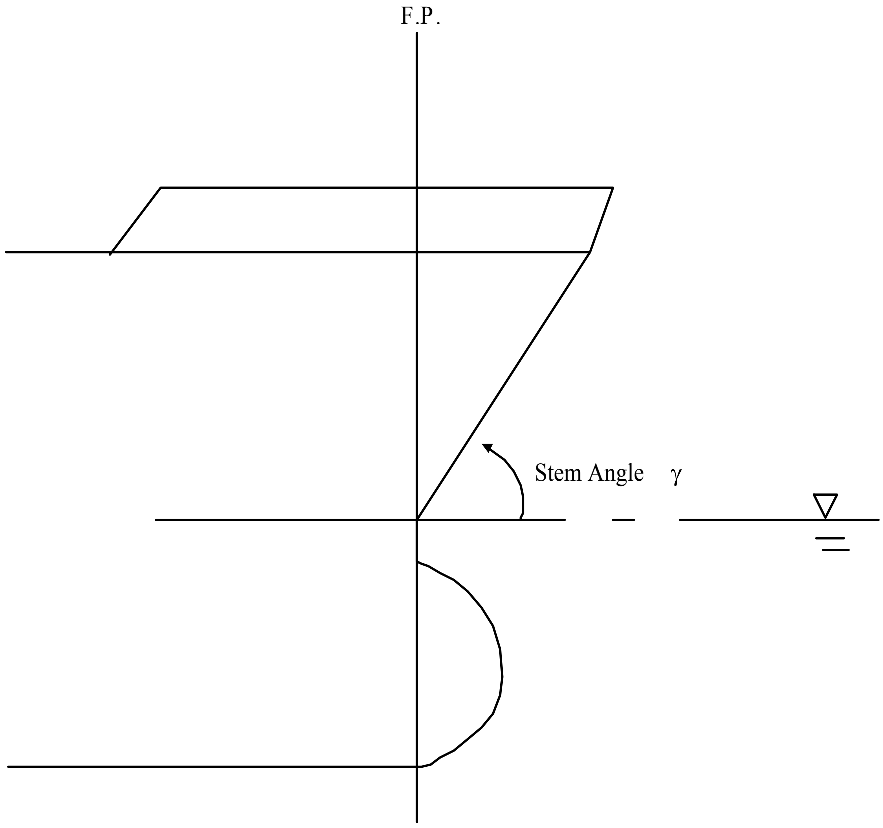


FIGURE 18
Ship Stem Angle, γ *(2000)*



13.5.2 Simultaneous Bowflare Slamming Pressure

For performing structural analyses to determine overall responses of the hull structures, the spatial distribution of instantaneous bowflare slamming pressures on the forebody region of the hull may be expressed by multiplying the calculated maximum bowflare slamming pressures, P_{ij}, at forward ship stations by a factor of 0.71 for the region between the stem and 0.3L from the FP.

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PART

5C

CHAPTER 1 Vessels Intended to Carry Oil in Bulk (150 meters (492 feet) or more in Length)

SECTION 4 Initial Scantling Criteria

1 General

1.1 Strength Requirement *(1995)*

This section specifies the minimum strength requirements for hull structure with respect to the determination of initial scantlings, including the hull girder, shell and bulkhead plating, longitudinals/ stiffeners and main supporting members. Once the minimum scantlings are determined, the strength of the resulting design is to be assessed in accordance with Section 5C-1-5. The assessment is to be carried out by means of an appropriate structural analysis as per 5C-1-5/9, in order to establish compliance with the failure criteria in 5C-1-5/3. Structural details are to comply with 5C-1-4/1.5.

The requirements for hull girder strength are specified in 5C-1-4/3. The required scantlings of double bottom structures, side shell and deck, and longitudinal and transverse bulkheads are specified in 5C-1-4/7 through 5C-1-4/17 below. 5C-1-4/Figure 1 shows the appropriate subsections giving scantling requirements for the various structural components of typical double hull tankers. For hull structures beyond 0.4L amidships, the initial scantlings are determined in accordance with Section 5C-1-6.

1.3 Calculation of Load Effects *(1995)*

Equations giving approximate requirements are given in 5C-1-4/7 through 5C-1-4/13 for calculating the maximum bending moments and shear forces for main supporting members clear of the end brackets, and axial loads for cross ties for typical structural arrangements and configurations (5C-1-4/Figure 2A and 5C-1-4/Figure 2B). For designs with different structural configurations, these local load effects may be determined from a 3D structural analysis at the early design stages, as outlined in 5C-1-5/9, for the combined load cases specified in 5C-1-3/9, excluding the hull girder load components. In this regard, the detailed analysis results are to be submitted for review.

1.5 Structural Details *(1995)*

The strength criteria specified in this Section and Section 5C-1-6 are based on assumptions that all structural joints and welded details are properly designed and fabricated and are compatible with the anticipated working stress levels at the locations considered. It is critical to closely examine the loading patterns, stress concentrations and potential failure modes of structural joints and details during the design of highly stressed regions. In this exercise, failure criteria specified in 5C-1-5/3 may be used to assess the adequacy of structural details.

1.7 Evaluation of Grouped Stiffeners *(1 July 2005)*

Where several members in a group with some variation in requirement are selected as equal, the section modulus requirement may be taken as the average of each individual requirement in the group. However, the section modulus requirement for the group is not to be taken less than 90% of the largest section modulus required for individual stiffeners within the group. Sequentially positioned stiffeners of equal scantlings may be considered a group.

FIGURE 1
Scantling Requirement Reference by Subsection *(1995)*

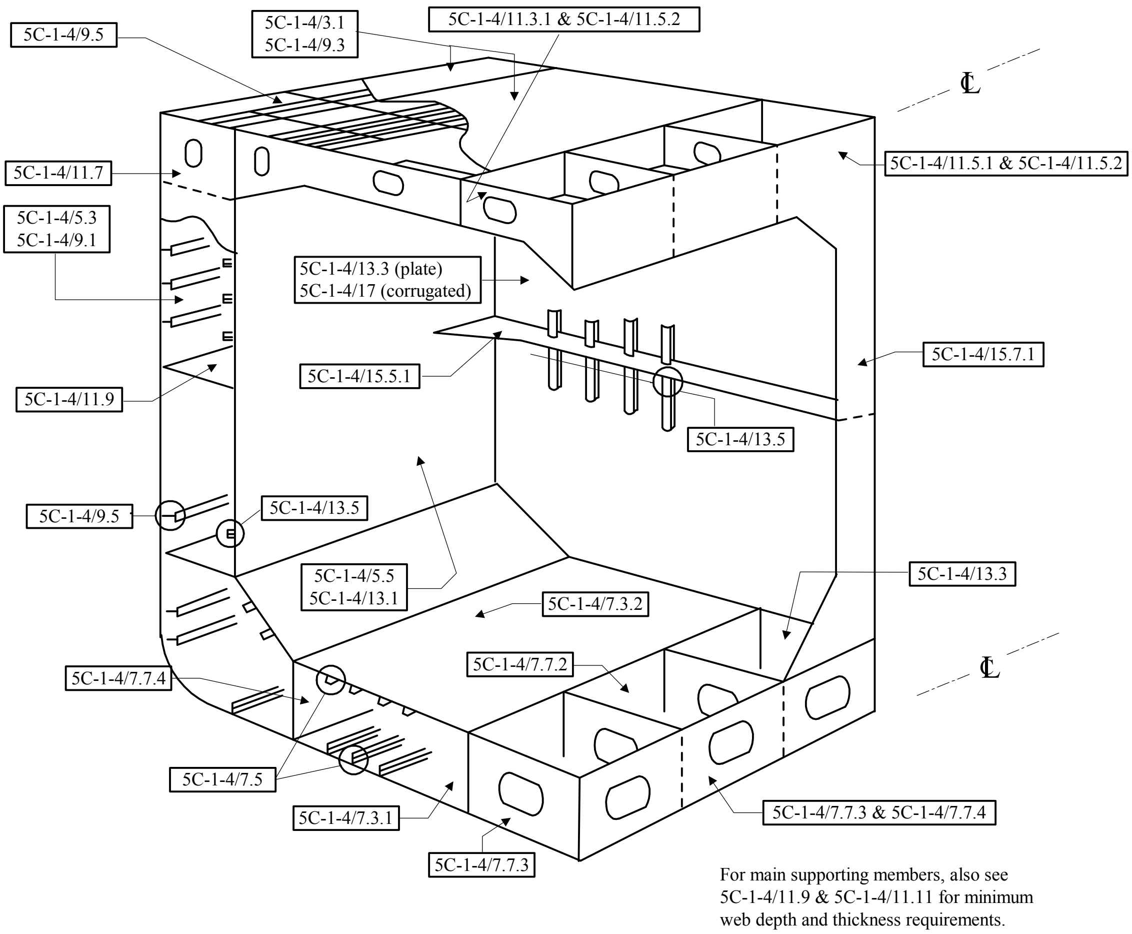


FIGURE 2A
Definitions of Spans (A) *(1995)*

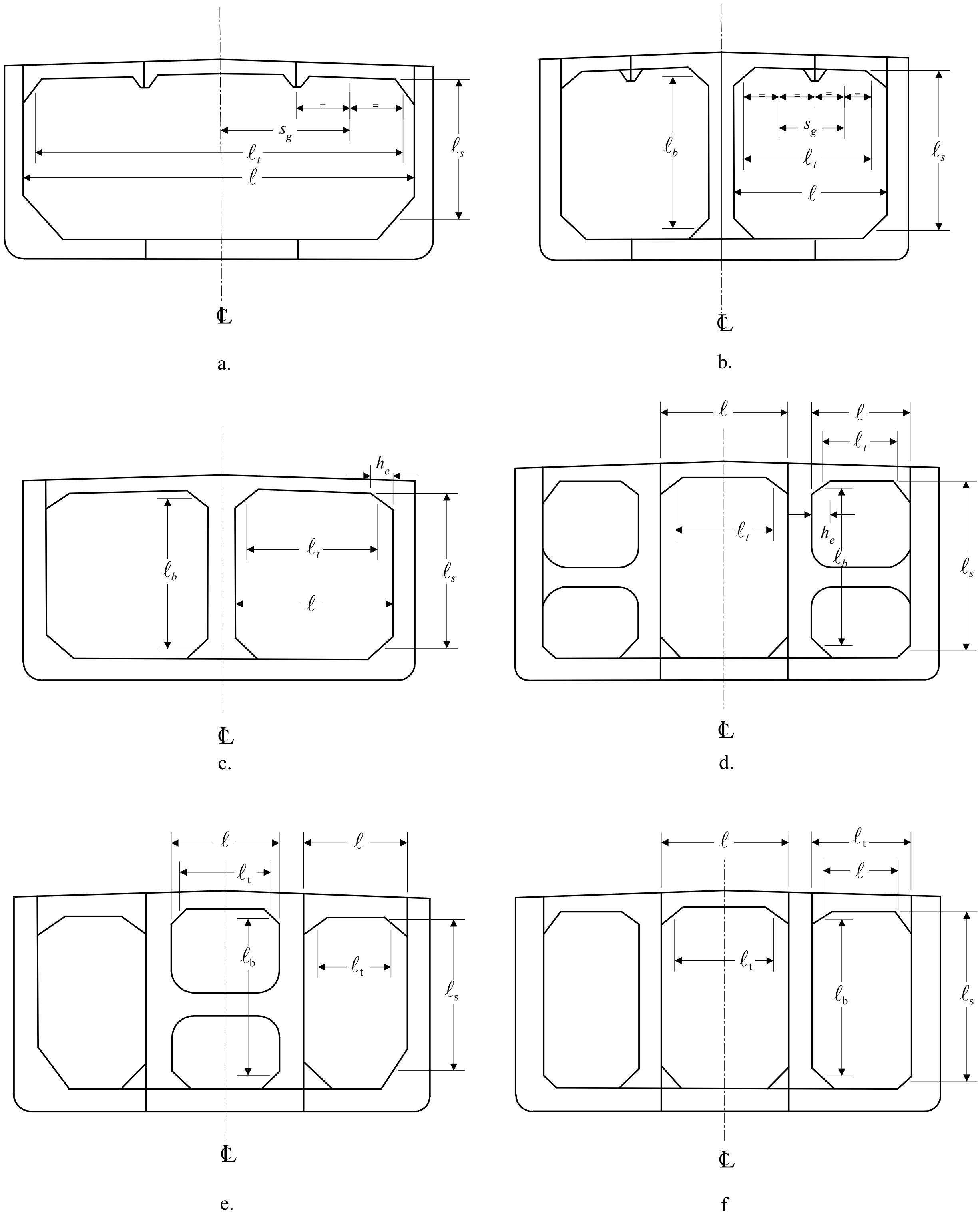
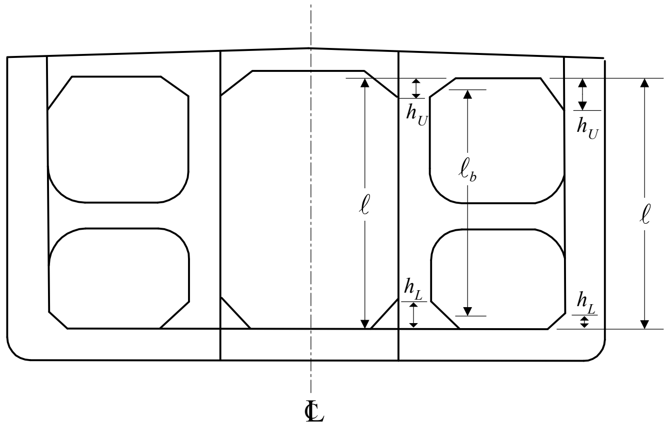
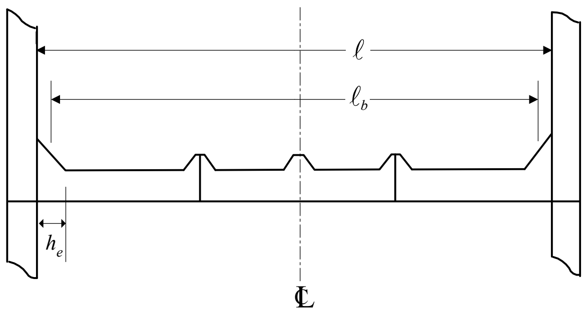


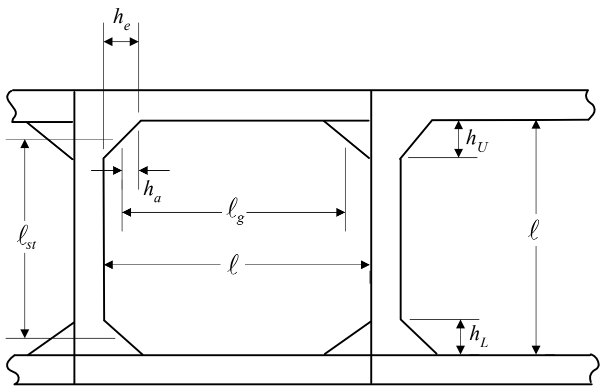
FIGURE 2B
Definitions of Spans (B) *(1995)*



a. Side Transverve and Vertical Web on Longitudinal Bulkhead



b. Horizontal Girder on Transverse Bulkhead



c. Deck Girder and Vertical Web on Transverse Bulkhead

3 Hull Girder Strength

3.1 Hull Girder Section Modulus *(1995)*

3.1.1 Hull Girder Section Modulus Amidships

The required hull girder section modulus amidships is to be calculated in accordance with 3-2-1/3.7, 3-2-1/5 and 3-2-1/9. For the assessment of ultimate strength as specified in Section 5C-1-5 and the determination of initial net structural scantlings, the net hull girder section modulus amidships, SM_n, is to be calculated in accordance with 5C-1-4/3.1.2 below.

3.1.2 Effective Longitudinal Members

The hull girder section modulus calculation is to be carried out in accordance with 3-2-1/9, as modified below. To suit the strength criteria based on a "net" ship concept, the nominal design corrosion values specified in 5C-1-2/Table 1 are to be deducted in calculating the net section modulus, SM_n.

3.3 Hull Girder Moment of Inertia *(1995)*

The hull girder moment of inertia is to be not less than required by 3-2-1/3.7.2.

5 Shearing Strength *(1997)*

5.1 General

The net thickness of the side shell and longitudinal bulkhead plating is to be determined based on the total vertical shear force, F_t, and the permissible shear stress, f_s, given below, where the outer longitudinal bulkheads (inner skin) are located no further than 0.075B from the side shell.

The nominal design corrosion values as given in 5C-1-2/Table 1 for the side shell and longitudinal bulkhead plating are to be added to the "net" thickness thus obtained.

$F_t = F_S + F_W$ kN (tf, Ltf)

$t = Fm/I f_s$ cm (in.)

where

F_S = still-water shear force based on the still-water shear force envelope curve for all anticipated loading conditions in accordance with 3-2-1/3.3, at location considered, in kN (tf, Ltf).

F_W = vertical wave shear force, as given in 3-2-1/3.5.3, in kN (tf, Ltf). F_W for in-port condition may be taken as zero.

t = t_s or t_i (see 5C-1-4/5.3 and 5C-1-4/5.5)

F = F_tD_s or $(F_t + R_i)D_i$ (see 5C-1-4/5.3 and 5C-1-4/5.5 below)

m = first moment of the "net" hull girder section, in cm^3 (in^3), about the neutral axis, of the area between the vertical level at which the shear stress is being determined and the vertical extremity of the section under consideration

I = moment of inertia of the "net" hull girder section at the position considered, in cm^4 (in^4)

f_s = $11.96/Q$ kN/cm^2 ($1.220/Q$ tf/cm^2, $7.741/Q$ Ltf/in^2) at sea

= $10.87/Q$ kN/cm^2 ($1.114/Q$ tf/cm^2, $7.065/Q$ Ltf/in^2) in port

Q = material conversion factor

= 1.0 for ordinary strength steel

= 0.78 for Grade H32 steel

= 0.72 for Grade H36 steel

= 0.68 for Grade H40 steel

For the purpose of calculating required thickness for hull girder shear, the sign of F_t may be disregarded unless algebraic sum with other shear forces, such as local load components, is appropriate.

5.3 Net Thickness of Side Shell Plating

$$t_s \geq F_t D_s m/I f_s \quad \text{cm (in.)}$$

where

D_s = shear distribution factor for side shell, as defined in 5C-1-4/5.3.1, 5C-1-4/5.3.2 or 5C-1-4/5.3.3 below.

F_t, m, I and f_s are as defined in 5C-1-4/5.1 above.

5.3.1 Shear Distribution Factor for Tankers with Two Outer Longitudinal Bulkheads (inner skin only)

$$D_s = 0.384 - 0.167A_{ob}/A_s - 0.190\, b_s/B$$

where

A_{ob} = total projected area of the net outer longitudinal bulkhead (inner skin) plating above inner bottom (one side), in cm^2 (in^2)

A_s = total projected area of the net side shell plating (one side), in cm^2 (in^2)

b_s = distance between outer side longitudinal bulkhead (inner skin) and side shell, in m (ft)

B = breadth of the vessel, in m (ft), as defined in 3-1-1/5.

5.3.2 Shear Distribution Factor for Tankers with Two Outer Longitudinal Bulkheads and a Centerline Swash or Oil-tight Longitudinal Bulkhead

$$D_s = 0.347 - 0.057A_{cb}/A_s - 0.137\, A_{ob}/A_s - 0.070b_s/B$$

where

A_{cb} = total area of the net centerline longitudinal bulkhead plating above inner bottom, in cm^2 (in^2)

A_s, A_{ob}, b_s and B are as defined in 5C-1-4/5.3.1 above.

5.3.3 Shear Distribution Factor for Tankers with Two Outer and Two Inner Longitudinal Bulkheads

$$D_s = 0.330 - 0.218A_{ob}/A_s - 0.043b_s/B$$

where

A_s, A_{ob}, b_s and B are as defined in 5C-1-4/5.3.1 above.

5.5 Thickness of Longitudinal Bulkheads

$t_i \geq (F_t + R_i)D_i\, m/I f_s$ cm (in.)

where

D_i = shear distribution factor

R_i = local load correction

i = *ob* for outer longitudinal bulkhead (inner skin)

= *ib* for inner longitudinal bulkhead

= *cb* for centerline longitudinal bulkhead

F_t, I, m and f_s are as defined above.

The other parameters, depending on the configuration of the tanker, are defined in 5C-1-4/5.5.1, 5C-1-4/5.5.2 and 5C-1-4/5.5.3 below.

5.5.1 Tankers with Two Outer Longitudinal Bulkheads (Inner Skin Only)

The net thickness of the outer longitudinal bulkhead plating at the position considered:

$t_{ob} \geq F_t D_{ob} m/I f_s$ cm (in.)

where

D_{ob} = $0.105 + 0.156A_{ob}/A_s + 0.190b_s/B$

A_s, A_{ob}, b_s, B, F_t, I, m and f_s are defined above.

5.5.2 Tankers with Two Outer Longitudinal Bulkheads and a Centerline Swash or Oil-tight Longitudinal Bulkhead

5.5.2(a) (1999) The net thickness of the centerline longitudinal bulkhead plating at the position considered:

$t_{cb} \geq (F_t + R_{cb})D_{cb} m/I f_s$ cm (in.)

where

R_{cb} = $W_c[(2N_{wcb}\, k_{cb} I/3H_{cb}\, D_{cb} m) - 1] \geq 0$

k_{cb} = $1 + A^*_{cb}/A_{cb} \leq 1.9$

D_{cb} = $0.229 + 0.152A_{cb}/A_s - 0.10A_{ob}/A_s - 0.198\, b_s/B$

W_c = local load, in kN (tf, Ltf), calculated according to 5C-1-4/5.7 and 5C-1-4/Figure 3a

N_{wcb} = local load distribution factor for the centerline longitudinal bulkhead

= $(0.66D_{cb} + 0.25)\,(n - 1)/n$

n = total number of transverse frame spaces in the center tank

H_{cb} = depth of the centerline longitudinal bulkhead above inner bottom, in cm (in.)

A^*_{cb} = total area of the net centerline longitudinal bulkhead plating above the lower edge of the strake under consideration, in cm^2 (in^2)

All other parameters are as defined in 5C-1-4/5.3.

5.5.2(b) The net thickness of the outer longitudinal bulkhead plating at the position considered:

$t_{ob} \geq F_t D_{ob} m/I f_s$ cm (in.)

where

D_{ob} = $0.106 - 0.093A_{cb}/A_s + 0.164A_{ob}/A_s + 0.202b_s/B$

All other parameters are as defined in 5C-1-4/5.3 and 5C-1-4/5.5.

5.5.3 Tankers with Two Outer and Two Inner Longitudinal Bulkheads

5.5.3(a) The net thickness of the inner longitudinal bulkhead plating at the position considered:

$t_{ib} \geq (F_t + R_{ib})D_{ib} m/I f_s$ cm (in.)

where

R_{ib} = $W_{c1}[(2N_{wib1}k_{ib}I/3H_{ib}D_{ib}m) - 1] + W_{c2}[(2N_{wib2}k_{ib}I/3H_{ib}D_{ib}m) - 1] \geq 0$

k_{ib} = $1 + A^*_{ib}/A_{ib} \leq 1.9$

D_{ib} = $0.058 + 0.173A_{ib}/A_s - 0.043b_s/B$

W_{c1}, W_{c2} = local load, in kN (tf, Ltf), calculated according to 5C-1-4/5.7 and 5C-1-4/Figure 3b

A_{ib} = total area of the net inner longitudinal bulkhead plating above inner bottom, in cm^2 (in^2)

A^*_{ib} = total area of the net inner longitudinal bulkhead plating above the lower edge of the strake under consideration, in cm^2 (in^2)

N_{wib1}, N_{wib2} = local load distribution factor for inner longitudinal bulkhead

N_{wib1} = $(0.49D_{ib} + 0.18)(n - 1)/n$ for local load W_{c1}

N_{wib2} = $(0.60D_{ib} + 0.10)(n - 1)/n$ for local load W_{c2}

H_{ib} = depth of the inner longitudinal bulkhead above inner bottom, in cm (in.)

All other parameters are as defined above.

5.5.3(b) The net thickness of the outer longitudinal bulkhead plating at the position considered:

$t_{ob} \geq F_t D_{ob} m/I f_s$ cm (in.)

where

D_{ob} = $0.013 + 0.153A_{ob}/A_s + 0.172\, b_s/B$

All other parameters are as defined above.

5.7 Calculation of Local Loads *(1995)*

In determining the shear forces at the ends of cargo tanks, the local loads are to be calculated as shown in the following example. The tank arrangement for this example is as shown in 5C-1-4/Figure 3. The ballast tanks within double bottom and double side are to be considered as being empty in calculating excess liquid head.

5.7.1 Tankers with Two Outer Longitudinal Bulkheads and a Centerline Swash or Oil-tight Longitudinal Bulkhead *(1 July 2000)*

Local load W_c may be denoted by $W_c(f)$ and $W_c(a)$ at the fore and aft ends of the center tank, respectively, in kN (tf, Ltf).

$$W_c(f) = W_c(a) = 0.5\rho g b_c \ell_c [k_s H_c + 0.71 k_s (a_v/g) H_c + 0.47 k_s \ell_c \sin\phi - 0.55(\rho_o/\rho) d_f + 0.2(\rho_o/\rho) C_1] \geq 0$$

but need not be taken greater than $0.5 k_s \rho g b_c \ell_c H_c$

where

k_s	=	load factor
	=	1.0 for all loads from ballast tanks
	=	0.878 for ρg of 10.05 kN/m^3 (1.025 tf/m^3, 0.0286 Ltf/ft^3) and 1.0 for ρg of 11.18 kN/m^3 (1.14 tf/m^3, 0.0318 Ltf/ft^3) and above for all loads from cargo tanks.
		For cargo ρg between 10.05 kN/m^3 (1.025 tf/m^3, 0.0286 Ltf/ft^3) and 11.18 kN/m^3 (1.14 tf/m^3, 0.0318 Ltf/ft^3), the factor k_s may be determined by interpolation
ρg	=	specific weight of the liquid, not to be taken less than 10.05 kN/m^3 (1.025 tf/m^3, 0.0286 Ltf/ft^3)
$\rho_o g$	=	specific weight of sea water, 10.05 kN/m^3 (1.025 tf/m^3, 0.0286 Ltf/ft^3)
ℓ_c, b_c	=	length and breadth, respectively, of the center tanks, in m (ft), as shown in 5C-1-4/Figure 3a
H_c	=	liquid head in the center tank, in m (ft)
a_v	=	vertical acceleration amidships with a wave heading angle of 0 degrees, in m/sec^2 (ft/sec^2), as defined in 5C-1-3/5.7.1(c)
g	=	acceleration of gravity = 9.8 m/sec^2 (32.2 ft/sec^2)
ϕ	=	pitch amplitude in degrees, as defined in 5C-1-3/5.7.1(a)
d_f	=	draft, as defined in 3-1-1/9, in m (ft)
C_1	=	as defined in 3-2-1/3.5

5.7.2 Tankers with Two Outer and Two Inner Longitudinal Bulkheads *(1 July 2000)*

Local loads W_{c1}, W_{c2} may be denoted by $W_{c1}(f)$, $W_{c2}(f)$ and, $W_{c1}(a)$, $W_{c2}(a)$ at the fore and aft ends of the center tank, respectively, in kN (tf, Ltf).

$$W_{c1}(f) = \frac{k_s \rho g b_{c1}}{\ell_c} [h_{c1} \ell_1 (\ell_2 + \frac{\ell_1}{2}) + h_{c2} \frac{\ell_2^2}{2}]$$

$$W_{c1}(a) = \frac{k_s \rho g b_{c1}}{\ell_c} [h_{c1} \frac{\ell_1^2}{2} + h_{c2} \ell_2 (\ell_1 + \frac{\ell_2}{2})]$$

$$W_{c2}(f) = \frac{k_s \rho g b_{c2}}{\ell_c} [h_{c3} \ell_1 (\ell_2 + \frac{\ell_1}{2}) + h_{c4} \frac{\ell_2^2}{2}]$$

$$W_{c2}(a) = \frac{k_s \rho g b_{c2}}{\ell_c} [h_{c3} \frac{\ell_1^2}{2} + h_{c4} \ell_2 (\ell_1 + \frac{\ell_2}{2})]$$

where

k_s = load factor, as defined in 5C-1-4/5.7.1

ρg = specific weight of the liquid, not to be taken less than 10.05 kN/m^3 (1.025 tf/m^3, 0.0286 Ltf/ft^3)

ℓ_c = length of the center tank, in m (ft), as shown in 5C-1-4/Figure 3b

ℓ_1, ℓ_2 = longitudinal distances from the respective center tank ends to the intermediate wing tank transverse bulkheads, in m (ft), as shown in 5C-1-4/Figure 3b

b_{c1} = breadth of the center tank, in m (ft), as shown in 5C-1-4/Figure 3b

b_{c2} = breadth of the center and wing tanks, in m (ft), as shown in 5C-1-4/Figure 3b

H_1, H_2 = liquid heads in the wing tanks, in m (ft), as shown in 5C-1-4/Figure 3b

h_{c1} = $H_c - H_1$, but not to be taken less than zero

h_{c2} = $H_c - H_2$, but not to be taken less than zero

h_{c3} = H_c or H_1, whichever is lesser

h_{c4} = H_c or H_2, whichever is lesser

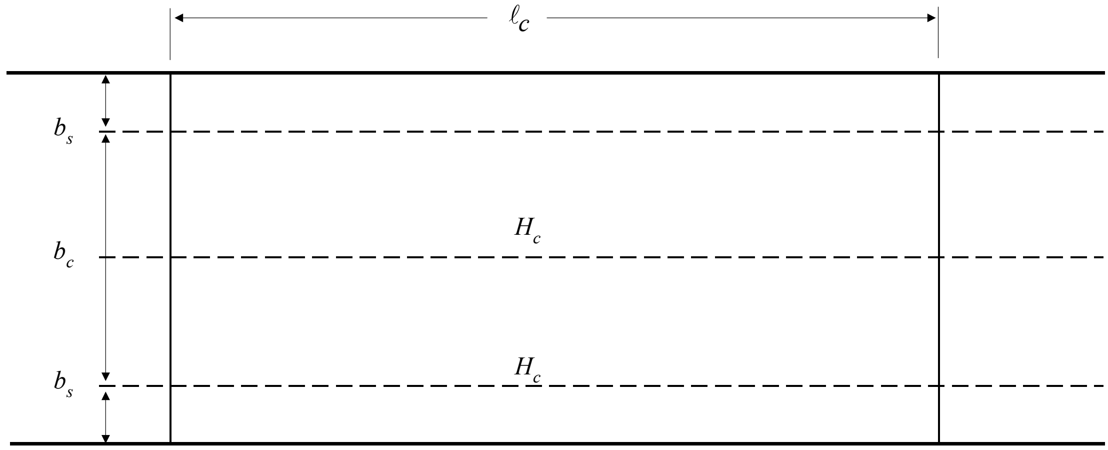
Where adjacent tanks are loaded with cargoes of different densities, the heads are to be adjusted to account for the difference in density. For locations away from the ends of the tanks, R_{cb} and R_{ib} may be determined using the calculated values of W_c at the locations considered.

5.9 Three Dimensional Analysis *(1995)*

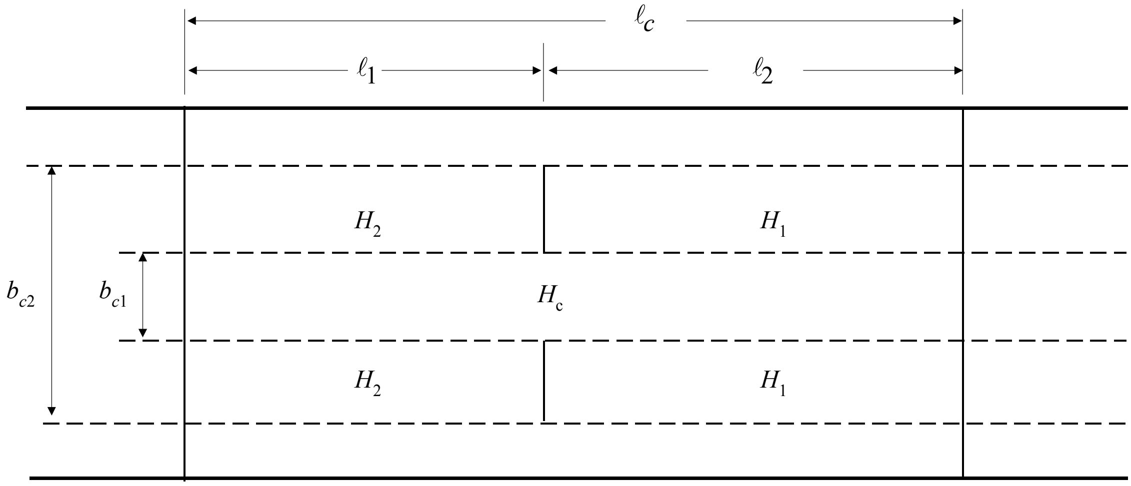
The total shear stresses in the side shell and longitudinal bulkhead plating (net thickness) may be calculated using a 3D structural analysis to determine the general shear distribution and local load effects for the critical shear strength conditions among all of the anticipated loading conditions.

FIGURE 3
Center Tank Region *(1995)*

a Tankers with Double Hull and Centerlilne Swash or Oil-tight Longitudinal Bulkhead.



b Tankers with Four Longitudinal Bulkheads



7 Double Bottom Structures

7.1 General *(1995)*

7.1.1 Arrangement

The depth of the double bottom and arrangement of access openings are to be in compliance with 5C-1-1/5. Centerline and side girders are to be fitted, as necessary, to provide sufficient stiffness and strength for docking loads as well as those specified in Section 5C-1-3.

Struts connecting the bottom and inner bottom longitudinals are not to be fitted.

7.1.2 Keel Plate

The net thickness of the flat plate keel is to be not less than that required for the bottom shell plating at that location by 5C-1-4/7.3.1 increased by 1.5 mm (0.06 in.), except where the submitted docking plan (see 3-1-2/11) specifies all docking blocks be arranged away from the keel.

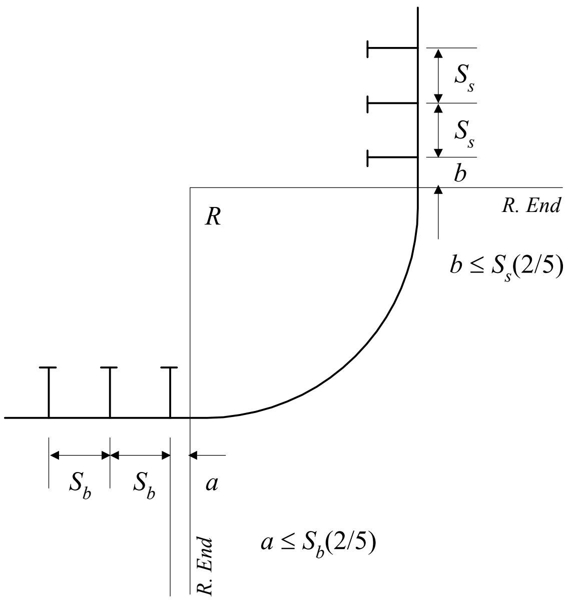
7.1.3 Bottom Shell Plating - Definition

The term "bottom shell plating" refers to the plating from the keel to the upper turn of the bilge for 0.4*L* amidships.

7.1.4 Bilge Longitudinals *(2004)*

Longitudinals around the bilge are to be graded in size from that required for the lowest side longitudinal to that required for the bottom longitudinals. Where longitudinals are omitted in way of the bilge, the bottom and side longitudinals are to be arranged so that the distance between the nearest longitudinal and the turn of the bilge is not more than 0.4*s* (*s* is the spacing of bottom or side longitudinals), as applicable (see-5C-1-4/Figure 4).

FIGURE 4



7.3 Bottom Shell and Inner Bottom Plating *(1997)*

The thickness of the bottom shell and inner bottom plating over the midship 0.4*L* is to satisfy the hull girder section modulus requirements in 3-2-1/3.7. The buckling and ultimate strength are to be in accordance with the requirements in 5C-1-5/5. In addition, the net thickness of the bottom shell and inner bottom plating is to be not less than the following.

7.3.1 Bottom Shell Plating *(1999)*

The net thickness of the bottom shell plating, t_n, is to be not less than t_1, t_2 and t_3, specified as follows:

$$t_1 = 0.73s(k_1 p/f_1)^{1/2} \quad \text{mm (in.)}$$

$$t_2 = 0.73s(k_2\, p/f_2)^{1/2} \quad \text{mm (in.)}$$

$$t_3 = cs(S_m f_y /E)^{1/2} \quad \text{mm (in.)}$$

where

s = spacing of bottom longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.500

p = $p_a - p_{uh}$ or p_b, whichever is greater, in N/cm^2 (kgf/cm^2, lbf/in^2)

p_{uh} = $0.12\gamma(h\ell_{wt}\tan\phi_e)^{1/2}$ where $\ell_{wt} \geq 0.20L$

= 0 where $\ell_{wt} \leq 0.15L$

Linear interpolation is to be used for intermediate values of ℓ_{wt}.

p_a and p_b are nominal pressures, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in load case "a" and "b" in 5C-1-3/Table 3 for bottom plating, respectively.

γ = specific weight of the ballast water, 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf/in^2-ft)

h = height of double side ballast tank at vessel's side, in m (ft)

ℓ_{wt} = length at tank top of double side ballast tank, in m (ft)

L = vessel length, as defined in 3-1-1/3.1, in m (ft)

ϕ_e = effective pitch amplitude, as defined in 5C-1-3/5.7.2 with $C_\phi = 1.0$

f_1 = permissible bending stress in the longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $(1 - 0.70\alpha_1 SM_{RB}/SM_B)S_m f_y \leq 0.40 S_m f_y$

f_1 = $(1 - 0.70\alpha_1 SM_{RB}/SM_B)S_m f_y \leq (0.40 + 0.1(190 - L)/40)\, S_m f_y$ for $L < 190$ m

α_1 = $S_{m1}f_{y1}/S_m f_y$

SM_{RB} = reference net hull girder section modulus based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

= $0.92SM$

SM = required gross hull girder section modulus at the location under consideration, in accordance with 3-2-1/3.7 and 3-2-1/5.5, based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

SM_B = design (actual) net hull girder section modulus to the bottom, in cm^2-m (in^2-ft), at the location under consideration

f_2 = permissible bending stress in the transverse direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.80\, S_m f_y$

S_m = strength reduction factor

= 1 for Ordinary Strength Steel, as specified in 2-1-2/Table 2

= 0.95 for Grade H32, as specified in 2-1-3/Table 2

= 0.908 for Grade H36, as specified in 2-1-3/Table 2

= 0.875 for Grade H40, as specified in 2-1-3/Table 2

S_{m1} = strength reduction factor for the bottom flange of the hull girder

f_y = minimum specified yield point of the material, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{y1} = minimum specified yield point of the bottom flange of the hull girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

E = modulus of elasticity of the material, may be taken as 2.06×10^7 N/cm^2 (2.1×10^6 kgf/cm^2, 30×10^6 lbf/in^2) for steel

c = $0.7N^2 - 0.2$, not to be less than $0.4Q^{1/2}$

N = $R_b(Q/Q_b)^{1/2}$

R_b = $(SM_{RBH}/SM_B)^{1/2}$

SM_{RBH} = reference net hull girder section modulus for hogging bending moment based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

= $0.92SM_H$

SM_H = required gross hull girder section modulus, in accordance with 3-2-1/3.7.1and 3-2-1/5.5, for hogging total bending moment at the location under consideration, based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

Q, Q_b = material conversion factor in 5C-1-4/5.1 for the bottom shell plating under consideration and the bottom flange of the hull girder, respectively.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

In addition to the foregoing, the net thickness of the bottom shell plating, outboard of $0.3B$ from the centerline of the vessel, is to be not less than that of the lowest side shell plating required by 5C-1-4/9.1 adjusted for the spacing of the longitudinals and the material factors.

7.3.2 Inner Bottom Plating *(1999)*

The net thickness of the inner bottom plating, t_n, is to be not less than t_1, t_2 and t_3, specified as follows:

$t_1 = 0.73s(k_1\, p/f_1)^{1/2}$ mm (in.)

$t_2 = 0.73s(k_2\, p/f_2)^{1/2}$ mm (in.)

$t_3 = cs(S_m f_y/E)^{1/2}$ mm (in.)

where

s = spacing of inner bottom longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.50

p = $p_a - p_{uh}$ or p_b, whichever is greater, in N/cm^2 (kgf/cm^2, lbf/in^2)

p_a and p_b are nominal pressures, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in load case "a" and "b" in 5C-1-3/Table 3 for inner bottom plating, respectively.

p_{uh} is defined in 5C-1-4/7.3.1.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

f_1 = permissible bending stress in the longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $(1 - 0.52\alpha_1 SM_{RB}/SM_B)S_m f_y \leq 0.57 S_m f_y$, where SM_B/SM_{RB} is not to be taken more than 1.4

f_2 = permissible bending stress in the transverse direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.85\ S_m f_y$

α_1 = $S_{m1} f_{y1}/S_m f_y$

S_m = strength reduction factor obtained from 5C-1-4/7.3.1 for the steel grade of inner bottom material

S_{m1} = strength reduction factor obtained from 5C-1-4/7.3.1 for the steel grade of bottom flange material.

f_y = minimum specified yield point of the inner bottom material, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{y1} = minimum specified yield point of the bottom flange material, in N/cm^2 (kgf/cm^2, lbf/in^2)

c = $0.7N^2 - 0.2$, not to be less than $0.4Q^{1/2}$

N = $R_b\ [(Q/Q_b)(y/y_n)]^{1/2}$

Q = material conversion factor in 5C-1-4/5.1 for the inner bottom plating

y = vertical distance, in m (ft), measured from the inner bottom to the neutral axis of the hull girder section

y_n = vertical distance, in m (ft), measured from the bottom to the neutral axis of the hull girder section

SM_{RB}, SM_B, R_b, Q_b and E are as defined in 5C-1-4/7.3.1.

Where the breadth of the center tank exceeds $0.6B$, or the wing ballast tanks are U-shaped, the net thickness of the inner bottom plating in the center tank, outboard of $0.3B$ from the centerline of the tank, is also to be not less than that of the adjacent strake on the outer longitudinal bulkhead (inner skin) required by 5C-1-4/13.1, adjusted for the spacing of the longitudinals and the material factors.

7.5 Bottom and Inner Bottom Longitudinals *(1 July 2005)*

The net section modulus of each bottom or inner bottom longitudinal, in association with the effective plating to which it is attached, is to be not less than obtained from the following equations:

$SM = M/f_b$ cm^3 (in^3)

where

M = $1000 ps\ell^2/k$ N-cm (kgf-cm, lbf-in.)

k = 12 (12, 83.33)

s = spacing of longitudinals, in mm (in.)

ℓ = span of the longitudinal between effective supports, as shown in 5C-1-4/Figure 5, in m (ft)

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-1-4/7.3.1 and 5C-1-4/7.3.2 for bottom and inner bottom longitudinals, respectively

f_b = permissible bending stresses, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $(1.0 - 0.65\alpha_1 SM_{RB}/SM_B)S_m f_y \leq 0.55 S_m f_y$ for bottom longitudinals

= $(1.0 - 0.50\alpha_1 SM_{RB}/SM_B)S_m f_y \leq 0.65 S_m f_y$ for inner bottom longitudinals

α_1 = $S_{m1} f_{y1}/S_m f_y$

S_m = strength reduction factor, as defined in 5C-1-4/7.3.1, for the material of longitudinals considered

S_{m1} = strength reduction factor, as defined in 5C-1-4/7.3.1, for the bottom flange material

f_y = minimum specified yield point for the material of longitudinals considered, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{y1} = minimum specified yield point of the bottom flange material, in N/cm^2 (kgf/cm^2, lbf/in^2)

SM_{RB} and SM_B are as defined in 5C-1-4/7.3.1.

The net section modulus of the bottom longitudinals, outboard of 0.3B from the centerline of the vessel, is also to be not less than that of the lowest side longitudinal required by 5C-1-4/9.5, adjusted for the span and spacing of the longitudinals and the material factors.

Where the breadth of center tank exceeds 0.6B, or the wing ballast tanks are U-shaped, the net section modulus of the inner bottom longitudinals in the center tank, outboard of 0.3B from the centerline of the tank, is also to be not less than that of the lowest outer longitudinal bulkhead longitudinal required by 5C-1-4/13.5, adjusted for the span and spacing of the longitudinals and the material factors.

In determining compliance with the foregoing, an effective breadth, b_e, of attached plating is to be used in calculation of the section modulus of the design longitudinal. b_e is to be obtained from line a) of 5C-1-4/Figure 6.

7.7 Bottom Girders/Floors *(1997)*

The minimum scantlings for bottom girders/floors are to be determined from 5C-1-4/7.7.1, 5C-1-4/7.7.2, 5C-1-4/7.7.3 and 5C-1-4/7.7.4, as follows:

7.7.1 Bottom Centerline Girder *(1999)*

The net thickness of the centerline girder amidships, where no centerline bulkhead is fitted, is to be not less than t_1 and t_2, as defined below:

$t_1 = (0.045L + 4.5)R$ mm

$= (0.00054L + 0.177)R$ in.

$t_2 = 10F_1/(d_b f_s)$ mm

$= F_1/(d_b f_s)$ in.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

$$t_3 = cs(S_m f_y /E)^{1/2} \qquad \text{mm (in.)}$$

where F_1 is the maximum shear force in the center girder, as obtained from the equations given below (see also 5C-1-4/1.3). Alternatively, F_1 may be determined from finite element analyses, as specified in 5C-1-5/9, with the combined load cases in 5C-1-5/9.9. However, in no case should F_1 be taken less than 85% of that determined from the equations below:

$$F_1 = 1000k\alpha_1\gamma\, n_1 n_2\, p\ell_s s_1 \qquad \text{N (kgf, lbf), for } \lambda \le 1.5$$

$$F_1 = 414k\gamma\, n_1 n_2\, pb_s s_1 \qquad \text{N (kgf, lbf), for } \lambda > 1.5$$

where

k = 1.0 (1.0, 2.24)

α_1 = $0.606 - 0.22\lambda$

λ = ℓ_s/b_s

γ = $2x/(\ell_s - s_3)$, ≤ 1.0

n_1 = $0.0374(s_1/s_3)^2 - 0.326(s_1/s_3) + 1.289$

n_2 = $1.3 - (s_3/12)$ for SI or MKS Units

= $1.3 - (s_3/39.37)$ for U.S. Units

ℓ_s = unsupported length of the double bottom structures under consideration, in m (ft), as shown in 5C-1-4/Figure 7

b_s = unsupported width of the double bottom structures under consideration, in m (ft), as shown in 5C-1-4/Figure 7.

s_1 = sum of one-half of girder spacing on each side of the center girder, in m (ft)

s_3 = spacing of floors, in m (ft)

x = longitudinal distance from the mid-span of unsupported length (ℓ_s) of the double bottom to the section of the girder under consideration, in m (ft).

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), as specified in 5C-1-3/Table 3

d_b = depth of double bottom, in cm (in.)

f_s = permissible shear stresses, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\, S_m f_y$

c = $0.7N^2 - 0.2$, not to be less than $0.4Q^{1/2}$ but need not be greater than $0.45(Q/Q_b)^{1/2}$

N = $R_b\,(Q/Q_b)^{1/2}$

Q = material conversion factor in 5C-1-4/5.1 for the bottom girder

s = spacing of longitudinal stiffeners on the girder, in mm (in.)

R = 1.0 for ordinary mild steel

= $f_{ym}/S_m f_{yh}$ for higher strength material

f_{ym} = specified minimum yield point for ordinary strength steel, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{yh} = specified minimum yield point for higher tensile steel, in N/cm^2 (kgf/cm^2, lbf/in^2)

L = length of vessel, in m (ft), as defined in 3-1-1/3.1.

S_m, E, R_b, Q_b and f_y are as defined in 5C-1-4/7.3.1.

7.7.2 Bottom Side Girder *(1999)*

The net thickness of the bottom side girders is to be not less than t_1 and t_2, as defined below:

$t_1 = (0.026L + 4.5)R$ mm

$= (0.00031L + 0.177)R$ in.

$t_2 = 10\, F_2/(d_b f_s)$ mm

$= F_2/(d_b f_s)$ in.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

$t_3 = cs(S_m f_y/E)^{1/2}$ mm (in.)

where F_2 is the maximum shear force in the side girders under consideration, as obtained from the equations given below (see also 5C-1-4/1.3). Alternatively, F_2 may be determined from finite element analyses, as specified in 5C-1-5/9, with the combined load cases in 5C-1-5/9.9. However, in no case should F_2 be taken less than 85% of that determined from the equations below:

$F_2 = 1000\, k\alpha_2\beta_1\gamma\, n_3 n_4\, p\ell_s s_2$ N (kgf, lbf), for $\lambda \le 1.5$

$F_2 = 285k\beta_1\gamma\, n_3 n_4\, pb_s s_2$ N (kgf, lbf), for $\lambda > 1.5$

where

k = 1.0 (1.0, 2.24)

α_2 = $0.445 - 0.17\lambda$

β_1 = $1.25 - (2z_1/b_s)$ for tankers with inner skin only [5C-1-4/Figure 7(d)]

= 1.0 for all other tankers

n_3 = $1.072 - 0.0715(s_2/s_3)$

n_4 = $1.2 - (s_3/18)$ for SI or MKS Units

= $1.2 - (s_3/59.1)$ for U.S. Units

s_2 = sum of one-half of girder spacings on both sides of the side girders, in m (ft)

z_1 = transverse distance from the centerline of the unsupported width b_s of the double bottom to the girder under consideration, in m (ft)

c = $0.7N^2 - 0.2$, not to be less than $0.4Q^{1/2}$, but need not be greater than $0.45(Q/Q_b)^{1/2}$

N = $R_b\,(Q/Q_b)^{1/2}$

Q = material conversion factor in 5C-1-4/5.1 for the bottom girder

s = spacing of longitudinal stiffeners on the girder, in mm (in.)

γ, ℓ_s, b_s, λ, s_3, p, d_b, f_s, L, R, S_m and f_y are as defined above.

7.7.3 Floors *(1997)*

The net thickness of the floors is to be not less than t_1 and t_2, as specified below:

$t_1 = (0.026L + 4.50)R$ mm

$= (0.00031L + 0.177)R$ in.

$t_2 = 10F_3/(d_b f_s)$ mm

$= F_3/(d_b f_s)$ in.

where F_3 is the maximum shear force in the floors under consideration, as obtained from the equation given below (see also 5C-1-4/1.3). Alternatively, F_3 may be determined from finite element analyses, as specified in 5C-1-5/9, with the combined load cases in 5C-1-5/9.9. However, in no case should F_3 be taken less than 85% of that determined from the equation below.

$F_3 = 1000k\alpha_3\beta_2 pb_s s_3$ N (kgf, lbf)

where

k = 1.0 (1.0, 2.24)

α_3 as shown in 5C-1-4/Figure 7.

ρ_0 = $\eta(0.66 - 0.08\eta)$, for $\eta \leq 2.0$

= 1.0, for $\eta > 2.0$, or for structures without longitudinal girders

β_2 = $1.05(2z_2/b_s)^2 \leq 1.0$ for tankers with inner skin only [5C-1-4/Figure 7(d)]

= $2z_2/b_s$ for all other tankers

η = $(\ell_s/b_s)(s_0/s_3)^{1/4}$

s_0 = average spacing of girders, in m (ft)

z_2 = transverse distance from the centerline of the unsupported width b_s of the double bottom to the section of the floor under consideration, in m (ft)

f_s = $0.45\ S_m f_y$ in N/cm^2 (kgf/cm^2, lbf/in^2)

ℓ_s, b_s, s_3, R, p, d_b, L, S_m and f_y are as defined above.

7.7.4 Bottom Girders under Longitudinal Bulkhead *(1 July 2005)*

The net thickness of the bottom centerline and side girders under longitudinal bulkheads is to be not less than t_1 and t_2, as defined below:

$t_1 = (0.045L + 3.5)R$ mm

$= (0.00054L + 0.138)R$ in.

The net thickness, t_2, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

$t_2 = cs(S_m f_y/E)^{1/2}$ mm (in.)

where

c = $0.7N^2 - 0.2$, not to be less than $0.4Q^{1/2}$

N = $R_b\,(Q/Q_b)^{1/2}$

Q = material conversion factor in 5C-1-4/5.1 for the bottom girder

s = spacing of longitudinal stiffeners on the girder, in mm (in.)

L, R, S_m and f_y are as defined above.

E, R_b and Q_b are as defined in 5C-1-4/7.3.1.

FIGURE 5
Unsupported Span of Longitudinal *(1995)*

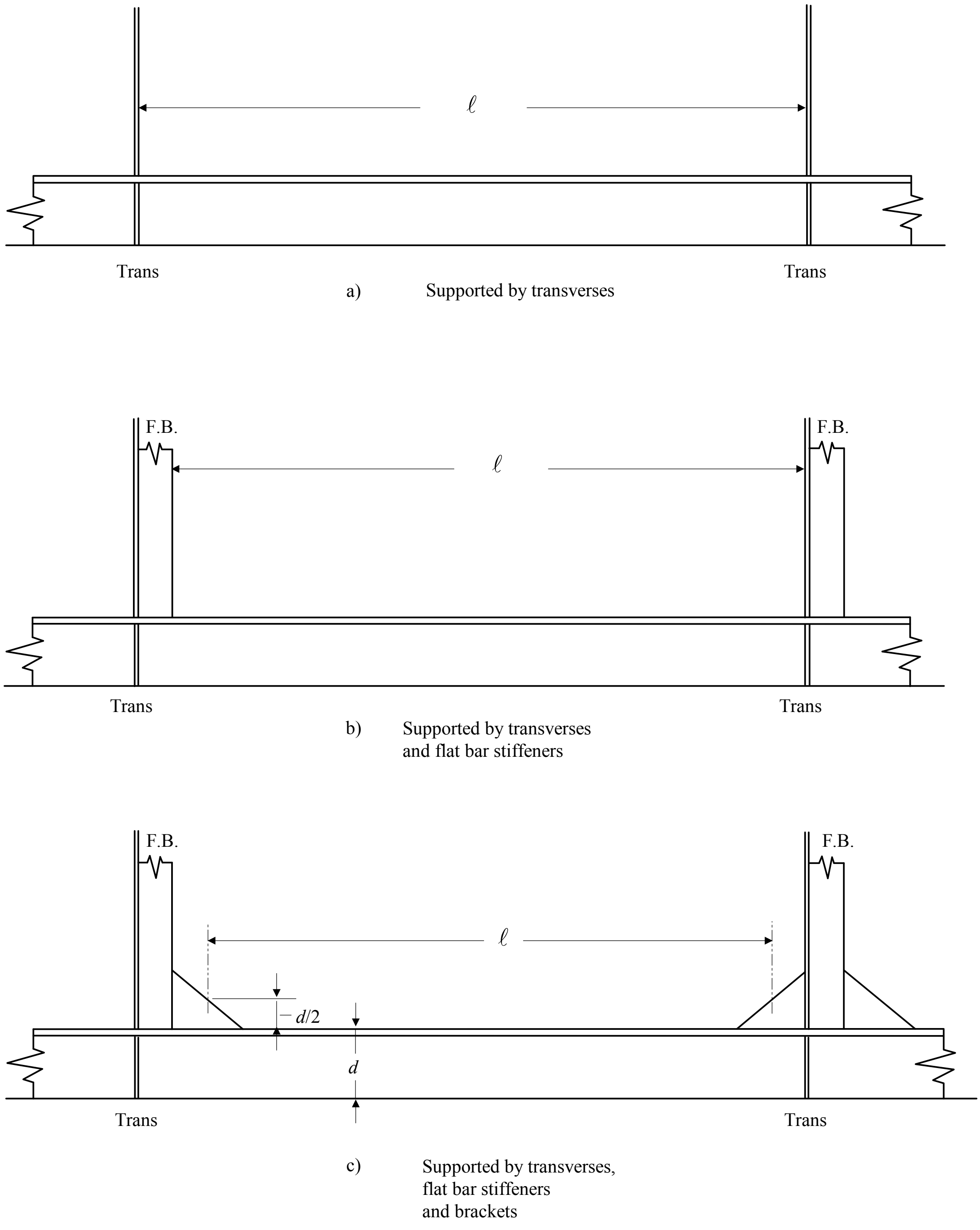
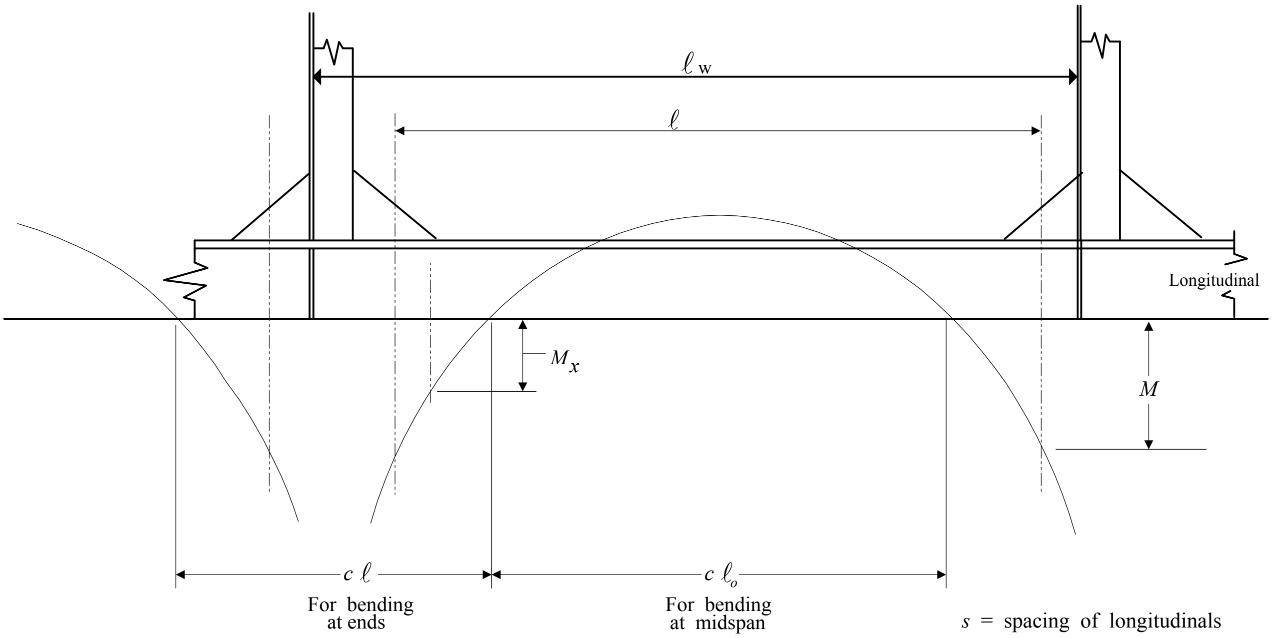


FIGURE 6
Effective Breadth of Plating b_e (1995)



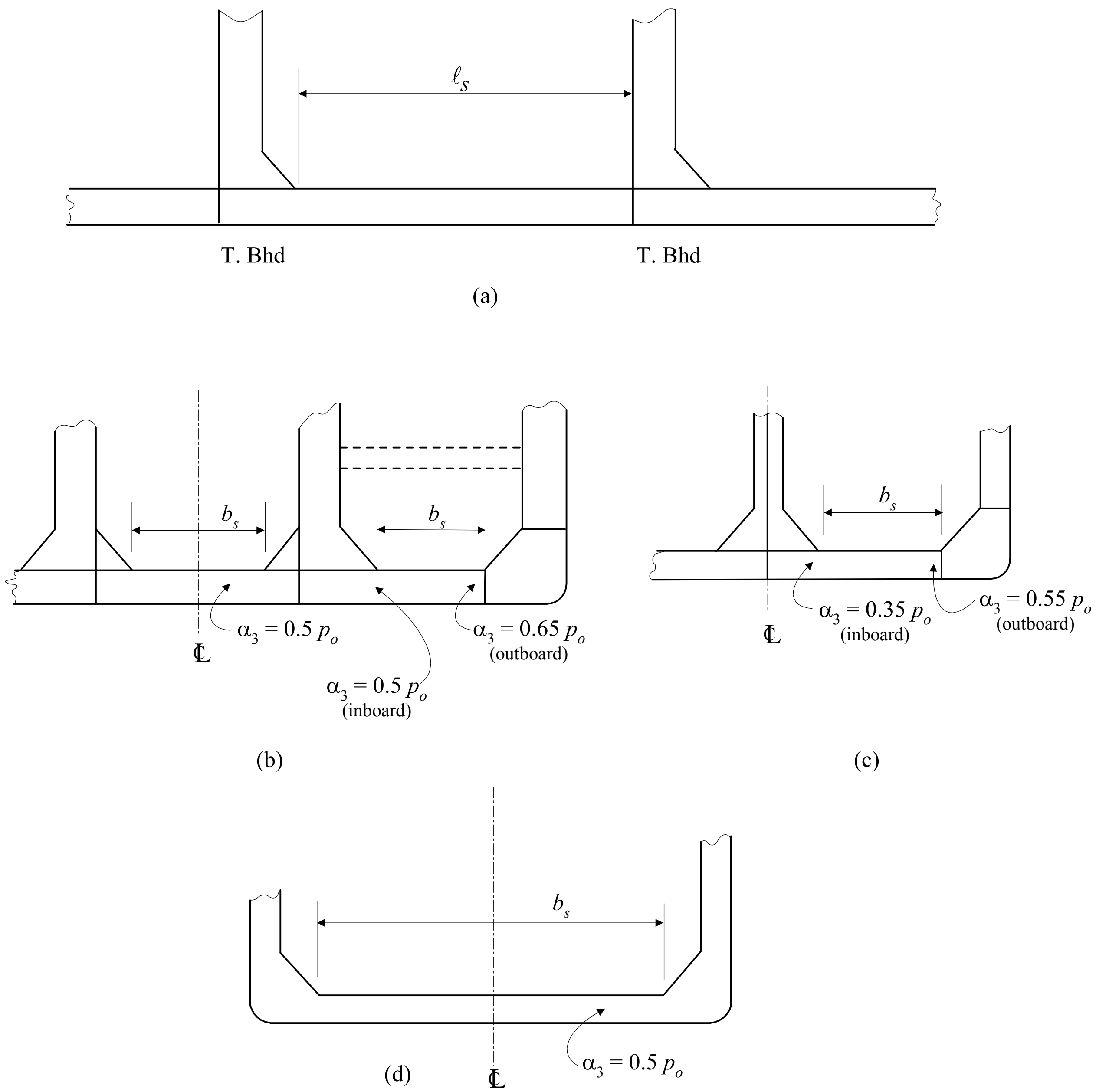
a) For bending at midspan

$c\ell_o/s$	1.5	2	2.5	3	3.5	4	4.5 and greater
b_e/s	0.58	0.73	0.83	0.90	0.95	0.98	1.0

b) For bending at ends [$b_e/s = (0.124c\ell/s - 0.062)^{1/2}$]

$c\ell/s$	1	1.5	2	2.5	3	3.5	4.0
b_e/s	0.25	0.35	0.43	0.5	0.55	0.6	0.67

FIGURE 7
Definitions of α_3, ℓ_s and b_s *(1995)*



9 Side Shell and Deck – Plating and Longitudinals

9.1 Side Shell Plating *(1 July 2005)*

The net thickness of the side shell plating, in addition to compliance with 5C-1-4/5.3, is to be not less than t_1, t_2 and t_3, as specified below for the midship 0.4L:

$t_1 = 0.73s(k_1 p/f_1)^{1/2}$ mm (in.)

$t_2 = 0.73s(k_2\, p/f_2)^{1/2}$ mm (in.)

$t_3 = cs(S_m f_y /E)^{1/2}$ mm (in.)

where

s = spacing of side longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.50

p = $p_a - p_{uo}$ or p_b, whichever is greater, in N/cm² (kgf/cm², lbf/in²)

p_{uo} = $0.24\gamma(h\ell_{wt}b_{wt} \tan \phi_e \tan \theta_e)^{1/3}$ where $\ell_{wt} \geq 0.20L$

= 0 where $\ell_{wt} \leq 0.15L$

Linear interpolation is to be used for intermediate values of ℓ_{wt}.

p_a and p_b are nominal pressures at the lower edge of each plate strake, in N/cm² (kgf/cm², lbf/in²), as defined in load case "a" and "b" 5C-1-3/Table 3 for side shell plating. t_1 and t_2 as calculated for each plate need not to be taken in excess of those calculated at the upper turn of the bilge. Where the wing ballast tanks are U-shaped, the nominal pressure may be taken at the lower edge of each plate, but is not to be less than that calculated at upper turn of bilge for J-shaped ballast tanks.

b_{wt} = breadth at tank top of double side ballast tank, in m (ft)

ϕ_e = effective pitch amplitude, as defined in 5C-1-3/5.7.2, with $C_\phi = 0.7$

θ_e = effective roll amplitude, as defined in 5C-1-3/5.7.2, with $C_\theta = 0.7$

L is vessel length, as defined in 3-1-1/3.1, in m (ft).

γ, h and ℓ_{wt} are also defined in 5C-1-4-/7.3.1.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

f_1 = permissible bending stress, in the longitudinal direction, in N/cm² (kgf/cm², lbf/in²)

= $[0.86 - 0.50\alpha_1(SM_{RB}/SM_B)(y/y_b)]S_m f_y$

$\leq 0.43\, S_m f_y$, for $L \geq 190$ m (623 ft), below neutral axis

$\leq [0.43 + 0.17(190 - L)/40]S_m f_y$, for $L < 190$ m (623 ft), below neutral axis.

SM_B/SM_{RB} is not to be taken more than 1.4.

= $0.43\, S_m f_y$, for $L \geq 190$ m (623 ft), above neutral axis

= $[0.43 + 0.17\,(190 - L)/40]S_m f_y$ for $L < 190$ m (623 ft), above neutral axis

f_2 = permissible bending stress in the vertical direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.80\, S_m f_y$

α_1 = $S_{m1} f_{y1} / S_m f_y$

S_m = strength reduction factor obtained from 5C-1-4/7.3.1 for the steel grade of side shell plating material

S_{m1} = strength reduction factor obtained from 5C-1-4/7.3.1 for the steel grade of bottom flange material

f_y = minimum specified yield point of the side shell material, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{y1} = minimum specified yield point of the bottom flange material, in N/cm^2 (kgf/cm^2, lbf/in^2)

y_b = vertical distance, in m (ft), measured from the upper turn of bilge to the neutral axis of the section

c = $0.7N^2 - 0.2$, not to be less than $0.4Q^{1/2}$

N = $R_d\,(Q/Q_d)^{1/2}$ for the sheer strake

= $R_d\,[(Q/Q_d)(y/y_n)]^{1/2}$ for other locations above neutral axis

= $R_b\,[(Q/Q_b)(y/y_n)]^{1/2}$ for locations below neutral axis

R_d = $(SM_{RDS}/SM_D)^{1/2}$

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the lower edge (upper edge) of the side shell strake, when the strake under consideration is below (above) the neutral axis for N.

= vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the lower edge of the side shell strake under consideration for f_1.

SM_{RDS} = reference net hull girder section modulus for sagging bending moment, based on the material factor of the deck flange of the hull girder, in cm^2-m (in^2-ft)

= $0.92SM_S$

SM_S = required gross hull girder section modulus, in accordance with 3-2-1/3.7.1and 3-2-1/5.5, for sagging total bending moment at the location under consideration, based on the material factor of the deck flange of the hull girder, in cm^2-m (in^2-ft)

Q, Q_d = material conversion factor in 5C-1-4/5.1 for the side shell plating under consideration and the deck flange of the hull girder, respectively.

y_n = vertical distance, in m (ft), measured from the bottom (deck) to the neutral axis of the section, when the strake under consideration is below (above) the neutral axis.

SM_{RB}, SM_B, R_b, Q_b and E are as defined in 5C-1-4/7.3.1. SM_D is as defined in 5C-1-4/9.5.

However, for plate panels above the neutral axis, t_3 need not be taken greater than the value that satisfies the following buckling requirement.

$$\frac{M_t}{SM_R} \le f_c$$

$$f_c = f_E \qquad \text{for } f_E \le P_r f_y$$

$$f_c = f_y\left[1 - P_r(1 - P_r)\frac{f_y}{f_E}\right] \qquad \text{for } f_E > P_r f_y$$

where

f_E = $\dfrac{c_1 \pi^2 E}{3(1-\nu^2)}\left(\dfrac{t_3}{s}\right)^2$

c_1 = 1.0 for plate panels between flat bars or bulb plates

= 1.1 for plate panels between angles or tee stiffeners

P_r = proportional linear elastic limit of the structure, may be taken as 0.6 for steel

ν = Poisson's ratio, may be taken as 0.3 for steel

M_t = total sagging bending moment

SM_R = section modulus at the center of the plate panel under consideration.

The minimum width of the sheer strake for the midship 0.4*L* is to be in accordance with 3-2-2/3.11.

The thickness of the sheer strake is to be increased 25% in way of breaks of superstructures, but this increase need not exceed 6.5 mm (0.26 in.).

In addition, the net thickness of the side shell plating is not to be taken less than t_4 obtained from the following equation:

$$t_4 = 90(s/1000 + 0.7)\,[B\,d\,/(S_m f_y)^2]^{1/4} + 0.5 \qquad \text{mm}$$

where

s = spacing of side longitudinal stiffeners, in mm

B = breadth of vessel, as defined in 3-1-1/5, in m

d = molded draft, as defined in 3-1-1/9, in m

All other parameters are as defined above.

The net thickness, t_4, is to be applied to the following extent of the side shell plating:

- *Longitudinal extent.* Between a section aft of amidships where the breadth at the waterline exceed 0.9*B*, and a section forward of amidships where the breadth at the waterline exceeds 0.6*B*.
- *Vertical extent.* Between 300 mm below the lowest ballast waterline to 0.25*d* or 2.2 m, whichever is greater, above the summer load line.

9.3 Deck Plating *(1 July 2005)*

The thickness of the strength deck plating is to be not less than that needed to meet the hull girder section modulus requirement in 3-2-1/3.7. The buckling and ultimate strength are to be in accordance with the requirements in 5C-1-5/5. In addition, the net thickness of deck plating is to be not less than t_1, t_2 and t_3, as specified below for the midship 0.4L:

$t_1 = 0.73s(k_1 p/f_1)^{1/2}$ mm (in.)

$t_2 = 0.73s(k_2\, p/f_2)^{1/2}$ mm (in.)

$t_3 = cs(S_m f_y/E)^{1/2}$ mm (in.)

where

s	=	spacing of deck longitudinals, in mm (in.)	
k_1	=	0.342	
k_2	=	0.50	
p	=	p_n	in cargo tank, in N/cm² (kgf/cm², lbf/in²)
	=	$p_n - p_{uh}$	in ballast tank, in N/cm² (kgf/cm², lbf/in²)

In no case is p to be taken less than 2.06 N/cm² (0.21 kgf/cm², 2.987 lbf/in²).

p_n is nominal pressure, in N/cm² (kgf/cm² lbf/in²), as defined in 5C-1-3/Table 3 for deck plating.

p_{uh} is defined in 5C-1-4/7.3.1.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

f_1	=	permissible bending stress in the longitudinal direction, in N/cm² (kgf/cm², lbf/in²)	
	=	$0.15\, S_m f_y$	
f_2	=	permissible bending stress in the transverse direction, in N/cm² (kgf/cm², lbf/in²)	
	=	$0.80\, S_m f_y$	
c	=	$0.5\,(0.6 + 0.0015L)$	for SI or MKS Units
	=	$0.5\,(0.6 + 0.00046L)$	for U.S. Units

c is not to be taken less than $(0.7N^2 - 0.2)$ for vessels having length less than 267 m (876 ft)

L	=	length of vessel, in m (ft), as defined in 3-1-1/3.1
N	=	$R_d\,(Q/Q_d)^{1/2}$
R_d	=	$(SM_{RDS}/SM_D)^{1/2}$
Q	=	material conversion factor in 5C-1-4/5.1 for the deck plating

S_m, f_y and E are as defined in 5C-1-4/7.3.1.

SM_{RDS} and Q_d are as defined in 5C-1-4/9.1.

SM_D is as defined in 5C-1-4/9.5.

t_3 need not be taken greater than the value that satisfies the following buckling requirement.

$$\frac{M_t}{SM_D} \le f_c$$

$$f_c = f_E \qquad \text{for } f_E \le P_r f_y$$

$$f_c = f_y\left[1 - P_r(1 - P_r)\frac{f_y}{f_E}\right] \qquad \text{for } f_E > P_r f_y$$

where

f_E = $\dfrac{c_1 c_2 \pi^2 E}{3(1-\nu^2)}\left(\dfrac{t_3}{s}\right)^2$

c_1 = 1.0 for plate panels between flat bars or bulb plates

= 1.1 for plate panels between angles or tee stiffeners

c_2 = 1.0 for plate panels within the cargo tank space

= 1.1 for plate panels within the side ballast tank space

P_r = proportional linear elastic limit of the structure, may be taken as 0.6 for steel

ν = Poisson's ratio, may be taken as 0.3 for steel

M_t = total sagging bending moment

The thickness of the stringer plate is to be increased 25% in way of breaks of superstructures, but this increase need not exceed 6.5 mm (0.25 in.). The required deck area is to be maintained throughout the midship 0.4*L* of the vessel or beyond the end of a superstructure at or near the midship 0.4*L* point. From these locations to the ends of the vessel, the deck area may be gradually reduced in accordance with 3-2-1/11.3. Where bending moment envelope curves are used to determine the required hull girder section modulus, the foregoing requirements for strength deck area may be modified in accordance with 3-2-1/11.3. Where so modified, the strength deck area is to be maintained a suitable distance from superstructure breaks and is to be extended into the superstructure to provide adequate structural continuity.

The structural drawings for major on-deck outfitting members are to be submitted. Special attention is to be paid to the attachments of deck fittings to deck plate so that harmful stress concentration or any failure due to cyclic loads can be avoided. If any structural reinforcement is not allowed due to a specific structural arrangement, the fatigue strength calculations of the attachment may be required for review.

9.5 Deck and Side Longitudinals *(1 July 2005)*

The net section modulus of each individual side or deck longitudinal, in association with the effective plating to which it is attached, is to be not less than obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

$M = 1000ps\ell^2/k$ N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 83.33)

p = $p_{ai} - p_{uo}$ or p_b, whichever is greater, for side longitudinals, in N/cm^2 (kgf/cm^2, lbf/in^2)

= p_n for deck longitudinals in cargo tank, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $p_n - p_{uh}$ for deck longitudinals in ballast tank, N/cm^2 (kgf/cm^2, lbf/in^2)

In no case is p to be taken less than 2.06 N/cm^2 (0.21 kgf/cm^2, 2.987 lbf/in^2).

p_a and p_b are nominal pressures, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in load case "a" and "b", at the side longitudinal considered, in 5C-1-3/Table 3 for side longitudinals, respectively.

p_n is nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in 5C-1-3/Table 3 for deck longitudinals.

$p_{uo}$and p_{uh} are defined in 5C-1-4/9.1 and 5C-1-4/7.3.1, respectively.

s and ℓ are as defined in 5C-1-4/7.5.

f_b = permissible bending stresses, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $(1.0 - 0.60\alpha_2 SM_{RD}/SM_D)S_m f_y$ for deck longitudinals

= $1.0[0.86 - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]\ S_m f_y \leq 0.75 S_m f_y$

for side longitudinals below neutral axis

= $2.0[0.86 - 0.52\alpha_2(SM_{RD}/SM_D)(y/y_n)]\ S_m f_y \leq 0.75 S_m f_y$

for side longitudinals above neutral axis

α_2 = $S_{m2} f_{y2}/S_m f_y$

S_m, f_y and α_1 are as defined in 5C-1-4/7.5.

S_{m2} = strength reduction factor, as obtained from 5C-1-4/7.3.1, for the steel grade of top flange material of the hull girder.

f_{y2} = minimum specified yield point of the top flange material of the hull girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

SM_{RD} = reference net hull girder section modulus based on the material factor of the top flange of the hull girder, in cm^2-m (in^2-ft)

= 0.92 SM

SM = required gross hull girder section modulus at the location under consideration, in accordance with 3-2-1/3.7 and 3-2-1/5.5, based on the material factor of the top flange of the hull girder, in cm^2-m (in^2-ft)

SM_D = design (actual) net hull girder section modulus at the deck, in cm^2-m (in^2-ft), at the location under consideration

SM_{RB} and SM_B are as defined in 5C-1-4/7.3.1.

y = vertical distance in m (ft) measured from the neutral axis of the section to the longitudinal under consideration at its connection to the associated plate

y_n = vertical distance, in m (ft), measured from the deck (bottom) to the neutral axis of the section, when the longitudinal under consideration is above (below) the neutral axis.

Where the wing ballast tanks are U-shaped, the net section modulus of deck longitudinals in the wing ballast tanks is to be not less than that of the uppermost side longitudinal, adjusted for the span and spacing of the longitudinal and the material factors.

Where the breadth of center tank exceeds $0.6B$, the net section modulus of deck longitudinals in the center tank, located outboard of $0.3B$ from the centerline of the tank, is also to be not less than that of the uppermost boundary longitudinal bulkhead longitudinal required by 5C-1-4/13.5 of this Section, adjusted for the span and spacing of the longitudinal and the material factors.

In determining compliance with the foregoing, an effective breadth, b_e, of attached plating is to be used in the calculation of the section modulus of the design longitudinal. b_e is to be obtained from line a) of 5C-1-4/Figure 6.

The net moment of inertia about the neutral axis of deck longitudinals and side longitudinals within the region of $0.1D$ from the deck, in association with the effective plating ($b_{wL}t_n$), is to be not less than obtained from the following equation:

$$i_o = kA_e\ell^2 f_y/E \quad \text{cm}^4 \text{ (in}^4\text{)}$$

where

k = 1220 (1220, 17.57)

A_e = net sectional area of the longitudinal with the associated effective plating $b_{wL}\, t_n$, in cm^2 (in^2)

b_{wL} = cs

c = $2.25/\beta - 1.25\beta^2$ for $\beta \geq 1.25$

= 1.0 for $\beta < 1.25$

β = $(f_y/E)^{1/2}\, s/t_n$

t_n = net thickness of the plate, in mm (in.)

D = depth of vessel, in m (ft), as defined in 3-1-1/7.

ℓ, s and f_y are as defined in 5C-1-4/7.5.

E is as defined in 5C-1-4/7.3.1.

11 Side Shell and Deck – Main Supporting Members *(1995)*

11.1 General *(1997)*

The main supporting members, such as transverses and girders, are to be arranged and designed with sufficient stiffness to provide support to the vessel's hull structures. In general, the deck transverses, side transverses and bottom floors are to be arranged in one plane to form continuous transverse rings. Deck girders, where fitted, are to extend throughout the cargo tank spaces and are to be effectively supported at the transverse bulkheads.

Generous transitions are to be provided at the intersections of main supporting members to provide smooth transmission of loads and to minimize the stress concentrations. Abrupt changes in sectional properties and sharp re-entrant corners are to be avoided. It is recommended that the intersection of the inner skin and inner bottom be accomplished by using generous sloping or large radiused bulkheads. Stool structures, where fitted, are to have sloping bulkheads on both sides.

The net section modulus and sectional area of the main supporting members required by Part 5C, Chapter 1 apply to those portions of the member clear of the end brackets. They are considered as the requirements of initial scantlings for deck transverses, side transverses, vertical webs on longitudinal bulkheads and horizontal girders and vertical webs on transverse bulkheads, and may be reduced, provided that the strength of the resultant design is verified with the subsequent total strength assessment in Section 5C-1-5. However, in no case should they be taken less than 85% of those determined from 5C-1-4/11 or 5C-1-4/15. (See also 5C-1-5/9.1). The structural properties of the main supporting members and end brackets are to comply with the failure criteria specified in 5C-1-5/3.

The section modulus of the main supporting members is to be determined in association with the effective plating to which they are attached, as specified in 3-1-2/13.

(1 July 2000) In calculation of the nominal pressure, ρg of the liquid cargoes is not to be taken less than 0.1025 kgf/cm^2-m (0.4444 lbf/in^2-ft) for main supporting members.

11.3 Deck Transverses

11.3.1 Section Modulus of Deck Transverses *(1 July 2005)*

The net section modulus of deck transverses is to be not less than obtained from the following equation (see also 5C-1-4/1.3):

$$SM = M/f_b \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

For deck transverses in wing cargo tanks (See 5C-1-4/Figure 2A-a, b, c, d, e, and f):

$$M = k(10{,}000\, c_1 \varphi\, ps\, \ell_t^2 + \beta_s M_s) \geq M_o \quad \text{N-cm (kgf-cm, lbf-in)}$$

For deck transverses in center cargo tanks (see 5C-1-4/Figure 2A-d, e and f)

$$M = k(10{,}000\, c_1 \varphi\, ps\, \ell_t^2 + \beta_b M_b) \geq M_o \quad \text{N-cm (kgf-cm, lbf-in)}$$

where

M_s = $10{,}000 c_2\, p_s\, s\, \ell_s^2$

M_b = $10{,}000 c_2\, p_b\, s\, \ell_b^2$

M_o = $10{,}000 k c_3\, ps\, \ell_t^2$

k = 1.0 (1.0, 0.269)

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid span of the deck transverse under consideration, as specified in 5C-1-3/Table 3, item 16. In no case is p to be taken less than 2.06 N/cm^2 (0.21 kgf/cm^2, 2.987 lbf/in^2).

p_s = corresponding nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-span of the side transverse (5C-1-3/Table 3, item 12)

p_b = corresponding nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-span of the vertical web on longitudinal bulkhead (5C-1-3/Table 3, item 13)

c_1 for tanks without deck girders:

= 0.30 for 5C-1-4/Figure 2A-c with non-tight centerline bulkhead

= 0.42 for all other cases

c_1 for tanks with deck girders:

= $0.30\alpha^2$ for 5C-1-4/Figure 2A-b with a non-tight centerline bulkhead, 0.05 min. and 0.30 max.

= $0.42\alpha^2$ for 5C-1-4/Figure 2A-a or 5C-1-4/Figure 2A-b with an oil-tight centerline bulkhead, 0.05 min. and 0.42 max.

α = $(\ell_g/\ell_t)[(s_g/s)(I_t/I_g)]^{1/4}$

ℓ_g = span of the deck girder, in m (ft), as indicated in 5C-1-4/Figure 2B-c

ℓ_t = span of the deck transverse, in m (ft), as indicated in 5C-1-4/Figure 2A, but is not to be taken as less than 60% of the breadth of the tank, except for tankers with a non-tight centerline bulkhead (5C-1-4/Figure 2A-b), for which the span is not to be taken as less than 30% of the breadth of the tank.

I_g, I_t = moments of inertia, in cm^4 (in^4), of the deck girder and deck transverse, clear of the brackets, respectively

s_g = spacing of the deck girder, in m (ft)

s = spacing of the deck transverses, in m (ft)

When calculating α, if more than one deck girder is fitted, average values of s_g, ℓ_g and I_g are to be used when the girders are not identical.

φ = $1 - [5(h_a/\alpha\ell_t)]$, for cargo tanks with deck girders, 0.6 minimum

= $1 - 5(h_a/\ell_t)$, for cargo tanks without deck girders, 0.6 minimum

h_a = distance, in m (ft), from the end of the span to the toe of the end bracket of the deck transverse, as indicated in 5C-1-4/Figure 8

β_s = $0.9[(\ell_s/\ell_t)(I_t/I_s)]$, 0.10 min. and 0.65 max.

β_b = $0.9[(\ell_b/\ell_t)(I_t/I_b)]$, 0.10 min. and 0.50 max.

ℓ_s and ℓ_b = spans, in m (ft), of side transverse and vertical web on longitudinal bulkhead, respectively, as indicated in 5C-1-4/Figure 2A. Where a cross tie is fitted and is located at a distance greater than $0.7\ell_s$ or $0.7\ell_b$ from the deck transverse, the effective span of the side transverse or the vertical web may be taken as that measured from the deck transverse to the cross tie and all coefficients determined as if there were no cross tie.

I_s and I_b = moments of inertia, in cm^4 (in^4), clear of the brackets, of side transverse and vertical web on longitudinal bulkhead, respectively

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.70\, S_m f_y$

S_m and f_y, as defined in 5C-1-4/7.3.1.

c_2 is given in 5C-1-4/Table 1.

c_3 = $2.0c_1$ for tankers with oil-tight longitudinal bulkheads and without deck girders (5C-1-4/Figure 2A-c, d, e and f)

= $1.6c_1$ for tankers with non-tight centerline longitudinal bulkhead and without deck girders (5C-1-4/Figure 2A-c)

= $1.1c_1$ for cargo tanks with deck girders

The section modulus of the deck transverse in the wing cargo tank is to be not less than that of the deck transverse in the center tank.

11.3.2 Sectional Area of Deck Transverses

The net sectional area of the web portion of deck transverses is to be not less than obtained from the following equation:

$A = F/f_s$ cm^2 (in^2)

$F = 1000k[c_1ps(0.50\ell - h_e) + c_2DB_c s]$ N (kgf, lbf)

where

k = 1.0 (1.0, 2.24)

c_2 = 0.05 for wing cargo tanks of tankers with four longitudinal bulkheads (5C-1-4/Figure 2A-d, e and f)

= 0 for other tanks (5C-1-4/Figure 2A-a, b, c, d, e and f)

c_1 for tanks with deck girders:

= $0.90\alpha^{1/2}$ for 5C-1-4/Figure 2A-a without longitudinal bulkhead and for 5C-1-4/Figure 2A-b with an oil-tight centerline bulkhead, 0.50 min. and 1.0 max.

= $0.60\alpha^{1/2}$ for 5C-1-4/Figure 2A-b with a non-tight centerline bulkhead, 0.45 min. and 0.85 max.

c_1 for tanks without deck girders:

= 1.10 for 5C-1-4/Figure 2A-c, with a nontight centerline longitudinal bulkhead

= 1.30 for all other cases (5C-1-4/Figure 2A-c, d, e and f)

ℓ = span of the deck transverse, in m (ft), as indicated in 5C-1-4/Figure 2A

h_e = length of the bracket, in m (ft), as indicated in 5C-1-4/Figure 2A-c and 5C-1-4/Figure 2A-d and 5C-1-4/Figure 8

D = depth of the vessel, in m (ft), as defined in 3-1-1/7

B_c = breadth of the center tank, in m (ft)

p, s and α, as defined in 5C-1-4/11.3.1

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\, S_m f_y$

S_m and f_y, as defined in 5C-1-4/7.3.1.

11.5 Deck Girders

11.5.1 Section Modulus of Deck Girders *(1 July 2005)*

The net section modulus of deck girders is to be not less than obtained from the following equation (see also 5C-1-4/1.3):

$SM = M/f_b$ cm^3 (in^3)

M equals M_1 or M_2, whichever is greater, as given below:

M_1 = $4200kps_g\ell_g^2$ N-cm (kgf-cm, lbf-in)

M_2 = $k(3000\varphi ps_g\ell_g^2 + 0.15M_b)$ N-cm (kgf-cm, lbf-in)

M_b = $10{,}000p_{st}s_g\ell_{st}^2$ N-cm (kgf-cm, lbf-in)

where

k	=	1.0 (1.0, 0.269)
ℓ_g	=	span, in m (ft), of the deck girder, as indicated in 5C-1-4/Figure 2B-c
ℓ_{st}	=	span, in m (ft), of the vertical web on transverse bulkhead, as indicated in 5C-1-4/Figure 2B-c
s_g	=	spacing, in m (ft), of the deck girder considered, as indicated in 5C-1-4/Figure 2A
φ	=	$1 - 5(h_a/\ell_g)$, 0.6 min.
h_a	=	distance, in m (ft), from the end of the span to the toe of the end bracket of the deck girder, as indicated in 5C-1-4/Figure 2B-c and 5C-1-4/Figure 8
p	=	nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), as specified in 5C-1-3/Table 3, item 17 for the girder considered. Where three or more deck girders are fitted in the cargo tank, p is to be not less than its value determined for the outermost girder clear of the end bracket of the deck transverse. In no case is p to be taken less than 2.06 N/cm^2 (0.21 kgf/cm^2, 2.987 lbf/in^2).
p_{st}	=	corresponding nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-span of the vertical web on the forward transverse bulkhead of cargo tank under consideration (5C-1-3/Table 3, item 17)
f_b	=	permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)
	=	$0.45\ S_m f_y$
	=	$(1.0 - 0.55\alpha_2 SM_{RD}/SM_D)S_m f_y \le 0.52 S_m f_y$ for $L < 190$ m

S_m and f_y, as defined in 5C-1-4/7.3.1.

11.5.2 Sectional Area of Deck Girder

The net sectional area of the web portion of deck girders is to be not less than obtained from the following equation:

$$A = F/f_s \qquad \text{cm}^2\ (\text{in}^2)$$

$$F = 1000kcps_g(0.5\ell - h_e) \qquad \text{N (kgf, lbf)}$$

where

k	=	1.0 (1.0, 2.24)
c	=	0.55 for one or two girders in the tank
	=	0.67 for three or more girders in the tank
ℓ	=	span of the deck girder, in m (ft), as indicated in 5C-1-4/Figure 2B-c
h_e	=	length of the bracket, in m (ft), as indicated in 5C-1-4/Figure 2B-c and 5C-1-4/Figure 8.

p and s_g are defined in 5C-1-4/11.5.1.

f_s	=	permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)
	=	$0.30\ S_m f_y$

S_m and f_y, as defined in 5C-1-4/7.3.1.

11.7 Web Sectional Area of Side Transverses

The net sectional area of the web portion of side transverses is to be not less than obtained from the following equation:

$A = F/f_s$ cm^2 (in^2)

The shear force F, in N (kgf, lbf), for the side transverse can be obtained from the following equations (see also 5C-1-4/1.3):

$F = 1000ks[K_U\,\ell(P_U + P_L) - h_U P_U]$ for upper part of transverse

$F = 1000ks[K_L\,\ell(P_U + P_L) - h_L P_L]$ or $350ksK_L\,\ell(P_U + P_L)$ whichever is greater for lower part of transverse

In no case is the shear force for the lower part of the transverse to be less than 120% of that for the upper part of the transverse.

where

k = 1.0 (1.0, 2.24)

ℓ = span, in m (ft), of the side transverse, as indicated in 5C-1-4/Figure 2B-a. Where one cross tie is fitted in the wing tank and is located at a distance of more than 0.7ℓ from the deck transverse, the effective span of the side transverse may be measured from the deck transverse to the cross tie and all coefficients determined as if there were no cross tie.

s = spacing, in m (ft), of the side transverses

P_U = nominal pressure, p, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-length of upper bracket, as specified in 5C-1-3/Table 3

P_L = nominal pressure, p, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-length of lower bracket, as specified in 5C-1-3/Table 3.

h_U = length of the upper bracket, in m (ft), as indicated in 5C-1-4/Figure 2B-a

h_L = length of the lower bracket, in m (ft), as indicated in 5C-1-4/Figure 2B-a

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\,S_m f_y$

K_U and K_L are given in 5C-1-4/Table 2.

S_m and f_y, as defined in 5C-1-4/7.3.1.

For tankers without cross ties in the wing cargo tank, the required sectional area of the lower side transverse is to extend to 0.15ℓ from the toe of the lower bracket or 0.33ℓ from the lower end of the span, whichever is greater.

For tankers with one cross tie, the sectional area required for the lower portion of the transverse is to be maintained up to the cross tie.

11.9 Minimum Thickness for Web Portion of Main Supporting Members *(1997)*

In general, the net thickness of the web plate of the main supporting members, except stringers in double side structures, is to be not less than t, as obtained below:

$$t = 0.012L + 7.7 \quad \text{mm}$$

$$= 0.144L \times 10^{-3} + 0.303 \quad \text{in.}$$

but t need not be taken greater than 11.0 mm (0.433 in.)

The net thickness of side stringers in double side structures is not to be less than t_1 and t_2, as specified below:

$$t_1 = 0.012L + 6.7 \quad \text{mm}$$

$$= 0.144L \times 10^{-3} + 0.264 \quad \text{in.}$$

but t_1 need not be taken greater than 10.0 mm (0.394 in.)

$$t_2 = cs(S_m f_y / E)^{1/2} \quad \text{mm (in.)}$$

where

L = the length of the vessel, in m (ft), as defined in 3-1-1/3.1

c = $0.7N^2 - 0.2$, not to be less than 0.33

s = spacing of longitudinals, in mm (in.)

S_m = strength reduction factor, obtained from 5C-1-4/7.3.1 for the steel grade of the side stringer

f_y = minimum specified yield point of the side stringer material, in N/cm^2 (kgf/cm^2, lbf/in^2)

N = $R_d\,[(Q/Q_d)(y/y_n)]^{1/2}$ for side stringers above neutral axis

= $R_b\,[(Q/Q_b)(y/y_n)]^{1/2}$ for side stringers below neutral axis

Q = material conversion factor 5C-1-4/5.1 for the side stringer under consideration

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the side stringer under consideration

E, R_b and Q_b are as defined in 5C-1-4/7.3.1. R_d, Q_d and y_n are as defined in 5C-1-4/9.1.

11.11 Proportions

In general, webs, girders and transverses are not to be less in depth than specified below, as a percentage of the span, ℓ_t, ℓ_b or ℓ_g, where applicable (see 5C-1-4/Figure 2A and 5C-1-4/Figure 2B). Alternative designs with stiffness equivalent to the specified depth/length ratio and the required section modulus may be considered, provided that the calculated results are submitted for review.

11.11.1 Deck Transverse

23% for deck transverses in wing cargo tanks of tankers with four side longitudinal bulkheads where no deck girders are fitted (see 5C-1-4/Figure 2A-d, e and f).

12.5% for deck transverses in center cargo tanks of tankers with four side longitudinal bulkheads where no deck girders are fitted (see 5C-1-4/Figure 2A-d, e and f). In this case, the depth is also to be not less than that of the transverse in the wing tank.

12.5% for deck transverses without deck girders for tankers with centerline longitudinal bulkhead (See 5C-1-4/Figure 2A-c).

8.5% for deck transverses in cargo tanks with one deck girder.

5.5% for deck transverses in cargo tanks with two deck girders.

3.5% for deck transverse in cargo tanks with three or more deck girders.

11.11.2 Deck Girder

20% for deck girders where only one is fitted in a tank.

12.5% for deck girders where two are fitted in a tank.

9.0% for deck girders where three or more are fitted in a tank.

11.11.3 Longitudinal Bulkhead Webs/Girders *(2005)*

14% for vertical webs of longitudinal bulkheads without strut and horizontal girders of longituditudinal bulkheads.

9.0% for vertical webs of longitudinal bulkheads with one or more struts

11.11.4 Transverse Bulkhead Webs/Girders

20.0% for vertical webs of transverse bulkheads where only one is fitted in a tank.

12.5% for vertical webs of transverse bulkheads where two are fitted in a tank.

9.0% for vertical webs of transverse bulkheads where three or more are fitted in a tank.

28% for horizontal girders of transverse bulkheads in wing tanks for tankers with four side longitudinal bulkheads (See 5C-1-4/Figure 2A-d, e and f).

20% for horizontal girders of transverse bulkheads in center tanks for tankers with four side longitudinal bulkheads (See 5C-1-4/Figure 2A-d, e and f), but not less in depth than horizontal girders in wing tanks

20% for horizontal girders of transverse bulkheads without vertical webs for tankers with centerline longitudinal bulkhead (See 5C-1-4/Figure 2A-c)

10% for horizontal girders of transverse bulkhead with one vertical web in the cargo tank

7% for horizontal girders of transverse bulkhead with two or more vertical webs in the cargo tank, except in the case where more than two vertical webs are fitted for tankers with centerline longitudinal bulkheads (See 5C-1-4/Figure 2A-b), or more than five vertical webs are fitted for tankers with outer longitudinal bulkheads only (See 5C-1-4/Figure 2A-a). In that case, horizontal girders are not to be less in depth than 15% of the maximum distance between two adjacent vertical webs or the end of span ℓ_b of the horizontal girder and next vertical web.

In no case are the depths of supporting members to be less than three times the depth of the slots for longitudinals. The thickness of the webs is to be not less than required by 5C-1-4/11.9.

11.13 Brackets

Generally, brackets are to have a thickness not less than that of the member supported, are to have flanges or face plates at their edges and are to be suitably stiffened.

11.15 Web Stiffeners and Tripping Brackets

11.15.1 Web Stiffeners

Stiffeners are to be fitted for the full depth of the webs of the main supporting member at the following intervals:

Floor	every longitudinal
Side	every longitudinal
Bulkhead	every second stiffener
Deck	every third longitudinal

Special attention is to be given to the stiffening of web plate panels close to change in contour of the web or where higher strength steel is used.

Web stiffener attachment to the deep webs, longitudinals and stiffeners is to be effected by continuous welds.

Where depth/thickness ratio of the web plating exceeds 200, a stiffener is to be fitted parallel to the flange or face plate at approximately one-quarter depth of the web from the flange or face plate.

Alternative system of web-stiffening of the main supporting members may be considered based on the structural stability of the web and satisfactory levels of the shear stresses in the welds of the longitudinals to the web plates.

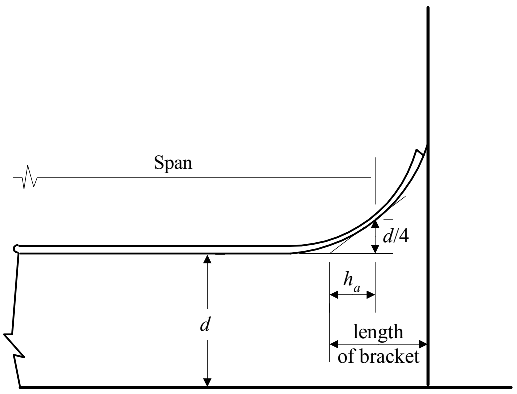
11.15.2 Tripping Bracket

Tripping brackets, arranged to support the flanges, are to be fitted at intervals of about 3 m (9.84 ft), close to any changes of section, and in line with the flanges of struts.

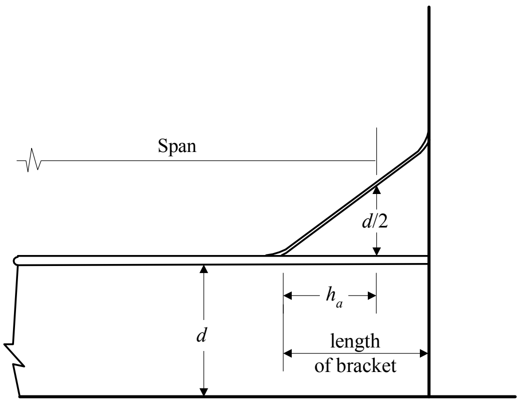
11.17 Slots and Lightening Holes

When slots and lightening holes are cut in transverses, webs, floors, stringers and girders, they are to be kept well clear of other openings. The slots are to be neatly cut and well rounded. Lightening holes are to be located midway between the slots and at about one-third of the depth of the web from the shell, deck or bulkhead. Their diameters are not to exceed one-third the depth of the web. In general, lightening holes are not to be cut in those areas of webs, floors, stringers, girders and transverses where the shear stresses are high. Similarly, slots for longitudinals are to be provided with filler plates or other reinforcement in these same areas. Where it is necessary to cut openings in highly stressed areas, they are to be effectively compensated. Continuous fillet welds are to be provided at the connection of the filler plates to the web and at the connection of the filler plate to the longitudinals.

FIGURE 8
Effectiveness of Brackets *(1995)*



Where face plate on the member is carried along the face of the bracket.



Where face plate on the member is not carried along the face of the bracket, and where the face plate area on the bracket is at least one-half the face plate area on the member.

Brackets are not to be considered effective beyond the point where the arm of the girder or web is 1.5 times the arm on the bulkhead or base.

TABLE 1
Coefficient c_2 For Deck Transverses *(1995)*

Structural Arrangement	*No cross ties (5C-1-4/Figure 2A-a, b, c and f)*	*Cross ties in wing cargo tank (5C-1-4/Figure 2A-d)*		*Cross ties in center cargo tank (5C-1-4/Figure 2A-e)*	
Location of Deck Transverse	All cargo tanks	Wing tank	Center tank	Wing tank	Center tank
c_2	0.40 [1]	0.37	0.13	0.40	0.14

Note

1 c_2 = 0.50 for tankers with an oil-tight centerline bulkhead which will be loaded from one side only.

TABLE 2
Coefficients K_U and K_L for Side Transverses *(1995)*

Arrangement of Cross Ties	K_U [1]	K_L [1]
No cross ties (5C-1-4/Figure 2A-a, b, c and f)	0.13	0.30
One cross tie in center cargo tank (5C-1-4/Figure 2A-e)		
One cross tie in wing cargo tank (5C-1-4/Figure 2A-d)	0.09	0.21

Note:

1 For tankers without cross ties in wing cargo tank (5C-1-4/Figure 2A-a, b, c, e and f) and having three or more side stringers, K_U = 0.10 and K_L = 0.22

13 Longitudinal and Transverse Bulkheads

13.1 Longitudinal Bulkhead Plating *(1 July 2005)*

The net thickness of the longitudinal bulkhead plating, in addition to complying with 5C-1-4/5.5, is to be not less than t_1, t_2 and t_3, as specified below:

$t_1 = 0.73s(k_1 p/f_1)^{1/2}$ mm (in.)

$t_2 = 0.73s(k_2 p/f_2)^{1/2}$ mm (in.)

$t_3 = cs(S_m f_y /E)^{1/2}$ mm (in.)

but not less than 9.5 mm (0.37 in.) where

s = spacing of longitudinal bulkhead longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.5

p = pressure at the lower edge of each plate, p_i, or maximum slosh pressure, p_s, whichever is greater, in N/cm^2 (kgf/cm^2, lbf/in^2).

In no case is p to be taken less than 2.06 N/cm^2 (0.21kgf/cm^2, 2.987 lbf/in^2).

p_i = p_n in cargo tank, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $p_n - p_{uo}$ in ballast tank, in N/cm^2 (kgf/cm^2, lbf/in^2)

p_n is nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as defined in 5C-1-3/Table 3 for longitudinal bulkhead plating.

p_{uo} is also defined in 5C-1-4/9.1.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

p_s = $k_s p_{is}$, not to be taken less than $k_s p_{is(mid)}$

p_{is} = nominal slosh pressure, as specified in 5C-1-3/11.5.1

$p_{is(mid)}$ = nominal slosh pressure at the mid-tank of the bulkhead at the same height as the point under consideration

k_s = b_t/ℓ_t, $0.9 \geq k_s \geq 0.65$ ($k_s = 0.9$ for $p_{is(mid)}$)

f_1 = permissible bending stress, in the longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $[1 - 0.28z/B - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]S_m f_y$, below neutral axis

= $[1 - 0.28z/B - 0.52\alpha_2(SM_{RD}/SM_D)(y/y_n)]S_m f_y$, above neutral axis

b_t and ℓ_t are the width and length, respectively, of the cargo tank being considered.

SM_B/SM_{RB} is not to be taken more than $1.2\alpha_1$ or 1.4, whichever is lesser.

α_1 = $S_{m1} f_{y1}/S_m f_y$

α_2 = $S_{m2} f_{y2}/S_m f_y$

S_m = strength reduction factor of the steel grade for the longitudinal bulkhead plating obtained from 5C-1-4/7.3.1

f_y = minimum specified yield point of the longitudinal bulkhead plating, in N/cm^2 (kgf/cm^2, lbf/in^2)

z = transverse distance, in m (ft), measured from the centerline of the section to the bulkhead strake under consideration

y_n = vertical distance, in m (ft), measured from the deck (bottom) to the neutral axis of the section, when the strake under consideration is above (below) the neutral axis.

f_2 = permissible bending stress, in the vertical direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $S_m f_y$

c = $0.7N^2 - 0.2$

c for the top strake is not to be taken less than $0.4Q^{1/2}$, but need not be greater than 0.45.

c for other strakes is not to be taken less than 0.33, but need not be greater than $0.45(Q/Q_d)^{1/2}$ for strakes above the neutral axis nor greater than $0.45(Q/Q_b)^{1/2}$ for strakes below the neutral axis.

N = $R_d[(Q/Q_d)(y/y_n)]^{1/2}$, for strake above the neutral axis

= $R_b[(Q/Q_b)(y/y_n)]^{1/2}$, for strake below the neutral axis

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the upper edge (lower edge) of the bulkhead strake, when the strake under consideration is above (below) the neutral axis for N

= vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the lower edge of the bulkhead strake under consideration for f_1

Q = material conversion factor in 5C-1-4/5.1 for the longitudinal bulkhead plating

B = vessel's breadth, in m (ft), as defined in 3-1-1/5.

SM_{RB}, SM_B, R_b, Q_b and E are as defined in 5C-1-4/7.3.1.

S_{m1} and f_{y1} are as defined in 5C-1-4/7.5.

R_d and Q_d are as defined in 5C-1-4/9.1.

SM_{RD}, SM_D, S_{m2} and f_{y2} are as defined in 5C-1-4/9.5.

For plate panels above the neutral axis, t_3 need not be taken greater than the value that satisfies the following buckling requirement.

$$\frac{M_t}{SM_R} \le f_c$$

$$f_c = f_E \qquad \text{for } f_E \le P_r f_y$$

$$f_c = f_y\left[1 - P_r(1 - P_r)\frac{f_y}{f_E}\right] \qquad \text{for } f_E > P_r f_y$$

where

f_E = $\dfrac{c_1 \pi^2 E}{3(1-\nu^2)}\left(\dfrac{t_3}{s}\right)^2$

c_1 = 1.0 for plate panels between flat bars or bulb plates

= 1.1 for plate panels between angles or tee stiffeners

P_r = proportional linear elastic limit of the structure, may be taken as 0.6 for steel

ν = Poisson's ratio, may be taken as 0.3 for steel

M_t = total sagging bending moment

SM_R = section modulus at the center of the plate panel under consideration.

The minimum width of the top strake for the midship 0.4L is to be obtained from the following equation:

b = $5L + 800$ mm for $L \leq 200$ m

= 1800 mm for $200 < L \leq 500$ m

b = $0.06L + 31.5$ in. for $L \leq 656$ ft

= 70.87 in. for $656 < L \leq 1640$ ft

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

b = width of top strake, in mm (in.)

13.3 Transverse Bulkhead Plating *(1999)*

The net thickness of transverse bulkhead plating is to be not less than t, as specified below:

$t = 0.73s(k_2\, p/f_2)^{1/2}$ mm (in.)

but not less than 9.5 mm (0.37 in.)

where

s = spacing of transverse bulkhead stiffeners, in mm (in.)

k_2 = 0.50

p = p_i or maximum slosh pressure, p_s, whichever is greater, in N/cm^2 (kgf/cm^2, lbf/in^2)

In no case is p to be taken less than 2.06 N/cm^2 (0.21 kgf/cm^2, 2.987 lbf/in^2).

p_i = p_n in cargo tank, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $p_n - p_{uh}$ in ballast tank, in N/cm^2 (kgf/cm^2, lbf/in^2)

p_n is nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as defined in 5C-1-3/Table 3 for transverse bulkhead plating.

p_{uh} is also defined in 5C-1-4/7.3.1.

p_s = $k_s p_{is}$, not to be taken less than $k_s p_{is(mid)}$

p_{is} = nominal slosh pressure, as specified in 5C-1-3/11.5.1

$p_{is(mid)}$ = nominal slosh pressure at the mid-tank of the bulkhead at the same height as the point under consideration.

k_s = ℓ_t/b_t, $0.9 \geq k_s \geq 0.65$ ($k_s = 0.9$ for $p_{is(mid)}$)

f_2 = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.85\ S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

ℓ_t, b_t are defined in 5C-1-4/13.1.

Where the wing ballast tanks are U-shaped, the net thickness of transverse bulkhead plating in the wing ballast tanks is also to be not less than as obtained from the above equation with the following substituted for p and f_2.

where

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified for side shell structure (item 3 case a) in 5C-1-3/Table 3, at the lower edge level of each transverse bulkhead plate.

f_2 = $S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

where the breadth of center tank exceeds $0.6B$, the net thickness of transverse bulkhead plating in the center tank ,outboard of $0.3B$ from the centerline of the tank, is also to be not less than as obtained from the above equation with the following substituted for p and f_2:

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified for inner skin longitudinal bulkhead structure (item 6 case a) in 5C-1-3/Table 3, at the lower edge level of each transverse bulkhead plate.

f_2 = $S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

13.5 Longitudinals and Vertical/Horizontal Stiffeners *(1 July 2005)*

The net section modulus of each individual longitudinal or vertical/horizontal stiffener on longitudinal and transverse bulkheads, in association with the effective plating to which it is attached, is to be not less than obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

$M = 1000c_1\ ps\ell^2/k$ N-cm (kgf-cm, lbf-in.)

where

k = 12 (12, 83.33)

c_1 = 1.0 for longitudinals and horizontal stiffeners

= $1 + \gamma\ell/10p$ for vertical stiffeners

γ = specific weight of the liquid, ≥ 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf/in^2-ft).

s = spacing of longitudinals or vertical/horizontal stiffeners, in mm (in.)

ℓ = span of longitudinals or stiffeners between effective supports, in m (ft)

p = pressure, p_i, in N/cm^2 (kgf/cm^2, lbf/in^2), at the longitudinal or stiffener considered, as specified in 5C-1-4/13.1 and 5C-1-4/13.3, or maximum slosh pressure, p_s, whichever is greater. For vertical stiffeners, pressure is to be taken at the middle of span of each stiffener.

p_s = $c_3 p_{is}$, not to be taken less than $c_3 p_{is(mid)}$

$p_{is(mid)}$ = nominal slosh pressure at the mid-tank of the bulkhead at the same height as the point under consideration

p_{is} = nominal slosh pressure, as specified in 5C-1-3/11.5.1

c_3 = as specified below:

for transverse bulkheads

0.60 for angle or T-bar, 0.68 for bulb plate or flat bar, and 0.73 for corrugation, if tank length ℓ_t is greater than 1.4 times tank width b_t and no transverse swash bulkheads in the tank.

Otherwise, $c_3 = c_{st}$ (c_{st} = 1.0 for $p_{is(mid)}$)

c_{st} = ℓ_t/b_t, $1.0 \geq c_{st} \geq 0.71$

for longitudinal bulkheads

0.60 for angle or T-bar, 0.68 for bulb plate or flat bar and 0.73 for corrugation, if tank width b_t is greater than 1.4 times tank length ℓ_t and no longitudinal swash bulkheads in the tank.

Otherwise $c_3 = c_{s\ell}$ ($c_{s\ell}$ = 1.0 for $p_{is(mid)}$)

$c_{s\ell}$ = b_t/ℓ_t, $1.0 \geq c_{s\ell} \geq 0.71$

f_b = permissible bending stresses, in N/cm^2 (kgf/cm^2, lbf/in^2).

= $0.70\, S_m f_y$ for transverse bulkhead stiffeners

= $1.4[1.0 - 0.28(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]S_m f_y \leq 0.90 S_m f_y$ for longitudinal bulkhead longitudinals below neutral axis

= $2.2[1.0 - 0.28(z/B) - 0.52\alpha_2(SM_{RD}/SM_D)(y/y_n)]S_m f_b \leq 0.90 S_m f_y$ for longitudinal bulkhead longitudinals above neutral axis

z = transverse distance, in m (ft), measured from the centerline of the vessel to the longitudinal under consideration at its connection to the associated plate

h = vertical distance, in m (ft), measured from the tank bottom to the longitudinal under consideration

H = depth of the tank, in m (ft)

B = vessel's breadth, in m (ft), as defined in 3-1-1/5.

S_m, f_y and α_1 are as defined in 5C-1-4/7.5.

α_2, y, y_n, SM_{RD} and SM_D are as defined in 5C-1-4/9.5.

SM_{RB} and SM_B are as defined in 5C-1-4/7.3.1.

The effective breadth of plating, b_e, is as defined in line a) of 5C-1-4/Figure 6.

Where the wing ballast tanks are U-shaped, the net section modulus of transverse bulkhead stiffeners in the wing ballast tanks is also to be not less than as obtained from the above equation with the following substituted for p and f_b:

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified for side shell structure (item 3 case a) in 5C-1-3/Table 3 at each transverse bulkhead stiffener level.

f_b = $S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

Where the breadth of center tank exceeds 0.6B, the net section modulus of transverse bulkhead stiffeners in the center tank, located outboard of 0.3B from the centerline of the tank, is also to be not less than as obtained from the above equation with the following substituted for p and f_b:

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified for inner skin longitudinal bulkhead structure (item 6 case a) in 5C-1-3/Table 3 at each transverse bulkhead stiffener level.

f_b = $S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

The net moment of inertia of longitudinals on the longitudinal bulkhead, with the associated effective plating, within the region of 0.1D from the deck is to be not less than i_o, as specified in 5C-1-4/9.5.

15 Bulkheads – Main Supporting Members *(1995)*

15.1 General

The main supporting members of longitudinal and transverse bulkheads are to be arranged and designed, as indicated in 5C-1-4/11.1.

15.3 Vertical Web on Longitudinal Bulkhead

15.3.1 Section Modulus of Vertical Web on Longitudinal Bulkhead *(1997)*

The net section modulus of the vertical web is to be not less than obtained from the following equation (see also 5C-1-4/1.3).

$$SM = M/f_b \qquad \text{cm}^3\ (\text{in}^3)$$

$$M = 10{,}000kcps\,\ell_b^2 \qquad \text{N-cm (kgf-m, lbf-in.)}$$

where

k = 1.0 (1.0, 0.269)

ℓ_b = span of member, in m (ft), as indicated in 5C-1-4/Figure 2B-a. Where a cross tie (in wing or center tank) is fitted and is located at a distance greater than 0.7ℓ_b from the deck transverse, the effective span of the vertical web may be measured from the deck transverse to the cross tie and all coefficients determined as if there were no cross ties. Where both the lower and upper ends of the vertical web are fitted with a bracket of the same or larger size on the opposite side, the span ℓ_b may be taken between the toes of the effective lower and upper brackets.

s = spacing of vertical webs, in m (ft)

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-span of the vertical web, as specified in 5C-1-3/Table 3.

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2 lbf/in^2)

= 0.70 $S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

c is given in 5C-1-4/Table 3.

For tankers without cross ties, and fitted with an oil-tight centerline bulkhead, the required section modulus of the web is to be maintained for $0.6\ell_b$, measured from the lower end of the web. The value of the bending moment, M, used for calculation of the required section modulus of the remainder of the web may be appropriately reduced, but by not more than 20%. Where the centerline bulkhead is non-tight, the required section modulus is to be maintained throughout.

15.3.2 Web Sectional Area of Vertical Webs on Longitudinal Bulkheads

The net sectional area of the web portion of vertical members is to be not less than obtained from the following equation:

$A = F/f_s$ cm^2 (in^2)

The shear force F, in N (kgf, lbf), may be obtained from the following equations (see also 5C-1-4/1.3).

$F = 1000ks[K_U\ell(P_U + P_L) - h_UP_U]$ for upper part of vertical web

$= 1000ks[K_L\ell(P_U + P_L) - h_LP_L]$ for lower part of vertical web

but F for lower part of vertical web is not to be less than

$= 1000\gamma ksK_L\ell(P_U + P_L)$

where

k = 1.0 (1.0, 2.24)

P_U = nominal pressure, p, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-length of upper bracket, as specified in 5C-1-3/Table 3.

P_L = nominal pressure, p, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-length of lower bracket, as specified in 5C-1-3/Table 3.

ℓ = span of the vertical web, in m (ft), as indicated in 5C-1-4/Figure 2B-a. Where a cross tie (in wing or center tank) is fitted and is located at a distance greater than 0.7ℓ from the deck transverse, the effective span of the vertical web may be measured from the deck transverse to the cross tie and all coefficients determined as if there were no cross ties.

s = spacing of the vertical webs, in m (ft)

h_U = length, in m (ft), of the upper bracket of the vertical web, as indicated in 5C-1-4/Figure 2B-a and 5C-1-4/Figure 8

h_L = length, in m (ft), of the lower bracket of the vertical web, as indicated in 5C-1-4/Figure 2B-a and 5C-1-4/Figure 8

γ = 0.57 for tankers without cross ties, (5C-1-4/Figure 2A-b, c and f)

= 0.50 for tankers with one cross tie, (5C-1-4/Figure 2A-d and e)

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\,S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

Coefficients K_U and K_L are given in 5C-1-4/Table 4.

For tankers without cross ties, the required sectional area of the lower part of the web is to be maintained for 0.6ℓ measured from the lower end of the web.

For tankers with one cross tie, the required sectional area of the lower part of the web is to be maintained up to the cross tie.

In no case is the shear force for the lower part of the vertical web to be taken less than 120% of that for the upper part of the vertical web.

TABLE 3
Coefficient c for Vertical Web on Longitudinal Bulkheads *(2001)*

Arrangement of Cross Ties	*For Upper pArt*	*For Lower Part*
No Cross Ties (5C-1-4/Figure 2A-b, c & f) 1) Tight Bhd	0.80	
2) Non-tight Centerline Bhd	0.28	
One Cross Tie in Center Tank, (5C-1-4/Figure 2A-e)	0.14	0.31
One Cross Tie in Wing Cargo Tank, (5C-1-4/Figure 2A-d)	0.18	0.36

TABLE 4
Coefficients K_U and K_L for Vertical Web on Longitudinal Bulkhead *(2001)*

Arrangement of Cross Ties	K_U	K_L
No Cross Ties (5C-1-4/Figure 2A-b, c & f) 1) Tight Bhd	0.18	0.28
2) Non-tight Centerline Bhd.	0.09	0.14
One Cross Tie in Center or Wing Cargo Tank, (5C-1-4/Figure 2A-d & e)	0.08	0.18

15.5 Horizontal Girder on Transverse Bulkhead

15.5.1 Section Modulus of Horizontal Girder on Transverse Bulkhead

The net section modulus of the horizontal girder is to be not less than obtained from the following equation (see also 5C-1-4/1.3).

$$SM = M/f_b \quad \text{cm}^3\ (\text{in}^3)$$

$$M = 10{,}000kcps\,\ell_b^2 \quad \text{N-cm (kgf-cm, lbf-in)}$$

where

k = 1.0 (1.0, 0.269)

ℓ_b = span of the horizontal girders, in m (ft), as indicated in 5C-1-4/Figure 2B-b.

For tankers with four longitudinal bulkheads, (5C-1-4/Figure 2A-d, e and f), ℓ_b is to be taken not less than 60% of the breadth of the wing cargo tanks.

s = sum of the half lengths, in m (ft), of the frames supported on each side of the horizontal girder.

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), calculated at the mid-span of the horizontal girder under consideration, as specified in 5C-1-3/Table 3.

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.70\ S_m f_y$

S_m and f_y, as defined in 5C-1-4/7.3.1.

c for transverse bulkheads without vertical webs

= 0.73 for tankers with an oil-tight centerline bulkhead (5C-1-4/Figure 2A-c)

= 0.55 for tankers with a non-tight centerline bulkhead (5C-1-4/Figure 2A-c)

= 0.83 in wing cargo tanks of vessels with four longitudinal bulkheads (5C-1-4/Figure 2A-d, e and f)

= 0.63 in the center tanks of vessels with four longitudinal bulkheads (5C-1-4/Figure 2A-d, e and f)

c for transverse bulkheads with vertical webs

For 5C-1-4/Figure 2A-b, tankers with oil-tight centerline bulkhead and 5C-1-4/Figure 2A-a

= $0.73\alpha^2$ for $\alpha < 0.5$

= $0.467\alpha^2 + 0.0657$ for $0.5 \le \alpha \le 1.0$

= $0.1973\alpha + 0.3354$ for $\alpha > 1.0$

c is not to be taken less than 0.013 and need not be greater than 0.73.

For 5C-1-4/Figure 2A-b, tankers with a non-tight centerline bulkhead

= $0.55\alpha^2$ for $\alpha < 0.5$

= $0.35\alpha^2 + 0.05$ for $0.5 \le \alpha \le 1.0$

= $0.15\alpha + 0.25$ for $\alpha > 1.0$

c is not to be taken less than 0.013 and need not to be greater than 0.55.

α = $0.9(\ell_{st}/\ell_b)[(I/I_v)(s_v/s)]^{1/4}$

if more than one vertical web is fitted on the bulkhead, average values of ℓ_{st}, s_v and I_v are to be used when these values are not the same for each web.

ℓ_{st} = span of the vertical web, in m (ft) (5C-1-4/Figure 2B-c)

s_v = spacing of the vertical webs, in m (ft)

I, I_v = moments of inertia, in cm^4 (in^4), of the horizontal girder and the vertical web clear of the end brackets.

15.5.2 Web Sectional Area of the Horizontal Girder on Transverse Bulkhead

The net sectional area of the web portion of the horizontal girder is to be not less than obtained from the following equation:

$A = F/f_s$ cm^2 (in^2)

$F = 1000\ kscp(0.5\ell - h_e)$ N (kgf, lbf)

where

k = 1.0 (1.0, 2.24)

c = 0.80 for transverse bulkheads without vertical webs

= $0.72\alpha^{1/2}$ for transverse bulkheads with vertical webs for $\alpha \geq 0.70$

= $0.887\alpha - 0.02$ for transverse bulkheads with vertical webs for $\alpha < 0.7$, 0.1 min. and 0.8 max.

ℓ = distance, in m (ft), between longitudinal bulkheads, as indicated in 5C-1-4/Figure 2B-b

s = sum of the half lengths, in m (ft), on each side of the horizontal girder, of the frames supported

h_e = length of the bracket, in m (ft), as indicated in 5C-1-4/Figure 2B-b

p and α are as defined in 5C-1-4/15.5.1.

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\ S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

15.7 Vertical Web on Transverse Bulkhead

15.7.1 Section Modulus of Vertical Web on Transverse Bulkhead

The net section modulus of the vertical web is to be not less than obtained from the following equation (see also 5C-1-4/1.3):

$SM = M/f_b$ cm^3 (in^3)

$M = 10{,}000kcps\,\ell_{st}^2$ N-cm (kgf-cm, lbf-in)

where

k = 1.0 (1.0, 0.269)

c = 0.83 for bulkheads without horizontal girders

= $0.83 - 0.52\alpha$ (but not less than 0.3) for transverse bulkheads with horizontal girders.

ℓ_{st} = span of the vertical web, in m (ft), (5C-1-4/Figure 2B-c)

s = spacing of vertical webs, in m (ft)

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-span of the vertical web, as specified in 5C-1-3/Table 3.

α = as defined in 5C-1-4/15.5.1, except that the values of s, ℓ_b and I are to be averaged in the case that more than one horizontal girder is fitted on the bulkhead.

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.70\ S_m f_y$

S_m and f_y, as defined in 5C-1-4/7.3.1.

The required section modulus for the web is to be maintained for a distance of $0.60\ell_{st}$ from the lower end of the span. Above that point, the value of the bending moment, M, used for the calculation of the required section modulus may be reduced by not more than 20%.

15.7.2 Web Sectional Area of Vertical Web on Transverse Bulkheads

The net sectional area of the web portion of vertical members is to be not less than obtained from the following equation:

$$A = F/f_s \qquad \text{cm}^2\ (\text{in}^2)$$

The shear force F in N (kgf, lbf) may be obtained from the following equations (see also 5C-1-4/1.3).

$F = 1000ks[0.18c\ell(P_U + P_L) - h_U P_U]$ for upper part of vertical web

$F = 1000ks[0.30c\ell(P_U + P_L) - h_L P_L]$ or $120ksc\ell(P_U + P_L)$ whichever is greater, for lower part of vertical web

where

k = 1.0 (1.0, 2.24)

c = 1.0 for transverse bulkheads without horizontal girders

= $1.13 - 0.6\alpha$ for transverse bulkheads with horizontal girders, 0.6 min. and 1.0 max.

P_U = nominal pressure, p, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-length of upper bracket, as specified in 5C-1-3/Table 3

P_L = nominal pressure, p, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-length of lower bracket, as specified in 5C-1-3/Table 3

ℓ = span of the vertical web, in m (ft), as indicated in 5C-1-4/Figure 2B-c

s = spacing of the vertical webs, in m (ft)

h_U = length, in m (ft), of the upper bracket, as indicated in 5C-1-4/Figure 2B-c and 5C-1-4/Figure 8

h_L = length, in m (ft), of the lower bracket, as indicated in 5C-1-4/Figure 2B-c and 5C-1-4/Figure 8

α is as defined in 5C-1-4/15.7.1.

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\, S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

The required sectional area of the lower portion of the web is to be maintained for a distance of 0.15ℓ from the toe of the lower bracket or 0.33ℓ measured from the lower end of the span, whichever is greater.

In no case is the shear force for the lower part of the vertical web to be taken less than 120% of that for the upper part of the vertical web.

15.9 Minimum Web Thickness, Proportions, Brackets, Stiffeners, Tripping Brackets, Slots and Lightening Holes

Requirements for these items are given in 5C-1-4/11.9, 5C-1-4/11.11, 5C-1-4/11.13, 5C-1-4/11.15 and 5C-1-4/11.17.

15.11 Cross Ties *(1 July 2005)*

Where cross ties are fitted as effective supports for the tank structural members, they are to be spaced so as to divide the supported members into spans of approximately equal length. The axial load imposed on cross ties, W, is to be not greater than the permissible load, W_a, both are as specified below (see also 5C-1-4/1.3). Alternatively, W may be determined from finite element analyses, as specified in 5C-1-5/9, with the combined load cases in 5C-1-3/9. However, in no case should W be taken less than 85% of that determined from the approximate equation below. For this purpose, an additional load case is also to be investigated, modifying load case 5 (of 5C-1-3/Table 1) with a full design draft and K_{f0} = 1.0 for external pressure where cross ties are located in wing cargo tanks. (See also 5C-1-5/9.1).

$$W = pbs \qquad \text{kN (tf, Ltf)}$$

$$W_a = 0.55 f_c A_s \qquad \text{kN (tf, Ltf)}$$

$$f_c = f_E \qquad \text{for } f_E \le P_r f_y$$

$$f_c = f_y \left[1 - P_r \left(1 - P_r \right) \frac{f_y}{f_E} \right] \qquad \text{for } f_E > P_r f_y$$

$$f_E = \pi^2 E / (\ell / r)^2$$

where

b	=	mean breadth of the area supported, in m (ft)
s	=	spacing of transverses, in m (ft)
p	=	nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the center of the area supported by the cross tie, as specified in 5C-1-3/Table 3, item 15
ℓ	=	unsupported span of the cross tie, in cm (in.)
r	=	least radius of gyration of the cross tie, in cm (in.)
A_s	=	net cross section area of the cross tie, in cm^2 (in^2)
f_y	=	minimum specified yield point of the material, in kN/cm^2 (tf/cm^2, Ltf/in^2)
P_r	=	proportional linear elastic limit of the structure, may be taken as 0.6 for steel
E	=	2.06×10^4 kN/cm^2 (2.1×10^3 tf/cm^2, 13.4×10^3 Ltf/in^2)

Special attention is to be paid to the adequacy of the welded connections for transmission of the tensile forces and also to the stiffening arrangements at the ends, in order to provide effective means for transmission of the compressive forces into the webs. In addition, horizontal stiffeners are to be located in line with and attached to the first longitudinal above and below the ends of the cross ties.

15.13 Nontight Bulkheads *(1 July 2005)*

Nontight bulkheads referred to in 5C-1-3/11.3.1 are to be fitted in line with transverse webs, bulkheads or other structures with equivalent rigidity. They are to be suitably stiffened. Openings in the nontight bulkhead are to have generous radii and their aggregate area is not to exceed 33%, nor to be less than 10% of the area of the nontight bulkhead. The net thickness of nontight bulkheads is to be not less than 11.0 mm (0.433 in.) for oil carriers with L less or equal to 300 meters and 12.0 mm (0.472 in.) for L over 300 meters. Section moduli of stiffeners and webs may be half of those required for watertight bulkheads in 3-2-9/5.3 and 3-2-9/5.7. In addition, the scantlings of the nontight bulkhead are to comply with the requirements of 5C-1-5/3.3 and 5C-1-5/5.3.3 using a finite element model in conjunction with the combined load cases in 5C-1-3/Table 1a.

Alternatively, the opening ratio and scantlings may be determined by an acceptable method of engineering analysis.

17 Corrugated Bulkheads *(1997)*

17.1 General

All vertically corrugated transverse and longitudinal bulkheads in cargo tanks are to be designed in compliance with the requirements specified in this subsection and the strength assessment criteria with respect to yielding, buckling and ultimate strength, and fatigue, as specified in Section 5C-1-5.

In general, the approximation equations given below are applicable to vertical corrugations with corrugation angles, ϕ (5C-1-4/Figure 10 or 5C-1-4/Figure 9), within the range between 60 and 90 degrees. For corrugation angles less than 60 degrees and corrugation in the horizontal direction, direct calculations may be required.

17.3 Plating *(1999)*

The net thickness of the vertically corrugated plating is not to be less than t_1, t_2, t_3 and t_4, obtained from the following equations:

$t_1 = 0.516k_1a(p_\ell/f_1)^{1/2}$ in mm (in.) for flange and web plating

$t_2 = 0.42k_2a(f_y/E)^{1/2}$ in mm (in.) for flange plating

$t_3 = k(a/k_3)\,(f_3)^{1/2}\,10^{-3}$ in mm (in.) for flange plating

$t_4 = 100F/(df_4)$ in mm (in.) for web plating

but not less than 9.5 mm (0.37 in.)

where

k = 0.728 (2.28, 0.605)

a = width of flange plating, in mm (in.) (5C-1-4/Figure 9 or 5C-1-4/Figure 10)

c = width of web plating, in mm (in.) (5C-1-4/Figure 9 or 5C-1-4/Figure 10)

d = depth of corrugation, in mm (in.) (5C-1-4/Figure 9 or 5C-1-4/Figure 10)

ϕ = corrugation angle, (5C-1-4/Figure 9 or 5C-1-4/Figure 10)

k_1 = $(1 - c/a + c^2/a^2)^{1/2}$

k_2 = $f_2/(0.73f_y)$

k_3 = $7.65 - 0.26(c/a)^2$

F = shear force, in N (kgf, lbf), imposed on the web plating at the lower end of corrugation span

= $k_4 s\ell(0.375p_\ell + 0.125p_u)$

k_4 = 10 (10, 12)

s = spacing of corrugation, in mm (in.), i.e., $a + c\cos\phi$, (5C-1-4/Figure 9 or 5C-1-4/Figure 10)

ℓ = span of corrugation, in m (ft), taken as the distance between lower and upper stools at centerline

p_ℓ, p_u = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower and upper ends of span, respectively, as specified in 5C-1-3/Table 3

f_1 = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.90\ S_m f_y$

f_2 = maximum vertical bending stress in the flange at the mid-depth of corrugation span to be calculated from 5C-1-4/17.5 below, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_3 = maximum vertical bending stress in the flange at the lower end of corrugation span to be calculated from 5C-1-4/17.5 below, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_4 = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.40\ S_m f_y$

E, S_m and f_y are as defined in 5C-1-4/7.3.1.

The plate thickness, as determined above based on the maximum anticipated pressures, is to be generally maintained throughout the entire corrugated bulkhead, except that the net thickness of plating above $^2/_3$ of span, ℓ, from the top of the lower stool may be reduced by 20%.

17.5 Stiffness of Corrugation *(1999)*

17.5.1 Depth/Length Ratio

The depth/length ratio (d/ℓ) of the corrugation is not to be less than $^1/_{15}$, where d and ℓ are as defined in 5C-1-4/17.3 above.

17.5.2 Section Modulus

The net section modulus for any unit corrugation is not to be less than obtained from the following equation for all anticipated service loading conditions.

$SM = M/f_b$ cm^3 (in^3)

$M = 1000(C_i/C_j)ps\,\ell_o^2/k$ N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 83.33)

ℓ_o = nominal length of the corrugation, in m (ft), measured from the mid-depth of the lower stool to the mid-depth of the upper stool

p = $(p_u + p_\ell)/2$, N/cm^2 (kgf/cm^2, lbf/in^2)

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.90\, S_m f_y$, for lower end of corrugation span ℓ

= $c_e f_y \leq 0.90 S_m f_y$, for the mid $\ell/3$ region of the corrugation

c_e = $2.25/\beta - 1.25/\beta^2$ for $\beta \geq 1.25$

= 1.0 for $\beta < 1.25$

β = $(f_y/E)^{1/2}\, a/t_f$

t_f = net thickness of the corrugation flange, in mm (in.)

C_i = the bending moment coefficients, as given below

Values of C_i (All Bulkheads with Lower and Upper Stools)

Bulkhead	*Lower End of Span ℓ*	*Mid-depth*	*Upper End of Span ℓ*
Trans. Bhd:			
(w/Long'l Bhd)	C_1	C_{m1}	$0.80C_{m1}$
(w/out Long'l Bhd)	C_2	C_{m2}	$0.65C_{m2}$
Long'l. Bhd.	C_3	C_{m3}	$0.65C_{m3}$

C_1 = $a_1 + b_1(kA_{dt}/B_d)^{1/2} \geq 0.6$

where $a_1 = 0.95 - 0.26/R_b$, $b_1 = -0.20 + 0.05/R_b$

C_{m1} = $a_{m1} + b_{m1}(kA_{dt}/B_d)^{1/2} \geq 0.55$

where $a_{m1} = 0.63 + 0.16/R_b$, $b_{m1} = -0.25 - 0.07/R_b$

C_2 = $a_2 + b_2(kA_{dt}/B_d)^{1/2} \geq 0.6$

where $a_2 = 0.84 - 0.07/R_b$, $b_2 = -0.24 + 0.02/R_b$

C_{m2} = $a_{m2} + b_{m2}(kA_{dt}/B_d)^{1/2} \geq 0.55$

where $a_{m2} = 0.56 + 0.05/R_b$, $b_{m2} = -0.34 - 0.03/R_b$

C_3 = $a_3 + b_3(kA_{d\ell}/L_d)^{1/2} \geq 0.6$

where $a_3 = 1.07 - 0.21/R_b$, $b_3 = -0.21 + 0.04/R_b$

C_{m3} = $a_{m3} + b_{m3}(kA_{d\ell}/L_d)^{1/2} \geq 0.55$

where $a_{m3} = 0.30 + 0.07/R_b$, $b_{m3} = -0.12 - 0.03/R_b$

C_j = the bending moment factors due to sloshing effect

Values of C_j (All Bulkheads with Lower and Upper Stools)

Bulkhead	*Mid-depth*	*Upper End of Span ℓ*
Trans. Bhd:	C_{mj1}	C_{mj2}
Long'l. Bhd.	C_{mj3}	C_{mj4}

C_{mj1} = $1.83\dfrac{P}{P_s} - 0.74 \geq 0.40$ if $\dfrac{P}{P_s} < 0.95$

= 1.0 if $\dfrac{P}{P_s} \geq 0.95$

C_{mj2} = $3.73\dfrac{P}{P_s} - 2.36 \geq 0.62$ if $\dfrac{P_n}{P_s} < 0.90$

= 1.0 if $\dfrac{P}{P_s} \geq 0.90$

C_{mj3} = $4.14\dfrac{P}{P_s} - 3.14 \geq 0.75$ if $\dfrac{P}{P_s} < 1.00$

= 1.0 if $\dfrac{P}{P_s} \geq 1.00$

C_{mj4} = $2.36\dfrac{P}{P_s} - 1.71 \geq 0.72$ if $\dfrac{P}{P_s} < 1.15$

= 1.0 if $\dfrac{P}{P_s} \geq 1.15$

P_s = $(p_{su} + p_{s\ell})/2$ N/cm^2 (kgf/cm^2, lbf/in^2)

P = $(p_u + p_\ell)/2$ N/cm^2 (kgf/cm^2, lbf/in^2)

$p_{s\ell}, p_{su}$ = sloshing pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower and upper ends of span, respectively, as specified in 5C-1-3/11.5, calculated at the same locations indicated for p_ℓ and p_u.

p_ℓ, p_u = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower and upper ends of span, respectively, as specified in 5C-1-3/Table 3, to be calculated at a section located $B/4$ from the C.L. when the vessel has one or no longitudinal bulkheads. For vessels with two longitudinal bulkheads, the nominal pressure is to be calculated at a section located $b/4$ from the outboard boundary of the center or the wing tank.

R_b = $kH_{st}(B_{ct} + B_{st})(1 + L_b/B_b + 0.5H_b/L_b)/(2B_b)$ for transverse bulkheads

= $H_{s\ell}\,(B_{c\ell} + B_{s\ell})(1 + B_b/L_b + 0.5H_b/B_b)/(2L_b)$ for longitudinal bulkheads

A_{dt} = cross sectional area, in m^2 (ft^2), enclosed by the outside lines of upper stool of transverse bulkhead

$A_{d\ell}$ = cross sectional area, in m^2 (ft^2), enclosed by the outside lines of upper stool of longitudinal bulkheads

B_{ct} = width of the bottom stool of transverse bulkhead, in m (ft), at the top (5C-1-4/Figure 10 or 5C-1-4/Figure 9)

$B_{c\ell}$ = width of the bottom stool of longitudinal bulkhead, in m (ft), at the top (5C-1-4/Figure 10)

B_{st} = width of the bottom stool of transverse bulkhead, in m (ft), at the inner bottom level (5C-1-4/Figure 10)

$B_{s\ell}$ = width of the bottom stool of longitudinal bulkhead, in m (ft), at the inner bottom level (5C-1-4/Figure 10)

H_b = double bottom height, in m (ft)

H_{st} = height of the bottom stool of transverse bulkhead, in m (ft), from the inner bottom to the top (5C-1-4/Figure 10 or 5C-1-4/Figure 9)

$H_{s\ell}$ = height of the bottom stool of longitudinal bulkhead, in m (ft), from the inner bottom to the top (5C-1-4/Figure 10)

B_b = transverse distance, in m (ft), between hopper tanks at the inner bottom level (5C-1-4/Figure 10 or 5C-1-4/Figure 9)

B_d = transverse distance, in m (ft), between upper wing tanks or between upper wing tank and centerline deck structure, at the deck level (see 5C-1-4/Figure 10 or 5C-1-4/Figure 9).

L_b = longitudinal distance, in m (ft), between bottom stools in the loaded tanks at the inner bottom level (5C-1-4/Figure 10 or 5C-1-4/Figure 9)

L_d = longitudinal distance, in m (ft), between upper stools in the loaded tanks at the deck level (5C-1-4/Figure 10)

k = 1 (1, 3.2808)

B = breadth of vessel, as defined in 3-1-1/5, in m (ft)

b = width of tank under consideration, in m (ft)

a, ℓ, s, p_u and p_ℓ are as defined in 5C-1-4/17.3 above.

E is as defined in 5C-1-4/7.3.

S_m and f_y are as defined in 5C-1-4/7.5.

The developed net section modulus SM may be obtained from the following equation, where a, c, d, t_f(net), and t_w(net), all in cm (in.), are as indicated in 5C-1-4/Figure 9.

$$SM = d(3at_f + ct_w)/6 \qquad \text{cm}^3 \ (\text{in}^3)$$

17.7 Bulkhead Stools

17.7.1 Lower Stool *(2004)*

The height of the lower stool is to be not less than three times the minimum depth of corrugation required by 5C-1-4/17.5.1 above. The net thickness and material of the stool top plate is not to be less than that required for the bulkhead plating in 5C-1-4/17.3 above. The net thickness and material of the upper portion of vertical or sloping stool side plate within the region of one meter from the stool top is not to be less than the required flange plate thickness to meet the bulkhead stiffness requirement at the lower end of the corrugation in 5C-1-4/17.5 above. The net thickness of the stool side plating and the net section modulus of the stool side stiffeners are not to be less than those required for plane transverse or longitudinal bulkhead plating and stiffeners in 5C-1-4/13.1, 5C-1-4/13.3 and 5C-1-4/13.5, with the corresponding tank pressure specified in 5C-1-3/Table 3. The ends of stool side vertical stiffeners are to be attached to brackets at the upper and lower ends of the stool.

The extension of the top plate beyond the corrugation is not to be less than the as-built flange thickness of the corrugation. The stool bottom is to be installed in line with double bottom floors or girders, fitted with proper brackets, and diaphragms are to be provided in the stool to effectively support the panels of the corrugated bulkhead. The width of the stool at the inner bottom is to be not less than 2.5 times the mean depth of the corrugation. Scallops in the brackets and diaphragms in way of the top and bottom connections to the plates and in the double bottom floors or girders are to be avoided.

17.7.2 Upper Stool

The upper stool is to have a depth generally not less than twice the minimum depth of corrugation, as specified in 5C-1-4/17.5, and is to be properly supported by girders or deep brackets.

The width of the stool bottom plate should generally be the same as that of the lower stool top plate. The net thickness of the stool bottom plate should generally be the same as that of the bulkhead plating, and the net thickness of the lower portion of the stool side plate is not to be less than 80% of that required for the bulkhead plating in 5C-1-4/17.3 above for the upper one-third portion of the bulkhead. The net thickness of the stool side plating and the net section modulus of the stool side stiffeners are not to be less than those required for plane transverse bulkhead plating and stiffeners in 5C-1-4/13.1, 5C-1-4/13.3 and 5C-1-4/13.5, with the corresponding tank pressure specified in 5C-1-3/Table 3. The ends of stool side stiffeners are to be attached to brackets at the upper and lower ends of the stool. Brackets or diaphragms are to be fitted to effectively support the web panels of the corrugated bulkhead. Scallops in the brackets and diaphragms in way of the connection to the stool bottom plate are to be avoided.

17.7.3 Alignment *(2001)*

Stool side vertical stiffeners and their brackets in the lower stool of the transverse bulkhead should align with the inner bottom longitudinal to provide appropriate load transmission between the stiffening members.

17.9 End Connections *(1 July 2001)*

The structural arrangements and size of the welding at the ends of corrugations are to be designed to develop the required strength of the corrugated bulkhead. Where shedder plates (slanting plates) are fitted at the end connection of the corrugation to the lower stool, appropriate means are to be provided to prevent the possibility of gas pockets being formed in way of these plates within the cargo tanks.

Welding for all connections and joints is to be in compliance with the Rules. The welded connection of the bulkhead to the stools within 10% of the depth of the corrugation from the outer surface of the corrugation, d_1, is to be double continuous with fillet size not less than 0.7 times the thickness of bulkhead plating or penetration welds of equal strength (see 5C-1-4/Figure 11).

FIGURE 9
Definition of Parameters for Corrugated Bulkhead *(1997)*
(Tankers without Longitudinal Bulkhead at Centerline)

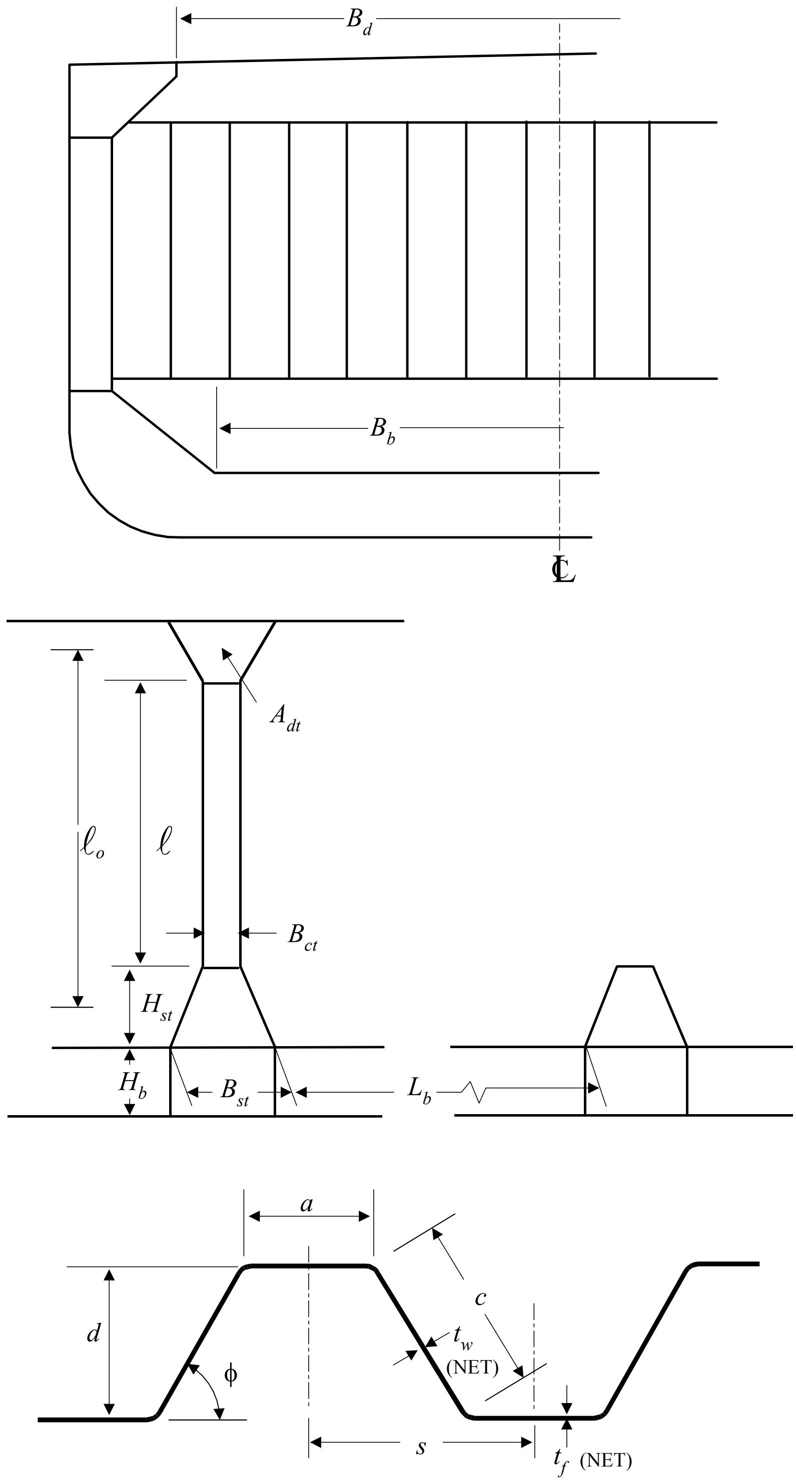


FIGURE 10
Definition of Parameters for Corrugated Bulkhead *(1997)*
(Tankers with Longitudinal Bulkhead at Centerline)

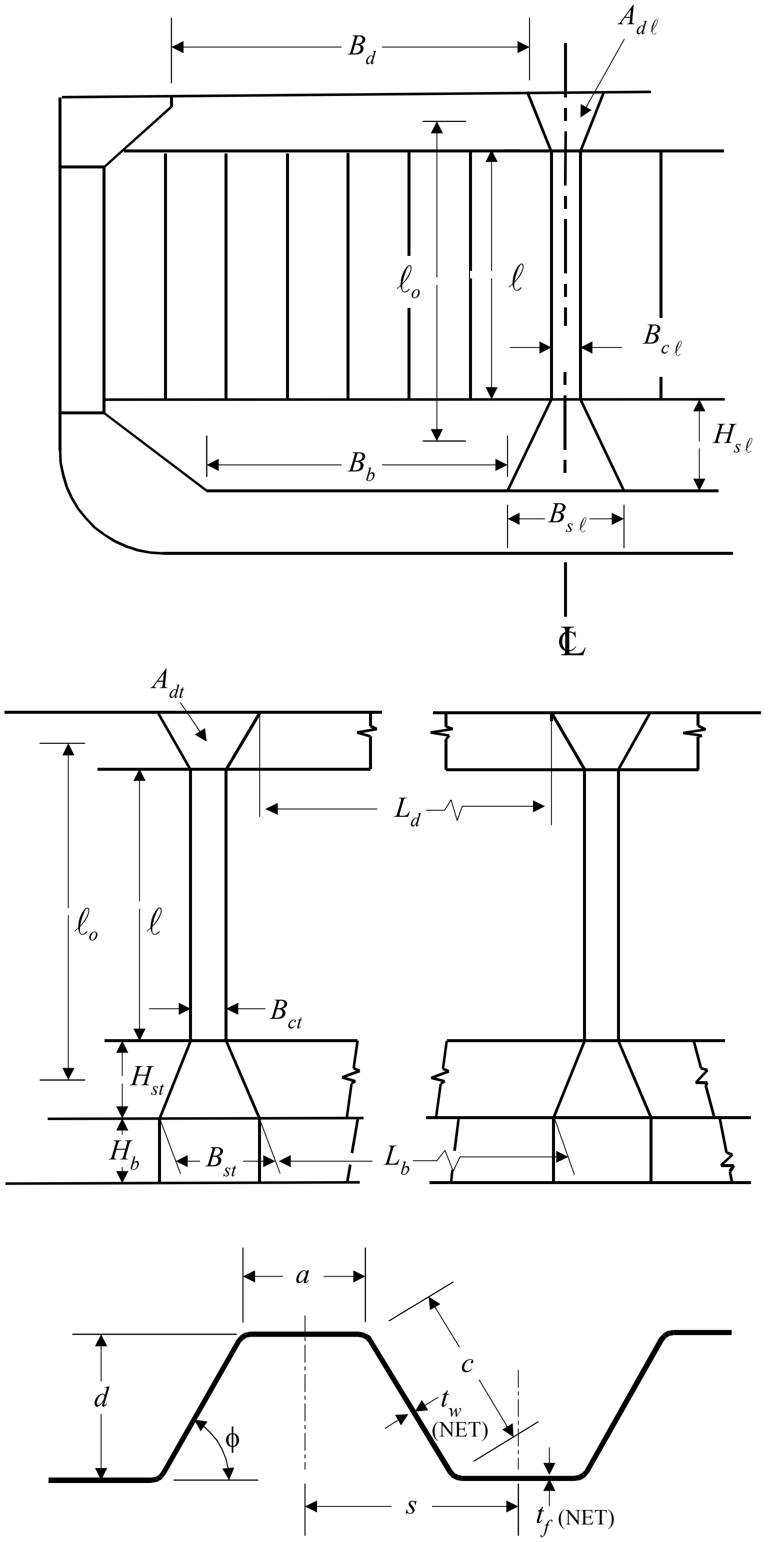
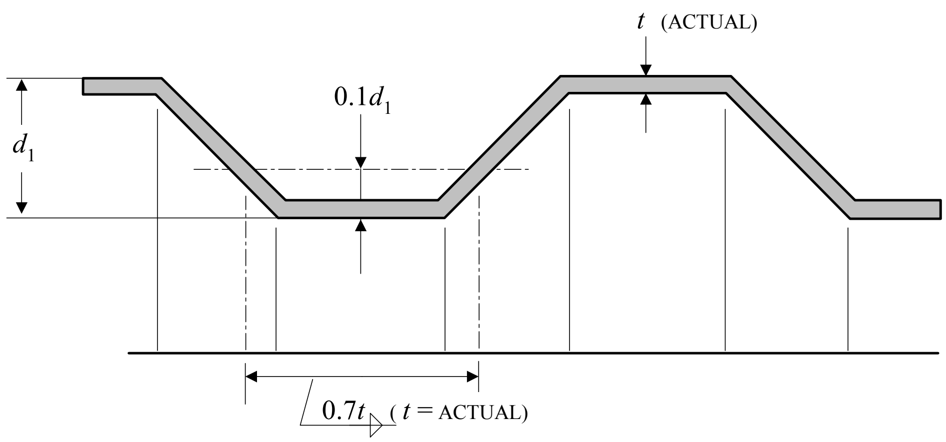


FIGURE 11
Corrugated Bulkhead End Connections



PART

5C

CHAPTER 1 Vessels Intended to Carry Oil in Bulk (150 meters (492 feet) or more in Length)

SECTION 5 Total Strength Assessment

1 General Requirements

1.1 General *(1995)*

In assessing the adequacy of the structural configuration and the initially selected scantlings, the strength of the hull girder and the individual structural member or element is to be in compliance with the failure criteria specified in 5C-1-5/3 below. In this regard, the structural response is to be calculated by performing a structural analysis, as specified in 5C-1-5/9, or by other equivalent and effective means. Due consideration is to be given to structural details, as specified in 5C-1-4/1.5.

1.3 Loads and Load Cases *(1995)*

In determination of the structural response, the combined load cases given in 5C-1-3/9.3 are to be considered together with sloshing loads specified in 5C-1-3/11. Bowflare/bottom slamming and other loads, as specified in 5C-1-3/13, are also to be considered as necessary.

1.5 Stress Components *(1995)*

The total stress in stiffened plate panels are divided into the following three categories:

1.5.1 Primary

Primary stresses are those resulting from hull girder bending. The primary bending stresses may be determined by simple beam method using the specified total vertical and horizontal bending moments and the effective net hull girder section modulus at the section considered. These primary stresses, designated by f_{L1} (f_{L1V}, f_{L1H} for vertical and horizontal bending, respectively), may be regarded as uniformly distributed across the thickness of plate elements, at the same level measuring from the relevant neutral axis of the hull girder.

1.5.2 Secondary

Secondary stresses are those resulting from bending of large stiffened panels between longitudinal and transverse bulkheads, due to local loads in an individual cargo or ballast tank.

The secondary bending stresses, designated by f_{L2} or f_{T2}, are to be determined by performing a 3D FEM analysis, as outlined in this section.

For stiffened hull structures, there is another secondary stress due to the bending of longitudinals or stiffeners with the associated plating between deep supporting members or floors. The latter secondary stresses are designated by f^*_{L2} or f^*_{T2}, and may be approximated by simple beam theory.

The secondary stresses, f_{L2}, f_{T2}, f^*_{L2} or f^*_{T2}, may be regarded as uniformly distributed in the flange plating and face plates.

1.5.3 Tertiary

Tertiary stresses are those resulting from the local bending of plate panels between stiffeners. The tertiary stresses, designated by f_{L3} or f_{T3}, can be calculated from classic plate theory. These stresses are referred to as point stresses at the surface of the plate.

3 Failure Criteria – Yielding

3.1 General

The calculated stresses in the hull structure are to be within the limits given below for the entire combined load cases specified in 5C-1-3/9.3.

3.3 Structural Members and Elements *(1999)*

For all structural members and elements, such as longitudinals/stiffeners, web plates and flanges, the combined effects of all of the calculated stress components are to satisfy the following limits:

$$f_i \le S_m f_y$$

where

f_i = stress intensity

= $(f_L^2 + f_T^2 - f_L f_T + 3 f_{LT}^2)^{1/2}$ N/cm² (kgf/cm², lbf/in²)

f_L = calculated total in-plane stress in the longitudinal direction including primary and secondary stresses

= $f_{L1} + f_{L2} + f^*_{L2}$ N/cm² (kgf/cm², lbf/in²)

f_{L1} = direct stress due to the primary (hull girder) bending, N/cm² (kgf/cm², lbf/in²)

f_{L2} = direct stress due to the secondary bending between bulkheads in the longitudinal direction, N/cm² (kgf/cm², lbf/in²)

f^*_{L2} = direct stress due to local bending of longitudinal between transverses in the longitudinal direction, N/cm² (kgf/cm², lbf/in²)

f_T = calculated total direct stress in the transverse/vertical direction, including secondary stresses

= $f_{T1} + f_{T2} + f^*_{T2}$ N/cm² (kgf/cm², lbf/in²)

f_{LT} = calculated total in-plane shear stress, N/cm² (kgf/cm², lbf/in²)

f_{T1} = direct stress due to sea and cargo load in the transverse/vertical direction, N/cm² (kgf/cm², lbf/in²)

f_{T2} = direct stress due to the secondary bending between bulkheads in the transverse/vertical direction, N/cm^2 (kgf/cm^2, lbf/in^2)

f^*_{T2} = direct stress due to local bending of stiffeners in the transverse/vertical direction, N/cm^2 (kgf/cm^2, lbf/in^2)

f_y = specified minimum yield point, N/cm^2 (kgf/cm^2, lbf/in^2)

S_m = strength reduction factor, as defined in 5C-1-4/7.3.1

For this purpose, f^*_{L2} and f^*_{T2} in the flanges of longitudinal and stiffener at the ends of span may be obtained from the following equation:

$$f^*_{L2}\,(f^*_{T2}) = 0.071 s p \ell^2/SM_L(SM_T) \qquad \text{N/cm}^2\ (\text{kgf/cm}^2,\ \text{lbf/in}^2)$$

where

s = spacing of longitudinals (stiffeners), in cm (in.)

ℓ = unsupported span of the longitudinal (stiffener), in cm (in.)

p = net pressure load, in N/cm^2 (kgf/cm^2, lbf/in^2), for the longitudinal (stiffener)

SM_L (SM_T) = net section modulus, in cm^3 (in^3), of the longitudinal (stiffener)

3.5 Plating *(1 July 2005)*

For plating away from knuckle or cruciform connections of high stress concentrations and subject to both in-plane and lateral loads, the combined effects of all of the calculated stress components are to satisfy the limits specified in 5C-1-5/3.3 with f_L and f_T modified as follows:

$$f_L = f_{L1} + f_{L2} + f^*_{L2} + f_{L3} \qquad \text{N/cm}^2\ (\text{kgf/cm}^2,\ \text{lbf/in}^2)$$

$$f_T = f_{T1} + f_{T2} + f^*_{T2} + f_{T3} \qquad \text{N/cm}^2\ (\text{kgf/cm}^2,\ \text{lbf/in}^2)$$

where

f_{L3}, f_{T3} = plate bending stresses between stiffeners in the longitudinal and transverse directions, respectively, and may be approximated as follows.

f_{L3} = $0.182p(s/t_n)^2$ N/cm^2 (kgf/cm^2, lbf/in^2)

f_{T3} = $0.266p(s/t_n)^2$ N/cm^2 (kgf/cm^2, lbf/in^2)

p = lateral pressures for the combined load case considered (see 5C-1-3/9), in N/cm^2 (kgf/cm^2, lbf/in^2)

s = spacing of longitudinals or stiffeners, in mm (in.)

t_n = net plate thickness, in mm (in.)

For plating within two longitudinals or stiffeners from knuckle or cruciform connections of high stress concentrations, the combined effects of the calculated stress components are to satisfy the following stress limit:

$$f_i \le 0.80\, S_m f_y$$

where

f_i = stress intensity

= $(f_L^2 + f_T^2 - f_L f_T + 3 f_{LT}^2)^{1/2}$ N/cm^2 (kgf/cm^2, lbf/in^2)

f_L = calculated total in-plane stress in the longitudinal direction including primary and secondary stresses

= $f_{L1} + f_{L2}$ N/cm^2 (kgf/cm^2, lbf/in^2)

f_T = calculated total direct stress in the transverse/vertical direction, including secondary stresses

= $f_{T1} + f_{T2}$ N/cm^2 (kgf/cm^2, lbf/in^2)

In addition, the failure criteria for knuckle or cruciform connections in 5C-1-5/11 are to be complied with.

$f_{L1}, f_{L2}, f^*_{L2}, f_{T1}, f_{T2}$ and f^*_{T2} are as defined in 5C-1-5/3.3.

5 Failure Criteria – Buckling and Ultimate Strength *(1995)*

5.1 General

5.1.1 Approach

The strength criteria given here correspond to either serviceability (buckling) state limits or ultimate state limits for structural members and panels, according to the intended functions and buckling resistance capability of the structure. For plate panels between stiffeners, buckling in the elastic range is acceptable, provided that the ultimate strength of the structure satisfies the specified design limits. The critical buckling stresses and ultimate strength of structures may be determined based on either well-documented experimental data or a calibrated analytical approach. When a detailed analysis is not available, the equations given in Appendix 5C-1-A2 may be used to assess the buckling strength.

5.1.2 Buckling Control Concepts

The strength criteria in 5C-1-5/5.3 through 5C-1-5/5.11 are based on the following assumptions and limitations with respect to buckling control in design.

5.1.2(a) The buckling strength of longitudinals and stiffeners is generally greater than that of the plate panels they support.

5.1.2(b) All longitudinals with their associated effective plating are to have moments of inertia not less than i_o given in 5C-1-A2/11.1.

5.1.2(c) The main supporting members, including transverses, girders and floors, with their associated effective plating are to have the moments of inertia not less than I_s given in 5C-1-A2/11.5.

In addition, tripping (e.g., torsional instability) is to be prevented, as specified in 5C-1-A2/9.5.

5.1.2(d) Face plates and flanges of girders, longitudinals and stiffeners are proportioned such that local instability is prevented. (See 5C-1-A2/11.7)

5.1.2(e) Webs of longitudinals and stiffeners are proportioned such that local instability is prevented. (See 5C-1-A2/11.9).

5.1.2(f) Webs of girders, floors and transverses are designed with proper proportions and stiffening systems to prevent local instability. Critical buckling stresses of the webs may be calculated from equations given in 5C-1-A2/3.

For structures which do not satisfy these assumptions, a detailed analysis of buckling strength using an acceptable method is to be submitted for review.

5.3 Plate Panels

5.3.1 Buckling State Limit *(1 July 2005)*

The buckling state limit for plate panels between stiffeners is defined by the following equation:

$$(f_{Lb}/f_{cL})^2 + (f_{Tb}/f_{cT})^2 + (f_{LT}/f_{cLT})^2 \leq 1.0$$

where

$f_{Lb} = f_{L1} + f_{L2}$	=	calculated total compressive stress in the longitudinal direction for the plate, in N/cm^2 (kgf/cm^2, lbf/in^2), induced by bending of the hull girder and large stiffened panels between bulkheads
$f_{Tb} = f_{T1} + f_{T2}$	=	calculated total compressive stress in the transverse/vertical direction, in N/cm^2 (kgf/cm^2, lbf/in^2)
f_{LT}	=	calculated total in-plane shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{cL}, f_{cT} and f_{cLT} are the critical buckling stresses corresponding to uniaxial compression in the longitudinal, transverse/vertical directions and edge shear, respectively, in N/cm^2 (kgf/cm^2, lbf/in^2), and may be determined from the equations given in 5C-1-A2/3.

f_L, f_T and f_{LT} are to be determined for the panel in question under the load cases specified in 5C-1-3/9 including the primary and secondary stresses, as defined in 5C-1-5/3.1.

5.3.2 Effective Width

When the buckling state limit specified in 5C-1-5/5.3.1 above is not satisfied, the effective width b_{wL} or b_{wT} of the plating given below is to be used instead of the full width between longitudinals, s, for determining the effective hull girder section modulus, SM_e, specified in 5C-1-5/5.13, and also for verifying the ultimate strength, as specified in 5C-1-5/5.3.3 below. When the buckling state limit in 5C-1-5/5.3.1 above is satisfied, the full width between longitudinals, s, may be used as the effective width, b_{wL}, for verifying the ultimate strength of longitudinals and stiffeners specified in 5C-1-5/5.5, and for determining the effective hull girder section modulus SM_e specified in 5C-1-5/5.13 below.

5.3.2(a) For long plate:

$$b_{wL}/s = C$$

C	=	$2.25/\beta - 1.25/\beta^2$	for $\beta \geq 1.25$
	=	1.0	for $\beta < 1.25$
β	=	$(f_y/E)^{1/2} s/t_n$	

s, t_n and E are as defined in 5C-1-5/5.3.1 above.

f_y	=	specified minimum yield point of the material, in N/cm^2 (kgf/cm^2, lbf/in^2)

5.3.2(b) (1999) For wide plate (compression in transverse direction):

$$b_{wT}/\ell = Cs/\ell + 0.115(1 - s/\ell)(1 + 1/\beta^2)^2 \leq 1.0$$

where

ℓ	=	spacing of transverses, in cm (in.)
s	=	longitudinal spacing, in cm (in.)

C, β are as defined in 5C-1-5/5.3.2(a) above.

5.3.3 Ultimate Strength *(1 July 2005)*

The ultimate strength of a plate panel between stiffeners is to satisfy all of the following equations:

$$(f_{Lb}/f_{uL})^2 + (f_{LT}/f_{uLT})^2 \le S_m$$

$$(f_{Tb}/f_{uT})^2 + (f_{LT}/f_{uLT})^2 \le S_m$$

$$(f_{Lb}/f_{uL})^2 + (f_{Tb}/f_{uT})^2 - \eta(f_{Lb}/f_{uL})(f_{Tb}/f_{uT}) + (f_{LT}/f_{uLT})^2 \le S_m$$

where

f_{Lb}, f_{Tb} and f_{LT} are as defined in 5C-1-5/5.3.1 above.

S_m is as defined in 5C-1-4/7.3.1.

η = $1.5 - \beta/2 \ge 0$

β is as defined in 5C-1-5/5.3.2 above.

f_{uL}, f_{uT} and f_{uLT} are the ultimate strengths with respect to uniaxial compression and edge shear, respectively, and may be obtained from the following equations, except that they need not be taken less than the corresponding critical buckling stresses specified in 5C-1-5/5.3.1 above.

$$f_{uL} = f_y b_{wL}/s$$

$$f_{uT} = f_y b_{wT}/\ell$$

$$f_{wLT} = f_{cLT} + 0.5(f_y - \sqrt{3} f_{cLT})/(1 + \alpha + \alpha^2)^{1/2}$$

where

$$\alpha = \ell/s$$

f_y, b_{wL}, b_{wT}, s, ℓ and f_{cLT} are as defined above.

For assessing the ultimate strength of plate panels between stiffeners, special attention is to be paid to the longitudinal bulkhead plating in the regions of high hull girder shear forces and the bottom and inner bottom plating in the mid portion of cargo tanks subject to bi-axial compression.

5.5 Longitudinals and Stiffeners

5.5.1 Beam-Column Buckling State Limits and Ultimate Strength *(2002)*

The buckling state limits for longitudinals and stiffeners are considered as the ultimate state limits for these members and are to be determined as follows:

$$f_a/(f_{ca}A_e/A) + mf_b/f_y \le S_m$$

where

f_a = nominal calculated compressive stress

= P/A, N/cm^2 (kgf/cm^2, lbf/in^2)

P = total compressive load, N (kgf, lbf)

f_{ca} = critical buckling stress, as given in 5C-1-A2/5.1, N/cm^2 (kgf/cm^2, lbf/in^2)

A = total net sectional area, cm^2 (in^2)

= $A_s + st_n$

A_s = net sectional area of the longitudinal, excluding the associated plating, cm^2 (in^2)

A_e = effective net sectional area, cm^2 (in^2)

= $A_S + b_{wL}t_n$

b_{wL} = effective width, as specified in 5C-1-5/5.3.2 above

E = Young's modulus, 2.06×10^7 N/cm^2 (2.1×10^6 kgf/cm^2, 30×10^6 lbf/in^2) for steel

f_y = minmum specified yield point of the longitudinal or stiffener under consideration, N/cm^2 (kgf/cm^2, lbf/in^2)

f_b = bending stress, N/cm^2 (kgf/cm^2, lbf/in^2)

= M/SM_e

M = maximum bending moment induced by lateral loads

= $c_m ps\ell^2/12$ N-cm (kgf-cm, lbf-in)

c_m = moment adjustment coefficient, and may be taken as 0.75

p = lateral pressure for the region considered, N/cm^2 (kgf/cm^2, lbf/in^2)

s = spacing of the longitudinals, cm (in.)

SM_e = effective section modulus of the longitudinal at flange, accounting for the effective breadth, b_e, cm^3 (in^3)

b_e = effective breadth, as specified in 5C-1-4/Figure 6, line b

m = amplification factor

= $1/[1 - f_a/\pi^2 E(r/\ell)^2] \geq 1.0$

S_m is as defined in 5C-1-4/7.3.1.

r and ℓ are as defined in 5C-1-A2/5.1.

5.5.2 Torsional-Flexural Buckling State Limit *(2002)*

In general, the torsional-flexural buckling state limit of longitudinals and stiffeners is to satisfy the ultimate state limits given below:

$$f_a/(f_{ct}A_e/A) \leq S_m$$

where

f_a = nominal calculated compressive stress in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in 5C-1-5/5.5.1 above

f_{ct} = critical torsional-flexural buckling stress in N/cm^2 (kgf/cm^2, lbf/in^2), and may be determined by equations given in 5C-1-A2/5.3.

A_e and A are as defined in 5C-1-5/5.5.1 above and S_m is as defined in 5C-1-4/7.3.1.

5.7 Stiffened Panels

5.7.1 Large Stiffened Panels between Bulkheads

For a double hull tanker, assessment of buckling state limit is not required for the large stiffened panels of the bottom and inner bottom structures, side shell and inner skin. Assessments of the buckling state limits are to be performed for large stiffened panels of the deck structure and other longitudinal bulkheads. In this regard, the buckling strength is to satisfy the following condition for uniaxially or orthogonally stiffened panels.

$$(f_{L1}/f_{cL})^2 + (f_{T1}/f_{cT})^2 \le S_m$$

where

f_{L1}, f_{T1} = the calculated average compressive stresses in the longitudinal and transverse/vertical directions, respectively, as defined in 5C-1-5/3.3 above

f_{cL}, f_{cT} = the critical buckling stresses for uniaxial compression in the longitudinal and transverse direction, respectively, and may be determined in accordance with 5C-1-A2/7, in N/cm^2 (kgf/cm^2, lbf/in^2)

S_m = strength reduction factor, as defined in 5C-1-4/7.3.1

5.7.2 Uniaxially Stiffened Panels between Transverses and Girders

The bucking strength of uniaxially stiffened panels between deep transverses and girders is also to be examined in accordance with the specifications given in 5C-1-5/5.7.1 above by replacing f_{L1} and f_{T1} with f_{Lb} and f_{Tb}, respectively. f_{Lb} and f_{Tb} are as defined in 5C-1-5/5.3.1 above.

5.9 Deep Girders and Webs

5.9.1 Buckling Criteria

In general, the stiffness of the web stiffeners along the depth of the web plating is to be in compliance with the requirements of 5C-1-A2/11.3. Web stiffeners which are oriented parallel to and near the face plate, and thus subject to axial compression, are also to satisfy the limits specified in 5C-1-5/5.5, considering the combined effect of the compressive and bending stresses in the web. In this case, the unsupported span of these parallel stiffeners may be taken between tripping brackets, as applicable.

The buckling strength of the web plate between stiffeners and flange/face plate is to satisfy the limits specified below.

5.9.1(a) For web plate:

$$(f_{Lb}/f_{cL})^2 + (f_b/f_{cb})^2 + (f_{LT}/f_{cLT})^2 \le S_m$$

where

f_{Lb} = calculated uniform compressive stress along the length of the girder, N/cm^2 (kgf/cm^2, lbf/in^2)

f_b = calculated ideal bending stresses, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{LT} = calculated total in-plane shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

S_m = strength reduction factor, as defined in 5C-1-4/7.3.1

f_{Lb}, f_b and f_{LT} are to be calculated for the panel in question under the combined load cases specified in 5C-1-3/9.3.

f_{cLb}, f_{cb} and f_{cLT} are critical buckling stresses with respect to uniform compression, ideal bending and shear, respectively, and may be determined in accordance with Appendix 5C-1-A2.

In the determination of f_{cL} and f_{cLT}, the effects of openings are to be considered.

5.9.1(b) For face plate and flange. The breadth to thickness ratio of face plate and flange is to satisfy the limits given in 5C-1-A2/11.

5.9.1(c) For large brackets and sloping webs. The buckling strength is to satisfy the limits specified in 5C-1-5/5.9.1(a) above for web plate.

5.9.2 Tripping

Tripping brackets are to be provided in accordance with 5C-1-A2/9.5.

5.11 Corrugated Bulkheads *(1997)*

5.11.1 Local Plate Panels

5.11.1(a) Buckling criteria. The buckling strength of the flange and web plate panels is not to be less than that specified below.

$$(f_{Lb}/R_\ell f_{cL})^2 + (f_{Tb}/R_t f_{cT})^2 + (f_{LT}/f_{cLT})^2 \le S_m \qquad \text{for flange panels}$$

$$(f_{Lb}/R_\ell f_{cL})^2 + (f_b/f_{cb})^2 + (f_{LT}/f_{cLT})^2 \le S_m \qquad \text{for web panels}$$

All of the parameter definitions and calculations are as specified in 5C-1-5/5.3.1 and 5C-1-5/5.9.1(a), except that f_{Lb} is the average compressive stress at the upper and lower ends of the corrugation, and an average value of f_{Tb}, f_{LT} and f_b, calculated along the entire length of the panel, should be used in the above equation.

5.11.1(b) Ultimate strength. The ultimate strength of flange panels in the middle one-third of the depth are to satisfy the following criteria, considering a portion of flange panel having a length of three times the panel width, a, with the worst bending moments in the mid-depth region for all load cases.

$$(f_{Lb}/f_{uL})^2 + (f_{Tb}/f_{uT})^2 \le S_m$$

where

f_{Lb} = the calculated average compressive bending stress in the region within $3a$ in length, N/cm^2 (kgf/cm^2, lbf/in^2)

f_{Tb} = horizontal compressive stresses, as specified in 5C-1-5/5.11.1(a) above

f_{uL} and f_{uT} may be calculated in accordance with 5C-1-5/5.3.3 above.

5.11.2 Unit Corrugation

Any unit corrugation of the bulkhead may be treated as a beam column and is to satisfy the buckling criteria (same as the ultimate strength) specified in 5C-1-5/5.5.1. The ultimate bending stress is to be determined in accordance with 5C-1-A2/5.5.

5.11.3 Overall Buckling

The buckling strength of the entire corrugation is to satisfy the equation given in 5C-1-5/5.7.1 with respect to the biaxial compression by replacing the subscripts "*L*" and "*T*" with "*V*" and "*H*" for the vertical and horizontal directions, respectively.

5.13 Hull Girder Ultimate Strength

In addition to the strength requirements specified in 5C-1-4/3.1, the maximum longitudinal bending stresses in the deck and bottom plating for the combined load cases given in 5C-1-3/9.3 are to be not greater than that given in 5C-1-5/5.13.1 below.

5.13.1

$$f_L \le S_m f_y$$

where

f_L = total direct stress in the longitudinal direction, N/cm^2 (kgf/cm^2, lbf/in^2)

= $f_{b1} + f_{b2}$

f_{b1} = effective longitudinal bending stress, N/cm^2 (kgf/cm^2, lbf/in^2)

= M_t / SM_e

M_t = $M_s + k_u\, k_c\, M_w$, $k_u = 1.15$, $k_c = 1.0$, N-cm (kgf-cm, lbf-in)

SM_e = effective section modulus, as obtained from 5C-1-5/5.13.2 below, cm^3 (in^3)

S_m = strength reduction factor, as defined in 5C-1-4/7.3.1

f_y = minimum specified yield point of the material, N/cm^2 (kgf/cm^2, lbf/in^2)

f_{b2} = secondary bending stress of large stiffened panel between longitudinal bulkheads and transverse bulkheads, N/cm^2 (kgf/cm^2, lbf/in^2)

5.13.2 Calculation of SM_e

For assessing the hull girder ultimate strength, the effective section modulus is to be calculated, accounting for the buckling of plate panels and shear lag effects, as applicable.

5.13.2(a) Effective width. The effective widths of the side, bottom shell, inner bottom plating and longitudinal bulkhead plating are to be used instead of the full width between longitudinals. The effective width, b_{wL} is given in 5C-1-5/5.3 above.

5.13.2(b) Shear lag. For double hull tankers without longitudinal bulkheads (except the inner skins), the effective breadths, B_e, of the deck and inner and outer bottom plating, are to be determined based on the cL/b ratio as defined below.

cL/b	=	12	10	9	8	7	6	5	4
$2B_e/B$	=	0.98	0.96	0.95	0.93	0.91	0.88	0.84	0.78

where

cL is the length between two points of zero bending moment, away from the midship, and may be taken as 60% of the vessel length.

b is the distance from the centerline of the vessel to the center of the side ballast tank, as shown in 5C-1-5/Figure 1.

For tankers with a centerline swash or oil tight longitudinal bulkhead, b may be taken as $^2/_3$ of that indicated in 5C-1-5/Figure 1.

For $cL/b > 12$, no shear lag effects need to be considered.

The effective sectional areas of deck, inner bottom and bottom longitudinals are to be reduced by the same ratio, $2B_e/B$, for calculating SM_e.

7 Fatigue Life *(1995)*

7.1 General

An analysis is to be made of the fatigue strength of welded joints and details in highly stressed areas, especially where higher strength steel is used. Special attention is to be given to structural notches, cutouts and bracket toes, and also to abrupt changes of structural sections. A simplified assessment of the fatigue strength of structural details may be accepted when carried out in accordance with Appendix 5C-1-A1.

The following subparagraphs are intended to emphasize the main points and to outline procedures where refined spectral analysis techniques are used to establish fatigue strength.

7.1.1 Workmanship

As most fatigue data available were experimentally developed under controlled laboratory conditions, consideration is to be given to the workmanship expected during construction.

7.1.2 Fatigue Data

In the selection of S-N curves and the associated stress concentration factors, attention is to be paid to the background of all design data and its validity for the details being considered. In this regard, recognized design data, such as those by AWS (American Welding Society), API (American Petroleum Institute), and DEN (Department of Energy), should be considered. Sample fatigue data and their applications are shown in Appendix 5C-1-A1 "Guide for Fatigue Strength Assessment of Tankers".

If other fatigue data are to be used, the background and supporting data are to be submitted for review.

In this regard, clarification is required whether or not the stress concentration due to the weld profile, certain structural configurations and also the heat effects are accounted for in the proposed S-N curve. Consideration is also to be given to the additional stress concentrations.

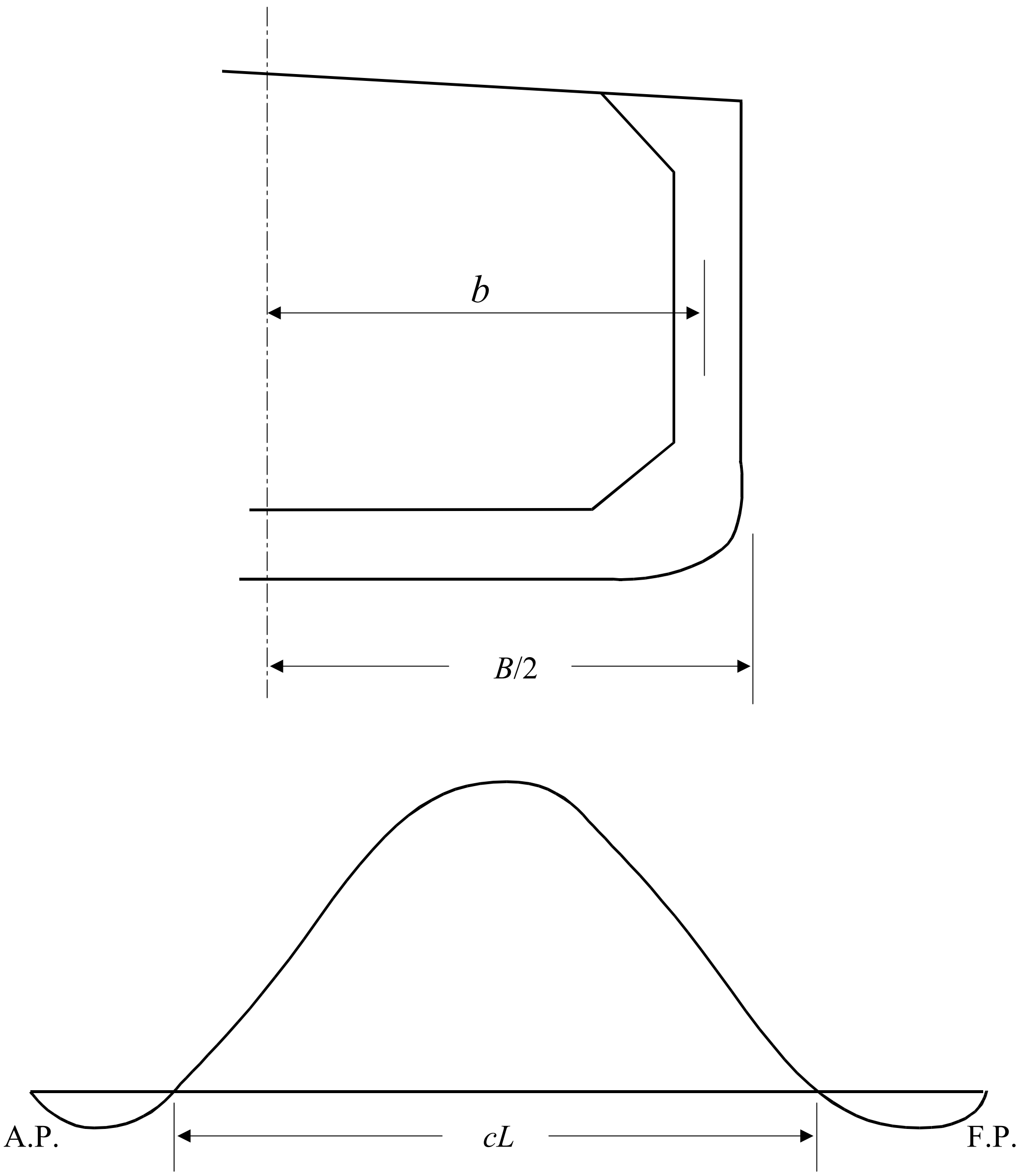
7.1.3 Total Stress Range

For determining total stress ranges, the fluctuating stress components resulting from the load combinations specified in 5C-1-A1/7.5 are to be considered.

7.1.4 Design Consideration

In design, consideration is to be given to the minimization of structural notches and stress concentrations. Areas subject to highly concentrated forces are to be properly configured and stiffened to dissipate the concentrated loads. See also 5C-1-4/1.5.

FIGURE 1
(1995)



7.3 Procedures

The analysis of fatigue strength for a welded structural joint/detail may be performed in accordance with the following procedures.

7.3.1 Step 1 – Classification of Various Critical Locations

The class designations and associated load patterns are given in 5C-1-A1/Table 1

7.3.2 Step 2 – Permissible Stress Range Approach

Where deemed appropriate, the total applied stress range of the structural details classified in Step 1 may be checked against the permissible stress ranges as shown in Appendix 5C-1-A1.

7.3.3 Step 3 – Refined Analysis

Refined analyses are to be performed, as outlined in 5C-1-5/7.3.3(a) or 5C-1-5/7.3.3(b) below, for the structural details for which the total applied stress ranges obtained from Step 2 are greater than the permissible stress ranges, or for which the fatigue characteristics are not covered by the classified details and the associated S-N curves.

The fatigue life of structures is generally not to be less than 20 years, unless otherwise specified.

7.3.3(a) Spectral analysis. Alternatively, a spectral analysis may be performed, as outlined in 5C-1-5/7.5 below, to directly calculate fatigue lives for the structural details in question.

7.3.3(b) Refined fatigue data. For structural details which are not covered by the detail classifications, proposed S-N curves and the associated SCFs, when applicable, may be submitted for consideration. In this regard, sufficient supporting data and background are also to be submitted for review. The refined SCFs may be determined by finite element analyses.

7.5 Spectral Analysis

Where the option in 5C-1-5/7.3.3(a) is exercised, a spectral analysis is to be performed in accordance with the following guidelines.

7.5.1 Representative Loading Patterns

Several representative loading patterns are to be considered to cover the worst scenarios anticipated for the design service life of the vessel with respect to hull girder local loads.

7.5.2 Environmental Representation

Instead of the design wave loads specified in Section 5C-1-3, a wave scatter diagram (such as Walden's Data) is to be employed to simulate a representative distribution of all of the wave conditions expected for the design service life of the vessel. In general, the wave data is to cover a time period of not less than 20 years. The probability of occurrence for each combination of significant wave height and mean period of the representative wave scatter diagram is to be weighted, based on the transit time of the vessel at each wave environment within anticipated shipping routes. The representative environment (the wave scatter diagram) is not to be taken less severe than North Atlantic Ocean in terms of fatigue damage.

7.5.3 Calculation of Wave Load RAOs

The wave load RAOs with respect to the wave-induced bending moments, shear forces, motions, accelerations and hydrodynamic pressures can then be predicted by ship motion calculation for a selected representative loading condition.

7.5.4 Generation of Stress Spectrum

The stress spectrum for each critical structural detail (spot) may be generated by performing a structural analysis, accounting for all of the wave loads separately for each individual wave group. For this purpose, the 3D structural model and 2D models specified in 5C-1-5/9 may be used for determining structural responses. The additional secondary and tertiary stresses are also to be considered.

7.5.5 Cumulative Fatigue Damage and Fatigue Life

Based on the stress spectrum and wave scatter diagram established above, the cumulative fatigue damage and the corresponding fatigue life can be estimated by the Palmgren-Miner linear damage rule.

9 Calculation of Structural Responses *(1995)*

9.1 Methods of Approach and Analysis Procedures *(1997)*

Maximum stresses in the structure are to be determined by performing structural analyses, as outlined below. Guidelines on structural idealization, load application and structural analysis are given in ABS *Guidance for Finite Element Analysis of Tanker Structures*.

In general, the strength assessment is to be focused on the results obtained from structures in the mid hold of a three hold length model. However, the deck transverse, the side transverse, the vertical web on longitudinal bulkheads, the horizontal girder and the vertical web on transverse bulkheads and the cross tie are to be assessed using the end holds of a three hold length model as well.

9.3 3D Finite Element Models *(1995)*

A simplified three-dimensional finite element model, representing usually three bays of tanks within 0.4*L* amidships, is required to determine the load distribution in the structure.

The same 3D model may be used for hull structures beyond 0.4*L* amidships with modifications to the structural properties and the applied loads, provided that the structural configurations are considered as representative of the location under consideration.

9.5 2D Finite Element Models *(1995)*

Two-dimensional fine mesh finite element models are required to determine the stress distribution in major supporting structures, particularly at intersections of two or more structural members.

9.7 Local Structural Models *(1995)*

A 3D fine mesh model is to be used to examine stress concentrations, such as at intersections of longitudinals with transverses and at cut outs.

9.9 Load Cases *(1995)*

When performing structural analysis, the eight combined load cases specified in 5C-1-3/9.1 are to be considered. In general, the structural responses for the still-water conditions are to be calculated separately to establish reference points for assessing the wave-induced responses. Additional load cases may be required for special loading patterns and unusual design functions, such as sloshing loads, as specified in 5C-1-3/11. Additional load cases may also be required for hull structures beyond the region of 0.4*L* amidships.

11 Critical Areas *(1 July 2005)*

The fatigue strength of the following critical areas is to be verified by fine mesh finite element models built in accordance with Appendix 5C-1-A1:

- Typical deck longitudinal connection at transverse bulkhead
- Typical bottom and inner bottom longitudinal connections at transverse bulkhead and the 1st web frames adjacent to transverse bulkhead
- Typical side shell longitudinal connections at transverse bulkhead and the 1st web frames adjacent to transverse bulkhead
- Critical areas of transverse web frames in 5C-1-5/Figure 2
- Critical areas of horizontal girders on transverse bulkhead in 5C-1-5/Figure 3
- Critical areas of buttress structure in 5C-1-5/Figure 4

The mesh size in way of high stress concentration is to be of plate thickness dimension (t). The element stress intensity at half plate thickness dimension (t/2) away from the weld toe is to satisfy the following stress limit:

$$f_i \le f_u$$

where

f_i = stress intensity

= $(f_L^2 + f_T^2 - f_L f_T + 3 f_{LT}^2)^{1/2}$ N/cm^2 (kgf/cm^2, lbf/in^2)

f_L = calculated total in-plane element stress in the longitudinal direction

f_T = calculated total in-plane element stress in the transverse/vertical direction

f_{LT} = calculated total in-plane element shear stress

f_u = the minimum tensile strength of the material

FIGURE 2
Critical Areas in Transverse Web Frame *(1 July 2005)*

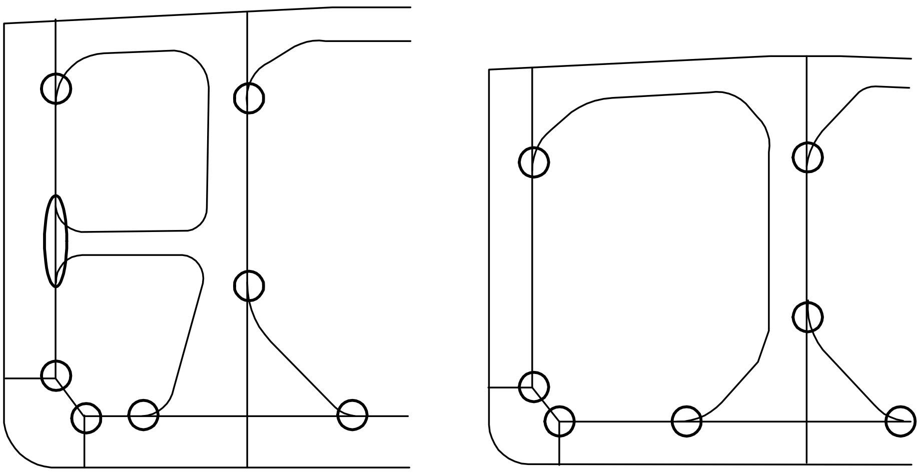


FIGURE 3
Critical Areas in Horizontal Girder on Transverse Bulkhead *(1 July 2005)*

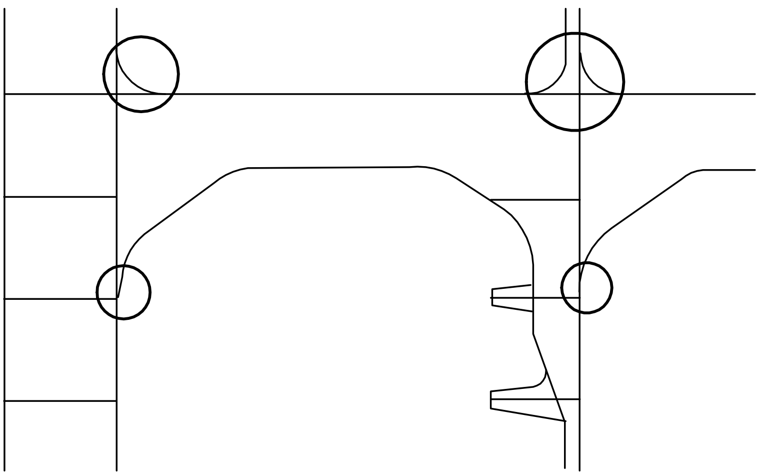
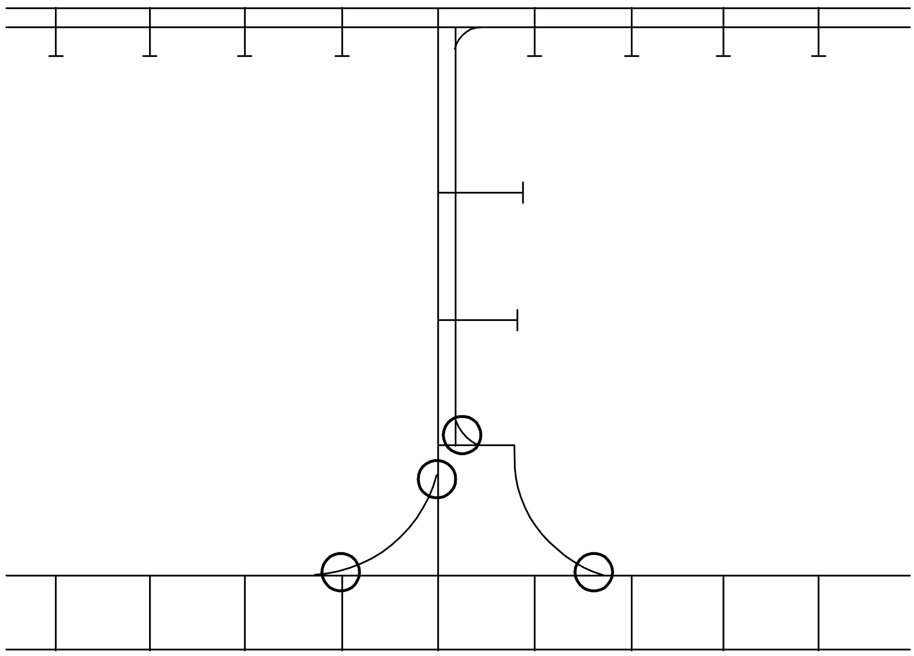


FIGURE 4
Critical Areas of Buttress Structure *(1 July 2005)*



PART

5C

CHAPTER 1 **Vessels Intended to Carry Oil in Bulk (150 meters (492 feet) or more in Length)**

SECTION 6 **Hull Structure Beyond 0.4L Amidships**

1 General Requirements

1.1 General

The structural configurations, stiffening systems and design scantlings of the hull structures located beyond 0.4*L* amidships, including the forebody, aft end and machinery spaces, are to be in compliance with 5C-2-2/17 and this Section of the Rules.

1.3 Structures within the Cargo Space Length *(2002)*

The scantlings of longitudinal structural members and elements in way of cargo spaces beyond the 0.4*L* amidships may be gradually reduced toward 0.125*L* from the ends, provided that the hull girder section modulus complies with 3-2-1/3.7.1 and that the strength of the structure satisfies the material yielding, buckling and ultimate strength criteria specified in 5C-1-5/3 and 5C-1-5/5.

The scantlings of main supporting members in way of the cargo space length beyond 0.4*L* amidships are to comply with the requirements of 5C-1-4/11. Where the structural configuration is different from that amidships due to the hull form of the vessel, additional evaluation is to be performed. The structural evaluation using the actual configuration is to be carried out to ensure that the arrangement of openings necessary for access (5C-1-1/5.21), ventilation (5C-1-1/5.25), fabrication, etc. is satisfactory.

3 Forebody Side Shell Structure *(2000)*

In addition to the requirements specified in other relevant sections of the Rules, the scantlings of the structure forward of 0.4*L* amidships are also to satisfy the requirements in 5C-1-6/3.1, 5C-1-6/3.3 and 5C-1-6/3.5 below.

The nominal design corrosion values in the forepeak tank may be taken as 1.5 mm in determining design scantlings.

3.1 Side shell Plating *(2002)*

3.1.1 Plating Forward of Forepeak Bulkhead

The net thickness of the side shell plating forward of the forepeak bulkhead is to be not less than t_1, t_2 and t_3, specified below.

$t_1 = 0.73s(k_1 p/f_1)^{1/2}$ in mm (in.)

$t_2 = 0.73s(k_2 p/f_2)^{1/2}$ in mm (in.)

$t_3 = 0.73sk(k_3 k_4 p_b/f_3)^{1/2}$ in mm (in.) for side shell and bow plating above *LWL* in the region from the forward end to the forepeak bulkhead

where

s = spacing of stiffeners, in mm (in.)

k_1 = 0.342 for longitudinally and $0.50k^2$ for transversely stiffened plating

k_2 = $0.50k^2$ for longitudinally and 0.342 for transversely stiffened plating

k_3 = 0.50

k_4 = 0.74

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

f_1 = 0.65 $S_m f_y$, in N/cm² (kgf/cm², lbf/in²) in the longitudinal direction

f_2 = 0.85 $S_m f_y$, in N/cm² (kgf/cm², lbf/in²) in the transverse (vertical) direction

f_3 = 0.85 $S_m f_y$, in N/cm² (kgf/cm², lbf/in²)

p = nominal pressure $|p_i - p_e|$, in N/cm² (kgf/cm², lbf/in²), as specified in 5C-1-3/Table 3, at the upper turn of bilge level amidships with the following modifications:

i) A_{ti} is to be calculated at the forward or aft end of the tank, whichever is greater

ii) A_e is to be calculated at the center of the panel in accordance with 5C-1-3/5.5.3, using L.C.7 with $k_{fo} = 1.0$ and x_o located amidships

iii) B_e is to be calculated at 0.05L from the FP in accordance with 5C-1-3/5.5 ($p_s + k_u p_d$, full draft, heading angle = 0, $k_u = 1.1$)

p_b = the maximum bow pressure = $k_u p_{bij}$

k_u = 1.1

p_{bij} = nominal bow pressure, as specified in 5C-1-3/13.1.1, at the lowest point of the panel, in N/cm² (kgf/cm², lbf/in²)

S_m and f_y, as defined in 5C-1-4/7.3.1.

3.1.2 Plating between Forepeak Bulkhead and 0.125L from FP

Aft of the forepeak bulkhead and forward of 0.125L from the FP, the side shell plating is to be not less than as given in 5C-1-6/3.1.1 with B_e calculated at 0.125L and the following permissible stress.

f_1 = permissible bending stress in the longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.50 S_m f_y$, for $L \geq 190$ m (623 ft)

= $[0.50 + 0.10(190 - L)/40]\, S_m f_y$, for $L < 190$ m (623 ft)

f_2 = $0.80 S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2), in the transverse (vertical) direction

3.1.3 Plating between 0.3L and 0.125L from FP

The net thickness of the side shell plating between 0.3L and 0.125L from the FP is to be determined from the equations in 5C-1-4/5.3 and 5C-1-6/3.1.2 above with B_e calculated at the longitudinal location under consideration. Between 0.3L and 0.25L from the FP, the internal pressure need not be greater than that obtained amidships. The permissible stress f_1 between 0.3L and 0.2L from the FP is to be obtained by linear interpolation between midship region (5C-1-4/9.1) and the permissible stress f_1, as specified in 5C-1-6/3.1.2.

3.3 Side Frames and Longitudinals

3.3.1 Side Frames and Longitudinals Forward of 0.3L from FP

The net section modulus of side longitudinals and frames in association with the effective plating to which they are attached is to be not less than that obtained from the following equation:

$SM = M/f_{bi}$ in cm^3 (in^3)

$M = 1000ps\ell^2/k$ in N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 83.33)

p = nominal pressure $|p_i - p_e|$, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-1-3/Table 3 with the following modifications:

i) A_{ti} is to be calculated at the forward or aft end of the tank, whichever is greater. Between 0.3L and 0.25L aft of the FP, the internal pressure need not be greater than that obtained amidships.

ii) A_e is to be calculated at the center of the panel in accordance with 5C-1-3/5.5.3 using L.C.7 with $k_{fo} = 1.0$ and x_o located amidships.

iii) B_e is to be calculated at the center of the panel in accordance with 5C-1-3/5.5 ($p_s + k_u p_d$, full draft, heading angle = 0, $k_u = 1.1$), with the distribution of p_d, as shown in 5C-1-6/Figure 1, at the side longitudinal and frame under consideration.

Longitudinal distribution of p_d may be taken as constant from the FP to forepeak bulkhead as per 5C-1-6/3.1.1 and from 0.125L to the forepeak bulkhead as per 5C-1-6/3.1.2. p_d is to be calculated in accordance with 5C-1-3/5.5 between 0.3L and 0.125L from the FP as per 5C-1-6/3.1.3.

f_{bi} = $0.80\ S_m f_y$ in N/cm^2 (kgf/cm^2, lbf/in^2), for longitudinals between 0.125*L* and 0.2*L* from the FP

= $0.85\ S_m f_y$ in N/cm^2 (kgf/cm^2, lbf/in^2), for longitudinals forward 0.125*L* from the FP

= $0.85\ S_m f_y$ in N/cm^2 (kgf/cm^2, lbf/in^2), for vertical frames (other than hold frames)

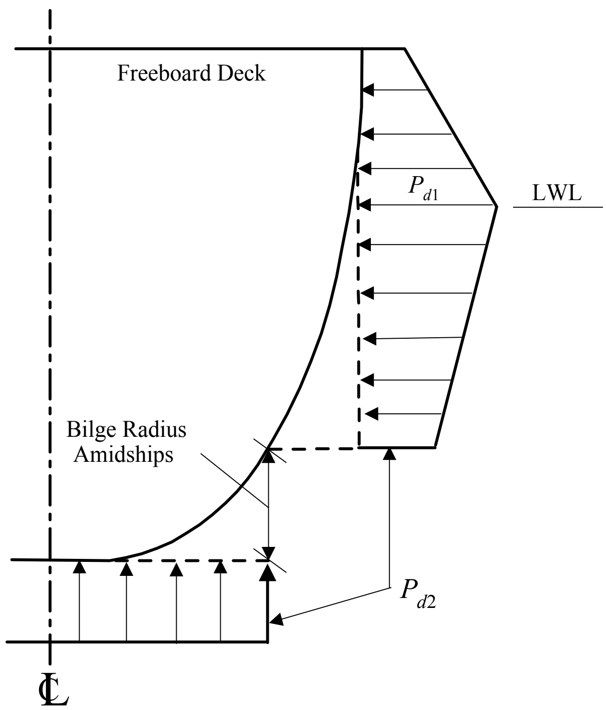
Between 0.3*L* and 0.2*L* from the FP, the permissible stress is to be obtained by linear interpolation between midship region and $0.80\ S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

s and ℓ are as defined in 5C-1-4/7.5.

For side longitudinal/stiffener in the region forward of 0.0125*L* from the FP and above *LWL*, the section modulus is not to be less than obtained from the above equation based on $p = p_b$, $f_b = 0.95\ S_m f_y$ and $k = 16$ (16, 111.1), where p_b is as defined in 5C-1-6/3.1 above.

FIGURE 1
Transverse Distribution of p_d *(2000)*



3.5 Side Transverses and Stringers in Forebody *(2002)*

The requirements of the subparagraphs below apply to the region forward of the cargo spaces where single side skin construction is used.

3.5.1 Section Modulus

The net section modulus of side transverse and stringer in association with the effective side shell plating is not to be less than obtained from the following equation:

$SM = M/f_b$ in cm^3 (in^3)

3.5.1(a) Longitudinally Framed Side Shell

For side stringer

$M = 1000 c_1 c_2 p s \ell_t \ell_s / k$ in N-cm (kgf-cm, lbf-in)

For side transverse, M is not to be less than M_1 or M_2, whichever is greater

$M_1 = 1000 c_3 p s \ell_t^2 (1.0 - c_4 \phi)/k$ in N-cm (kgf-cm, lbf-in)

$M_2 = 850 p_1 s \ell_{t1}^2 / k$ in N-cm (kgf-cm, lbf-in)

where

k = 0.12 (0.12, 0.446)

c_1 = 0.125 + 0.875ϕ, but not less than 0.3

Coefficients c_2, c_3 and c_4 are given in the tables below.

Coefficient c_2

Number of Side Stringers Between Platforms (flats)	*No Stringer*	*One Stringer*	*More than one Stringer*
Top Stringer			0.70
Stringers Between Top and Lowest Stringers	0.0	0.90	0.75
Lowest Stringer			0.80

Coefficient c_3

Number of Side Stringers Between Platforms (flats)	*No Stringer*	*One Stringer*	*More than one Stringer*
Transverse above Top Stringer		0.55	0.55
Transverse Between Top and Lowest Stringers	0.85	—	0.64
Transverse Below Lowest Stringer		0.68	0.68

Coefficient c_4

Number of Side Stringers Between Platforms (flats)	*No Stringer*	*One Stringer*	*More than one Stringer*
Transverses	0.0	0.75	0.80

p = nominal pressure, $|p_i - p_e|$, in kN/m^2 (tf/m^2, Ltf/ft^2), over the side transverses using the same load cases as specified in 5C-1-3/Table 3 for side transverses with the following modifications.

i) A_e is to be considered for case "a" and calculated in accordance with 5C-1-3/5.5.3 using L.C.7 with k_{fo} = 1.0 and x_o located amidships

ii) B_e is to be calculated in accordance with 5C-1-3/5.5 ($p_s + k_u p_d$, full draft, heading angle = 0, k_u = 1) with the distribution of p_d as shown in 5C-1-6/Figure 1.

B_i, A_e and B_e may be taken at the center of the side shell panel under consideration.

p_1 = nominal pressure, $|p_i - p_e|$, in kN/m^2 (tf/m^2, Ltf/ft^2), using the same load cases as specified in 5C-1-3/Table 3 for side transverses with the following modifications.

i) A_e is to be considered for case "a" and calculated in accordance with 5C-1-3/5.5.3 using L.C.7 with k_{fo} = 1.0 and x_o located amidships

ii) B_e is to be calculated in accordance with 5C-1-3/5.5 ($p_s + k_u p_d$, full draft, heading angle = 0, k_u = 1) with the distribution of p_d as shown in 5C-1-6/Figure 1.

B_i, A_e and B_e, calculated at the midspan ℓ_{s1} (between side stringers or between side stringer and platform, flat as shown in 5C-1-6/Figure 2) of the side transverse under consideration.

For side transverses

s = sum of half distances, in m (ft), between side transverse under consideration and adjacent side transverses or transverse bulkhead

For side stringers

s = $0.45\ell_s$

ϕ = $1/(1 + \alpha)$

α = $1.33(I_t/I_s)(\ell_s/\ell_t)^3$

I_t = moment of inertia, in cm^4 (in^4) (with effective side plating), of side transverse. I_t is to be taken as an average of those at the middle of each span ℓ_{t1} between side stringers or side stringer and platform (flat), clear of the bracket

I_s = moment of inertia, in cm^4 (in^4) (with effective side plating), of side stringer at the middle of the span ℓ_s, clear of the bracket

ℓ_t, ℓ_s = spans, in m (ft), of the side transverse (ℓ_t) and side girder (ℓ_s) under consideration, as shown in 5C-1-6/Figure 2

ℓ_{t1} = span, in m (ft), of side transverse under consideration between stringers, or stringer and platform (flat), as shown in 5C-1-6/Figure 2b

When calculating α, if more than one side transverse or stringer is fitted and they are not identical, average values of I_t and I_s within side shell panel (panel between transverse bulkheads and platforms, flats) are to be used.

f_b = permissible bending stress in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.75\ S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

The bending moment for side transverse below stringer (or below the platform if no stringer is fitted) is not to be less than 80% of that for side transverse above stringer (or above platform if no stringer is fitted).

3.5.1(b) Transversely Framed Side Shell

For side transverse

$M = 1000 c_1 p s \ell_t \ell_s / k$ in N-cm (kgf-cm, lbf-in)

For side stringer, M is not to be less than M_1 or M_2, whichever is greater

$M_1 = 1000 c_2 p s \ell_s^2 (1.0 - c_3 \phi_1)/k$ in N-cm (kgf-cm, lbf-in)

$M_2 = 1100 p_1 s \ell_{s1}/k$ in N-cm (kgf-cm, lbf-in)

where

k = 0.12 (0.12, 0.446)

c_1 = $0.10 + 0.7\phi_1$, but not to be taken less than 0.085

If no side transverses are fitted between transverse bulkheads

c_2 = 1.1

c_3 = 0

If side transverses are fitted between transverse bulkheads

c_2 = 0.8

c_3 = 0.8

p = nominal pressure, $|p_i - p_e|$, in kN/m^2 (tf/m^2, Ltf/ft^2), over the side stringers using the same load cases as specified in 5C-1-3/Table 3 for side transverses in lower wing tank. A_{ti}, A_e and B_e may be taken at the center of the side shell panel under consideration with the following modifications:

i) A_e is to be calculated in accordance with 5C-1-3/5.5.3 using L.C.7 with $k_{fo} = 1.0$ and x_o located amidships

ii) B_e is to be calculated in accordance with 5C-1-3/5.5 ($p_s + k_u p_d$, full draft, heading angle = 0, $k_u = 1$) with the distribution of p_d as shown in 5C-1-6/Figure 1.

p_1 = nominal pressure, $|p_i - p_e|$, in kN/m^2 (tf/m^2, Ltf/ft^2), using the same load cases as specified in 5C-1-3/Table 3 for side transverses in lower wing tank, with A_{ti}, A_e and B_e calculated at the midspan ℓ_{s1} (between side transverses or between side transverse and transverse bulkhead, as shown in 5C-1-6/Figure 2a) of the side stringer under consideration, with the following modifications:

i) A_e is to be calculated in accordance with 5C-1-3/5.5.3 using L.C.7 with $k_{fo} = 1.0$ and x_o located amidships

ii) B_e is to be calculated in accordance with 5C-1-3/5.5 ($p_s + k_u p_d$, full draft, heading angle = 0, $k_u = 1$) with the distribution of p_d as shown in 5C-1-6/Figure 1.

For side stringers

s = sum of half distances, in m (ft), between side stringer under consideration and adjacent side stringers or platforms (flats)

For side transverses

s = $0.45\ell_t$

ϕ_1 = $\alpha/(1 + \alpha)$

ℓ_{s1} = span, in m (ft), of the side stringer under consideration between side transverses or side transverse and transverse bulkhead, as shown in 5C-1-6/Figure 2a

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.75\ S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

ℓ_t, ℓ_s and α are as defined in 5C-1-6/3.5.1(a) above.

3.5.2 Sectional Area of Web

The net sectional area of the web portion of the side transverse and side stringer is not to be less than obtained from the following equation:

$A = F/f_s$

3.5.2(a) Longitudinally Framed Side Shell

For side stringer

$F = 1000kc_1p\ell s$ in N (kgf, lbf)

For side transverse, F is not to be less than F_1 or F_2, whichever is greater

$F_1 = 850kc_2p\ell s(1.0 - c_3\phi - 2h_e/\ell)$ N (kgf, lbf)

$F_2 = 1700kc_2p_1s(0.5\ell_1 - h_e)$ N (kgf, lbf)

where

k = 0.5 (0.5, 1.12)

Coefficients c_1, c_2 and c_3 are given in the tables below.

Coefficient c_1

Number of Side Stringers Between Platforms (flats)	*No Stringer*	*One Stringer*	*More than one Stringer*
Stringers	0.0	0.52	0.40

Coefficient c_2

Number of Side Stringers Between Platforms (flats)	*No Stringer*	*One Stringer*	*More than one Stringer*
Transverses Above Top Stringer	1.0	0.9	0.9
Transverse Between Top and Lowest Stringers		—	0.95
Transverse Below Lowest Stringer		1.0	1.0

Coefficient c_3

Number of Side Stringers Between Platforms (flats)	*No Stringer*	*One Stringer*	*More than one Stringer*
Transverses	0.0	0.5	0.6

ℓ = span, in m (ft), of the side transverse under consideration between platforms (flats), as shown in 5C-1-6/Figure 2b

ℓ_1 = span, in m (ft), of the side transverse under consideration between side stringers or side stringer and platform (flat), as shown in 5C-1-6/Figure 2b

h_e = length, in m (ft), of the end bracket of the side transverse, as shown in 5C-1-6/Figure 2b

To obtain F_1, h_e is equal to the length of the end bracket at the end of span ℓ of side transverse, as shown in 5C-1-6/Figure 2b.

To obtain F_2, h_e is equal to the length of the end bracket at the end of span ℓ_1 of side transverse, as shown in 5C-1-6/Figure 2b.

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\, S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

p, p_1, ϕ and s are as defined in 5C-1-6/3.5.1(a) above.

The shear force for the side transverse below the lowest stringer (or below the platform if no stringer is fitted), is not to be less than 110% of that for the side transverse above the top stringer (or above the platform if no stringer is fitted).

3.5.2(b) Transversely Framed Side Shell

For side transverse

$F = 850kc_1p\ell s$ in N (kgf, lbf)

For side stringer, F is not to be less than F_1 or F_2, whichever is greater.

$F_1 = 1000kp\ell s(1.0 - 0.6\phi_1 - 2h_e/\ell)$ in N (kgf, lbf)

$F_2 = 2000kp_1s(0.5\ell_1 - h_e)$ in N (kgf, lbf)

where

k = 0.5 (0.5, 1.12)

c_1 = $0.1 + 0.7\phi_1$, but not to be taken less than 0.2

ℓ = span, in m (ft), of the side stringer under consideration between transverse bulkheads, as shown in 5C-1-6/Figure 2a

ℓ_1 = span, in m (ft), of the side stringer under consideration between side transverses or side transverse and bulkhead, as shown in 5C-1-6/Figure 2a

h_e = length, in m (ft), of the end bracket of the side stringer under consideration, as shown in 5C-1-6/Figure 2a

To obtain F_1, h_e is equal to the length of the end bracket at the end of span ℓ of the side stringer, as shown in 5C-1-6/Figure 2a.

To obtain F_2, h_e is equal to the length of the end bracket at the end of span ℓ_1 of the side stringer, as shown in 5C-1-6/Figure 2a.

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\, S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

p, p_1, ϕ_1 and s are as defined in 5C-1-6/3.5.1(a) above.

3.5.3 Depth of Transverse/Stringer

The depths of side transverses and stringers, d_w, are neither to be less than obtained from the following equations nor to be less than 2.5 times the depth of the slots, respectively.

3.5.3(a) Longitudinally Framed Shell

For side transverse

If side stringer is fitted between platforms (flats)

$d_w = (0.08 + 0.80\alpha)\ell_t$ for $\alpha \le 0.05$

$= (0.116 + 0.084\alpha)\ell_t$ for $\alpha > 0.05$

and need not be greater than $0.2\ell_t$

If no side stringer is fitted between platforms (flats), d_w is not to be less than $0.2\ell_t$ or $0.06D$, whichever is greater.

For side stringer

$d_w = (0.42 - 0.9\alpha)\ell_s$ for $\alpha \le 0.2$

$= (0.244 - 0.0207\alpha)\ell_s$ for $\alpha > 0.2$

α is not to be taken greater than 8.0 to determine the depth of the side stringer.

ℓ_t, ℓ_s and α are as defined in 5C-1-6/3.5.1(a) above.

D is as defined in 3-1-1/7.

3.5.3(b) Transversely Framed Side Shell

For side stringer

If side transverse is fitted between transverse bulkheads

$d_w = (0.08 + 0.80\alpha_1)\ell_s$ for $\alpha_1 \le 0.05$

$= (0.116 + 0.084\alpha_1)\ell_s$ for $\alpha_1 > 0.05$

and need not be greater than $0.2\ell_s$

If no side transverse is fitted between transverse bulkheads

$d_w = 0.2\ell_s$

For side transverse

$d_w = (0.277 - 0.385\alpha_1)\ell_t$ for $\alpha_1 \le 0.2$

$= (0.204 - 0.205\alpha_1)\ell_t$ for $\alpha_1 > 0.2$

α_1 is not to be taken greater than 7.5 to determine the depth of the side transverse

where

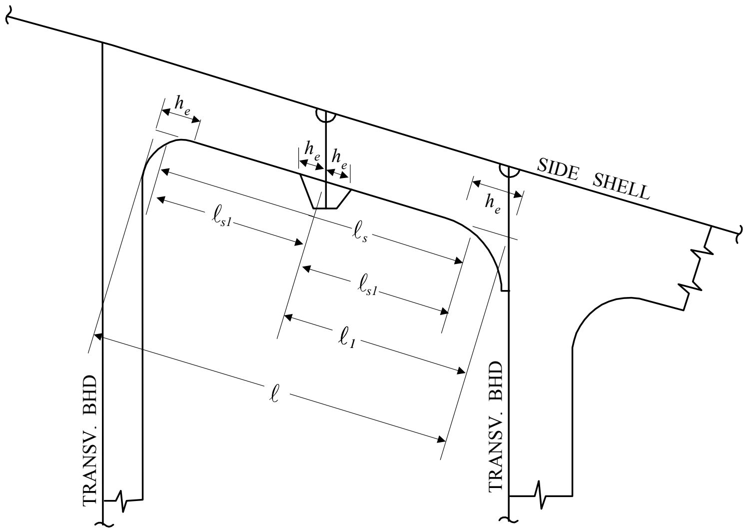
$\alpha_1 = 1/\alpha$

ℓ_t, ℓ_s and α are as defined in 5C-1-6/3.5.1(a) above.

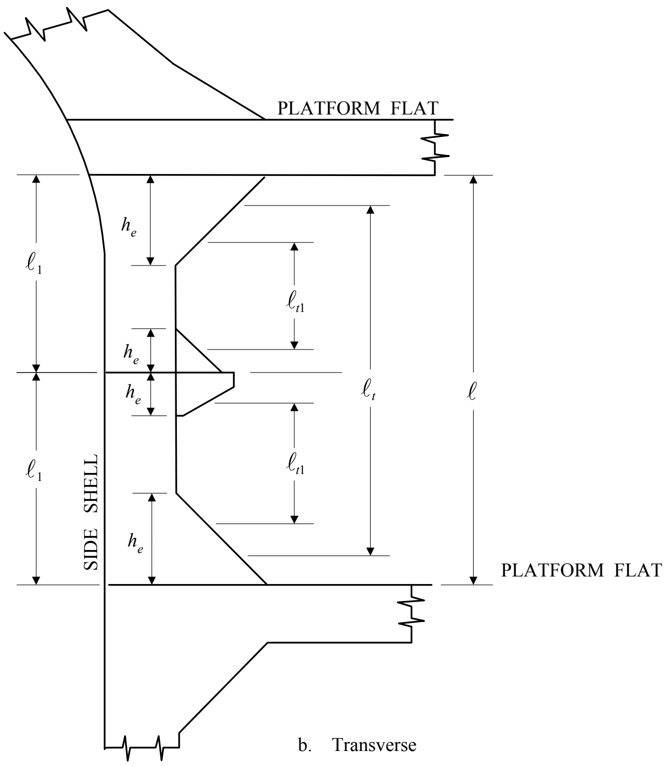
3.5.4 Thickness

The net thickness of side transverse and stringer is not to be less than 9.5 mm (0.374 in.)

FIGURE 2
Definition of Spans *(2000)*



a. Stringer



b. Transverse

5 Transition Zone *(2000)*

In the transition zone between the forepeak and the No. 1 cargo tank region, due consideration is to be given to the proper tapering of major longitudinal members within the forepeak such as flats, decks, horizontal ring frames or side stringers aft into the cargo hold. Where such structure is in line with longitudinal members aft of the forward cargo tank bulkhead, this may be effected by fitting of large tapering brackets. These brackets are to have a taper of 4:1.

7 Forebody Strengthening for Slamming *(2000)*

Where the hull structure is subject to slamming, as specified in 5C-1-3/13, proper strengthening will be required as outlined below. For strengthening to account for bottom slamming, the requirements of this subsection apply to vessels with a heavy ballast draft forward of less than $0.04L$ and greater than $0.025L$. Vessels with heavy ballast draft forward equal to or less than $0.025L$ will be subject to special consideration.

7.1 Bottom Slamming

7.1.1 Bottom Plating

When bottom slamming, as specified in 5C-1-3/13, is considered, the bottom structure in the region of the flat of bottom forward of $0.25L$ measured from the FP is to be in compliance with the following requirement.

The net thickness of the flat of bottom plating forward of $0.25L$ measured from the FP is not to be less than t obtained from the following equation:

$$t = 0.73s(k_2\, k_3\, p_s/f)^{1/2} \quad \text{in mm (in.)}$$

where

s = spacing of longitudinal or transverse stiffeners, in mm (in.)

k_2 = $0.5\,k^2$ for longitudinally stiffened plating

k_3 = 0.74

k = $(3.075\,(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

p_s = the design slamming pressure = $k_u\, p_{si}$

For determination of t, the pressure p_s is to be taken at the center of the supported panel.

p_{si} = nominal bottom slamming pressure, as specified in 5C-1-3/13.3.1, in N/cm^2 (kgf/cm^2, lbf/in^2)

k_u = slamming load factor = 1.1

The maximum nominal bottom slamming pressure occurring along the vessel is to be applied to the bottom plating between the foremost extent of the flat of bottom and $0.125L$ from the FP. The pressure beyond this region may be gradually tapered to the longitudinal location where the nominal slamming pressure is calculated as zero.

f = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.85\ S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

7.1.2 Bottom Longitudinals and Stiffeners

The section modulus of the stiffener, including the associated effective plating on the flat of bottom forward of 0.25L measured from the FP, is not to be less than obtained from the following equation:

$SM = M/f_b$ in cm^3 (in^3)

$M = 1000 p_s s \ell^2/k$ in N-cm (kgf-cm, lbf-in)

where

k = 16 (16, 111.1)

p_s = the design slamming pressure = $k_u p_{si}$

For determination of M, the pressure p_s is to be taken at the midpoint of the span ℓ.

p_{si} = nominal bottom slamming pressure, as specified in 5C-1-3/13.3.1, in N/cm^2 (kgf/cm^2, lbf/in^2)

k_u = slamming load factor = 1.1

The maximum nominal bottom slamming pressure occurring along the vessel is to be applied to the bottom stiffeners between the foremost extent of the flat of bottom and 0.125L from the FP. The pressure beyond this region may be gradually tapered to the longitudinal location where the nominal slamming pressure is calculated as zero.

s = spacing of longitudinal or transverse stiffeners, in mm (in.)

ℓ = the unsupported span of the stiffener, in m (ft)

f_b = $0.9 S_m f_y$ for transverse and longitudinal stiffeners in the region forward of 0.125L measured from the FP

= $0.8 S_m f_y$ for longitudinal stiffeners in the region between 0.125L and 0.25L measured from the FP

The effective breadth of plating b_e is as defined in 5C-1-4/7.5.

Struts connecting the bottom and inner bottom longitudinals are not to be fitted.

7.1.3 Bottom Floors

The arrangements and scantlings of floors are to be adequate for bottom slamming loads, as specified in 5C-1-3/13.

The spacing of floors forward of amidships need not be less than the spacing amidships.

7.3 Bowflare Slamming

When bowflare slamming, as specified in 5C-1-3/13.5, is considered, the side shell structure above the waterline in the region between 0.0125L and 0.25L from the FP is to be in compliance with the following requirements.

7.3.1 Side Shell Plating

The net thickness of the side shell plating between 0.0125L and 0.25L from the FP is not to be less than t_1 or t_2, whichever is greater, obtained from the following equations:

$t_1 = 0.73s(k_1 p_s/f_1)^{1/2}$ in mm (in.)

$t_2 = 0.73s(k_2 p_s/f_2)^{1/2}$ in mm (in.)

where

p_s = the maximum slamming pressure = $k_u p_{ij}$

p_{ij} = nominal bowflare slamming pressure, as specified in 5C-1-3/13.5.1, at the lowest point of the panel, in N/cm^2 (kgf/cm^2, lbf/in^2)

k_u = slamming load factor = 1.1

f_1 = 0.85 $S_m f_y$ for side shell plating forward of 0.125L from the FP, in N/cm^2 (kgf/cm^2, lbf/in^2)

= 0.75 $S_m f_y$ for side shell plating in the region between 0.125L and 0.25L from the FP, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_2 = 0.85 $S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

k_1 = 0.342 for longitudinally stiffened plating

= 0.5 for transversely stiffened plating

k_2 = 0.5 for longitudinally stiffened plating

= 0.342 for transversely stiffened plating

s, S_m and f_y are as defined in 5C-1-6/7.1.1 above.

7.3.2 Side Longitudinals and Stiffeners

The section modulus of the stiffener, including the associated effective plating, is not to be less than obtained from the following equation:

$SM = M/f_b$ in cm^3 (in^3)

$M = 1000 p_s s \ell^2/k$ in N-cm (kgf-cm, lbf-in)

where

k = 16 (16, 111.1)

ℓ = unsupported span of the stiffener, in m (ft)

p_s = the maximum slamming pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in 5C-1-6/7.3.1, at the midpoint of the span ℓ

s and f_b are as defined in 5C-1-6/7.1 above.

The effective breadth of plating, b_e, is as defined in 5C-1-4/7.5.

7.3.3 Side Transverses and Side Stringers *(1 July 2008)*

For the region between 0.0125L and 0.25L from the FP, the net section modulus and sectional area requirements for side transverses and side stringers in 5C-1-6/3.5 are to be met with the bow flare slamming pressure as specified in 5C-1-3/13.5.1 and with the permissible bending stress of $f_b = 0.64 S_m f_y$ and the permissible shear stress of $f_s = 0.38 S_m f_y$.

PART

5C

CHAPTER **1** **Vessels Intended to Carry Oil in Bulk (150 meters (492 feet) or more in Length)**

SECTION **7** **Cargo Oil and Associated Systems**

1 General

1.1 Application

1.1.1 Flash Point

The provisions of Part 5C, Chapter 1, Section 7 (referred to as Section 5C-1-7) apply primarily to vessels intended to carry in bulk oil or petroleum products having a flash point of 60°C (140°F), closed cup test, or below. Vessels intended to carry in bulk only oil or petroleum products having a flash point exceeding 60°C (140°F) may comply with the provisions of 5C-1-7/1.9 hereunder.

1.1.2 Class Notations

The provisions of Section 5C-1-7 form a part of the necessary condition for assigning the classification notation **Oil Carrier.** For vessels intended to carry in bulk only oil or petroleum products having a flash point exceeding 60°C (140°), the notation **Fuel Oil Carrier** is to be assigned. See 5C-1-1/1.1 and 5C-2-1/1.1.

Where requested by the owner, vessels in which all cargo piping and valve control piping are located above the double bottom will be assigned the notation **CPP** (Cargo Piping Protected). **CPP** is not a condition of classification. See 5C-1-7/3.3.4.

Where a cargo vapor emission control system is installed, the provisions of 5C-1-7/21 are applicable. Systems satisfying these provisions will be assigned with the notation **VEC**. Systems satisfying the additional provisions of 5C-1-7/21.19 for lightering operation will be assigned with the notation **VEC-L**.

1.1.3 AMS Notation

The provisions of Part 4, pertaining to assigning the machinery class notation **AMS**, are applicable to oil carriers and fuel oil carriers in addition to the provisions of this section. See 4-1-1/1.5.

1.1.4 Combination Carriers

Combination carriers when engaged in the carriage of oil are to comply with these requirements. In general, combination carriers are not permitted to carry oil and bulk cargoes simultaneously.

1.3 Definitions

1.3.1 Crude Oil Carrier

Crude Oil Carrier is a vessel engaged in the trade of carrying crude oil. Crude oil means any liquid hydrocarbon mixture occurring naturally in the earth whether or not treated to render it suitable for transportation and includes:

- Crude oil from which certain distillate fractions may have been removed; and
- Crude oil to which certain distillate fractions may have been added.

1.3.2 Product Carrier

Product Carrier is a vessel engaged in the trade of carrying oil other than crude oil.

1.3.3 Oil Carrier

As used throughout the Rules, *Oil Carrier* means any vessel engaged in the trade of carrying crude oil or other oil products having a flash point of 60°C (140°F) or less.

1.3.4 Fuel Oil Carrier

As used throughout the Rules, *Fuel Oil Carrier* means any vessel engaged in the trade of carrying oil or oil products having a flash point above 60°C (140°F).

1.3.5 Combination Carrier

Combination Carrier is a vessel designed to carry either oil or solid cargoes in bulk.

1.3.6 Segregated Ballast

Segregated Ballast is the ballast water introduced into a tank which is completely separated from the cargo oil and fuel oil systems and which is permanently allocated to the carriage of ballast or cargoes other than oil.

1.3.7 Cargo Area

Cargo Area is that part of the vessel that contains cargo tanks, slop tanks and cargo pump rooms including pump rooms, cofferdams, ballast and void spaces adjacent to cargo tanks and also deck areas throughout the entire length and breadth of the part of the vessel over the above mentioned spaces.

1.3.8 Hazardous Areas

Areas where flammable or explosive gases or vapors are normally present or likely to be present are known as *Hazardous Areas*. The flammable or explosive atmosphere may be expected to exist continuously or intermittently. Typically, the cargo area, spaces around cargo tank openings, spaces around disconnectable cargo oil pipe joints, etc. are to be regarded as hazardous areas. The word 'hazardous', where used in this section, means the presence of a flammable atmosphere. See 5C-1-7/31.5.

1.5 Plans and Data to be Submitted

The following plans and data specific to oil carriers are to be submitted:

Booklet showing standard construction details for piping, see 4-6-1/9.5.

General arrangement showing the location of the cargo pump room, cargo pumps and cargo tanks.

Cargo oil pumping and tank stripping system.

Cargo oil heating system.

Arrangement of cargo pumps, including drives and drive shaft bulkhead gland arrangements.

Cargo pump room ventilation.

Pipe tunnel/duct keel ventilation.

Gas detection systems for cargo pump room and pipe tunnel/duct keel.

Bilge pumping arrangements for cargo pump rooms and cofferdams.

Segregated ballast or ballast system, as applicable.

Cargo tanks venting and gas freeing systems including details of the pressure/vacuum valves.

Inert gas system, including inert gas generating plant, all control and monitoring devices, and inert gas distribution piping.

Cargo vapor emission control system, see further details in 5C-1-7/21.3.

Crude oil washing system and operational manual.

Oil discharge monitoring and control system and operational manual.

Fixed deck foam fire extinguishing system.

Fixed fire extinguishing system for cargo pump room.

Hazardous area plan and electrical equipment data, see 4-8-1/5.3.2.

Other electrical systems and installation, see 4-8-1/5.

1.7 Some General Principles

1.7.1 Basic Requirements

The provisions of Section 5C-1-7 are intended to address flammable and pollution hazards of cargo oil and are to be read in conjunction with the requirements in Part 5C, Chapter 1 and Part 5C, Chapter 2.

With respect to flammability hazards, these provisions (following the intent of SOLAS) seek to:

- Segregate cargo oil from its ignition sources;
- Reduce the flammability of cargo oil vapor and air mixtures by means of:

  Cargo tank inerting,

  Effective dispersion of vapor released to the atmosphere, and

  Forced ventilation of enclosed spaces such as cargo pump room;
- Observe the safety of electrical equipment in hazardous areas; and
- Provide effective means of extinguishing fires should they break out.

With respect to pollution hazards, these requirements (following the intent of MARPOL Annex I) seek to:

- Provide segregated ballast;
- Separation of ballast piping from cargo piping, ballast piping from cargo tank and cargo piping from ballast tanks;
- Provide effective means for cargo tank cleaning;
- Provide means for processing and discharging contaminated waters.

1.7.2 Spaces Adjacent to Cargo Tanks

Tanks and spaces separated from cargo tanks by a single deck or bulkhead may be contaminated by cargo oil or vapor due to possible impairment of the common boundary. These tanks and spaces are therefore, in principle, to be regarded as hazardous spaces. Piping serving or having an opening into these tanks or spaces is likewise to be regarded as contaminated and, therefore, is not permitted to enter machinery and other spaces normally containing sources of ignition. Fuel oil bunker tanks adjacent to cargo oil tanks and associated bunker fuel oil piping are specifically excluded from this consideration.

1.7.3 Piping Passing Through Cargo Tanks

Piping passes through cargo oil tanks, due to possible deterioration or leakage in the pipe or pipe joints, may lead to contamination of liquid within the piping by cargo oil or vapor. Such piping is therefore, in principle, not permitted to enter machinery and other spaces normally containing sources of ignition. Steam systems used for heating cargo oil tanks, and hydraulic systems used for operating valves located in cargo tanks are specifically excluded from this consideration. See 5C-1-7/9.3 and 5C-1-7/3.5, respectively.

1.9 Cargo Oil Having a Flash Point Exceeding 60°C *(2004)*

1.9.1

For vessels intended to carry in bulk only oil or petroleum products having a flash point exceeding 60°C (140°F), the provisions of Section 5C-1-7 apply only where appropriate. In general, the provisions addressing flammable hazards of oil and vapor, such as that described in principle in 5C-1-7/1.7, do not apply; only the provisions for oil pollution prevention apply. The following may be used as guidance for applicability:

i) Cargo oil piping, tank level gauging, venting and heating systems: the provisions of 4-6-4/13 for fuel oil storage and transfer systems may apply in lieu of the provisions in Section 5C-1-7; however, pollution prevention measures in Section 5C-1-7 are applicable. Specifically, the following provisions of Section 5C-1-7 are applicable:

- 5C-1-7/3.3.1, except 5C-1-7/3.3.1(c), 5C-1-7/3.3.1(d) and 5C-1-7/3.3.1(e), for cargo pumps;
- 5C-1-7/3.3.4, except 5C-1-7/3.3.4(e) for cargo piping – pollution prevention measures;
- 5C-1-7/3.5, for remotely operated valves;
- 5C-1-7/11, cargo tank venting, only if pressure/vacuum valve controlled venting is provided;
- 5C-1-7/11.9, vent outlets from cofferdams and ballast tanks adjacent to cargo tanks;
- 5C-1-7/21, cargo vapor emission control system, where provided.

ii) Bilge and ballast systems: the provisions of 4-6-4/5 and 4-6-4/7 may apply in lieu of the provisions of Section 5C-1-7; however, pollution prevention measures in Section 5C-1-7 are applicable. Specifically, the following provisions of Section 5C-1-7 are applicable:

- 5C-1-7/5.3.1, except 5C-1-7/5.3.1(b), for ballast pumps;
- 5C-1-7/5.3.2(a) and 5C-1-7/5.3.2(d) for ballast pipe routing;
- 5C-1-7/5.3.3 and 5C-1-7/5.3.4 for discharge of segregated ballast water, dirty ballast water, etc.,
- 5C-1-7/7.1, 5C-1-7/7.3.3 and 5C-1-7/7.5 for bilge system of pump room, where a pump room is provided.

iii) Cargo tank protection: a fixed deck foam system complying with 5C-1-7/27 is to be provided.

iv) Electrical systems: provisions of Part 4, Chapter 8 will suffice; provisions of 5C-1-7/31 need not apply.

v) *(2007)* Electrical systems: Vessels subject to SOLAS are to comply with the requirements of Clause 4.3.1 of IEC 60092-502 (1999) "Electrical Installations in Ships – Tankers – Special Features" in accordance with Chapter II-1, Regulation 45.11 of the 2004 Amendments to SOLAS.

vi) *(2007)* Electrical systems: Vessels subject to SOLAS are to comply with the requirements of Clause 4.3.2 of IEC 60092-502 (1999) "Electrical Installations in Ships – Tankers – Special Features" when cargoes are heated to a temperature within 15°C of their flashpoint in accordance with Chapter II-1, Regulation 45.11 of the 2004 Amendments to SOLAS.

1.9.2 *(2004)*

For integrated cargo and ballast system requirements, see 5C-1-7/33.

3 Cargo Oil, Stripping and Crude Oil Washing Systems

3.1 General

The following requirements are specific to cargo oil handling, cargo oil stripping and crude oil washing systems. Requirements not specifically addressed in this section, such as piping material, piping design, fabrication, testing, general installation details and component certification, as given in Section 4-6-1, Section 4-6-2 and Section 4-6-3, are to be complied with, as applicable.

3.3 Cargo Oil System

3.3.1 Cargo Pumps

3.3.1(a) Certification. Cargo pumps are to be certified in accordance with 4-6-1/7.3.

3.3.1(b) Alternative means of pumping. In general, should a cargo pump be inoperable, there is to be an alternative means of pumping from the cargo tanks. This requirement may be met by the provision of at least two cargo pumps. Where a single deep well or submerged pump is installed in each cargo tank, an emergency means for pumping out the tank is to be provided. For this purpose, a portable pump, which can be used safely, may be accepted.

3.3.1(c) Prime movers. Cargo and stripping pump prime movers that contain a source of vapor ignition are not to be installed in the same space as the pumps and piping. Such prime movers are to be separated from the pumps by a gastight bulkhead.

3.3.1(d) Cargo and stripping pump drive shaft. Where the pump prime mover is separated from the pump by a gastight bulkhead, a flexible coupling is to be fitted in the drive shaft passing through this gastight bulkhead. A stuffing box or a bulkhead gland is to be provided in way of the shaft penetration at the gastight bulkhead.

Such stuffing box or bulkhead gland is to be gas tight and is to be designed to prevent any leakage of gas from the pump room into the machinery space.

Means are to be provided for lubricating the stuffing boxes or bulkhead glands from outside the pump room. The sealing part of these stuffing boxes or bulkhead glands is to be of non-sparking construction. If a bellows piece is incorporated in the design, it is to be pressure tested before being fitted.

3.3.1(e) Temperature alarm. *(1 July 2002)* Temperature sensing devices are to be provided for pump bulkhead shaft glands, pump bearings and pump casings for pumps located in pump room (see 5C-1-7/3.3.1(c), 5C-1-7/5.3.1(b) and 5C-1-7/7.3.1). High temperature audible and visual alarms are to be provided at the cargo control room or at the pump control station.

3.3.1(f) Relief valve. A relief valve is to be installed in the discharge of each cargo and stripping pump. The outlet from the relief valve is to be led to the suction side of the pump. This relief valve need not be fitted in the case where centrifugal pumps are installed and the piping is designed to withstand the shut-off head of the pumps.

3.3.1(g) Cargo pump bypass. A by-pass is to be fitted around the cargo pump where cargo loading is arranged through the riser or suction piping. The bypass may be omitted if the cargo pump is of a type designed to allow flow through.

3.3.1(h) Pressure gauges. One pressure gauge for each pump is to be located at the pump discharge. Where pumps are operated by prime movers external to the pump room, additional pressure gauges are to be installed at either the cargo control room or at the pump prime mover operating station.

3.3.2 Cargo Oil Piping – Safety Measures

3.3.2(a) Independence of cargo piping. Cargo piping systems are to be independent of all other piping systems, except for emergency connection to the ballast system, see 5C-1-7/5.3.1(c), and approved connection to the inert gas main, see 5C-1-7/25.25.4.

3.3.2(b) Routing. Cargo piping is not to be led outside of the cargo area, except where permitted for bow or stern loading and unloading in 5C-1-7/3.3.3. Cargo piping is not to pass through fuel-oil tanks or spaces containing machinery where sources of ignition are normally present. See also 5C-1-7/3.3.4(a).

3.3.2(c) Provision for expansion. Provisions are to be made for the expansion of cargo piping. This may be achieved by the use of expansion bellows, slip joints or pipe bends.

3.3.2(d) Static electricity. Cargo piping is be grounded in accordance with the requirements of 4-6-2/9.15. Cargo loading lines inside the tanks are to be led as low as practicable to reduce the risk of generating static electricity due to free fall of oil in the tank.

3.3.2(e) Ordinary cast iron. Ordinary cast iron may be used in cargo piping, except that in cargo piping on weather decks it may be accepted for pressures up to 16 bar (16.3 kgf/cm^2, 232 psi) only. Ordinary cast iron is not to be used for cargo manifolds and associated valves and fittings for connection to cargo handling hoses. See also 4-6-2/3.1.3 for other limitations for use of ordinary cast iron.

3.3.3 Bow or Stern Loading and Unloading

Where bow or stern loading and unloading connections are provided, the arrangements are to be as follows:

i) Cargo lines outside of the cargo area are to be installed outside accommodation spaces, service spaces, machinery spaces and control stations.

ii) Pipe joints outside of the cargo area are to be welded, except for connections to the manifold or the loading and unloading equipment.

iii) The cargo loading and unloading lines are to be clearly identified and provided with means to segregate them from the cargo main line when not in use. The separation is to be achieved by:

- Two valves, located in the cargo area, which can be locked in the closed position, and fitted with means to detect leakage past the valves; or
- One valve together with another closing device providing an equivalent standard of segregation, such as a removable spool piece or spectacle flange.

iv) The loading and unloading connection is to be fitted with a shut-off valve and a blank flange. The blank flange may be omitted if an equivalent means of closing is incorporated in the connection to the hose coupling.

v) Arrangements are to be provided for cargo lines outside of the cargo area for easy draining to a slop tank or cargo tank and for cleaning and inerting. Spill containment is to be provided under the loading and unloading manifold. The space within 3 m (10 ft) from the oil spill containment boundary and the manifold is considered to be hazardous. Accordingly, there is to be no source of ignition present within this space. Electrical equipment, if installed in this space, is to be of the certified safe type, see 5C-1-7/31.9.

vi) Means of communication (e.g., telephones, two-way portable radios, etc.) are to be provided onboard between the cargo control station and the location of the cargo shore connection. See also 5C-1-7/11.11.1 for measures for preventing liquid rising in the vent pipes.

vii) *(2003)* Fixed deck fire extinguishing system complying with the requirements of 5C-1-7/27.19.

3.3.4 Cargo Piping – Pollution Prevention Measures

3.3.4(a) Routing. For oil carriers and fuel oil carriers of 5,000 tonnes deadweight and above, cargo piping, including cargo tank vent and sounding pipes, is not to pass through ballast tanks. Short runs of such pipes may be permitted, provided they have all joints welded and are of wall thickness not less than that in Column E of 4-6-2/Table 4 or equivalent construction. See also 5C-1-7/5.3.2(a) for ballast pipe routing.

For vessels less than 5,000 tonnes deadweight, cargo piping passing through ballast tanks is to be steel with a minimum thickness according to Column E of 4-6-2/Table 4, or equivalent construction. In such cargo piping, all joints are to be welded or have extra heavy flanges; no gland-type expansion joint is permitted. The number of flanged joints is to be kept to a minimum.

Where at the request of the owner, cargo piping and the valve control piping are located above the double bottom, the vessel will be assigned with the notation **CPP** (Cargo Piping Protected). This applies also to cargo piping and valve control piping installed in pipe tunnel or duct keel.

3.3.4(b) Stripping and small diameter lines. For crude oil carriers of 20,000 tonnes deadweight and above and product carriers of 30,000 tonnes and above, means are to be provided to drain all cargo tanks and all oil lines at completion of cargo discharge, where necessary by connection to a stripping device. The line and pump drainings are to be capable of being discharged either ashore and to a cargo tank or a slop tank. For discharge ashore, a special small diameter line is to be provided and is to be connected to the vessel's deck discharge manifold outboard of the manifold valves on both sides of the vessel. The cross sectional area of the small diameter line is not to exceed 10% of that of the main cargo discharge line

3.3.4(c) Sea chests. Where it is necessary to provide a sea connection to the cargo oil pumps to enable ballasting of cargo tanks during severe weather conditions, tank cleaning, etc., a means of isolating the pumps from the sea chests when they are not being used for this operation is to be provided. This is to be achieved by a blank flange or a removable spool piece. The spool piece, if used, is to be stowed as in 5C-1-7/3.3.4(d) below. A shut-off valve is to be fitted on each side of the blank flange or the removable spool piece.

Alternatively, two valves are to be installed at the sea chest connection. One of these valves is to be capable of being locked in the closed position and means – such as a test cock – are to be provided for detecting leakage past these valves.

3.3.4(d) Connection to ballast system. Connection of the cargo system to the ballast system by a removable spool piece is only permitted in an emergency. The arrangements of the spool piece are to include a non-return valve to prevent cargo from entering the ballast system, and shut-off valves and blind flanges on both the ballast end and the cargo end of the connection. The spool piece is to be stowed in a conspicuous manner so that it may be readily available whenever the need arises. A permanent notice is to be displayed to prohibit unauthorized use of the spool piece

3.3.4(e) Crude oil washing system. For crude oil carriers of 20,000 tonnes deadweight and above, a crude oil washing system is to be installed which complies with:

- MARPOL 73/78, Annex I, Regulations 13B,
- IMO Resolutions A.446 (XI) *Revised specifications for the design, operation and control of crude oil washing systems*,
- IMO Resolution A.497 (XII) *Amendments to the revised specifications for the design, operation and control of crude oil washing systems*, and
- IMO Resolution A.897 (21) *Amendments to the revised specifications for the design, operation and control of crude oil washing systems [Resolution A.446 (XI) as amended by resolution A.497 (XII)]*

Where a crude oil washing system is fitted on a vessel of less than these deadweight sizes, only requirements concerning safety need be complied with.

The crude oil washing system is to be operated only when the cargo tank is inerted with an inert gas system complying with 5C-1-7/25.

3.3.4(f) Slop tanks. For oil and fuel oil carriers of 150 gross tonnage and above, slop tanks of number and sizes complying with 5C-1-1/5.1 and MARPOL 73/78, Annex I, Regulation 15 (2) are to be provided to receive dirty ballast residues, tank washings and other oil residues. Slop tanks are to be so designed in respect of the position of inlets, outlets, baffles or weirs, where fitted, so as to avoid excessive turbulence and entrainment of oil or emulsion with water.

3.3.5 Cargo Oil Piping Pressure Tests

After installation, cargo oil piping systems are to be tested to 1.5 times the design pressure of the system.

3.5 Remotely Operated Valves

3.5.1 Alternative Means of Operation

Remotely operated valves, if located on deck or in the pump room, are to be provided with local, manual means of operation. This may be a hand wheel or a connection to a portable hand-pump. Where such valves are located in cargo tanks and such local manual means are not practicable, alternative means are to be provided for pumping out the cargo tank in the event of a valve actuator failure. The installation of two independent suctions will be acceptable as an alternative means.

3.5.2 Valve Actuators

Valve actuators are to be of a type that will prevent the valve from opening in the event of the loss of pressure in the actuating system. Means are to be provided for indicating open/close position of the valve.

3.5.3 Valve Actuating System

A pneumatic system is not to be used for actuating valves installed in cargo tanks. Where the actuating system is hydraulic, arrangements are to be made to lead the hydraulic oil tank vent to the weather and to fit the vent opening with a flame screen. Hydraulic piping is, in general, to enter the cargo tank through the highest part of the tank. System operating pressures, on both the outflow and the return sides, are to be higher than the highest static head of the cargo tank.

5 Ballast System and Oily Water Handling

5.1 Segregated Ballast

For purposes of oil pollution prevention, every crude oil carrier of 20,000 tonnes deadweight and above and every product carrier of 30,000 tonnes deadweight and above are to be provided with segregated ballast tanks. The capacity of the segregated ballast tanks is to be such that the vessel may operate safely on ballast voyages without recourse to the use of cargo tanks for water ballast. However, ballast water may be carried in cargo tanks in case of severe weather or other emergency conditions, provided that such cargo tanks have been previously crude oil washed. See 5C-1-1/5 and MARPOL 73/78, Annex I, Regulation 13.

5.3 Ballast System

5.3.1 Ballast Pumps

5.3.1(a) Certification. Ballast pumps are to be certified in accordance with 4-6-1/7.3.

5.3.1(b) Ballast pump prime movers. Ballast pumps are to be located in the cargo pump room or other similar spaces within the cargo area and are to comply with the same requirements as cargo pumps in 5C-1-7/3.3.1(c), 5C-1-7/3.3.1(d) and 5C-1-7/3.3.1(e).

5.3.1(c) Deballasting. Where only one ballast pump is provided, a second means of deballasting is to be provided. This may be by means of an eductor or a temporary connection between the ballast and cargo piping. The temporary connection may be a portable spool piece arranged in accordance with 5C-1-7/3.3.4(d).

5.3.2 Ballast Piping

5.3.2(a) Routing. For purposes of minimizing oil contamination, for oil carriers or fuel oil carriers of 5,000 tonnes deadweight and above, ballast piping, including vents and sounding piping for segregated ballast tanks, is not to pass through cargo tanks. However, short runs of such pipe may be permitted, provided they are all welded steel pipes with a minimum wall thickness not less than that in Column E of 4-6-2/Table 4, or equivalent construction. See 5C-1-7/3.3.4(a) for cargo pipe routing.

For vessels less than 5,000 tonnes deadweight, ballast piping passing through cargo tanks is to be steel with a minimum thickness according to Column E of 4-6-2/Table 4, or equivalent construction. In such ballast piping, all joints are to be welded or have extra heavy flanges; no gland-type expansion joint is permitted. The number of flanged joints is to be kept to a minimum.

5.3.2(b) Hazards. Ballast piping passing through cargo tanks (where permitted) or connected to ballast tanks adjacent to cargo tanks is not to lead into or pass through spaces where sources of ignition are normally present. See 5C-1-7/1.7.

5.3.2(c) Use of fire main. The fire main may be used for ballasting, or deballasting with eductors, provided the branch pipe from the fire main used for this purpose is led from the upper deck and fitted with a stop-check valve.

5.3.2(d) Provision for expansion. Provisions are to be made for the expansion of ballast piping. This may be achieved by the use of expansion bellows, slip joints or pipe bends.

5.3.3 Discharge of Segregated Ballast

Provisions are to be made so that segregated ballast can be discharged above the waterline in the deepest ballast condition. Alternatively, discharge below the waterline is permitted if discharge procedures in accordance with MARPOL 73/78 Annex I are adhered to.

5.3.4 Discharge of Dirty Ballast and Oil Contaminated Water

5.3.4(a) Processing. Means are to be provided to allow dirty ballast or oil contaminated water from cargo tank areas to be processed prior to discharging. These means are to include slop tanks [see 5C-1-7/3.3.4(f)], oil/water interface detectors [see 5C-1-7/5.3.4(c)] and oil discharge monitoring and control system [see 5C-1-7/5.3.4(b)].

5.3.4(b) Oil discharge monitoring and control system. Oil and fuel oil carriers of 150 gross tonnage and above are to be provided with an oil discharge monitoring and control system complying with MARPOL 73/78, Annex I, Regulation 15 (3) (a) and IMO Resolution A.586 (14).

5.3.4(c) Oil water interface detector. Oil carriers and fuel oil carriers of 150 gross tonnage and above are to be provided with an effective oil/water interface detector complying with IMO Resolution MEPC.5(XIII) for determination of oil/water interface in slop tanks. It is to be available for use in other tanks where the separation of oil and water is effected, and from which effluent is intended to discharge directly to the sea.

5.3.4(d) Discharge to sea (2005). Provisions are to be made for the discharge to be led to the open deck or to either side of the vessel above the waterline in the deepest ballast condition. Alternatively, discharge below the waterline is permitted if discharge procedures in accordance with MARPOL 73/78 Annex I are adhered to. The discharge is to be monitored by the oil discharge monitoring and control system. The discharge lines for dirty ballast and oil-contaminated water may be permitted to pass through fuel oil tanks, provided that the lines have all joints welded and are of wall thickness not less than that in Column E of 4-6-2/Table 4 or equivalent construction.

5.3.4(e) Discharge to shore. Means are to be provided to discharge dirty ballast water or oil contaminated water to shore reception facilities. A discharge manifold for this purpose is to be located on the open deck on both sides of the vessel. A cargo oil pump, through the emergency connection in 5C-1-7/3.3.4(d), may be used for this purpose.

7 Bilge System

7.1 General

Provision is to be made for removing drainage from pump room bilges and cofferdams in the cargo area. Bilge systems for machinery spaces and spaces outside the cargo area are not to be used for this purpose.

Overboard discharge of oil or oil-contaminated water from cargo pump room bilges and cofferdams in the cargo area is to be prohibited unless processed in accordance with 5C-1-7/5.3.4(a).

7.3 Pump Room and Cofferdams Bilge System

The bilge system for the cargo pump room and cofferdams are to be provided with a dedicated bilge pump, an eductor or a connection to the suction of a cargo or stripping pump.

7.3.1 Dedicated Bilge Pump

Where a bilge pump or eductor is used, it is not to be located, nor is the piping to pass through, machinery space or other similar spaces where sources of vapor ignition is normally present. Bilge pumps located in the cargo pump room are to comply with the same requirements as cargo pumps in 5C-1-7/3.3.1(c), 5C-1-7/3.3.1(d) and 5C-1-7/3.3.1(e).

7.3.2 Cargo or Stripping Pumps as Bilge Pump

Where bilge suction is provided from a cargo or stripping pump, a stop-check valve is to be fitted in the branch connection to the bilges. Where the bilge suction branch connection is arranged such that it is subjected to the static head of oil from the filling line during loading, a shut-off valve, in addition to the stop-check valve, is to be provided in the bilge branch suction connection.

7.3.3 Bilge Pump and Valve Control *(2005)*

Pump-room bilge suction and discharge valves and the bilge-pump controls are to be operable in the pump room, unless Flag Administrations have a specific requirement for remote operation, either from an accessible position outside the pump room or from the pump room casing above the freeboard deck.

7.5 Bilge Alarms

A high level of liquid in the pump room bilge is to activate an audible and visible alarm in the cargo control room and on the navigation bridge.

7.7 Discharge of Machinery Space Bilges into Slop Tank

When bilge pumps in the machinery space are arranged to discharge into a cargo slop tank, the discharge piping is to be arranged as follows:

i) The discharge line is to enter the cargo slop tank from the weather deck through the tank top.

ii) The tank penetration is to be located as close to a vertical tank boundary as practicable.

iii) Within the tank, to prevent the free fall of liquid, the discharge line is to be as short as practicable and the outlet is to be arranged to discharge against the vertical boundary.

iv) A stop-check valve is to be provided in the discharge line and is to be located within the machinery space as close to the machinery space bulkhead as possible.

v) *(2006)* In order to prevent cargo vapor from entering the machinery spaces, a loop seal is to be provided in the discharge line. This loop seal is to be located outside the machinery space, and preferably, in the cargo pump room. The height of the loop seal is to provide a static head greater than the pressure setting of the cargo slop tank pressure/vacuum valve, or a minimum of 762 mm (30 in.), whichever is greater. A means is to be provided to prevent the loop seal from freezing where exposed to the weather.

vi) A non-return valve is to be located in the discharge line on deck as close to the tank penetration as practicable.

9 Cargo Heating Systems

9.1 Temperature

The temperature of the heating medium is not to exceed 220°C (428°F).

9.3 Steam Heating System

9.3.1 Cargo Oil Backflow

To minimize the risk of cargo oil or vapor returning to the machinery space through the steam heating system, the following arrangements are to be provided:

- The steam supply and return lines are to be led into the cargo tanks from above the main deck.
- Means are to be fitted to determine whether the condensate return is contaminated with oil.
- All joints in the heating elements within cargo tanks are to be welded. Flanged joints are permitted for installation purposes, but are to be kept to a minimum.

9.3.2 Inspection Tank

An inspection tank is to be provided for detection of oil contamination in the condensate return. The tank is to be of the closed type, dedicated to the cargo heating system only, with no interconnection to any other system, and vented to the weather. The vent outlet is to be fitted with a corrosion resistant flame screen. The inspection tank may be located within the machinery space, in which case, the vent is to terminate outside of the cargo area and the area within 3 m (10 ft) of the outlet is to be considered hazardous.

9.5 Thermal Oil Heating System

9.5.1 General Requirements

Fired and exhaust gas thermal oil heaters are to meet the requirements in 4-4-1/13. The automatic burner and flow regulation control systems are to be capable of maintaining the thermal oil at the desired temperature. In no case is the temperature to exceed that indicated in 5C-1-7/9.1.

9.5.2 Indirect Heating Systems *(2005)*

9.5.2(a) Heating of cargo oil with flash point below 60°C (140°F) is to be by means of a secondary circuit, which is to be located entirely in the cargo area.

Vents from the thermal oil expansion tank and that from the oil storage tank are to be led to the weather.

9.5.2(b) The thermal oil expansion tank for the secondary system may be located outside of the cargo tank area, provided that the requirements in 5C-1-7/9.5.3iii) and iv) are complied with.

9.5.3 Direct Heating System *(2005)*

Heating systems with a single circuit may be used, provided that the following additional requirements are complied with:

i) The system is arranged so that a positive pressure is maintained in the heating coils of at least 3 m (10 ft) water column above the static head of the cargo and vapor. This pressure differential is to be maintained whether the thermal oil circulating pumps are in operation or not.

ii) The valves which could isolate individual heating coils in the cargo tanks are provided with locking arrangements to ensure that the coils are under static pressure at all times.

iii) The thermal oil expansion tank is fitted with high- and low-level alarms.

iv) A means is provided in the thermal oil expansion tank to detect the presence of cargo oil vapor. Portable equipment may be acceptable, provided that the use of this device will not cause the escape of cargo oil vapor into the machinery space.

11 Cargo Tank Venting

11.1 General Principles

The venting systems of cargo tanks are to be entirely distinct from the vent pipes of the other compartments of the vessel. The arrangements and position of openings in the cargo tank deck from which emission of flammable vapors can occur are to be such as to minimize the possibility of flammable vapors being admitted to enclosed spaces containing a source of ignition, or collecting in the vicinity of deck machinery and equipment which may constitute an ignition hazard. In accordance with this general principle, the criteria in 5C-1-7/11.3 to 5C-1-7/11.19 will apply.

11.3 Venting Capacity

The venting arrangements are to be so designed and operated as to ensure that neither pressure nor vacuum in cargo tanks is to exceed design parameters and be such as to provide for:

i) The flow of the small volumes of vapor, air or inert gas mixtures caused by thermal variations in a cargo tank in all cases through pressure/vacuum valves;

ii) The passage of large volumes of vapor, air or inert gas mixtures during cargo loading and ballasting, or during discharging; and

iii) A secondary means of allowing full flow relief of vapor, air or inert gas mixtures to prevent overpressure or underpressure in the event of the failure of the arrangements in ii). Alternatively, pressure sensors may be fitted in each tank protected by the arrangements required in ii), with a monitoring system in the vessel's cargo control room or the position from which cargo operations are normally carried out. Such monitoring system is also to provide an alarm facility which is activated by detection of overpressure or underpressure conditions within a tank.

11.5 Vent Piping

11.5.1 Venting Arrangement

The venting arrangements in each cargo tank may be independent or combined with other cargo tanks and may be incorporated into the inert gas piping.

11.5.2 Combined Venting System

Where the arrangements are combined with other cargo tanks, either stop valves or other acceptable means are to be provided to isolate each cargo tank. Where stop valves are fitted, they are to be provided with locking arrangements, which are to be under the control of the responsible vessel's officer. There is to be a clear visual indication of the operational status of the valves or other acceptable means. Where tanks have been isolated, it is to be ensured that relevant isolation valves are opened before cargo loading, ballasting or discharging of the tanks is commenced. Any isolation must continue to permit the flow caused by thermal variations in a cargo tank, in accordance with 5C-1-7/11.3i).

11.5.3 Isolation from Common Venting System

Where it is intended to load, ballast or discharge a cargo tank or a cargo tank group while it is isolated from the common venting system, such cargo tank or cargo tank group is to be fitted with means of overpressure and underpressure protection as in 5C-1-7/11.3iii).

11.7 Self-draining of Vent Piping

The venting arrangements are to be connected to the top of each cargo tank and are to be self-draining to the cargo tanks under all normal conditions of trim and list of the vessel. Where it may not be possible to provide self-draining lines, permanent arrangements are to be provided to drain the vent lines to a cargo tank.

11.9 Flame Arresting Devices

The venting system is to be provided with devices to prevent the passage of flame into the cargo tanks. The design, testing and locating of these devices are to comply with the following IMO documents:

- MSC/Circ.677 Revised standards for the design, testing and locating of devices to prevent the passage of flame into cargo tanks in tankers, and
- MSC/Circ.450/Rev.1 Revised factors to be taken into consideration when designing cargo tank venting and gas freeing arrangements.

Vent outlets from cofferdams and ballast tanks adjacent to cargo tanks are to be fitted with corrosion resistant flame screens having a clear area through the mesh of not less than the area of the pipe. However, on vessels intended to carry in fuel oil or petroleum products having a flash point exceeding 60°C (140°F), the vent outlets from cofferdams and ballast tanks adjacent to these cargo tanks need not be fitted with flame screens.

11.11 Protection for Tank Overpressurization and Vacuum

11.11.1 Liquid Rising in Vent Pipes

Provision is to be made to guard against liquid rising in the venting system to a height which would exceed the design head of cargo tanks. This is to be accomplished by:

i) High level alarms or overflow control systems or other equivalent means,

ii) Gauging devices, and

iii) Cargo tank filling procedures.

In the event that protection is by means of an overflow control system, an analysis is to be submitted to indicate that, in the worst overflowing condition, the tanks will not be overpressurized.

11.11.2 Pressure/Vacuum Valve Setting

Where pressure/vacuum valves are installed, the pressure setting of these valves is to be in accordance with the following table:

	Vessel Size	*Pressure/Vacuum setting*
a)	103 m (337 ft) in length or more	$P \leq 0.21$ bar (0.21 kgf/cm^2, 3 psi) $V \geq -0.07$ bar (–0.07 kgf/cm^2, –1 psi)
b)	61 m (200 ft) in length or less	$P \leq 0.12$ bar (0.12 kgf/cm^2, 1.7 psi) $V \geq -0.07$ bar (–0.07 kgf/cm^2, –1 psi)
c)	Vessels of intermediate lengths	Interpolate between (a) and (b)
d)	Vessels with specially designed integral tanks (see 5C-1-1/1.13 and 5C-2-1/1.15).	$P \leq 0.69$ bar (0.70 kg/cm^2, 10 psi)

P = Pressure above atmospheric; V = Pressure below atmospheric

In addition, calculations are to be submitted to show that the cargo tanks will not be subjected to a pressure or vacuum in excess of the P/V valve setting. See 5C-1-7/21.5.2(d) for pressure/vacuum valve capacity correction.

11.13 Position of Pressure/Vacuum Valves

Openings for pressure release required by 5C-1-7/11.3i) are to:

i) Have as great a height as is practicable above the cargo tank deck to obtain maximum dispersal of flammable vapors, but in no case less than 2 m above the cargo tank deck;

ii) Be arranged at the furthest distance practicable, but not less than 5 m from the nearest air intakes and openings to enclosed spaces containing a source of ignition and from deck machinery and equipment which may constitute an ignition hazard.

11.15 Pressure/Vacuum Valve By-pass

Pressure/vacuum valves required by 5C-1-7/11.3i) may be provided with a by-pass arrangement when they are located in a vent main or masthead riser. Where such an arrangement is provided, there are to be suitable indicators to show whether the by-pass is open or closed.

11.17 Vent Outlets for Large Flow Volumes

Vent outlets for cargo loading, discharging and ballasting required by paragraph 5C-1-7/11.3ii) are to:

i) Permit the free flow of vapor mixtures; or permit the throttling of the discharge of the vapor mixtures to achieve a velocity of not less than 30 m/s (100 ft/s);

ii) Be so arranged that the vapor mixture is discharged vertically upwards;

iii) Where the method is by free flow of vapor mixtures, be such that the outlet is to be not less than 6 m above the cargo tank deck or fore and aft gangway if situated within 4 m (13.2 ft) of the gangway and located not less than 10 m (33 ft) measured horizontally from the nearest air intakes and openings to enclosed spaces containing a source of ignition and from deck machinery and equipment which may constitute an ignition hazard;

iv) Where the method is by high velocity discharge, be located at a height not less than 2 m (6.6 ft) above the cargo tank deck and not less than 10 m (33 ft) measured horizontally from the nearest air intakes and openings to enclosed spaces containing a source of ignition and from deck machinery and equipment which may constitute an ignition hazard. These outlets are to be provided with high velocity devices of an approved type;

v) Be designed on the basis of the maximum designed loading rate multiplied by a factor of at least 1.25 to take account of gas evolution, in order to prevent the pressure in any cargo tank from exceeding the design pressure. The master is to be provided with information regarding the maximum permissible loading rate for each cargo tank and in the case of combined venting systems, for each group of cargo tanks.

11.19 Arrangement for Combination Carriers

In combination carriers, the arrangement to isolate slop tanks containing oil or oil residues from other cargo tanks are to consist of blank flanges which will remain in position at all times when cargoes other than liquid cargoes having flash point of 60°C (140°F) or less are carried.

13 Cargo Tank Level Gauging

Means are to be provided to measure the level of liquid in cargo tanks. Such means are to be as specified below.

13.1 Cargo Tanks Fitted with Inert Gas System

Cargo tanks fitted with an inert gas system are to be provided with approved closed level gauging devices which will not permit the escape of cargo vapor to the atmosphere when being used. Such devices may be of the fixed or portable type.

13.3 Cargo Tanks not Fitted with Inert Gas System

Cargo tanks not fitted with an inert gas system may be provided with sounding pipes, ullage measurement fittings, etc., which allow a limited amount of cargo vapor to escape into the atmosphere when being used. Such devices are to be installed in the weather.

15 Cargo Tank Purging and/or Gas-freeing

15.1 General

Arrangements for purging and/or gas freeing are to be such as to minimize the hazards due to the dispersal of flammable vapors in the atmosphere and to flammable mixtures in a cargo tank. Reference may be made to IMO documents MSC/Circ.677 and MSC/Circ.450/Rev.1 (see 5C-1-7/11.9).

15.3 Vessels Fitted with Inert Gas System

When the vessel is provided with an inert gas system, the cargo tanks are to first be purged in accordance with the provisions of 5C-1-7/25.25 until the concentration of hydrocarbon vapors in the cargo tanks has been reduced to less than 2% by volume. Thereafter, venting may be at the cargo tank deck level.

15.5 Vessels without Inert Gas System

When the vessel is not provided with an inert gas system, the operation is to be such that the flammable vapor is initially discharged:

i) Through the vent outlets, as specified in 5C-1-7/11.17; or

ii) Through outlets at least 2 m (6.6 ft) above the cargo tank deck level with a vertical efflux velocity of at least 30 m/s (100 ft/s) maintained during the gas-freeing operation; or

iii) Through outlets at least 2 m (6.6 ft) above the cargo tank deck level with a vertical efflux velocity of at least 20 m/s (66 ft/s) and which are protected by suitable devices to prevent the passage of flame.

When the flammable vapor concentration at the outlet has been reduced to 30% of the lower flammable limits, gas-freeing may thereafter be continued at the cargo tank deck level.

17 Ventilation and Gas Detection

17.1 Cargo Pump Room Ventilation

17.1.1 General *(2006)*

Cargo pump rooms are to be mechanically ventilated and discharges from the exhaust fans are to be led to a place on the open deck where such discharges will not cause a fire or explosion hazard. The ventilation of these rooms is to have sufficient capacity to minimize the possibility of accumulation of flammable vapors. The number of changes of air is to be at least 20 per hour, based upon the gross volume of the space. The air ducts are to be arranged so that all of the space is effectively ventilated. In particular, the intakes are to be arranged as per 5C-1-7/17.1.2. The ventilation is to be of the suction type using fans of the non-sparking construction. See 5C-1-7/17.1.3. The inlets and outlets of cargo pump room ventilation systems are to be capable of being closed from outside the cargo pump room. The means of closing are to be easily accessible, as well as prominently and permanently marked, and are to indicate whether the shut-off is open or closed.

17.1.2 Arrangements of Air Intakes

The ventilation trunking within the cargo pump room is to be arranged as follows:

17.1.2(a) Main intakes. *(2005)* The main intakes are to be located just above the platform plates on bottom longitudinals or inner bottom so that the air in the bilge spaces can be extracted. The platform plates are to be of the open grating type to allow the free flow of air.

17.1.2(b) Emergency intakes. Emergency intakes (or intake) are to be provided at approximately 2 m (6.5 ft) above the lowest platform plating so that they can be used when the main intakes, as stated in 5C-1-7/17.1.2(a), are sealed off due to flooding in the bilges. The air change, when only the emergency intakes are in use, is to be at least 15 air changes per hour.

17.1.2(c) Dampers. Where the emergency intakes share the main exhaust ducts with the main intakes, the emergency intakes are to be provided with dampers capable of being opened or closed from the exposed main deck and within the pump room. The dampers may be omitted if the fan capacity and intakes dimensions are sized such that, with both main and emergency intakes operating simultaneously, the main intakes are still capable of providing at least 20 air changes per hour.

17.1.3 Fans and Fan Motors

Fan motors are to be located outside the pump room and outside the ventilation ducts. Fans are to be of non-sparking construction in accordance with 4-8-3/11. Provision is to be made for remote or automatic shutdown of the fan motors upon release of the fire-extinguishing medium.

17.1.4 Gas Detection System *(1 July 2002)*

The cargo pump room is to be fitted with a fixed gas detection system complying with the following:

i) The system is to be arranged to continuously measure the concentration of hydrocarbon gas. A system using sequential sampling may be installed, provided the system is dedicated to pump room sampling only, so as to optimize sampling cycle.

ii) Sampling points or detector heads are to be located in suitable positions in order that potentially dangerous leakages are readily detected. Suitable positions may be the exhaust ventilation duct and lower part of the pump room above the floor plate level.

iii) The system is to give a visual indication in the cargo control room of the level of concentration of hydrocarbon and gases, and is to initiate a continuous visual and audible alarm if the concentration exceeds 10% of the lower flammable limit. Such alarm is to be provided in the cargo control room, pump room, engine control room and on the navigation bridge.

iv) Components of the system installed in the cargo pump room are to be of the intrinsically safe type (Ex ia or ib). See 5C-1-7/31.9.

17.3 Precautions for Ventilation of Accommodation and Machinery Spaces

The arrangement of ventilation inlets and outlets and other deckhouse and superstructure boundary space openings are to be such as to complement the provisions of 5C-1-7/11. Such vents, especially for machinery spaces, are to be situated as far aft as practicable. Due consideration in this regard is to be given when the vessel is equipped to load or discharge at the stern. Sources of ignition such as electrical equipment are to be so arranged as to avoid an explosion hazard.

17.5 Pipe Tunnel or Duct Keel Ventilation

17.5.1 General

A permanent mechanical ventilating system is to be provided for a pipe tunnel or duct keel. Where a permanent lighting system is installed in such a space, the ventilation system is to be capable of providing at least eight (8) changes of air per hour, based on the gross volume of the space. The system is to have mechanical exhaust, natural or mechanical supply, and ducting, as required to effectively purge this space and all connecting access trunks. Fan motors are to be located outside the space in question and outside the ventilation ducts. Fans are to be of non-sparking construction in accordance with 4-8-3/11.

17.5.2 Gas Detection System

An approved gas detection system complying with 5C-1-7/17.1.4 is to be provided to monitor the pipe tunnel.

17.7 Portable Gas Detectors *(2001)*

Every oil carrier is to be provided with at least two portable gas detectors capable of measuring flammable vapor concentrations in air and at least two portable oxygen (O_2) analyzers, unless each gas detector can also function as an oxygen analyzer. See also 5C-1-7/19.5.1 and 5C-1-7/25.33. Suitable means are to be provided for the calibration of the instruments.

17.9 Gas Sampling System Installation

Gas sampling systems with gas-analyzing/measurement units not certified safe for installation in a hazardous area may have such units installed in a safe area, such as the cargo control room, or the navigation bridge, provided that the following installation details are complied with.

i) The gas-analyzing unit is to be mounted on the forward bulkhead of the safe space, except as specially permitted in vi).

ii) The sampling lines are not to run through safe spaces, except where specially permitted in vi).

iii) Bulkhead penetrations of sampling pipes between safe and hazardous areas are to be of approved types and have the same fire integrity as the division penetrated. An isolation valve is to be fitted in each of the sampling lines at the bulkhead on the safe side.

iv) The gas sampling pipes are to be equipped with flame arresters. Sample gas is to be exhausted to the atmosphere with outlets away from sources of ignition.

v) *(2001)* The gas detection equipment, including sampling piping, sampling pumps, solenoids, analyzing units, etc., are to be located in a reasonably gas-tight steel cabinet (e.g., fully enclosed steel cabinet with gasketed door) which is to be monitored by its own sampling point. At a gas concentration above 30% of the lower flammable limit inside the steel cabinet, the entire analyzing unit is to be automatically shutdown. Shutdown of the unit is to be alarmed at both the cargo control room and the navigation bridge.

vi) Where the cabinet cannot be mounted directly on the forward bulkhead, sampling pipes are to be of steel or other equivalent material and without detachable connections, except for the connection points for isolating valves at the bulkhead and for the analyzing units. Runs of the sampling pipes within the safe space are to be as short as possible.

17.11 Ventilation for Combination Carriers

In combination carriers, all cargo spaces and any enclosed spaces adjacent to cargo spaces are to be capable of being mechanically ventilated. The mechanical ventilation may be provided by portable fans. An approved fixed gas warning system capable of monitoring flammable vapors is to be provided in cargo pump rooms and pipe ducts and cofferdams adjacent to slop tanks (see 5C-1-7/17.1.4 and 5C-1-7/17.5.2). Suitable arrangements are to be made to facilitate measurement of flammable vapors in all other spaces within the cargo tank area. Such measurements are to be made possible from open deck or easily accessible positions.

19 Double Hull Space Inerting, Ventilation and Gas Measurement

19.1 Air Supply

Double hull and double bottom spaces in way of cargo tanks are to be fitted with suitable connections for the supply of air.

19.3 Vessels Fitted with Inert Gas System

On oil carriers required to be fitted with inert gas systems:

i) Double hull spaces are to be fitted with suitable connections for the supply of inert gas;

ii) Where such spaces are connected to a permanently fitted inert gas distribution system, means are to be provided to prevent hydrocarbon gases from the cargo tanks entering the double hull spaces through the system;

iii) Where such spaces are not permanently connected to an inert gas distribution system, appropriate means are to be provided to allow connection to the inert gas main.

19.5 Provisions for Gas Measurement

19.5.1 Portable Gas Measuring Detectors *(2001)*

Suitable portable detectors for measuring oxygen and flammable vapor concentrations are to be provided. See 5C-1-7/17.7 regarding the required number of detectors. In selecting these detectors, due attention is to be given for their use in combination with the fixed gas-sampling-line systems referred to in 5C-1-7/19.5.2.

19.5.2 Fixed Gas Sampling System

Where the atmosphere in double hull spaces cannot be reliably measured using flexible gas sampling hoses, such spaces are to be fitted with permanent gas sampling lines. The configurations of such line systems are to be adapted to the design of such spaces.

19.5.3 Piping of Gas Sampling Lines

The materials of construction and the dimensions of gas sampling lines are to be such as to prevent restriction. Where plastic materials are used, they are to be electrically conductive.

19.5.4 Gas Sampling System Installation

For gas sampling systems with gas-analyzing/measurement units not certified safe for installation in a hazardous area, see 5C-1-7/17.9.

21 Cargo Vapor Emission Control Systems

21.1 Application

While the installation of a cargo vapor control system is optional for classification purposes, where installed, the provisions of 5C-1-7/21 are applicable. These provisions cover systems employed to collect cargo oil vapor, primarily during cargo loading operations, for disposal at shore facilities. Systems satisfying these provisions will be assigned with the notation **VEC**. Systems satisfying the additional provisions of 5C-1-7/21.19 for lightering operation will be assigned with the notation **VEC-L**.

21.3 Plans and Data to be Submitted

Where a cargo vapor emission control system is to be installed, the following plans and particulars are to be submitted.

- Cargo vapor emission control and collection piping; associated venting and inert gas systems; drainage arrangements; bill of materials.
- Maximum allowable cargo transfer rate; pressure/vacuum valve capacity test reports and settings; associated calculations (see 5C-1-7/21.5).
- Tank gauging systems; overfill control, instrumentation and alarm systems; overfill settings.
- Hazardous locations and certified safe electrical equipment in these locations.

21.5 Cargo Transfer Rate

21.5.1 Maximum Allowable Cargo Transfer Rate

The cargo vapor emission control system is to be designed for a predetermined maximum allowable cargo transfer rate, which is not to exceed the least of the following:

i) The maximum design loading rate used to determine the pressure setting of the pressure/vacuum valves.

ii) The maximum design discharge rate used to determine the vacuum setting of the pressure/vacuum valves.

iii) A rate determined by pressure drop calculations where, for a given pressure at the vapor reception facility connection to the vessel, the pressure in any tank connected to the system exceeds 80 percent of the pressure setting of any pressure/vacuum valve in the cargo tank venting system.

21.5.2 Calculations

The following calculations are to be submitted to substantiate the adequacy of the proposed cargo transfer rates. In these calculations, for tanks connected to the pressure/vacuum breaker, the capacity of the pressure/vacuum breaker may be taken into account.

21.5.2(a) Pressure/vacuum valve pressure relief capacity. Calculations are to verify that, at the set relief pressure, the valve can discharge vapor at a flow rate equal to 1.25 times maximum design loading rate specified in 5C-1-7/21.5.1i) while maintaining a pressure in the tank not exceeding the design head of the tank. Where spill valve or rupture disks are fitted (see 5C-1-7/21.15.5), the pressure maintained in the tank is not to exceed the designed opening pressures of these devices.

21.5.2(b) Pressure/vacuum valve vacuum relief capacity. Calculations are to verify that, at the maximum designed discharge rate specified in 5C-1-7/21.5.1ii), the vacuum relief setting will not allow the tank to exceed its allowable designed vacuum.

21.5.2(c) System pressure drop. Calculations are to demonstrate that the requirement of 5C-1-7/21.5.1iii) is satisfied for each cargo handled. The pressure drop through the system, from the most remote cargo tank to the vessel shipside vapor connection, is to be determined. Hoses normally carried onboard the vessel are to be included in the calculation. The calculations are to be performed at several transfer rates, including the maximum transfer rate, assuming a 50 percent cargo vapor and air mixture and a vapor growth rate appropriate for the specific cargo being considered in the calculation.

21.5.2(d) Pressure/vacuum valve capacity correction. Where the capacities of a pressure/ vacuum valve are obtained by testing with air only, the following equations may be used to correct the capacities for cargo oil vapor.

$$Q_A = Q_L \cdot R \cdot F$$

$$R = 1 + 0.25\frac{P_v}{0.88} \quad \text{SI \& MKS units}$$

$$R = 1 + 0.25\frac{P_v}{12.5} \quad \text{US units}$$

$$F = \sqrt{\frac{\rho_{va}}{\rho_a}}$$

where

Q_A	=	required air equivalent volumetric flow rate; m^3/h (gpm) (or consistent system of units)
Q_L	=	cargo transfer rate; m^3/h (gpm) (or consistent system of units)
R	=	vapor growth rate; to be as calculated above or 1.25, whichever is larger; dimensionless
F	=	density correction factor; dimensionless
P_v	=	saturated vapor pressure, absolute, at 46.1°C (115°F); barA (kgf/cm^2A, psiA)
ρ_{va}	=	vapor-air mixture density at 46.1°C (115°F) and pressure setting of pressure/vacuum valve; kg/m^3 (lb/ft^3) (or consistent system of units)
ρ_a	=	air density at 46.1°C (115°F) and pressure setting of pressure/vacuum valve; kg/m^3 (lb/ft^3) (or consistent system of units)

21.7 Vapor Collection Piping

Vapor collection piping is not to interfere with the proper operation of the cargo tank venting system. Suitable means, located on deck, are to be provided to isolate the vapor collection system from the inert gas system. This requirement may be considered met if the vapor collection system is connected to the inert gas main forward of the non-return devices and the positive means of closure required by 5C-1-7/25.19.8. Means are to be provided to drain and collect condensate from each low point in the vapor collection piping system.

Vessels collecting vapors from incompatible cargoes simultaneously are to have a means of maintaining separation of the vapors throughout the collection system.

21.9 Ship Side Vapor Connection

21.9.1 Location and Valve

The ship side vapor connection to shore facilities is to be installed as close to each cargo transfer manifold as practicable in an easily accessible position and is to be fitted with a shutoff valve capable of manual operation.

21.9.2 Connection Flange

The ship side vapor connection flange, vapor hose flange or vapor line adapter flange, as applicable, for connection to shore facilities is to have dimensions meeting ANSI B16.5 *Pipe Flanges and Flanged Fitting* for Class 150 flanges. The flange face of the ship side vapor connection flange is to be fitted with a protruding stud, 12.7 mm ($^1/_2$ in.) in diameter and at least 25.4 mm (1 in.) long. This is to facilitate its centering with the vapor hose flange, whose flange face is to be drilled with a corresponding hole of 16 mm ($^5/_8$ in.) in diameter.

21.9.3 Color Code and Labeling

The last 1.0 m (3.3 ft) of vapor piping inboard of the vapor connection flange is to be painted red/yellow/red with the red bands 0.1 meter (0.33 feet) wide, and the yellow band 0.8 meter (2.64 feet) wide. The yellow band is to be labeled with "VAPOR" in black letters at least 50 mm (2 in.) high.

21.9.4 Hoses

Hoses, carried onboard for shore/lightering vapor connection, are to comply with the following:

- Maximum allowable working pressure is to be at least 0.34 bar (0.35 kgf/cm^2, 5 psi).
- Maximum allowable vacuum is to be at least 0.14 bar (0.14 kgf/cm^2, 2 psi) below atmospheric.
- Burst pressure is not to be less than five times its maximum allowable working pressure.
- Electrically continuous.
- Abrasion resistant and non-kinking.
- Provided with hose handling equipment, e.g., hose saddles.

21.11 Pressure/Vacuum Protection of Cargo Tanks

21.11.1 Pressure/Vacuum Valves

For vessels intended to operate with vapor emission control systems, the cargo tanks are to be equipped with a venting system complying with 5C-1-7/11. Each tank venting system is to be fitted with a pressure/vacuum relief valve of suitable setting and capacity (see 5C-1-7/21.11.2). A pressure/vacuum breaker installed in an inert gas main may also be considered for satisfying this purpose.

21.11.2 Pressure/Vacuum Valve Relief Capacity and Setting

21.11.2(a) Relief capacity. The pressure relief capacity of the pressure/vacuum valve (or breaker) installed in the venting system is to be based on 1.25 times the designed loading rate. The vacuum relief capacity is to be based on the maximum discharge rate. See 5C-1-7/11.17 and 5C-1-7/21.5. Relief capacities are to be verified by tests (e.g., in accordance with API Standard 2000) or by calculations, as in the case of pressure/vacuum breaker. Flame arrestors, where fitted, are to be included in the tests or calculations. Test or calculation reports are to be submitted for review.

21.11.2(b) Settings. The maximum pressure and vacuum settings are to be in accordance with 5C-1-7/11.11. Further, the pressure relief setting is not to cause the valve to open at a pressure of less than 0.07 bar (0.07 kg/cm^2, 1 psig). The vacuum relief setting is not to open at less than 0.03 bar (0.03 kg/cm^2, 0.5 psi) below atmospheric pressure in the tank vapor space.

21.11.3 Valve Operational Checks

The pressure/vacuum valve (or breaker) is to have a mechanical means to check its proper operation and to ensure that it will not remain in the open position. A pressure/vacuum breaker of the liquid filled type is to be fitted with a level gauge, complete with mechanical protection, for determining its set pressure.

21.11.4 Pressure/Vacuum Displays and Alarms

Displays of pressure/vacuum in the vapor collection piping are to be fitted at each cargo transfer control station. In addition, high and low pressure (or vacuum) alarms, set as follows, are also to be fitted:

- For high-pressure alarm, no higher than 90% of the lowest pressure setting of pressure/vacuum valves in the venting system.
- For low-pressure alarm, no lower than 0.01 bar (0.01 kgf/cm^2, 0.144 psi) for inerted cargo tanks; and no lower than the lowest vacuum setting of the pressure/vacuum valve in the venting system for non-inerted tanks.

Sensors for the displays and alarms are to be installed in the main vapor collection line and are to be capable of being isolated for maintenance.

21.13 Gauging Systems

A closed tank gauging system capable of measuring the full height of the tank is to be fitted. If portable gauging devices are used, the number of devices available is to be equal to the maximum number of tanks that can be loaded simultaneously, plus two additional units. A tank level display is to be provided at each cargo transfer control station.

21.15 Tank Overfill Protection

21.15.1 High Level and Overfill Alarms

Each cargo tank is to be fitted with a high level alarm and an overfill alarm, which are to be independent of each other. The overfill alarm is at least to be independent of the tank gauging system. The alarm systems are to be self-monitoring (or fitted with other means of testing) and provided with alarms for failure of tank level sensor circuits and power supply. All alarms are to have visual and audible signals and are to be given at each cargo transfer control station. In addition, overfill alarms are also to be given in the cargo deck area in such a way that they can be seen and heard from most locations.

21.15.2 Level Alarm Setting

The high level alarm is to be set at no less than that corresponding to 95% of tank capacity, and before the overfill alarm level is reached. The overfill alarm is to be set so that it will activate early enough to allow the crew in charge of the transfer operations to stop the transfer before the tank overflows.

21.15.3 Alarm Labels

At each cargo transfer control station, the high level alarms and the overfill alarms are to be identified with the labels "HIGH LEVEL ALARM" and "TANK OVERFILL ALARM", respectively, in black letters at least 50 mm (2 inches) high on a white background.

21.15.4 Operational Checks

Each alarm system is to have a means of checking locally at the tank to assure proper operation prior to the cargo transfer operation. This is not required if the system has a self-monitoring feature.

21.15.5 Mechanical Overfill Control Devices

Installation of spill valves, rupture disks and other such devices will not alleviate the alarm requirements in 5C-1-7/21.15.1 and 5C-1-7/21.15.2. Where fitted, they are to meet the following provisions.

21.15.5(a) Spill Valves. Spill valves are to be designed to relieve cargo at a pressure higher than the pressure setting of the pressure/vacuum valves at maximum cargo transfer rate and vapor rate of 1.25 times maximum cargo transfer rate. At relieving, the tank is to be subjected to a pressure no higher than the design head of the tank. Construction of spill valves is to meet a recognized standard such as ASTM F1271 *Standard Specification for Spill Valves for Use in Marine Tank Liquid Overpressure Protection Applications*. Spill valves are to be so installed as to preclude unwarranted opening due to sloshing.

21.15.5(b) Rupture Disks. The installation of rupture disks is to meet the intent of 5C-1-7/21.15.5(a), with the exception of compliance with ASTM F1271.

21.17 Electrical Installations

Electrical installations are to meet 5C-1-7/31.

21.19 Vapor Collection for Lightering Operations

21.19.1 General

Lightering is the transfer of cargo oil from one vessel to another. Provisions in 5C-1-7/21.19 are intended for service vessels, which receive and transport cargo oil between a facility and another vessel. The vapor collection system of such a vessel is to meet the requirements of 5C-1-7/21.1 through 5C-1-7/21.17 and the additional provisions of 5C-1-7/21.19.

21.19.2 Oxygen Analyzer

Service vessels are to be fitted with an oxygen analyzer within 3 m (10 ft) of its vapor connection flange. The analyzer is to provide a display of the oxygen content in the vapor collection piping as well as giving an alarm when the oxygen content exceeds 8 percent by volume, at the cargo transfer control station. Means for testing and calibrating the oxygen analyzer are to be provided onboard.

21.19.3 Hose Inerting

Means for inerting the transfer hose between vessels is to be provided on the service vessel.

21.19.4 Insulating Flange

A means of electrical insulation (i.e., an insulating flange or a length of non-conducting hose) is to be provided at the vessel vapor connection flange.

21.19.5 Detonation Arrestor

Where the cargo tanks of the lightered vessel are not inerted, a detonation arrestor is to be installed in the vapor collection piping not more than 3 meters (10 feet) inboard of the vapor connection flange on the service vessel. The detonation arrestor is to be capable of arresting a detonation from either side of the device, and be built to a recognized standard.

21.19.6 Vapor Balancing

Vapor balancing is not to be utilized when only the vessel to be lightered has inerted tanks.

21.21 Instruction Manual

An instruction manual including procedures relating to vapor emission control operations is to be submitted solely for verification that the information in the manual on the cargo vapor emission control system is consistent with the design information considered in the review of the system. The instruction manual is also to include:

- Cargo tanks to which the cargo vapor emission control system applies; and
- Maximum cargo transfer rate and maximum specific weight of cargo vapor considered.

23 Cargo Tank Protection

23.1 Inert Gas System and Deck Foam System

For oil carriers of 20,000 tonnes deadweight and upwards, the protection of the cargo tanks deck area and cargo tanks are to be achieved by a fixed deck foam system and a fixed inert gas system, in accordance with the requirements of 5C-1-7/25 and 5C-1-7/27, respectively, except that, in lieu of these installations, alternative arrangements and equipment, as indicated below, may be accepted.

Oil carriers of less than 20,000 tonnes deadweight are to be provided with a deck foam system or equivalent.

23.1.1 Alternative to Deck Foam System

To be considered equivalent, the system proposed in lieu of the deck foam system is to be:

i) Capable of extinguishing spill fires and also preclude ignition of spilled oil not yet ignited; and

ii) Capable of combating fires in ruptured tanks.

23.1.2 Alternative to Inert Gas System

To be considered equivalent, the system proposed in lieu of the fixed inert gas system is to be:

i) Capable of preventing dangerous accumulations of explosive mixtures in intact cargo tanks during normal service throughout the ballast voyage and necessary in-tank operations; and

ii) So designed as to minimize the risk of ignition from the generation of static electricity by the system itself.

23.3 Crude Oil Washing

All crude oil carriers, regardless of size, operating with a cargo tank cleaning procedure using crude oil washing, are to be fitted with an inert gas system complying with the requirements of 5C-1-7/25 and with fixed tank washing machines.

23.5 Fire Main Isolation Valve

Isolation valves are to be fitted in the fire main at poop front in a protected position and on the tank deck at intervals of not more than 40 m (131 ft) to preserve the integrity of the fire main system in case of fire or explosion.

23.7 Fireman's Outfits

Oil carriers are to carry two fireman's outfits in addition to those required in 4-7-3/15.5.2(a).

25 Inert Gas System

25.1 General

The inert gas system is to be so designed and operated as to render and maintain the atmosphere of the cargo tanks to be non-flammable at all times, except when such tanks are required to be gas free. In the event that the inert gas system is unable to meet the operational requirement set out above and it has been assessed that it is impractical to effect a repair, then cargo discharge, deballasting and necessary tank cleaning should only be resumed when the "emergency conditions" laid down in the IMO documents MSC/Circ.282, 353 and 387 *Guidelines for Inert Gas Systems* are complied with.

Throughout this subsection the term "cargo tank" also includes "slop tanks".

25.3 Basic Requirements

The system is to be capable of:

i) Inerting empty cargo tanks by reducing the oxygen content of the atmosphere in each tank to a level at which combustion cannot be supported;

ii) Maintaining the atmosphere in any part of any cargo tank with an oxygen content not exceeding 8% by volume and at a positive pressure at all times in port and at sea, except when it is necessary for such a tank to be gas free;

iii) Eliminating the need for air to enter a tank during normal operations, except when it is necessary for such a tank to be gas free;

iv) Purging empty cargo tanks of hydrocarbon gas so that subsequent gas freeing operations will at no time create a flammable atmosphere within the tank.

25.5 System Capacity and Oxygen Content

25.5.1 Capacity

The system is to be capable of delivering inert gas to the cargo tanks at a rate of at least 125% of the maximum rate of discharge capacity of the vessel expressed as a volume flow rate.

25.5.2 Oxygen Content

The system is to be capable of delivering inert gas with an oxygen content of not more than 5% by volume in the inert gas supply main to the cargo tanks at any required rate of flow.

25.7 Source of Inert Gas

25.7.1 Acceptable Sources

The inert gas supply may be treated flue gas from main or auxiliary boilers. Systems using flue gases from one or more separate gas generators or other sources or any combination thereof may be accepted, provided that an equivalent standard of safety is achieved. All flue gas plants are to be fitted with automatic control so that inert gas of suitable volume and quality can be delivered upon demand under all service conditions. Systems using stored carbon dioxide are not permitted unless the risk of ignition from the generation of static electricity by the system itself is minimized.

25.7.2 Fuel Oil Pumps for Inert Gas Generators

Two fuel oil pumps are to be fitted to the inert gas generator. Only one fuel oil pump may be permitted on condition that sufficient spares for the fuel oil pump and its prime mover are carried onboard to enable any failure of the fuel oil pump and its prime mover to be rectified by the vessel's crew.

25.7.3 Pump Certification

The fuel oil pumps serving the boiler or inert gas generator are to be certified in accordance with 4-6-1/7.3.1vi).

25.9 Flue Gas Isolating Valves

Flue gas isolating valves are to be fitted in the inert gas supply mains between the boiler uptakes and the flue gas scrubber. These valves are to be provided with indicators to show whether they are open or shut, and precautions are to be taken to maintain them gastight and to keep the seatings clear of soot. Arrangements are to be made to ensure that boiler soot blowers cannot be operated when the corresponding flue gas valve is open.

25.11 Flue Gas Scrubber

25.11.1 General

A flue gas scrubber is to be fitted which will effectively cool the volume of gas specified in 5C-1-7/25.5 and remove solids and sulfur combustion products. The cooling water arrangements are to be such that an adequate supply of water will always be available without interfering with any essential services on the vessel. Provision is also to be made for an alternative supply of cooling water.

Scrubbers, blowers, non-return devices, scrubber effluent and other drain piping, which may be subjected to corrosive action of the gas and liquid are to be either constructed of corrosion resistant material or lined with rubber, glass epoxy resin or equivalent coating. See ABS *Guidance Manual for Material Selection and Inspection of Inert Gas Systems* 1980.

25.11.2 Filters

Filters or equivalent devices are to be fitted to minimize the amount of water carried over to the inert gas blowers.

25.11.3 Scrubber Location

The scrubber is to be located aft of all cargo tanks, cargo pump rooms and cofferdams separating these spaces from machinery spaces of category A.

25.11.4 Pump Certification

The cooling water pumps serving the flue gas scrubber are to be certified in accordance with 4-6-1/7.3.1vi).

25.13 Blowers

25.13.1 Number of Blowers

At least two blowers are to be fitted which together are to be capable of delivering to the cargo tanks at least the volume of gas required by 5C-1-7/25.5. Where two blowers are fitted, the total required gas capacity is preferably to be divided equally between the two blowers. In no case is one blower to be less than $^1/_3$ of the total required gas capacity.

In the system with a gas generator only, one blower may be permitted if that system is capable of delivering the total volume of gas required by 5C-1-7/25.5 to the protected cargo tanks, provided that sufficient spares for the blower and its prime mover are carried onboard to enable any failure of the blower and its prime mover to be rectified by the vessel's crew.

25.13.2 Blower Piping

The inert gas system is to be so designed that the maximum pressure which it can exert on any cargo tank will not exceed the test pressure of any cargo tank [0.24 bar (0.24 kgf/cm^2, 3.5 psi)]. Suitable shut-off arrangements are to be provided on the suction and discharge connections of each blower. Arrangements are to be provided to enable the functioning of the inert gas plant to be stabilized before commencing cargo discharge. Oil-fired inert gas generators are to be provided with arrangements to vent off-specification inert gas to the atmosphere, e.g., during startup or in the event of equipment failure. If the blowers are to be used for gas freeing, their air inlets are to be provided with blanking arrangements.

25.13.3 Blower Location

The blowers are to be located aft of all cargo tanks, cargo pump rooms and cofferdams separating these spaces from machinery spaces of category A.

25.15 Flue Gas Leakage

25.15.1 General

Special consideration is to be given to the design and location of scrubber and blowers with relevant piping and fittings in order to prevent flue gas leakage into enclosed spaces.

25.15.2 Leakage During Maintenance

To permit safe maintenance, an additional water seal or other effective means of preventing flue gas leakage is to be fitted between the flue gas isolating valves and scrubber or incorporated in the gas entry to the scrubber.

25.17 Gas Regulating Valve

25.17.1 Gas Flow Regulation

A gas regulating valve is to be fitted in the inert gas supply main. This valve is to be automatically controlled to close, as required in 5C-1-7/25.37.3 and 5C-1-7/25.37.4. It is also to be capable of automatically regulating the flow of inert gas to the cargo tanks unless means are provided to automatically control the speed of the inert gas blowers required in 5C-1-7/25.13.

25.17.2 Location of Gas Regulating Valve

The gas regulating valve is to be located at the forward bulkhead of the forward-most gas safe space through which the inert gas supply main passes. A gas safe space is a non-hazardous spaces (see 5C-1-7/1.3.8).

25.19 Non-return Devices

25.19.1 General

At least two non-return devices, one of which is to be a water seal, are to be fitted in the inert gas supply main, in order to prevent the return of hydrocarbon vapor to the machinery space uptakes or to any gas safe space under all normal conditions of trim, list and motion of the vessel. They are to be located between the gas regulating valve required by 5C-1-7/25.17 and the after-most connection to any cargo tank or cargo pipeline.

25.19.2 Location of Non-return Devices

The non-return devices referred to in 5C-1-7/25.19.1 are to be located in the cargo area on deck.

25.19.3 Water Supply to Water Seal

The water seal is to be capable of being supplied by two separate pumps, each of which is to be capable of maintaining an adequate supply at all times.

25.19.4 Function of Water Seal

The arrangement of the seal and its associated fittings is to be such that it will prevent backflow of hydrocarbon vapors and will ensure the proper functioning of the seal under operating conditions.

25.19.5 Anti-freeze Arrangement for Water Seal

Provision are to be made to ensure that the water seal is protected against freezing, in such a way that the integrity of the seal is not impaired by overheating.

25.19.6 Water Loop Protection for Gas Safe Spaces

A water loop or other approved arrangement is also to be fitted to each associated water supply and drain pipe and each venting or pressure-sensing pipe leading to gas safe spaces. Means are to be provided to prevent such loops from being emptied by vacuum.

25.19.7 Hydrostatic Head of Water Seal and Water Loop

The deck water seal and all loop arrangements are to be capable of preventing return of hydrocarbon vapors at a pressure equal to the test pressure of the cargo tanks.

25.19.8 Non-return Valve

The second device is to be a non-return valve or equivalent capable of preventing the return of vapors or liquids and fitted forward of the deck water seal. It is to be provided with a positive means of closure. As an alternative to a positive means of closure, an additional valve having such means of closure may be provided forward of the non-return valve to isolate the deck water seal from the inert gas main to the cargo tanks.

25.19.9 Venting Arrangement

As an additional safeguard against the possible leakage of hydrocarbon liquids or vapors back from the deck main, means are to be provided to permit the section of the line between the valve having positive means of closure referred to 5C-1-7/25.19.8 and the gas regulating valve referred to in 5C-1-7/25.17 to be vented in a safe manner when the first of these valves is closed.

25.21 Branching of Inert Gas Main

25.21.1 General

The inert gas main may be divided into two or more branches forward of the non-return devices required by 5C-1-7/25.19.

25.21.2 Branch Piping Isolating Valves

25.21.2(a) Oil carriers. The inert gas supply mains are to be fitted with branch piping leading to each cargo tank. Branch piping for inert gas is to be fitted with either a stop valve or an equivalent means of control for isolating each tank. Where stop valves are fitted, they are to be provided with locking arrangements, which are to be under the control of a responsible officer of the vessel. The control system operated is to provide positive indication of the operational status of such valves.

25.21.2(b) Combination carriers. In combination carriers, the arrangement to isolate the slop tanks containing oil or oil residues from other tanks is to consist of blank flanges which will remain in position at all times when cargoes other than oil are being carried, except as provided for in the relevant section of IMO's *Revised Guidelines for Inert Gas Systems.*

25.21.3 Overpressure and Vacuum Protection of Isolated Tanks

Means are to be provided to protect cargo tanks against the effect of overpressure or vacuum caused by thermal variations when the cargo tanks are isolated from the inert gas mains. See also 5C-1-7/11.5.

25.21.4 Self-draining of Piping

Piping systems are to be so designed as to prevent the accumulation of cargo or water in the pipelines under all normal conditions. See also 5C-1-7/11.7.

25.21.5 External Supply Connection

Suitable arrangements are to be provided to enable the inert gas main to be connected to an external supply of inert gas. The arrangements are to consist of a 250 mm (10 in.) nominal pipe size bolted flange, isolated from the inert gas main by a valve and located forward of the non-return valve referred to in 5C-1-7/25.19.8. The design of the flange is to conform to the appropriate Class in the Standards adopted for the design of other external connections in the vessel's cargo piping system.

25.23 Venting for Large Gas Volumes

The arrangements for the venting of all vapors displaced from the cargo tanks during loading and ballasting are to comply with 5C-1-7/11.17 and are to consist of either one or more mast risers, or a number of high velocity vents. The inert gas supply mains may be used for such venting.

25.25 Inerting, Purging or Gas-freeing of Empty Tanks

The arrangements for inerting, purging or gas freeing of empty tanks, as required in 5C-1-7/25.3, are to be such that the accumulation of hydrocarbon vapors in pockets formed by the internal structural members in a tank is minimized.

25.25.1 Position of Gas Outlet Pipe

On individual cargo tanks, the gas outlet pipe, if fitted, is to be positioned as far as practicable from the inert gas/air inlet and in accordance with 5C-1-7/11. The inlet of such outlet pipes may be located either at deck level or at not more than 1 m above the bottom of the tank.

25.25.2 Size of Gas Outlet Pipe

The cross sectional area of such gas outlet pipe is to be such that an exit velocity of at least 20 m/s (66 ft/s) can be maintained when any three tanks are being simultaneously supplied with inert gas. Their outlets are to extend not less than 2 m (6.6 ft) above deck level.

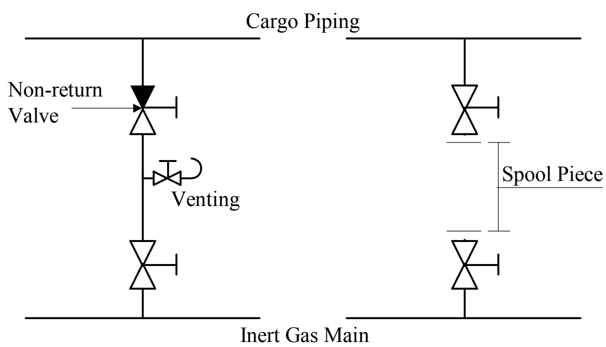
25.25.3 Blanking of Gas Outlet Pipe

Each gas outlet is to be fitted with suitable blanking arrangements.

25.25.4 Connection to Cargo Piping

25.25.4(a) Acceptable connection arrangement. If a connection is fitted between the inert gas supply mains and the cargo piping system, arrangements are to be made to ensure an effective isolation, having regard to the large pressure difference which may exist between the systems. This is to consist of two shut-off valves with an arrangement to vent the space between the valves in a safe manner or an arrangement consisting of a spool-piece with associated blanks. See 5C-1-7/Figure 1.

FIGURE 1
Connection between Inert Gas Main and Cargo Piping



25.25.4(b) Non-return valve. The valve separating the inert gas supply main from the cargo main and which is on the cargo main side is to be a non-return valve with a positive means of closure.

25.27 Pressure/Vacuum-breaking Devices

25.27.1 General

One or more pressure/vacuum-breaking devices are to be provided on the inert gas supply main to prevent the cargo tanks from being subject to:

i) A positive pressure in excess of the test pressure of the cargo tank if the cargo were to be loaded at the maximum specified rate and all other outlets were left shut; or

ii) A negative pressure in excess of 700 mm (27.5 in.) water gauge if cargo were to be discharged at the maximum rated capacity of the cargo pumps and the inert gas blowers were to fail.

Such devices are to be installed on the inert gas main unless they are installed in the venting system required by 5C-1-7/11.1 or on individual cargo tanks.

25.27.2 Location and Design

The location and design of the devices are to be in accordance with 5C-1-7/11.

25.29 Instrumentation at Gas Blower Outlets

Means are to be provided for continuously indicating the temperature and the pressure of the inert gas at the discharge side of the gas blowers, whenever the gas blowers are operating.

25.31 Monitoring of Inert Gas

25.31.1 Instrumentation at Inert Gas Supply Main

Instrumentation is to be fitted for continuously indicating and permanently recording when the inert gas is being supplied:

i) The pressure of the inert gas supply mains forward of the non-return devices, required by 5C-1-7/25.19.1; and

ii) The oxygen content of the inert gas in the inert gas supply mains on the discharge side of the gas blowers.

25.31.2 Cargo Control Room Displays

The devices in 5C-1-7/25.31.1 are to be placed in the cargo control room, where provided. But where no cargo control room is provided, they are to be placed in a position easily accessible to the officer in charge of the cargo operations.

25.31.3 Navigation Bridge and Machinery Control Room Displays

In addition, displays are to be fitted:

i) In the navigation bridge to indicate at all times the pressure referred to in 5C-1-7/25.31.1i) and the pressure in the slop tanks of combination carriers, whenever those tanks are isolated from the inert gas supply main; and

ii) In the machinery control room or in the machinery space to indicate the oxygen content referred to in 5C-1-7/25.31.1ii).

25.33 Portable Detectors *(2001)*

Portable detectors for measuring oxygen and flammable vapor concentration in inerted atmospheres are to be provided. This requirement may be satisfied by the detectors addressed in 5C-1-7/17.7, provided the flammable vapor concentration detectors are capable of measuring concentrations of flammable vapors in an inerted atmosphere as well as in air. Otherwise, two additional flammable vapor concentration detectors capable of measuring concentrations of flammable vapors in an inerted atmosphere are to be carried onboard. In addition, suitable arrangement are to be made on each cargo tank such that the condition of the tank atmosphere can be determined using these portable detectors.

25.35 Calibration of Instruments

Suitable means are to be provided for the zero and span calibration of both fixed and portable gas concentration measurement instruments, referred to in 5C-1-7/25.31 and 5C-1-7/25.33.

25.37 Alarms and Shutdowns

25.37.1 Alarms for Flue Gas Type Systems

For inert gas systems of the flue gas type, audible and visual alarms are to be provided to indicate:

i) Low water pressure or low water flow rate to the flue gas scrubber, as referred to in 5C-1-7/25.11.1;

ii) High water level in the flue gas scrubber, as referred to in 5C-1-7/25.11.1;

iii) High gas temperature, as referred to in 5C-1-7/25.29;

iv) Failure of the inert gas blowers, as referred to in 5C-1-7/25.13;

v) Oxygen content in excess of 8% by volume, as referred to in 5C-1-7/25.31.1ii);

vi) Failure of the power supply to the automatic control system for the gas regulating valve and to the indicating devices, as referred to in 5C-1-7/25.17 and 5C-1-7/25.31.1;

vii) Low water level in the water seal, as referred to in 5C-1-7/25.19.1;

viii) Gas pressure less than 100 mm water gauge, as referred to in 5C-1-7/25.31.1i). The alarm arrangement are to be such as to ensure that the pressure in slop tanks in combination carriers can be monitored at all times; and

ix) High gas pressure, as referred to in 5C-1-7/25.31.1i).

25.37.2 Alarms for Inert Gas Generator Type Systems

For inert gas systems of the inert gas generator type, audible and visual alarms are to be provided in accordance with 5C-1-7/25.37.1, plus the following:

i) Insufficient fuel oil supply;

ii) Failure of the power supply to the generator (This condition is to also automatically shutdown the gas-regulating valve.);

iii) Failure of the power supply to the automatic control system for the generator.

In addition, the fuel oil supply to the gas generator is to be automatically shutdown in the event of a) low water pressure (or flow) to scrubber; and b) high gas temperature.

25.37.3 Automatic Shut-down of the Inert Gas Blowers and Gas Regulating Valve

Automatic shut-down of the inert gas blowers and gas regulating valve is to be arranged on predetermined limits being reached with respect to 5C-1-7/25.37.1i), 5C-1-7/25.37.1ii) and 5C-1-7/25.37.1iii).

25.37.4 Automatic Shut-down of the Gas Regulating Valve

Automatic shutdown of the gas regulating valve is to be arranged with respect to 5C-1-7/25.37.1iv).

25.37.5 Suspension of Cargo Tank Operations

With respect to 5C-1-7/25.37.1v), when the oxygen content of the inert gas exceeds 8% by volume, immediate action is to be taken to improve the gas quality. Unless the quality of the gas improves, all cargo tank operations are to be suspended so as to avoid air being drawn in to the tanks, and the isolation valve referred to in 5C-1-7/25.19.8 is to be closed.

25.37.6 Alarms in Cargo Control Room and Machinery Space

The alarms required in 5C-1-7/25.37.1v), 5C-1-7/25.37.1vi) and 5C-1-7/25.37.1viii) are to be fitted in the machinery space and cargo control room, where provided, but in each case, in such a position that they are immediately received by responsible members of the crew.

25.37.7 Dry Water Seal Water Supply

As per the intent of 5C-1-7/25.37.1vii), an adequate reserve of water is to be maintained at all times and the integrity of the arrangements to permit the automatic formation of the water seal when the gas flow ceases is also to be maintained. The audible and visual alarm on the low level of the water in the water seal is to operate when the inert gas is not being supplied.

25.37.8 Additional Low Inert Gas Pressure Protection

An audible alarm system independent of that required in 5C-1-7/25.37.1viii) or automatic shutdown of cargo pumps is to be provided to operate on predetermined limits of low pressure in the inert gas mains being reached.

25.39 Instruction Manuals

Detailed instruction manuals are to be provided onboard, covering the operations, safety and maintenance requirements and occupational health hazards relevant to the inert gas system and its application to the cargo tank system. The manuals are to include guidance on procedures to be followed in the event of a fault or failure of the inert gas system. Reference is to be made to the IMO document MSC/Circ.282, 353 and 387 *Guidelines for Inert Gas Systems.*

25.41 Nitrogen Generator Inert Gas Systems

25.41.1 Application

The requirements of 5C-1-7/25.41 apply where inert gas is produced by separating air into its component gases by passing compressed air through a bundle of hollow fibers, semi-permeable membranes or absorber materials. Where such systems are provided in place of the boiler flue gas or oil-fired inert gas generators, the following requirements are also applicable for the piping arrangements, alarms and instrumentation downstream of the gas generator:

5C-1-7/25.17.1	5C-1-7/25.17.2	5C-1-7/25.21	5C-1-7/25.23	5C-1-7/25.25
5C-1-7/25.27	5C-1-7/25.31.1i)	5C-1-7/25.31.2	5C-1-7/25.31.3	5C-1-7/25.33
5C-1-7/25.35	5C-1-7/25.37.1vi)	5C-1-7/25.37.1viii)	5C-1-7/25.37.1ix)	5C-1-7/25.37.3
5C-1-7/25.37.4	5C-1-7/25.37.6	5C-1-7/25.37.8	5C-1-7/25.39	

25.41.2 Nitrogen Generator

25.41.2(a) Capacity. A nitrogen generator consists of a feed air treatment system and any number of membrane or absorber modules in parallel necessary to meet the required capacity which is to be at least 125% of the maximum discharge capacity of the vessel expressed as a volume.

25.41.2(b) Gas specification. The nitrogen generator is to be capable of delivering high purity nitrogen with oxygen content not exceeding 5% by volume. The system is to be fitted with automatic means to discharge "off-spec" gas to the atmosphere during start-up and abnormal operation. The block and bleed arrangement indicated in 5C-1-7/25.41.4 is not to be used for this purpose.

25.41.2(c) Air compressors. The system is to be provided with two air compressors. The total required capacity of the system is preferably to be divided equally between the two compressors, and in no case is one compressor to have a capacity less than $^1/_3$ of the total capacity required.

Only one air compressor may be accepted, provided that sufficient spares for the air compressor and its prime mover are carried onboard to enable their failure to be rectified by the vessel's crew.

25.41.2(d) Feed air treatment. A feed air treatment system is to be fitted to remove free water, particles and traces of oil from the compressed air, and to preserve the specification temperature.

25.41.2(e) Nitrogen receiver. Where fitted, a nitrogen receiver/buffer tank may be installed in a dedicated compartment or in the separate compartment containing the air compressor and the generator or may be located in the cargo area. Where the nitrogen receiver/buffer tank is installed in an enclosed space, the access is to be arranged only from the open deck and the access door is to open outwards. Permanent ventilation and alarm are to be fitted as in 5C-1-7/25.41.3.

In order to permit maintenance, means of isolation are to be fitted between the generator and the receiver.

25.41.2(f) Enriched gases. The oxygen-enriched air from the nitrogen generator and the nitrogen-product enriched gas from the protective devices of the nitrogen receiver are to be discharged to a safe location on the open deck.

25.41.3 Location of Installation

The air compressor and the nitrogen generator may be installed in the engine room or in a separate compartment. Where a separate compartment is provided, it is to be:

- Treated as 'other machinery spaces' with respect to fire protection,
- Positioned outside the cargo area,
- Fitted with an independent mechanical extraction ventilation system providing at least six (6) air changes per hour,
- Fitted with a low oxygen alarm,
- Arranged with no direct access to accommodation spaces, service spaces and control stations.

25.41.4 Non-return Devices

At least two non-return devices are to be fitted in the inert gas supply main. One of the non-return devices is to be of the double block and bleed arrangement (two shut-off valves in series with a venting valve in between) for which the following conditions apply:

i) The operation of the valve is to be automatically executed. Signal(s) for opening/closing are to be taken from the process directly (e.g., inert gas flow or differential pressure).

ii) Alarm for faulty operation of the valves is to be provided (e.g., the operation of "blower stop" and "supply valve(s) open" is an alarm condition).

iii) Upon loss of power, the block valves are to automatically close and the bleed valve is to automatically open.

The second non-return device is to be equipped with positive means of closure.

25.41.5 Instrumentation

25.41.5(a) Compressed air. Instrumentation is to be provided for continuously indicating the temperature and pressure of air:

i) At the discharge side of the compressor,

ii) At the entrance side of the nitrogen generator.

25.41.5(b) Inert gas (2007). Instrumentation is to be fitted for continuously indicating and permanently recording the oxygen content of the inert gas downstream the nitrogen generator when inert gas is being supplied. This instrumentation is to be placed in the cargo control room where provided. Where no cargo control room is provided, they are to be placed in a position easily accessible to the officer in charge of the cargo operation.

25.41.5(c) Alarms. Audible and visual alarms are to be provided to indicate:

i) Low air pressure from compressor, as referred to in 5C-1-7/25.41.5(a)i);

ii) High air temperature, as referred to in 5C-1-7/25.41.5(a)i);

iii) High condensate level at automatic drain of water separator, as referred to in 5C-1-7/25.41.2(d),

iv) Failure of electrical heater, if fitted,

v) Oxygen content in excess of that specified in 5C-1-7/25.41.2(b),

vi) Failure of power supply to the instrumentation, as referred to in 5C-1-7/25.41.5(b).

These alarms are to be fitted in the machinery space and cargo control room, where provided, but in each case, in such a position that they are immediately received by responsible members of the crew.

25.41.6 Automatic Shutdown

Automatic shutdown of the system is to be arranged for the alarm conditions in 5C-1-7/25.41.5(c)i) through 5C-1-7/25.41.5(c)v).

25.41.7 Non-mandatory Systems

Where a nitrogen inerting system is installed on an oil carrier which is not required to be fitted with an inert gas system (i.e., oil carriers of less than 20,000 tonnes deadweight not fitted with crude oil washing systems), it is to comply with the requirements in 5C-1-7/25.41, except for:

- 5C-1-7/25.41.1;
- 5C-1-7/25.41.2(a) and 5C-1-7/25.41.2(c); and
- where the connections to the cargo tanks, hold spaces or cargo piping are not permanent, the non-return devices required by 5C-1-7/25.41.4 may be substituted by two non-return valves.

27 Fixed Deck Foam System

27.1 General

The arrangements for providing foam are to be capable of delivering foam to the entire cargo tank deck area as well as into any cargo tank, the deck of which has been ruptured.

The system is to be capable of simple and rapid operation. The main control station for the system is to be suitably located outside of the cargo tank area, adjacent to the accommodation spaces and readily accessible and operable in the event of fire in the areas protected.

Reference is to be made to IMO MSC/Circ.582 *Guidelines for the performance and testing criteria and surveys of low-expansion foam concentrates for fixed fire extinguishing system*.

27.3 Foam Solution Supply Rate

The rate of supply of foam solution is to be not less than the greatest of the following:

i) 0.6 liters/min/m^2 (0.015 gal/min/ft^2) of the cargo deck area, where cargo deck area means the maximum breadth of the vessel multiplied by the total longitudinal extent of the cargo tank spaces,

ii) 6 liters/min/m^2 (0.15 gal/min/ft^2) of the horizontal sectional area of the single tank having the largest such area; or

iii) 3 liters/min/m^2 (0.075 gal/min/ft^2) of the area protected by the largest monitor, such area being entirely forward of the monitor, but not less than 1,250 liters per minute.

27.5 Foam Concentrate Quantity

Sufficient foam concentrate is to be supplied to ensure at least:

- 20 minutes of foam generation in oil carriers fitted with an inert gas installation; or
- 30 minutes of foam generation in oil carriers not fitted with an inert gas installation;

when using solution rates stipulated in 5C-1-7/27.3i), 5C-1-7/27.3ii) or 5C-1-7/27.3iii), whichever is the greatest.

The foam expansion ratio (i.e., the ratio of the volume of foam produced to the volume of the mixture of water and foam-making concentrate supplied) is not to generally exceed 12:1.

Where systems essentially produce low expansion foam but at an expansion ratio slightly in excess of 12:1, the quantity of foam solution available is to be calculated as for 12:1 expansion ratio systems.

When medium expansion ratio foam (between 50:1 and 150:1 expansion ratio) is employed the application rate of the foam and the capacity of a monitor installation are to be submitted for consideration in each case.

27.7 Required Foam Monitor and Foam Applicator Capacities

Foam from the fixed foam system is to be supplied by means of monitors and foam applicators. At least 50% of the foam solution supply rate required in 5C-1-7/27.3i) and 5C-1-7/27.3ii) is to be delivered from each monitor.

On oil carriers of less than 4,000 tonnes deadweight, foam applicators may be installed in lieu of foam monitors. In which case, the capacity of each applicator is to be at least 25% of the foam solution supply rate required in 5C-1-7/27.3i) or 5C-1-7/27.3ii).

27.9 Minimum Foam Monitor Capacity

The number and position of monitors are to be such as to comply with 5C-1-7/27.1. The capacity of any monitor is to be at least 3 liters/min (0.075 gpm) of foam solution per square meter of deck area protected, such area being entirely forward of the monitor. Such capacity is not to be less than 1250 liters/min (330 gpm).

The distance from the monitor to the farthest extremity of the protected area forward of that monitor is not to be more than 75% of the monitor throw in still air conditions.

27.11 Installation at Poop Front

A monitor and hose connection for a foam applicator are to be situated both port and starboard at the front of the poop or accommodation spaces facing the cargo tanks deck.

On oil carriers of less than 4,000 tonnes deadweight, a hose connection for a foam applicator is to be situated both port and starboard at the front of the poop or accommodation spaces facing the cargo tanks deck.

27.13 Use and Minimum Capacity of Foam Applicators

Applicators are to be provided to ensure flexibility of action during fire-fighting operations and to cover areas screened from the monitors. The capacity of any applicator is to be not less than 400 liters/min (106 gpm) and the applicator throw in still air conditions is to be not less than 15 meters. The number of applicators provided is to be not less than four. The number and disposition of foam main outlets is to be such that foam from at least two applicators can be directed on to any part of the cargo tanks deck area.

27.15 Foam Main and Fire Main Isolation Valves

Valves are to be provided in the foam main, and in the fire main when this is an integral part of the deck foam system, immediately forward of any monitor position to isolate damaged sections of these mains.

27.17 Simultaneous Operation

Operation of a deck foam system at its required output is to permit the simultaneous use of the minimum required number of jets of water at the required pressure from the fire main.

27.19 Bow or Stern Loading and Unloading *(2003)*

Ships fitted with bow or stern loading and unloading arrangements are to be provided with one additional foam monitor meeting the requirements of 5C-1-7/27.7 and one additional applicator meeting the requirements of 5C-1-7/27.13. The additional monitor is to be located to protect the bow or stern loading and unloading arrangements. The area of the cargo line forward or aft of the cargo block area is to be protected by the above-mentioned applicator.

29 Cargo Pump Room Protection

29.1 Fixed Fire Extinguishing System

Each pump room is to be provided with one of the following fixed fire-extinguishing systems operated from a readily accessible position outside the pump room:

i) A CO_2 system complying with the provisions of 4-7-3/3 (or SOLAS Reg. II-2/5) and with the following:

- The alarm referred to in 4-7-3/3.1.5 (or SOLAS Reg. II-2/5.1.6) is to be safe for use in a flammable cargo vapor/air mixture (see 5C-1-7/Table 1, item c4). The electrical alarm actuating mechanism is to be located outside the pump room. Pneumatic alarms are also acceptable; where fitted, air, and not CO_2, is to be used for testing of pneumatic alarms;
- A notice is to be exhibited at the controls stating that due to the electrostatic ignition hazard, the system is to be used only for fire extinguishing and not for inerting purposes.

ii) A high-expansion foam system complying with the provisions of 4-7-3/5.1 (or SOLAS Reg. II-2/9), provided that the foam concentrate supply is suitable for extinguishing fires involving the cargo carried.

iii) A fixed pressure water-spray system complying with the provisions of 4-7-3/7 (or SOLAS Reg. II-2/10).

29.3 Required Quantity of Fire-extinguishing Medium

Where the fire-extinguishing medium used in the cargo pump room system is also used in systems serving other spaces, the quantity of medium provided or its delivery rate need not be more than the maximum required for the largest compartment.

31 Electrical Installations

31.1 Application *(2007)*

i) These requirements are additional to, or modifying those of, Section 4-8-1 through Section 4-8-4, as appropriate.

ii) These requirements address electrical safety associated with hazardous areas of oil carriers.

iii) Oil carriers subject to SOLAS are to comply with the requirements of IEC 60092-502 (1999) "Electrical Installations in Ships – Tankers – Special Features" in accordance with Chapter II-1, Regulation 45.11 of the 2004 Amendments to SOLAS. Oil carriers subject to SOLAS that comply with the electrical safety requirements of IEC 60092-502 (1999), associated with hazardous areas, will not be required to meet 5C-1-7/31.5, 5C-1-7/31.7, 5C-1-7/31.9, 5C-1-7/Table 1 and 5C-1-7/31.11.

31.3 Limited Use of Earthed Distribution Systems

An earthed distribution system is not to be used, except for the following applications:

i) Earthed intrinsically-safe circuits.

ii) Control circuits and instrumentation circuits where technical or safety reasons preclude the use of a system without an earthing connection, provided the current in the hull is limited to 5 A or less in both normal and fault conditions.

iii) Limited and locally earthed systems, provided that any possible resultant earth current does not flow directly through any hazardous areas.

iv) Alternating-current power networks of 1 kV (rms, line to line) and over, provided that any possible resultant earth current does not flow directly through any hazardous areas.

31.5 Hazardous Areas

The following are to be regarded as hazardous areas (see also 5C-1-7/Figure 2).

31.5.1 Enclosed Spaces

i) Cargo tanks and cargo piping.

ii) Cofferdams, ballast and peak tanks; underdeck walkways and duct keel; and trunks:

- which are adjacent to cargo tanks;
- through which cargo piping passes; or
- which are served by piping either (1) connected to cargo oil system, (2) passed through cargo tank, or (3) also serving spaces located immediately adjacent to cargo tanks.

iii) Cargo pump rooms.

iv) Compartments for storage of cargo hoses.

v) Where permitted (by SOLAS Reg. II-2/56), any enclosed or semi-enclosed space:

- immediately above cargo tanks,
- aft or forward of all cargo tanks but having bulkheads immediately above and in-line with cargo tank end bulkheads (unless the corner-to-corner common boundary is eliminated by means of a diagonal plate welded across the corner),
- immediately above cargo pump room (unless separated by a gastight bulkhead and suitably mechanically ventilated), or
- immediately above vertical cofferdams, ballast tanks, fuel oil tanks, etc. adjacent to cargo tanks (unless separated by a gastight deck and suitably mechanically ventilated).

vi) Enclosed and semi-enclosed spaces having a direct access or opening into any space described in 5C-1-7/31.5.1ii) through 5C-1-7/31.5.1v).

vii) Enclosed or semi-enclosed spaces having an opening (door, ventilation port, etc.) within the hazardous areas defined in 5C-1-7/31.5.2.

31.5.2 Open Deck Spaces *(2006)*

i) Areas on open deck over all cargo tanks (including all ballast tanks within cargo tank area) and to the full breadth of the vessel plus 3 m (10 ft) fore and aft on open deck, up to a height of 2.4 m (8 ft) above the deck.

ii) Areas on open deck within 3 m (10 ft) of openings to the spaces in 5C-1-7/31.5.1. These include, but not limited to, the following:

- Any opening (e.g., tank hatch, tank ullage port, etc.) of cargo tank;
- Any opening (e.g., hatch, air vent pipe head, sounding pipe head, etc.) of cofferdams, ballast tanks, peak tanks, fuel oil tanks, etc., which are adjacent to cargo tanks.
- Cargo manifold valves, cargo valves, cargo pipe flanges and similar pipe fittings.
- Cargo pump room entrances and cargo pump room ventilation openings.

iii) Areas on open deck in way of cargo tank vents:

- within 3 m (10 ft) measured spherically with outlet as center;
- during the flow of small volume of vapor, air or inert gas mixtures caused by thermal variations in cargo tanks, spaces up to 5 m (16.5 ft), measured spherically with outlet as center, from pressure/vacuum valves; and
- during the flow of large volume of vapor, air or inert gas mixtures when cargo loading and ballasting or when discharging, spaces up to 10 m (33 ft), measured cylindrically with vertical vent pipe as axis and extending vertically without limit, from free flow vents and high velocity vents.

(2006) Note: Anchor windlass and chain locker openings are not to be located within the above areas since these constitute an ignition hazard.

iv) Areas on open deck in way of cargo manifold valve spillage containment coaming and other coamings intended to keep spillage from accommodation and service spaces:

- area within the coaming, and
- areas within 2.4 m (8 ft) above the deck up to 3 m (10 ft) from the edge of the coaming.

31.5.3 Forepeak Tank and Spaces Above Forepeak Tank *(2002)*

31.5.3(a) Forepeak tank adjacent to cargo tank. Where the forepeak tank is adjacent to a cargo tank,

i) The forepeak tank is to be considered as hazardous [see 5C-1-7/31.5.1ii)],

ii) Sounding and vent piping arrangements for the forepeak tank are to lead to the weather [see 5C-1-7/31.5.2ii)],

iii) A permanent arrangement leading from the forepeak tank to the weather is to be provided to allow measurement of flammable gas concentrations within the tank by a suitable portable instrument,

iv) Any access opening to the forepeak tank must be from the open deck, and

v) Enclosed spaces above the forepeak tank are to be regarded as hazardous unless the space is:

- separated from the forepeak tank by gastight deck having no access opening; and
- provided with mechanical ventilation.
- not adjacent to cargo tanks.

See also 5C-1-7/31.5.1.

31.5.3(b) Forepeak tank not adjacent to cargo tank. Where the forepeak tank is not adjacent to a cargo oil tank, but is served by piping which also serves spaces adjacent to cargo tank(s),

i) The forepeak tank is to be considered as hazardous [see 5C-1-7/31.5.1ii)],

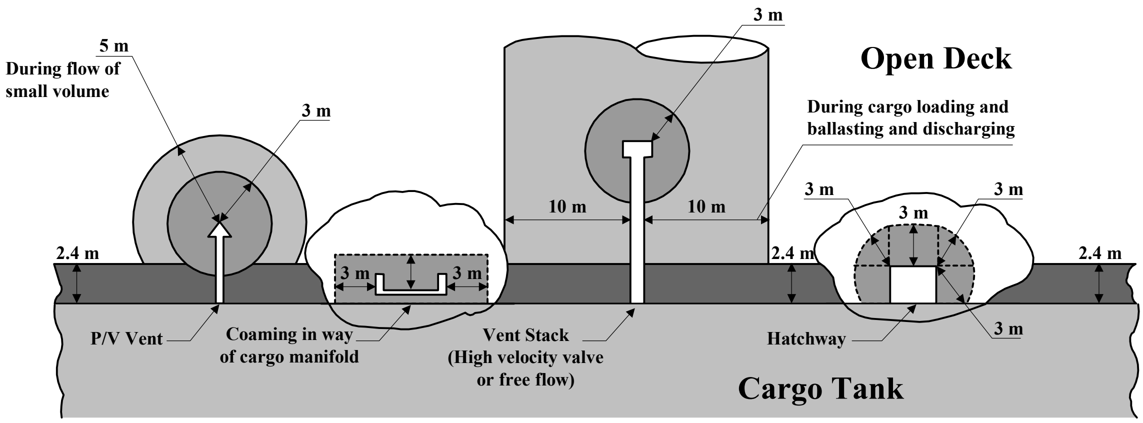
ii) Sounding and vent piping arrangements for the forepeak tank are to lead to the weather [see 5C-1-7/31.5.2ii)],

iii) A permanent arrangement leading from the forepeak tank to the weather is to be provided to allow measurement of flammable gas concentrations within the tank by a suitable portable instrument,

iv) Enclosed spaces above the forepeak tank without direct access to the forepeak tank and not adjacent to a cargo tank may be regarded as non-hazardous unless 5C-1-7/31.5.1 applies. Where a direct access is provided from such an enclosed space into the forepeak tank, the enclosed space may be regarded as non-hazardous if:

- The direct access is a bolted gas-tight manhole, and
- A warning sign is provided at the manhole stating that the tank may only be opened after it has been proven to be gas free or the electrical equipment which is not electrically safe in the enclosed space has been isolated, and
- The enclosed space is not adjacent to cargo tanks.

FIGURE 2
Hazardous Areas on Open Deck



31.7 Air Locks

Enclosed and semi-enclosed spaces, other than machinery spaces of category A, having an access or opening into hazardous areas [see 5C-1-7/31.5.1vi) and 5C-1-7/31.5.1vii)], need not be regarded as hazardous areas themselves provided the access is through a double door air lock of either type described below. Openings to machinery space of category A are to be located away from hazardous areas.

31.7.1 Type 1 Air Lock

31.7.1(a) Doors. The air-lock is to consist of two gas-tight steel doors of the self closing type, with no hold-back arrangement, spaced at least 1.5 m (5 ft) but not more than 2.5 m (8 ft) apart, and the space is provided with mechanical ventilation.

31.7.1(b) Relative pressurization. The non-hazardous space is to be maintained at overpressure relative to the external hazardous area. The relative overpressure or air flow is to be continuously monitored and so arranged that in the event of ventilation failure, an audible and visual alarm is given at a manned control station and the electrical supply to all equipment (not of the certified safe type) is to be automatically disconnected. A time delay on the disconnect will be considered where deemed necessary.

31.7.1(c) Safety precautions. Machinery necessary for propulsion and maneuvering, anchoring and mooring, as well as the emergency generator and emergency fire pump, where the shutdown of which could in itself introduce a hazard, is not to be located in spaces protected by a Type 1 air lock.

31.7.2 Type 2 Air Lock

31.7.2(a) Doors. The air lock is to consist of two gas-tight steel doors of self closing type, with no hold-back arrangement, spaced at least 1.5 m (5 ft) but not more than 2.5 m (8 ft) apart.

31.7.2(b) Relative pressurization. The non-hazardous space and the air lock are to be maintained at overpressure relative to the external hazardous area by independent mechanical ventilation systems arranged such that a single failure will not result in the simultaneous loss of overpressure in both the non-hazardous space and the air-lock. Failure of either ventilation system is to be alarmed at a manned control station.

31.9 Electrical Equipment Permitted in Hazardous Areas

Electrical equipment and its wiring are not to be installed in any hazardous areas unless essential for operation purposes. Electrical equipment intended for installation in hazardous areas is to be of the certified safe type and is to be selected in accordance with 5C-1-7/Table 1, based on the class of hazardous area at its location of installation.

31.11 Cable Installation in Hazardous Areas

All cables installed within the hazardous areas are to be provided with metallic braiding or metallic armoring, or to be of mineral-insulated copper or stainless steel sheathed type. A non-metallic impervious sheath is to be applied over the metallic braiding, armoring or sheathing for cables installed in locations subject to corrosion. Cables installed on open deck or on fore and aft gangways are, in addition, to be protected against mechanical damage (see 4-8-4/21.15.2). Cables and protective supports are to be so installed as to avoid strain or chafing and, for long runs of cables, due allowance made for the effects of expansion/contraction or working of the hull.

TABLE 1
Electrical Equipment in Hazardous Areas of Oil Carriers

Hazardous area	*Acceptable electrical equipment*	
Cargo tanks and cargo piping, 5C-1-7/31.5.1i)	a1	Ex ia intrinsically-safe apparatus.
Cofferdams, ballast tanks, peak tanks, 5C-1-7/31.5.1ii)	b1	Ex ia intrinsically-safe apparatus.
	b2	Transducers for depth sounding or speed log; or electrodes for impressed current system, subject to installation requirements of 5C-1-7/31.13.
Cargo pump rooms, 5C-1-7/31.5.1iii)	c1	Intrinsically-safe apparatus.
	c2	Electrical devices as described in item b2
	c3	Explosion-proof lighting fixtures.
	c4	Explosion proof fire extinguishing system alarm, general alarm and communication.
	c5	Through-run of cables in extra-heavy pipe, see 5C-1-7/31.15.3.
Compartments for cargo hoses, and enclosed or semi-enclosed spaces above cargo tanks, 5C-1-7/31.5.1iv) & 5C-1-7/31.5.1v).	d1	Intrinsically-safe apparatus.
	d2	Explosion-proof type lighting fixtures
	d3	Through-runs of cable.
Enclosed or semi-enclosed spaces having opening to hazardous areas, 5C-1-7/31.5.1vi) and 5C-1-7/31.5.1vii).	e1	Intrinsically-safe apparatus and explosion proof equipment.
	e2	Electrical devices as described in b2
	e3	Through-run of cable
Areas on open deck as defined in 5C-1-7/31.5.2	f1	Explosion-proof, intrinsically-safe, increased safety or pressurized equipment with enclosures suitable for use on open deck.
	f2	Through-runs of cables with mechanical protection, see 5C-1-7/31.11.

Notes

1 Intrinsically safe refers to Ex ia and Ex ib, except where specified otherwise.

2 Explosion proof refers to Ex d IIA T3.

3 Increased safety refers to Ex e IIA T3.

4 Pressurized or purged Ex p may substitute for 2 and 3 above.

31.13 Echo Sounder; Speed Log; Impressed Current System *(2005)*

Hull fittings penetrating the shell and containing transducers for depth sounding or speed log devices, or containing terminals for anodes or electrodes of impressed current cathodic protection system are not to be installed in cargo tanks. However, they may be installed in hazardous areas, such as cofferdams adjacent to cargo tanks, as permitted by 5C-1-7/Table 1, provided all of the following are complied with:

i) Hull fittings containing terminals or shell-plating penetrations are to be housed within a gas-tight enclosure and are not to be located adjacent to cargo tank bulkheads.

ii) The box containing actual electrical connection of the cable, such as a terminal box or junction box, is to be filled with insulating material, such as silicon grease, silicon sealing or equivalent and also is to be of gastight construction.

iii) All associated cables passing through these spaces are to be installed in steel pipes with at least extra-heavy wall thickness with all joints welded and with corrosion-resistant coating.

iv) Cable gland with gastight packing is to be provided for the cable at both ends of the cable conduit pipe.

v) Cable inside of the vertical cable conduit pipe is to be suitably supported, e.g., by sand-filling or by strapping to a support-wire. Alternatively, the cable inside of the vertical conduit pipe may be accepted without provided support if the mechanical strength of the cable is sufficient to prevent cable damage due to the cable weight within the conduit pipe under continuous mechanical load. Supporting documentation is to be submitted to verify the mechanical strength of the cable with respect to the cable weight inside of the conduit.

31.15 Cargo Oil Pump Room

31.15.1 Ventilation and Gas Detection

Ventilation arrangements of and the provision of a gas detection system in the cargo pump room are to be in accordance with 5C-1-7/17.1.

31.15.2 Lighting

31.15.2(a) Lighting fitted outside the pump room. As far as practicable, lighting fixtures for the pump-room are to be permanently wired and fitted outside of the pump room. Pump rooms adjacent to engine rooms or similar safe spaces may be lighted through substantial glass lenses permanently fitted in the bulkhead or deck. The construction of the glass lens port is to be as follows:

- Capable of maintaining watertight and gastight integrity of the bulkhead and deck.
- Suitably protected from mechanical damage.
- Provided with a steel cover capable of being closed and secured on the side of the safe space.
- Both the glass lens and its sealing arrangement will not be impaired by working of the hull.
- Structural strength of the pierced bulkhead or deck is suitably reinforced. See 5C-1-1/5.11 and 5C-2-1/5.5.

31.15.2(b) Lighting fitted inside the pump room. As an alternative to 5C-1-7/31.15.2(a), certified safe lighting fixtures (see 5C-1-7/Table 1) may be installed in the pump room, provided they are wired with moisture-resisting jacketed (impervious-sheathed) and armored or mineral-insulated metal-sheathed cable. Lighting circuits are to be so arranged that the failure of any one branch circuit will not leave the pump room in darkness. All switches and protective devices are to be located outside the pump room. See also 4-8-4/27.11 for lighting circuits in hazardous areas.

31.15.2(c) Lighting/Ventilation Interlock. (1 July 2002) Lighting in cargo pump rooms, except emergency lighting, is to be interlocked with the ventilation system such that the ventilation system is to be in operation when switching on the lighting. Failure of the ventilation system is not to cause the lighting to go out.

31.15.3 Cables Passing Through Pump Room

Where it is necessary for cables, other than intrinsically safe circuits and that supplying lighting fixtures in pump room, to pass through cargo pump rooms, they are to be installed in extra-heavy steel pipes, or equivalent.

31.17 Pipe Tunnel or Duct Keel

31.17.1 Ventilation and Gas Detection

Pipe tunnels, duct keels and similar spaces are to be provided with a ventilation system (see 5-1-7/17.5.1) and a gas detection system (see 5C-1-7/17.5.2).

31.17.2 Lighting

Where a permanent lighting system is installed in enclosed spaces such as pipe tunnels, double bottoms, or duct keels, it is to be in accordance with 5C-1-7/31.15.2. The switches are to be accessible to authorized personnel only.

33 Integrated Cargo and Ballast Systems *(2004)*

33.1 Application

The following requirements are applicable to integrated cargo and ballast systems installed on tankers (i.e., cargo ships constructed primarily to carry liquid cargo in bulk) regardless of the flash point of the cargoes. The integrated cargo and ballast system means any integrated hydraulic and/or electric system used to drive both cargo and ballast pumps (including active control and safety systems but excluding passive components, e.g., piping).

33.3 Functional Requirements

The operation of cargo and/or ballast systems may be necessary, under certain emergency circumstances or during the course of navigation, to enhance the safety of tankers. As such, measures are to be taken to prevent cargo and ballast pumps becoming inoperative simultaneously due to a single failure in the integrated cargo and ballast system, including its control and safety systems.

33.5 Design Features

The following design features are to be fitted:

i) The emergency stop circuits of the cargo and ballast systems are to be independent from the circuits for the control systems. A single failure in the control system circuits or the emergency stop circuits is not to render the integrated cargo and ballast system inoperative.

ii) Manual emergency stops of the cargo pumps are to be arranged in such a way that they do not cause the ballast pump power pack to stop and thus make the ballast pumps inoperable.

iii) The control systems are to be provided with backup power supply, which may be satisfied by a duplicate power supply from the main switchboard. The failure of any power supply is to provide audible and visible alarm activation at each location where the control panel is fitted.

iv) In the event of failure of the automatic or remote control systems, a secondary means of control is to be made available for the operation of the integrated cargo and ballast system. This is to be achieved by manual overriding and/or redundant arrangements within the control systems.

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PART

5C

CHAPTER **1 Vessels Intended to Carry Oil in Bulk (150 meters (492 feet) or more in Length)**

APPENDIX **1 Guide for Fatigue Strength Assessment of Tankers**

1 General

1.1 Note

This Guide provides a designer-oriented approach to fatigue strength assessment which may be used for certain structural details in lieu of more elaborate methods such as spectral fatigue analysis. The term "assessment" is used here to distinguish this approach from the more elaborate analysis.

The criteria in this Guide are developed from various sources, including the Palmgren-Miner linear damage model, S-N curve methodologies, a long-term environment data of the North-Atlantic Ocean (Walden's Data), etc., and assume workmanship of commercial marine quality acceptable to the Surveyor. The capacity of structures to resist fatigue is given in terms of permissible stress range to allow designers the maximum flexibility possible.

While this is a simplified approach, a good amount of effort is still required in applying these criteria to the actual design. For this reason, PC-based software has been developed and is available to the clients. Interested parties are kindly requested to contact the nearest ABS plan approval office for more information.

1.3 Applicability *(1995)*

The criteria in this Guide are specifically written for tankers to which Part 5C, Chapter 1 is applicable.

1.5 Loadings *(1995)*

The criteria have been written for ordinary wave-induced motions and loads. Other cyclic loadings, which may result in significant levels of stress ranges over the expected lifetime of the vessel, are also to be considered by the designer.

Where it is known that a vessel will be engaged in long-term service on a route with a more severe environment (e.g., along the west coast of North America to Alaska), the fatigue strength assessment criteria in this Guide are to be modified, accordingly.

1.7 Effects of Corrosion *(1995)*

To account for the mean wastage throughout the service life, the total stress range calculated using the net scantlings (i.e., deducting nominal design corrosion values, see 5C-1-2/Table 1) is modified by a factor C_f See 5C-1-A1/9.1.1.

1.9 Format of the Criteria *(1995)*

The criteria in this Guide are presented as a comparison of fatigue strength of the structure (capacity) and fatigue inducing loads (demands), as represented by the respective stress ranges. In other words, the permissible stress range is to be not less than the total stress range acting on the structure.

5C-1-A1/5 provides the basis to establish the permissible stress range for the combination of the fatigue classification and typical structural joints of tankers. 5C-1-A1/7 presents the procedures to be used to establish the applied total stress range. 5C-1-A1/11 provides typical stress concentration factors (SCFs) and guidelines for direct calculation of the required SCFs. 5C-1-A1/13 provides the guidance for assessment of stress concentration factors and the selection of compatible S-N data where a fine mesh finite element approach is used.

3 Connections to be Considered for the Fatigue Strength Assessment

3.1 General *(1995)*

These criteria have been developed to allow consideration of a broad variation of structural details and arrangements, so that most of the important structural details anywhere in the vessel can be subjected to an explicit (numerical) fatigue assessment using these criteria. However, where justified by comparison with details proven satisfactory under equal or more severe conditions, an explicit assessment can be exempted.

3.3 Guidance on Locations *(1995)*

As a general guidance for assessing fatigue strength for a tanker, the following connections and locations should be considered:

3.3.1 Connections of Longitudinal Stiffeners to Transverse Web/Floor and to Transverse Bulkhead

3.3.1(a) Two (2) to three (3) selected side longitudinals in the region from the 1.1 draft to about $^1/_3$ draft in the midship region and also in the region between 0.15L and 0.25L from F.P., respectively

3.3.1(b) One (1) to two (2) selected longitudinals from each of the following groups:

- Deck longitudinals, bottom longitudinals, inner bottom longitudinals and longitudinals on side longitudinal bulkheads
- One longitudinal on each of the longitudinal bulkheads within 0.1D from the deck is to be included

For these structural details, the fatigue assessment is to be first focused on the flange of the longitudinal at the rounded toe welds of attached flat bar stiffeners and brackets, as illustrated for Class F item 2) and Class F_2 item 1) in 5C-1-A1/Table 1.

Then, the critical spots on the web plate cut-out, on the lower end of the stiffener as well as the weld throat are also to be checked for the selected structural detail. For illustration, see 5C-1-A1/11.3.1 and 5C-1-A1/11.3.2(a), 5C-1-A1/11.3.2(b) and 5C-1-A1/11.3.2(c).

Where the longitudinal stiffener end bracket arrangements are different on opposing sides of a transverse web, both configurations are to be checked.

3.3.2 Shell, Bottom, Inner Bottom or Bulkhead Plating at Connections to Webs or Floors (for Fatigue Strength of Plating)

3.3.2(a) One (1) to two (2) selected locations of side shell plating near the summer LWL amidships and between 0.15L and 0.25L from F.P. respectively

3.3.2(b) One (1) to two (2) selected locations in way of bottom and inner bottom amidships

3.3.2(c) One (1) to two (2) selected locations of lower strakes of side longitudinal bulkhead amidships

3.3.3 Connections of the Slope Plate to Inner Bottom and Side Longitudinal Bulkhead Plating at the Lower Cargo Tank Corners

One selected location amidships at transverse web and between webs, respectively

For this structural detail, the value of f_R, the total stress range as specified in 5C-1-A1/9.1, is to be determined from fine mesh F.E.M. analyses for the combined load cases, as specified for Zone B in 5C-1-A1/7.5.2.

3.3.4 End bracket Connections for Transverses and Girders

One (1) to two (2) selected locations in the midship region for each type of bracket configuration

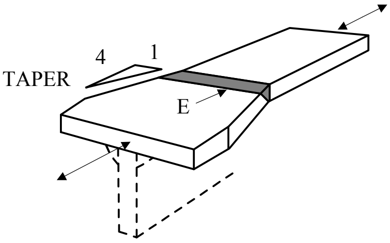
3.3.5 Other Regions and Locations

Other regions and locations, highly stressed by fluctuating loads, as identified from structural analysis.

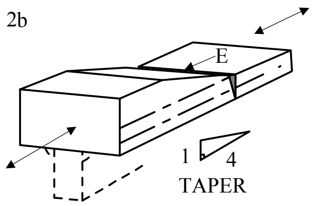
TABLE 1
Fatigue Classification for Structural Details *(1995)*

Class Designation	*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* *kgf/mm²*
B	Parent materials, plates or shapes as-rolled or drawn, with no flame-cut edges	0.7	92.2*
		0.8	75.9
		0.9	64.2
		1.0	55.6
C	1) Parent material with automatic flame-cut edges	0.7	79.2
	2) Full penetration seam welds or longitudinal fillet welds made by an automatic submerged or open arc process, and with no stop-start positions within the length	0.8	63.9
		0.9	53.3
		1.0	45.7
D	1) Full penetration butt welds between plates of equal width and thickness made either manually or by an automatic process other than submerged arc, from both sides, in downhand position	0.7	59.9
		0.8	47.3
		0.9	38.9
	2) Welds in C-2) with stop-start positions within the length	1.0	32.9
E	1) Full penetration butt welds made by other processes than those specified under D-1)	0.7	52.8
		0.8	41.7
	2) Full penetration butt welds made from both sides between plates of unequal widths machined to a smooth transition with a slope not more than 1 in 4. Plates of different thickness are to be likewise machined with a slope not more than 1 in 3, unless a transition within the weld bead is approved.	0.9	34.2
		1.0	29.0

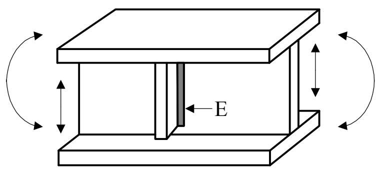
2a



2b



3) Welds of brackets and stiffeners to web plate of girders

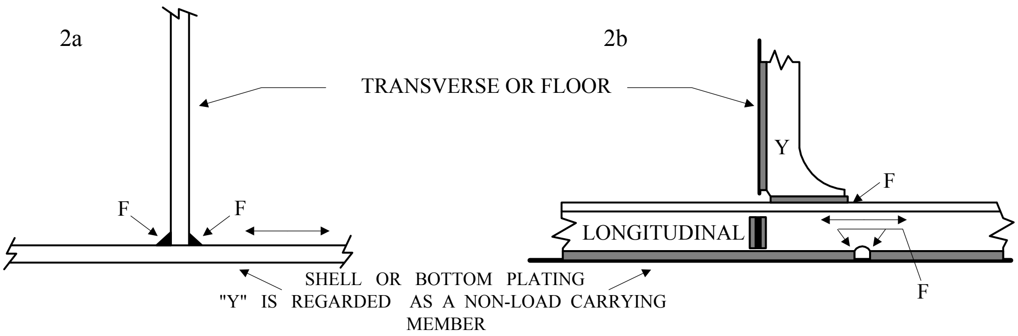


*1) The permissible stress range cannot be taken greater than two times the specified minimum tensile strength of the material.

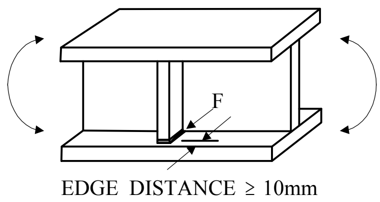
2) To obtain the permissible stress range in SI and U.S. Units, the conversion factors of 9.807 (N/mm²) and 1422 (lbf/in²), respectively, may be used.

TABLE 1 (continued)
Fatigue Classification for Structural Details *(1995)*

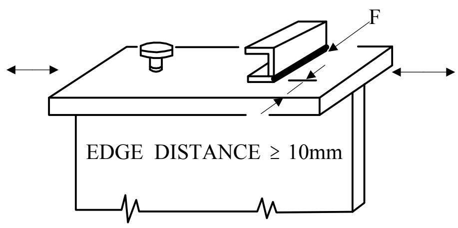
Class Designation	*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* kgf/mm^2
F	1) Full penetration butt welds made on a permanent backing strip between plates of equal width/thickness or between plates of unequal width/thicknesse, as specified in E-2. 2) Rounded fillet welds as shown below	0.7	44.7
		0.8	35.3
		0.9	29.0
		1.0	24.5



3) Welds of brackets and stiffeners to flanges



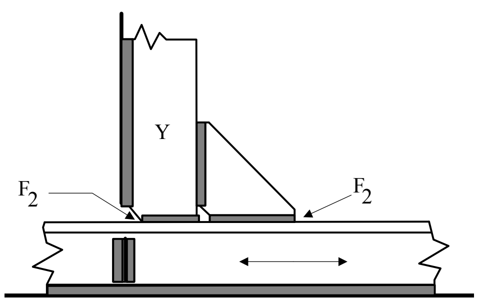
4) Attachments on plate or face plate

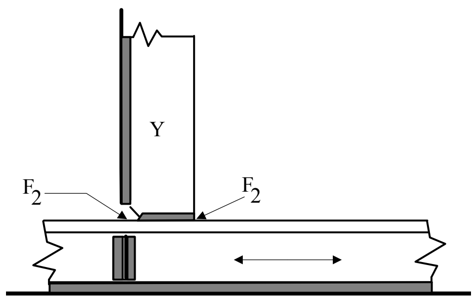


(Class G for edge distance < 10 mm)

TABLE 1 (continued)
Fatigue Classification for Structural Details *(1995)*

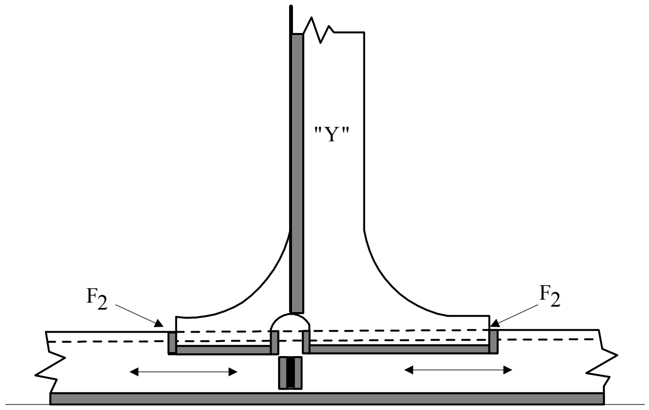
Class Designation	*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* kgf/mm^2
F_2	1) Fillet welds as shown below with rounded welds and no undercutting	0.7	39.3
		0.8	31.1
		0.9	25.5
		1.0	21.6



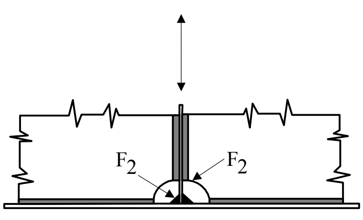


"Y" is a non-load carrying member

2) Overlapped joints with soft-toe brackets as shown below



3) Fillet welds with any undercutting at the corners dressed out by local grinding



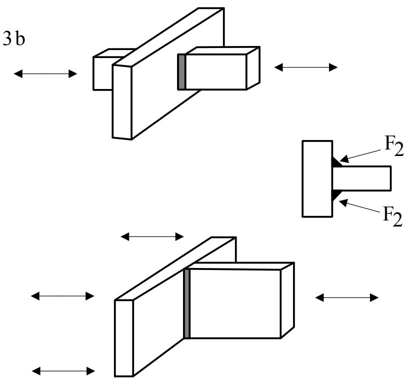
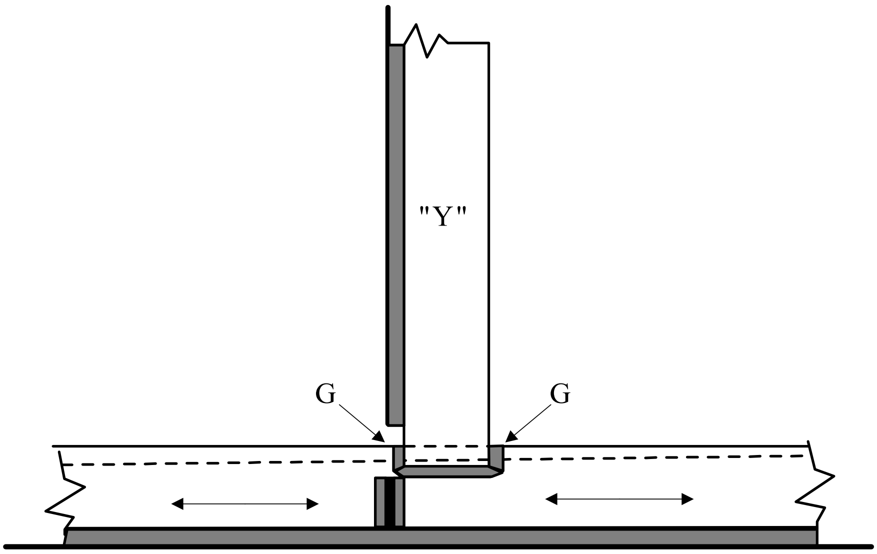


TABLE 1 (continued) Fatigue Classification for Structural Details *(1995)*

Class Designation	*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* kgf/mm^2
G	1) Fillet welds in $F_2 - 1$) without rounded toe welds or with limited minor undercutting at corners or bracket toes	0.7	32.8
		0.8	25.9
	2) Overlapped joints as shown below	0.9	21.3
		1.0	18.0



3) Fillet welds in $F_2 - 3$) with minor undercutting
4) Doubler on face plate or flange

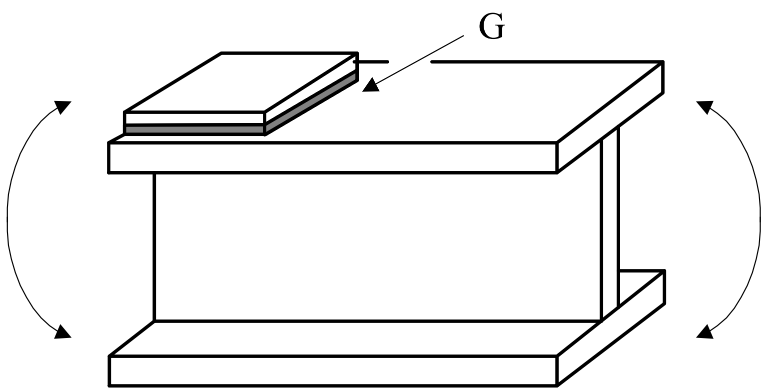
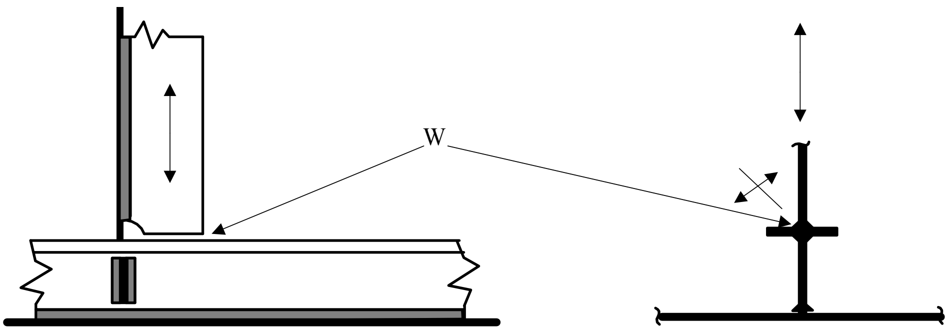


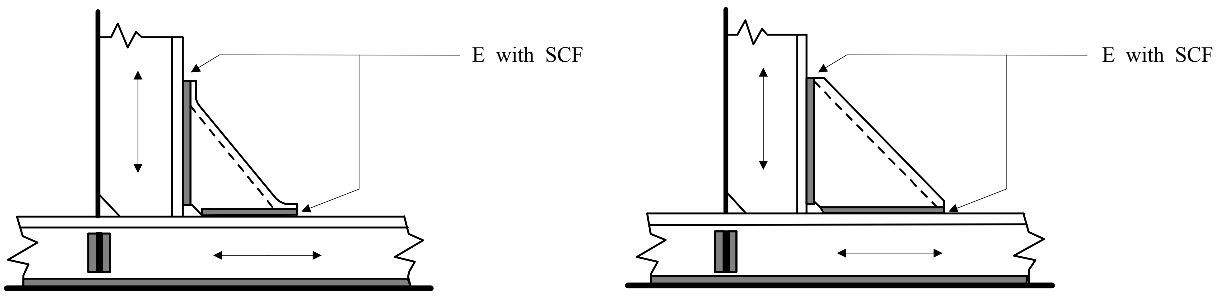
TABLE 1 (continued)
Fatigue Classification for Structural Details *(1995)*

Class Designation	*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* *kgf/mm²*
W	Fillet welds-weld throat	0.7	28.3
		0.8	22.3
		0.9	18.4
		1.0	15.5



Notes:

1 For brackets connecting two or more load carrying members, an appropriate stress concentration factor (SCF) determined from fine mesh 3D or 2D finite element analysis is to be used. In this connection, the fatigue class at bracket toes may be upgraded to class E as shown below.



2 Additional information on stress concentration factors and the selection of compatible S-N data is given in 5C-1-A1/11.

5 Permissible Stress Range

5.1 Assumptions *(1995)*

The fatigue strength of a structural detail under the loads specified here, in terms of a long-term, permissible stress range, is to be evaluated using the criteria contained in this section. The key assumptions employed are listed below for guidance.

- A linear cumulative damage model (i.e., Palmgren-Miner's Rule) has been used in connection with the S-N data in 5C-1-A1/Figure 1 (extracted from Ref. 1*).
- Cyclic stresses due to the loads in 5C-1-A1/7 have been used and the effects of mean stress have been ignored.
- The target design life of the vessel is taken at 20 years.
- The long-term stress ranges on a detail can be characterized using a modified Weibull probability distribution parameter (γ).
- Structural details are classified and described in 5C-1-A1/Table 1, "Fatigue Classification of Structural Details".
- Simple nominal stress (e.g., determined by P/A and M/SM) is the basis of fatigue assessment, rather than more localized peak stress in way of weld.

* Ref 1: "Offshore Installations: Guidance on Design, Construction and Certification", Department of Energy, U.K., Fourth Edition—1990, London: HMSO

The structural detail classification in 5C-1-A1/Table 1 is based on joint geometry and direction of the dominant load. Where the loading or geometry is too complex for a simple classification, a finite element analysis of the details is to be carried out to determine stress concentration factors. 5C-1-A1/13 contains guidance on finite element analysis modeling to determine stress concentration factors for weld toe locations that are typically found at longitudinal stiffener end connections.

5.3 Criteria *(1995)*

The permissible stress range obtained using the criteria in 5C-1-A1/5 is to be not less than the fatigue inducing stress range obtained from 5C-1-A1/7.

5.5 Long Term Stress Distribution Parameter, γ *(2002)*

In 5C-1-A1/Table 1, the permissible stress range is given as a function of the long-term distribution parameter, γ, as defined below.

$$\gamma = 1.40 - 0.2\alpha L^{0.2} \quad \text{for } 150 < L < 305 \text{ m}$$

$$= 1.40 - 0.16\alpha L^{0.2} \quad \text{for } 492 < L < 1000 \text{ ft}$$

$$\gamma = 1.54 - 0.245\alpha^{0.8} L^{0.2} \quad \text{for } L > 305 \text{ m}$$

$$= 1.54 - 0.19\alpha^{0.8} L^{0.2} \quad \text{for } L > 1000 \text{ ft}$$

where

α	=	1.0 for deck structures, including side shell and longitudinal bulkhead structures within 0.1D from the deck
	=	0.93 for bottom structures, including inner bottom and side shell, and longitudinal bulkhead structures within 0.1D from the bottom
	=	0.86 for side shell and longitudinal bulkhead structures within the region of 0.25D upward and 0.3D downward from the mid-depth
	=	0.80 for transverse bulkhead structures

α may be linearly interpolated for side shell and longitudinal bulkhead structures between 0.1D and 0.25D (0.2D) from the deck (bottom).

L and D are the vessel's length and depth, as defined in 3-1-1/3.1 and 3-1-1/7.

5.7 Permissible Stress Range *(1995)*

5C-1-A1/Table 1 contains a listing of the permissible stress ranges, PS, for various categories of structural details with 20-year minimum design fatigue life. The permissible stress range is determined for the combination of the types of connections/details, the direction of dominant loading and the parameter, γ, as defined in 5C-1-A1/5.5. Linear interpolation may be used to determine the values of permissible stress range for a value of γ between those given.

(2003) For vessels designed for a fatigue life in excess of the minimum design fatigue life of 20 years (see 5C-1-1/1.2), the permissible stress ranges, PS, calculated above are to be modified by the following equation:

$$PS[Y_r] = C(20/Y_r)^{1/m}\, PS$$

where

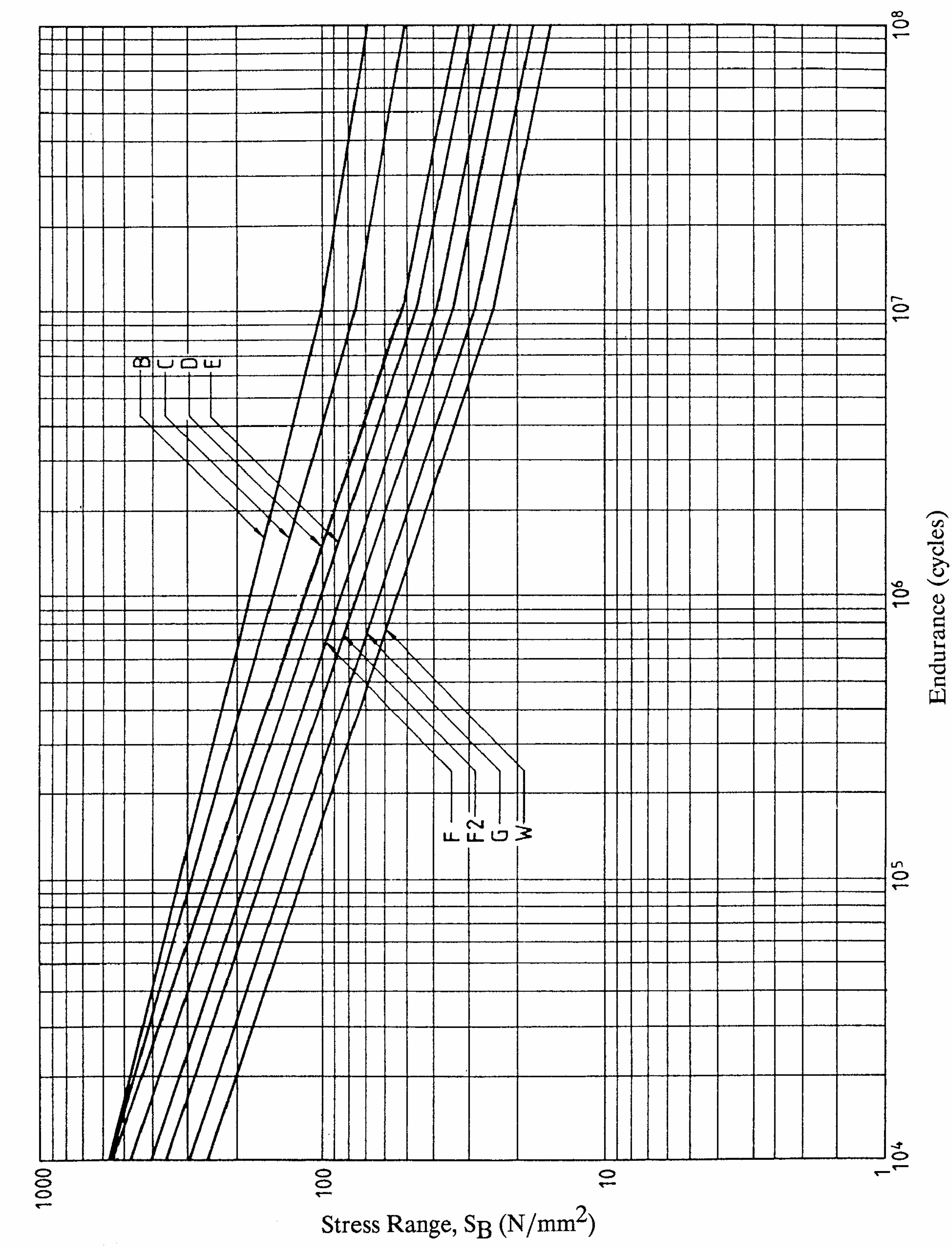
$PS[Y_r]$	=	permissible stress ranges for the target design fatigue life of Y_r
Y_r	=	target value in years of "design fatigue life" set by the applicant in five (5) year increments
m	=	3 for Class D through W of S-N curve, 3.5 for Class C or 4 for Class B curves
C	=	correction factor related to target design fatigue life considering the two-segment S-N curves (see 5C-1-A1/Table 1A).

TABLE 1A
Coefficient, C

Long-term stress distribution parameter γ	*Target Design Fatigue Life, years* Y_r	*S-N Curve Classes*		
		B	*C*	*D through W*
0.7	20	1.000	1.000	1.000
	30	1.004	1.006	1.011
	40	1.007	1.012	1.020
	50	1.010	1.016	1.028
0.8	20	1.000	1.000	1.000
	30	1.005	1.008	1.014
	40	1.009	1.015	1.025
	50	1.013	1.021	1.035
0.9	20	1.000	1.000	1.000
	30	1.006	1.010	1.016
	40	1.012	1.019	1.030
	50	1.017	1.026	1.042
1.0	20	1.000	1.000	1.000
	30	1.008	1.012	1.019
	40	1.015	1.022	1.035
	50	1.020	1.031	1.049

Note: Linear interpolations may be used to determine the values of C where Y_r = 25, 35 and 45

FIGURE 1
Basic Design S-N Curves *(1995)*



Notes (For 5C-1-A1/Figure 1)

a) Basic design S-N curves

The basic design curves consist of linear relationships between $\log(S_B)$ and $\log(N)$. They are based upon a statistical analysis of appropriate experimental data and may be taken to represent two standard deviations below the mean line.

Thus the basic S-N curves are of the form:

$$\log(N) = \log(K_2) - m \log(S_B)$$

where

$$\log(K_2) = \log(K_1) - 2\sigma$$

N is the predicted number of cycles to failure under stress range S_B;

K_1 is a constant relating to the mean S-N curve;

σ is the standard deviation of log N;

m is the inverse slope of the S-N curve.

The relevant values of these terms are shown in the table below.

The S-N curves have a change of inverse slope from m to $m + 2$ at $N = 10^7$ cycles.

Details of basic S-N curves

Class	K_1	K_1 $\log_{10}$	K_1 $\log_e$	m	*Standard deviation* $\log_{10}$	*Standard deviation* $\log_e$	K_2
B	2.343×10^{15}	15.3697	35.3900	4.0	0.1821	0.4194	1.01×10^{15}
C	1.082×10^{14}	14.0342	32.3153	3.5	0.2041	0.4700	4.23×10^{13}
D	3.988×10^{12}	12.6007	29.0144	3.0	0.2095	0.4824	1.52×10^{12}
E	3.289×10^{12}	12.5169	28.8216	3.0	0.2509	0.5777	1.04×10^{12}
F	1.726×10^{12}	12.2370	28.1770	3.0	0.2183	0.5027	0.63×10^{12}
F_2	1.231×10^{12}	12.0900	27.8387	3.0	0.2279	0.5248	0.43×10^{12}
G	0.566×10^{12}	11.7525	27.0614	3.0	0.1793	0.4129	0.25×10^{12}
W	0.368×10^{12}	11.5662	26.6324	3.0	0.1846	0.4251	0.16×10^{12}

7 Fatigue Inducing Loads and Determination of Total Stress Ranges

7.1 General *(1995)*

This section provides: 1) the criteria to define the individual load components considered to cause fatigue damage (see 5C-1-A1/7.3); 2) the load combination cases to be considered for different regions of the hull containing the structural detail being evaluated (see 5C-1-A1/7.5); and 3) procedures to idealize the structural components to obtain the total stress range acting on the structure.

7.3 Wave-induced Loads – Load Components *(1995)*

The fatigue-inducing load components to be considered are those induced by the seaway. They are divided into the following three groups:

- Hull girder wave-induced bending moments (both vertical and horizontal), see 3-2-1/3.5 and 5C-1-3/5.1.
- External hydrodynamic pressures, and
- Internal tank loads (inertial liquid loads and added static head due to ship's motion).

7.5 Fatigue Assessment Zones and Controlling Load Combination *(1995)*

Depending on the location of the structural details undergoing the fatigue assessment, different combinations of load cases are to be used to find the appropriate stress range, as indicated below for indicated respective zones.

7.5.1 Zone A

Zone A consists of deck and bottom structures, and side shell and longitudinal bulkhead structures within 0.1D (D is vessel's molded depth) from deck and bottom, respectively. For Zone A, stresses are to be calculated based on the wave-induced loads specified in 5C-1-3/Table 1, as follows.

7.5.1(a) Calculate dynamic component of stresses for load cases LC1 through LC4, respectively.

7.5.1(b) Calculate two sets of stress ranges, one each for the following two pairs of combined loading cases.

LC1 and LC2, and

LC3 and LC4

7.5.1(c) Use the greater of the stress ranges obtained by 5C-1-A1/7.5.1(b).

7.5.2 Zone B

Zone B consists of side shell and longitudinal bulkhead structures within the region between 0.25 upward and 0.30 downward from the mid-depth and all transverse bulkhead structures. The total stress ranges for Zone B may be calculated based on the wave-induced loads specified in 5C-1-3/Table 1, as follows:

7.5.2(a) Calculate dynamic component of stresses for load cases LC5 through LC8, respectively.

7.5.2(b) Calculate two sets of stress ranges, one each for the following two pairs of combined loading cases.

LC5 and LC6, and

LC7 and LC8

7.5.2(c) Use the greater of the stress ranges obtained by 5C-1-A1/7.5.2(b).

7.5.3 Transitional Zone

Transitional zone between A and B consists of side shell and longitudinal bulkhead structures between 0.1D and 0.25D (0.2D) from deck (bottom).

$$f_R = f_{R(B)} - [f_{R(B)} - f_{R(A)}]\, y_u / 0.15D \qquad \text{for upper transitional zone}$$

$$f_R = f_{R(B)} - [f_{R(B)} - f_{R(A)}]\, y_\ell / 0.1D \qquad \text{for lower transitional zone}$$

where

$f_{R(A)}, f_{R(B)}$ = the total stress range based on the combined load cases defined for Zone A or Zone B, respectively

y_u, y_ℓ = vertical distances from 0.25D (0.3D) upward (downward) from the mid-depth to the location considered

7.5.4 Vessels with Either Special Loading Patterns or Special Structural Configuration

For vessels with either special loading patterns or special structural configurations/features, additional load cases may be required for determining the stress range.

7.7 Primary Stress f_{d1} *(1995)*

f_{d1v} and f_{d1h} may be calculated by a simple beam approach. For assessing fatigue strength of side shell and longitudinal bulkhead plating at welded connections, the value of wave-induced primary stress is to be taken as that of maximum principal stress at the location considered to account for the combined load effects of the direct stresses and shear stresses. For calculating the value of f_{d1v} for longitudinal deck members, normal camber may be disregarded.

7.9 Secondary Stress f_{d2}

f_{d2} may be obtained from orthotropic plating or grillage methods with appropriate boundary conditions.

For those connections specified in 5C-1-A1/3.3.1, the wave-induced secondary bending stress f_{d2} may be ignored.

7.11 Additional Secondary Stresses f^*_{d2} and Tertiary Stresses f_{d3}

7.11.1 Calculation of f^*_{d2} *(1 July 2005)*

Where required, the additional secondary stresses acting at the flange of a longitudinal stiffener, f^*_{d2}, may be approximated by

$$f^*_{d2} = C_t C_y M/SM \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

$M = C_d p s \ell^2/12$ N-cm (kgf-cm, lbf-in), at the supported ends of longitudinal

Where flat bar stiffeners or brackets are fitted, the bending moment, M, given above, may be adjusted to the location of the bracket's toe, i.e., M_X in 5C-1-4/Figure 6.

Where a longitudinal has remarkably different support stiffness at its two ends (e.g., a longitudinal connected to a transverse bulkhead on one end), considerations should be given to the increase of bending moment at the joint.

C_d = 1.15 for longitudinal stiffener connections at the transverse bulkhead for all longitudinals

= 1.0 elsewhere

p = wave-induced local net pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), for the specified location and load cases at the mid-span of the longitudinal considered

s = spacing of longitudinal stiffener, in cm (in.)

ℓ = unsupported span of longitudinal/stiffener, in cm (in.), as shown in 5C-1-4/Figure 5

SM = net section modulus of longitudinal with the associated effective plating, in cm^3 (in^3), at flange or point considered. The effective breadth, b_e, in cm (in.), may be determined as shown in 5C-1-4/Figure 6.

C_y = $0.656(d/z)^4$ for side shell longitudinals only where $z/d \geq 0.9$, but $C_y \geq 0.30$

= 1.0 elsewhere

z = distance above keel of side shell longitudinal under consideration

d = scantling draft, m (ft)

C_t = correction factor for the combined bending and torsional stress induced by lateral loads at the welded connection of the flat bar stiffener or bracket to the flange of longitudinal, as shown in 5C-1-4/Figure 5.

= $1.0 + \alpha_r$ for unsymmetrical sections, fabricated or rolled

= 1.0 for tee and flat bars

α_r = $C_n C_p SM/K$

C_p = $31.2 d_w (e/\ell)^2$

e = horizontal distance between web centerline and shear center of the cross section, including longitudinal and the effective plating

≈ $d_w b_f^2 t_f u/(2SM)$ cm (in.)

K = St. Venant torsion constant for the longitudinal's cross section, excluding the associated plating.

= $[b_f t_f^3 + d_w t_w^3]/3$ cm^4 (in^4)

C_n = coefficient given in 5C-1-A1/Figure 2, as a function of ψ, for point (1) shown in 5C-1-A2/Figure 1.

u = $1 - 2b_1/b_f$

ψ = $0.31\ell\,(K/\Gamma)^{1/2}$

Γ = warping constant

= $mI_{yf} d_w^2 + d_w^3 t_w^3/36$ cm^6 (in^6)

I_{yf} = $t_f b_f^3 (1.0 + 3.0u^2 A_w/A_s)/12$ cm^4 (in^4)

A_w = $d_w t_w$ cm^2 (in^2)

A_s = net sectional area of the longitudinals, excluding the associated plating, cm^2 (in^2)

m = $1.0 - u(0.7 - 0.1d_w/b_f)$

d_w, t_w, b_1, b_f, t_f, all in cm (in.), are as defined in 5C-1-A2/Figure 1.

For general applications, a_r need not be taken greater than 0.65 for a fabricated angle bar and 0.50 for a rolled section.

For connection as specified in 5C-1-A1/3.3.2, the wave-induced additional secondary stress f^*_{d2} may be ignored.

7.11.2 Calculation of f_{d3}

For welded joints of a stiffened plate panel, f_{d3} may be determined based on the wave-induced local loads as specified in 5C-1-A1/7.11.1 above, using the approximate equations given below. For direct calculation, non-linear effect and membrane stresses in the plate may be considered.

For plating subjected to lateral load, f_{d3} in the longitudinal direction is determined as:

f_{d3} = $0.182p(s/t_n)^2$ N/cm^2 (kgf/cm^2, lbf/in^2)

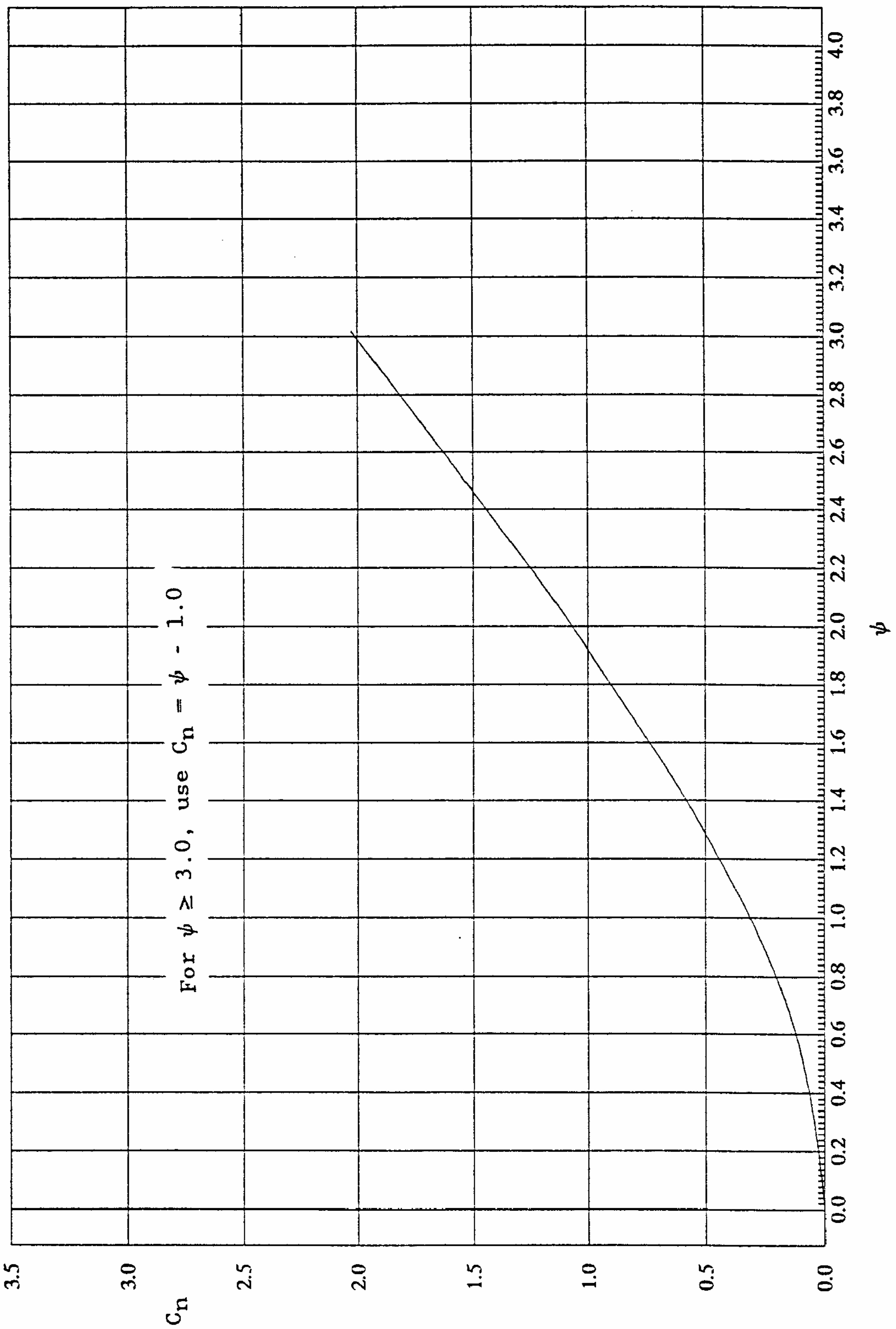
where

p = wave-induced local net pressure, in N/cm^2 (kgf/cm^2, lbf/in^2)

s = spacing of longitudinal stiffeners, in cm (in.)

t_n = net thickness of plate, in mm (in.)

FIGURE 2
$C_n = C_n\ (\psi)$ *(1995)*



9 Resulting Stress Ranges

9.1 Definitions *(1995)*

9.1.1

The total stress range, f_R, is computed as the sum of the two stress ranges, as follows:

$$f_R = c_f\,(f_{RG} + f_{RL}) \qquad \text{N/cm}^2\ (\text{kgf/cm}^2,\ \text{lbf/in}^2)$$

where

f_{RG} = global dynamic stress range, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $|(f_{d1vi} - f_{d1vj}) + (f_{d1hi} - f_{d1hj})|$

f_{RL} = local dynamic stress range, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $c_w|(f_{d2i} + f^*_{d2i} + f_{d3i}) - (f_{d2j} + f^*_{d2j} + f_{d3j})|$

c_f = adjustment factor to reflect a mean wasted condition

= 0.95

c_w = coefficient for the weighted effects of the two paired loading patterns

= 0.75

f_{d1vi}, f_{d1vj} = wave-induced component of the primary stresses produced by hull girder vertical bending, in N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively

f_{d1hi}, f_{d1hj} = wave-induced component of the primary stresses produced by hull girder horizontal bending, in N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively

f_{d2i}, f_{d2j} = wave-induced component of the secondary bending stresses produced by the bending of cross-stiffened panels between transverse bulkheads, in N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively

f^*_{d2i}, f^*_{d2j} = wave-induced component of the additional secondary stresses produced by the local bending of the longitudinal stiffener between supporting structures (e.g., transverse bulkheads and web frames), in N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively

f_{d3i}, f_{d3j} = wave-induced component of the tertiary stresses produced by the local bending of plate elements between the longitudinal stiffeners in, N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively

For calculating the wave-induced stresses, sign convention is to be observed for the respective directions of wave-induced loads, as specified in 5C-1-3/Table 1. The wave-induced local loads are to be calculated with the sign convention for the external and internal loads. However, the total of the external and internal pressures, including both static and dynamic components, need not be taken less than zero.

These wave-induced stresses are to be determined based on the net ship scantlings (see 5C-1-A1/1.3) and in accordance with 5C-1-A1/7.5 through 5C-1-A1/7.11. The results of direct calculation, where carried out, may also be considered.

11 Determination of Stress Concentration Factors (SCFs)

11.1 General *(1995)*

This section contains information on stress concentration factors (SCFs) to be considered in the fatigue assessment.

Where, for a particular example shown, no specific value of SCF is given when one is called for, it indicates that a finite element analysis is needed. When the fine mesh finite element approach is used, additional information on calculations of stress concentration factors and the selection of compatible S-N data is given in 5C-1-A1/13.

11.3 Sample Stress Concentration Factors (SCFs) *(1 July 2001)*

11.3.1 Cut-outs (Slots) for Longitudinals *(1995)*

SCFs, fatigue classifications and peak stress ranges may be determined in accordance with 5C-1-A1/Table 2 and 5C-1-A1/Figure 3.

TABLE 2
K_s (SCF) Values

	K_s (SCF)					
Configuration	*Unsymmetrical Flange*			*Symmetrical Flange*		
Location	[1]	[2]	[3]	[1]	[2]	[3]
Single-sided Support	2.0	2.1	—	1.8	1.9	—
Single-sided Support with F.B. Stiffener	1.9	2.0	—	1.7	1.8	—
Double-sided Support	3.0	2.6	2.4	2.7	2.4	2.2
Double-sided Support with F.B. Stiffener	2.8	2.5	2.3	2.5	2.3	2.1

Notes:

a The value of K_s is given, based on nominal shear stresses near the locations under consideration.

b Fatigue classification

Locations [1] and [2]: Class C or B as indicated in 5C-1-A1/Table 1

Location [3]: Class F

c The peak stress range is to be obtained from the following equations:

1 For locations [1] and [2] *(1999)*

$$f_{Ri} = c_f\,[K_{si} f_{si} + f_{ni}]$$

where

c_f = 0.95

f_{si} = $f_{sc} + \alpha_i f_{swi}$, $f_{si} \geq f_{sc}$

α_i = 1.8 for single-sided support

= 1.0 for double-sided support

f_{ni} = normal stress range in the web plate

f_{swi} = shear stress range in the web plate

= F_i/A_w

F_i is the calculated web shear force range at the location considered. A_w is the area of web.

f_{sc} = shear stress range in the support (lug or collar plate)

= $C_y P/(A_c + A_s)$

C_y is as defined in 5C-1-A1/7.11.1.

P = $s\ell p_o$

p_o = fluctuating lateral pressure

A_c	=	sectional area of the support or of both supports for double-sided support
A_s	=	sectional area of the flat bar stiffener, if any
K_{si}	=	SCFs given above
s	=	spacing of longitudinal/stiffener
ℓ	=	spacing of transverses

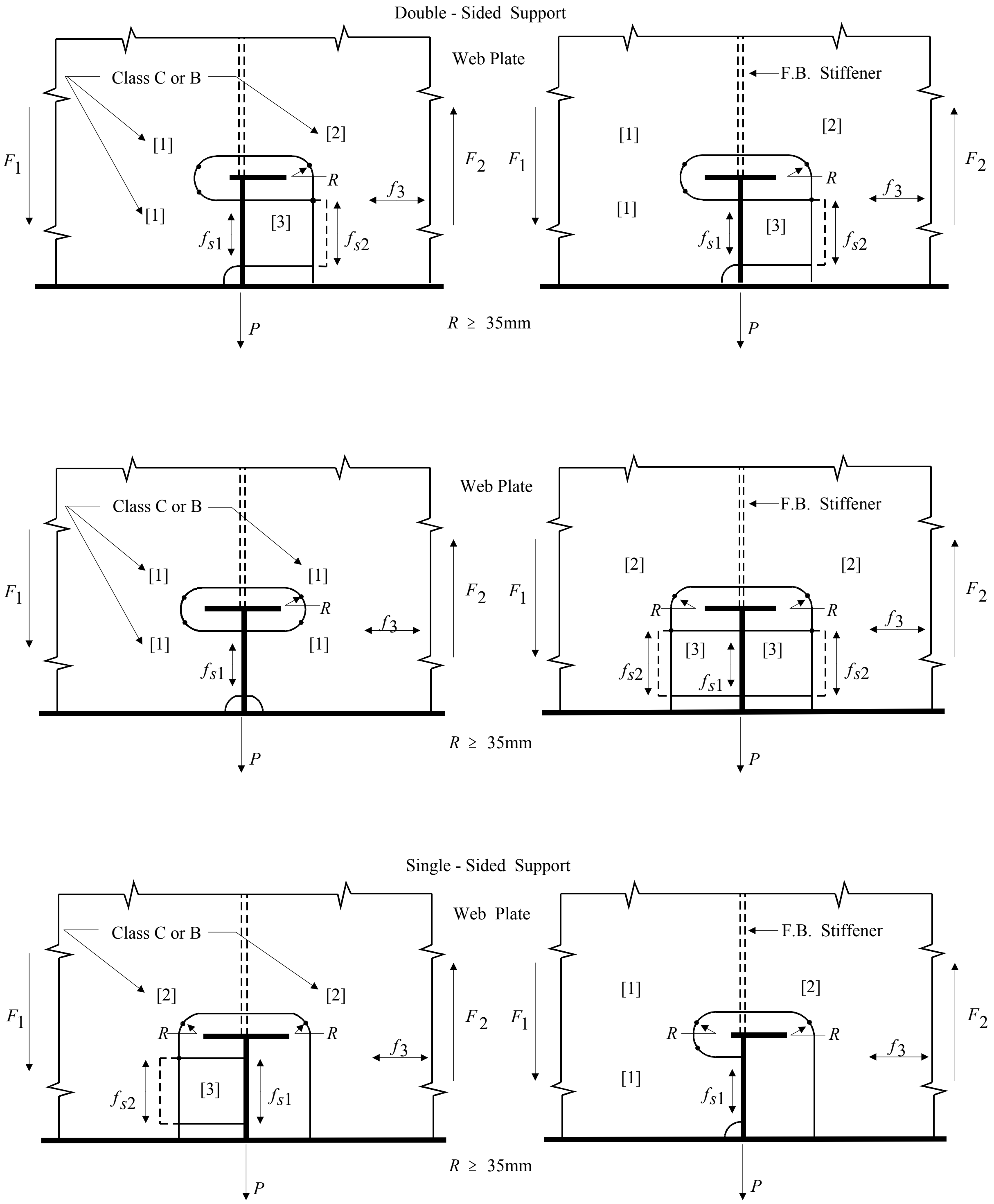
2 For location [3]

$$f_{R3} = c_f[f_{n3}^2 + (K_s f_{s2})^2]^{1/2}$$

where

c_f	=	0.95
f_{n3}	=	normal stress range at location [3]
f_{s2}	=	shear stress range, as defined in 1 above, near location [3].
K_s	=	SCFs given above

FIGURE 3
Cut-outs (Slots) For Longitudinal *(1995)*



11.3.2 Flat Bar Stiffener for Longitudinals *(1999)*

11.3.2(a) For assessing fatigue life of a flat bar stiffener at location [1] or [2] as shown in 5C-1-A1/Figure 4, the peak stress range is to be obtained from the following equation:

$$f_{Ri} = [(\alpha_i f_s)^2 + f_{Li}^2]^{1/2} \qquad (i = 1 \text{ or } 2)$$

where

f_s = nominal stress range in the flat bar stiffener.

= $c_f C_y P/(A_s + A_c)$

P, A_s, A_c, c_f are as defined in 5C-1-A1/11.3.1 and C_y in 5C-1-A1/7.11.1. For flat bar stiffener with soft-toed brackets, the brackets may be included in the calculation of A_s.

f_{Li} = stress range in the longitudinal at Location i (i = 1 or 2), as specified in 5C-1-A1/9

α_i = stress concentration factor at Location i (i = 1 or 2) accounting for misalignment and local distortion

At location [1]

For flat bar stiffener without brackets

α_1 = 1.50 for double-sided support connection

= 2.00 for single-sided support connection

For flat bar stiffener with brackets

α_1 = 1.00 for double-sided support connection

= 1.25 for single-sided support connection

At location [2]

For flat bar stiffener without brackets

α_2 = 1.25 for single or double-sided support connection

For flat bar stiffener with brackets

α_2 = 1.00 for single or double-sided support connection

11.3.2(b) For assessing the fatigue life of the weld throat as shown in 5C-1-A1/Table 1, Class W, the peak stress range f_R at the weld may be obtained from the following equation:

$$f_R = 1.25 f_s A_s / A_{sw}$$

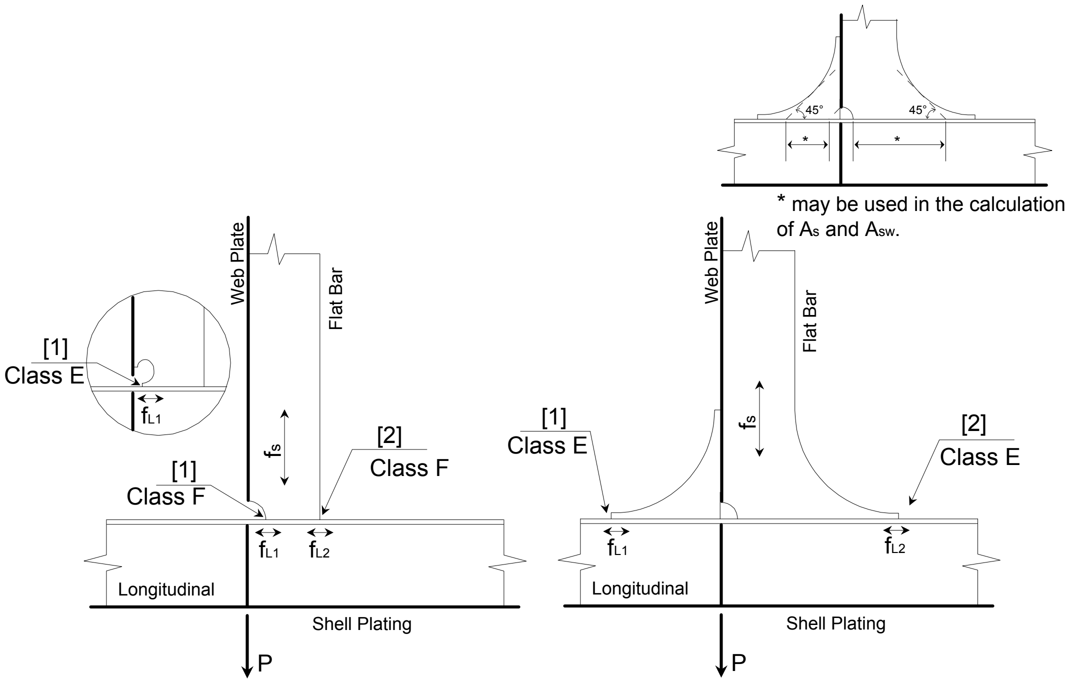
where

A_{sw} = sectional area of the weld throat. Brackets may be included in the calculation of A_{sw}.

f_s and A_s are as defined in 5C-1-A1/11.3.2(a) above.

11.3.2(c) For assessing fatigue life of the longitudinal, the fatigue classification given in 5C-1-A1/Table 1 for a longitudinal as the only load-carrying member is to be considered. Alternatively, the fatigue classification shown in 5C-1-A1/Figure 4, in conjunction with the combined stress effects, f_R, may be used. In calculation of f_R, the α_i may be taken as 1.25 for both locations [1] and [2].

FIGURE 4
Fatigue Classification for Longitudinals in way of Flat Bar Stiffener

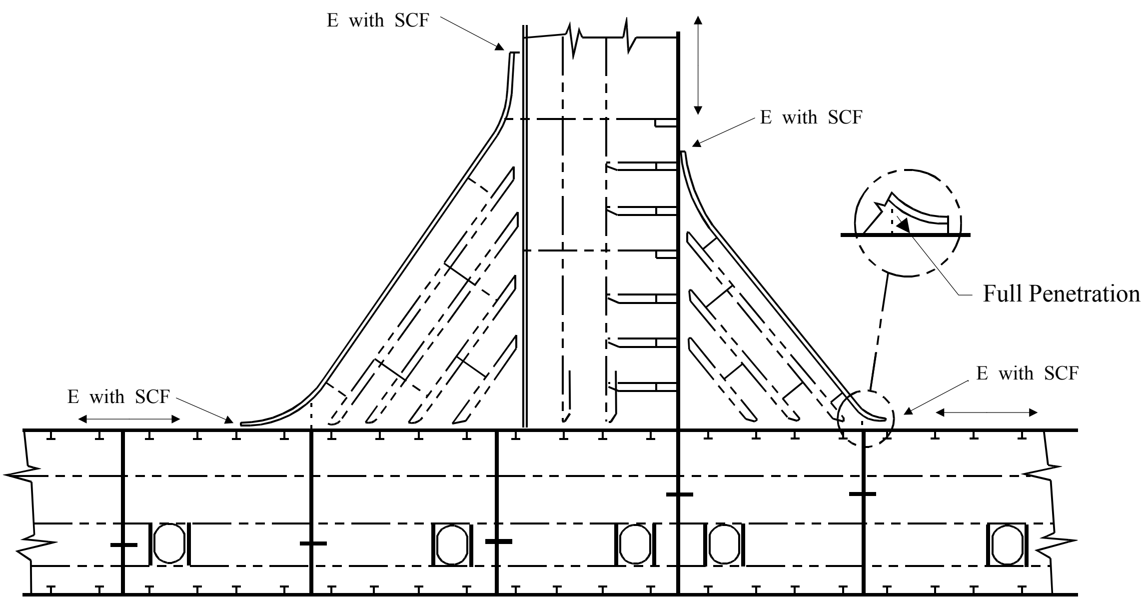


F.B. without Brackets F.B. with Brackets

11.3.3 Connection Between Transverse Bulkhead Vertical Web and Double Bottom Girder *(1995)*

Fatigue class designation and SCFs may be determined as shown in 5C-1-A1/Figure 5.

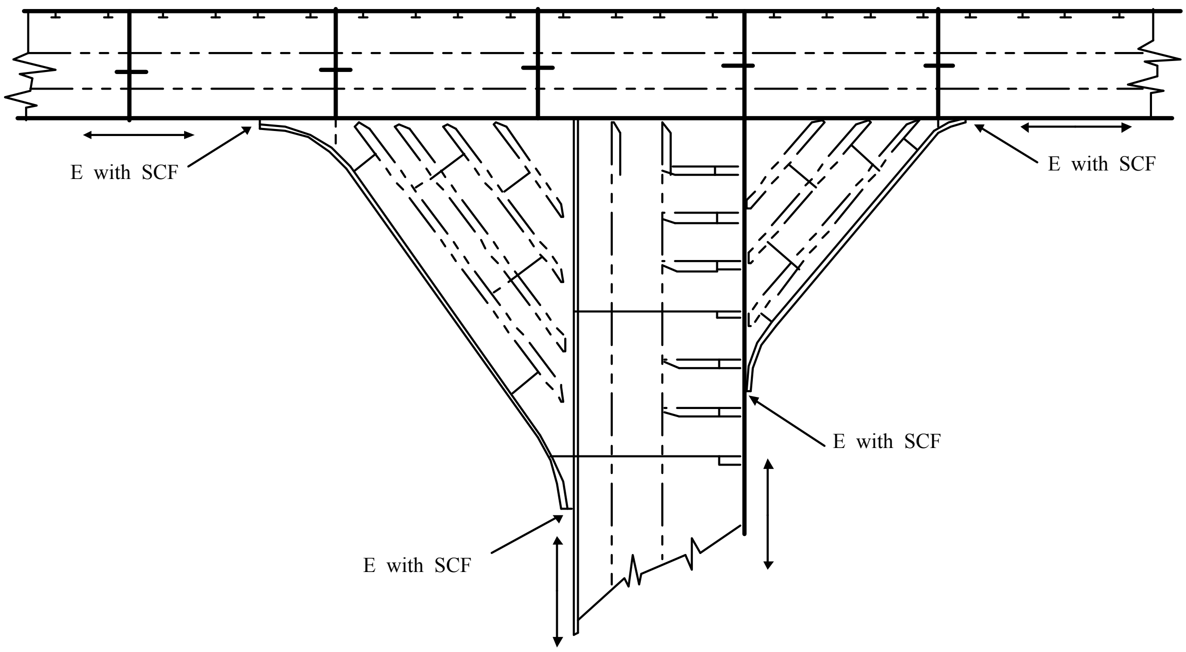
FIGURE 5



11.3.4 Connection Between Transverse Bulkhead Vertical Web and Deck Girder *(1995)*

Fatigue class designation and SCFs may be determined as shown in 5C-1-A1/Figure 6.

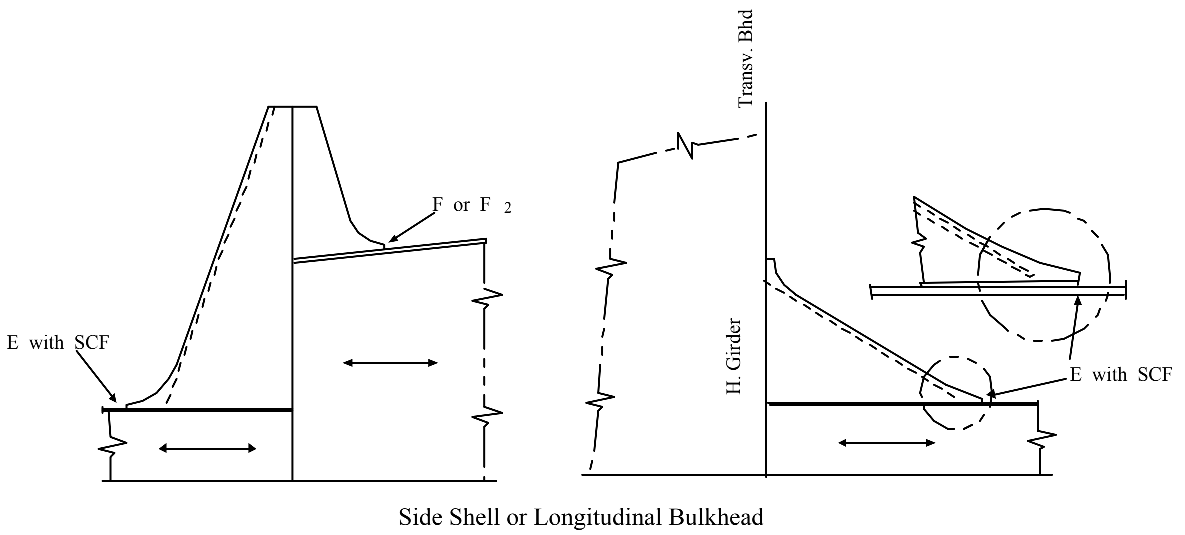
FIGURE 6



11.3.5 End Connections of Transverse Bulkhead Horizontal Girder to Longitudinal of Side Shell or Longitudinal Bulkhead *(1995)*

Fatigue class designation and SCFs may be determined as shown in 5C-1-A1/Figure 7.

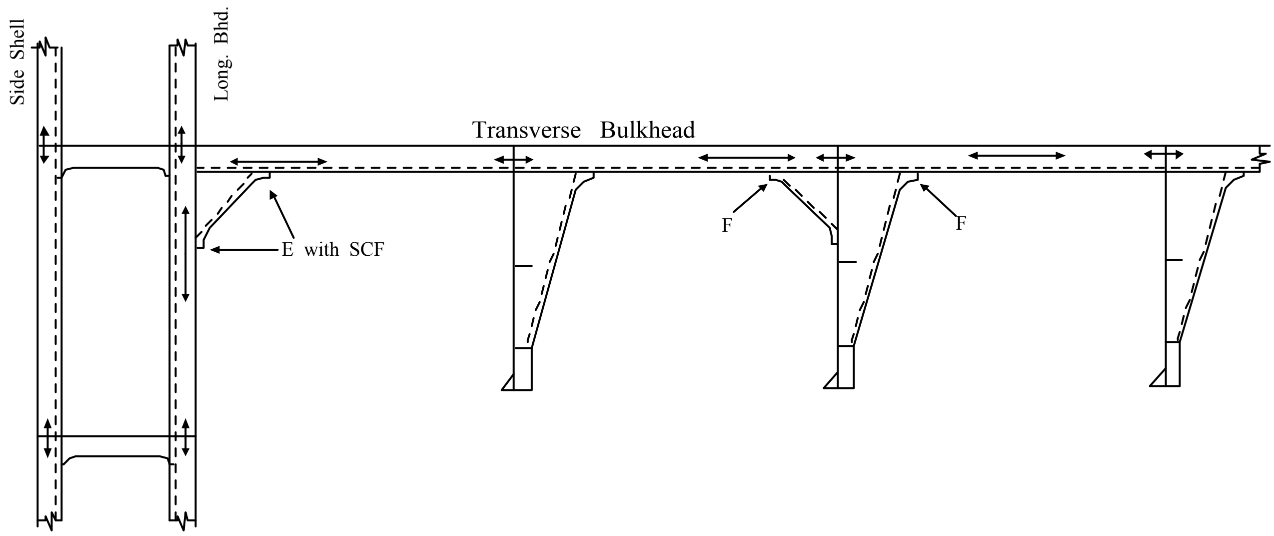
FIGURE 7



11.3.6 Connection of Transverse Bulkhead to Longitudinal Bulkhead *(1995)*

Fatigue class designation and SCFs may be determined as shown in 5C-1-A1/Figure 8.

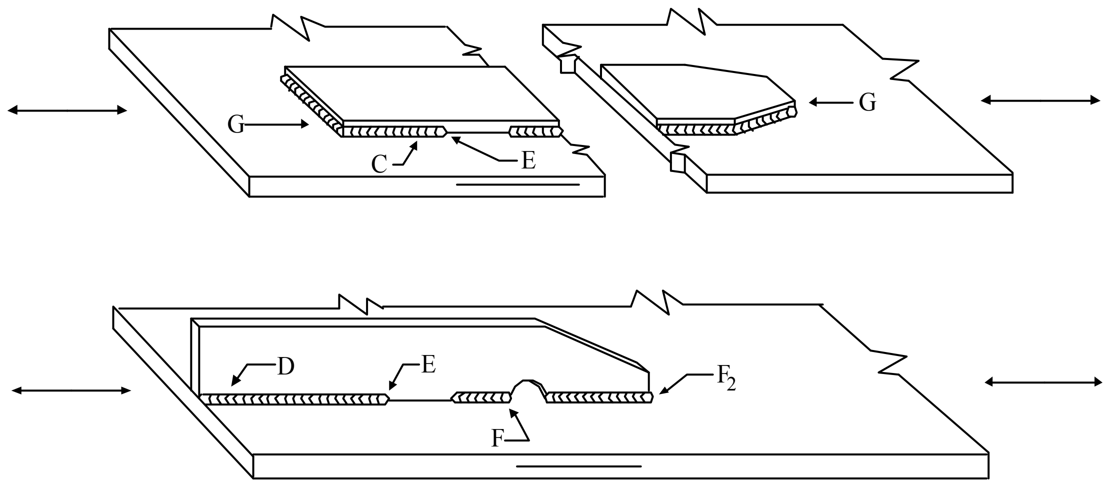
FIGURE 8



11.3.7 Doublers and Non-load Carrying Members on Deck or Shell Plating *(1995)*

Fatigue class designation may be determined as shown in 5C-1-A1/Figure 9.

FIGURE 9
Doublers and Non-load Carrying Members on Deck or Shell Plating



13 Stress Concentration Factors Determined From Finite Element Analysis

13.1 Introduction *(1995)*

S-N data and stress concentration factors (SCFs) are related to each other and therefore should be considered together so that there is a consistent basis for the fatigue assessment.

The following guidance is intended to help make correct decisions.

13.3 S-N Data *(1995)*

S-N data are presented as a series of straight-lines plotted on log-log scale. The data reflect the results of numerous tests, which often display considerable scatter. The recommended design curves for different types of structural details and welded connections recognize the scatter in test results in that the design curves have been based on the selection of the lower bound, 95% confidence limit. In other words, about 2.5% of the test failure results fall below this curve. Treating the design curve in this manner introduces a high, yet reasonable degree of conservatism in the design and fatigue evaluation processes.

Individual S-N curves are presented to reflect certain generic structural geometry or arrangements. 5C-1-A1/Table 1 and 5C-1-A1/11.3 contain sketches of weld connections and other details typically found in ship structures, giving a list of the S-N classification. This information is needed to assess the fatigue strength of a detail. Also needed is a consistent way to establish the demands or load effects placed on the detail, so that a compatible assessment can be made of the available strength versus the demand. Here is where interpretation and judgment enter the fatigue assessment.

S-N curves are obtained from laboratory sample testing. The applied reference stress on the sample which is used to establish the S-N data is referred to as the nominal stress. The nominal stress is established in a simple manner, such as force divided by area and bending moment divided by section modulus (P/A & M/SM). The structural properties used to establish the nominal stress are taken from locations away from any discontinuities to exclude local stress concentration effects arising from the presence of a weld or other local discontinuity. In an actual structure, it is rare that a match will be found with the tested sample geometry and loading. One is then faced with the problem of making the appropriate interpretation.

13.5 S-N Data and SCFs *(2003)*

Selection of appropriate S-N data appears to be rather straightforward with respect to "standard details" offered in 5C-1-A1/Table 1 or other similar reference. However, in the case of welded connections in complex structures, it is required that SCFs be used to modify the nominal stress range. An often quoted example of the need to modify nominal stress for fatigue assessment purposes is one shown in 5C-1-A1/Figure 10 below, relating to a hole drilled in the middle of a flat plate traversed by a butt weld.

In this example, the nominal stress S_N is P/Area, but the stress to be used to assess the fatigue strength at point A is S_A or $S_N \cdot$ SCF. This example is deceptively simple because it does not tell the entire story. The most obvious deficiency of the example is that one needs to have a definitive and consistent basis to obtain the SCF. There are reference books which indicate that based on the theory of elasticity, the SCF to be applied in this case is 3.0. However, when the SCF is computed using the finite element analysis techniques, the SCF obtained can be quite variable depending on the mesh size. The example does not indicate which S-N curve should be applied, nor does the example say how it may be necessary to alter the selection of the design S-N data in consideration of the aforementioned finite element analysis issues. Therefore, if such interpretation questions exist for a simple example, the higher difficulty of appropriately treating more complex structures should be evident.

Referring to the S-N curves to be applied to welded connections (for example, S-N curves D-W in 5C-1-A1/Figure 1), the SCFs resulting from the presence of the weld itself are already accounted for in these curves. If one were to have the correct stress distribution in the region – from the weld to a location sufficiently away from the weld toe (where the stress is suitably established by the nominal stress obtained from P/A and M/SM) – the stress distribution may be generically separated into three distinct segments, as shown in 5C-1-A1/Figure 11 below.

- Region III is a segment where the stress gradient is controlled by the nominal stress gradient.
- Region II is a segment where the nominal stress gradient is being modified due to the presence of other structure, such as the bracket end shown in the figure. This must be accounted for to obtain an appropriate stress to be used in the fatigue analysis at the weld toe.
- Region I is a segment where the stress gradient is being modified due to the presence of the weld metal itself. The stress concentration due to the weld is already accounted for in the S-N design curve and will not be discussed further. Since the typical way to determine the stress distribution is via planar/linear elements which ignore the weld, this is consistent with the method of analysis.

This general description of the stress distribution is again inconclusive because one does not know in advance and with certainty the distances from the weld toe to where the indicated changes of slope for the stress gradient occur. For this reason, definite rules need to be established to determine the slopes, and with this knowledge, criteria established to be used to find the stress at the weld toe which should be used in the fatigue assessment.

In this regard, two approaches can be used to find the stress at the weld toe, which reflect two methods of structural idealization. One of these arises from the use of a conventional beam element idealization of the structure including the end bracket connection, and the other arises from the use of a fine mesh finite element idealization.

Using a beam element idealization, the nominal stress at any location (i.e., P/A and M/SM) can be obtained (see 5C-1-4/Figure 6 for a sample beam element model).

In the beam element idealization, there will be questions as to whether or not the geometric stress concentration due to the presence of other structure is adequately accounted for. This is the “Segment II” stress gradient previously described. In the beam modeling approach shown in the figure, the influence on stresses arising from the “carry over” of forces and bending moments from adjacent structural elements has been accounted for (albeit approximately). At the same time, the strengthening effect of the brackets has been conservatively ignored. Hence for engineering purposes, this approach is considered to be sufficient in conjunction with the nominal stress obtained at the location of interest and the nominal S-N curve, i.e., the F or F_2 Class S-N data, as appropriate.

In the fine mesh finite element analysis approach, one needs to define the element size to be used. This is an area of uncertainty because the calculated stress distribution can be unduly affected by both the employed mesh size and the uniformity of the mesh adjacent to the weld toe. Therefore, it is necessary to establish “rules”, as given below, to be followed in the producing of the fine mesh model adjacent to the weld toe. Furthermore, since the area adjacent to the weld toe (or other discontinuity of interest) may be experiencing a large and rapid change of stress (i.e., a high stress gradient), it is also necessary to provide a rule which can be used to establish the stress at the location where the fatigue assessment is to be made.

5C-1-A1/Figure 12 shows an acceptable method which can be used to extract and interpret the “near weld toe” element stresses and to obtain a (linearly) extrapolated stress at the weld toe. When plate or shell elements are used in the modeling, it is recommended that each element size is to be equal to the plate thickness. When stresses are obtained in this manner, the use of the E Class S-N data is considered to be acceptable.

Weld hot spot stress can be determined from linear extrapolation of surface component stresses at $t/2$ and $3t/2$ from weld toe. The principal stresses at hot spot are then calculated based on the extrapolated stresses and used for fatigue evaluation. Description of the numerical procedure is given in 5C-1-A1/13.7 below.

FIGURE 10
(1995)

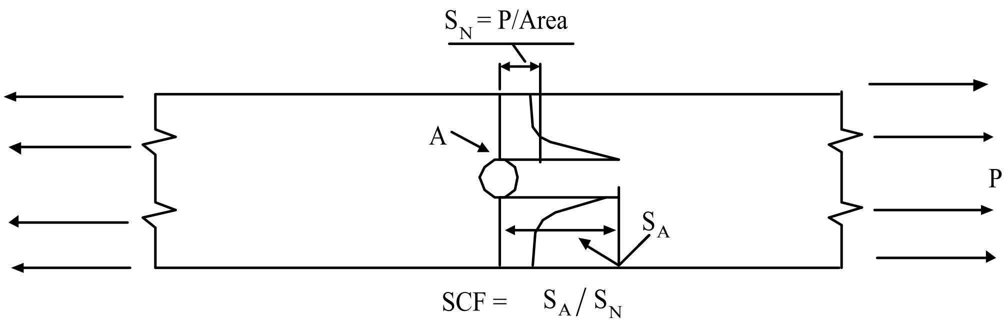


FIGURE 11
(1995)

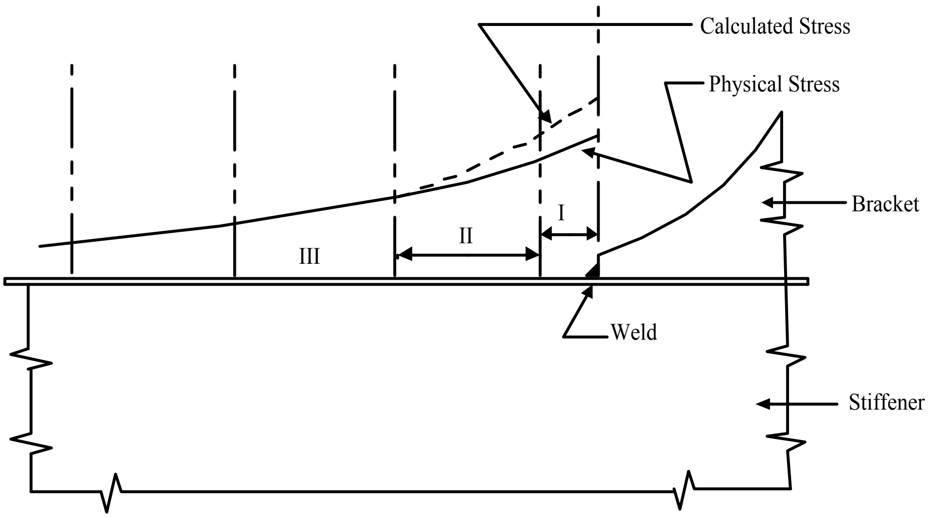
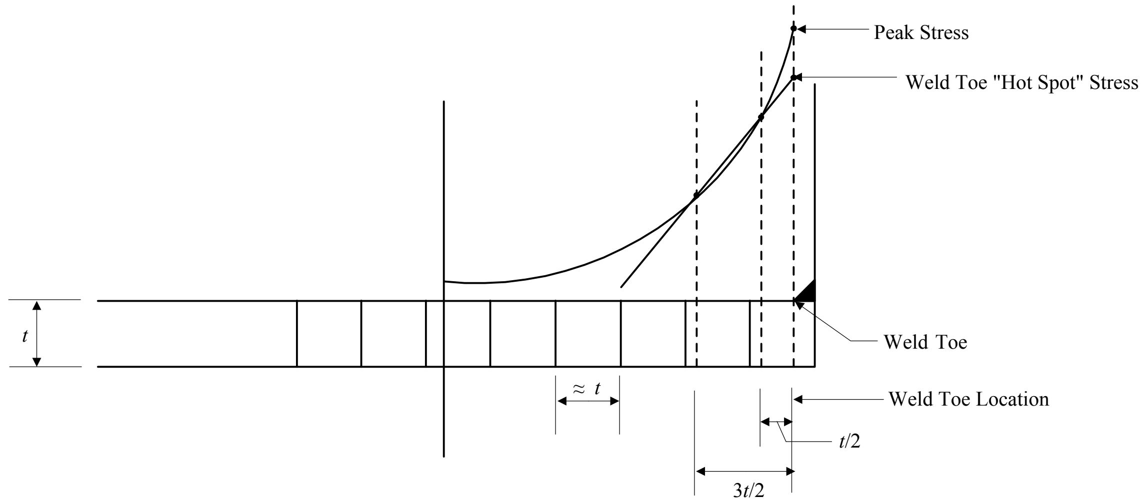


FIGURE 12
(2003)



13.7 Calculation of Hot Spot Stress for Fatigue Analysis of Ship Structures *(2003)*

The algorithm described in the following is applicable to obtain the hot spot stress for the point at the toe of a weld. The weld typically connects either a flat bar member or a bracket to the flange of a longitudinal stiffener, as shown in 5C-1-A1/Figure 13.

Consider the four points, P_1 to P_4, measured by the distances X_1 to X_4 from the weld toe, designated as the origin of the coordinate system. These points are the centroids of four neighboring finite elements, the first of which is adjacent to the weld toe. Assuming that the applicable surface component stresses, S_i, at P_i have been determined from FEM analysis, the corresponding stresses at "hot spot", i.e., the stress at the weld toe, can be determined by the following procedure:

13.7.1

Select two points, L and R, such that points L and R are situated at distances $t/2$ and $3t/2$ from the weld toe; i.e.,

$$X_L = t/2, \qquad X_R = 3t/2$$

where t denotes the thickness of the member to which elements 1 to 4 belong (e.g., the flange of a longitudinal stiffener).

13.7.2

Let $X = X_L$ and compute the values of four coefficients, as follows:

$$C_1 = [(X - X_2)(X - X_3)(X - X_4)] / [(X_1 - X_2)(X_1 - X_3)(X_1 - X_4)]$$

$$C_2 = [(X - X_1)(X - X_3)(X - X_4)] / [(X_2 - X_1)(X_2 - X_3)(X_2 - X_4)]$$

$$C_3 = [(X - X_1)(X - X_2)(X - X_4)] / [(X_3 - X_1)(X_3 - X_2)(X_3 - X_4)]$$

$$C_4 = [(X - X_1)(X - X_2)(X - X_3)] / [(X_4 - X_1)(X_4 - X_2)(X_4 - X_3)]$$

The corresponding stress at Point L can be obtained by interpolation as:

$$S_L = C_1S_1 + C_2S_2 + C_3S_3 + C_4S_4$$

13.7.3

Let $X = X_R$ and repeat the step in 5C-1-A1/13.7.2 to determine four new coefficients. The stress at Point R can be interpolated likewise, i.e.,

$$S_R = C_1S_1 + C_2S_2 + C_3S_3 + C_4S_4$$

13.7.4 *(2003)*

The corresponding stress at hot spot, S_0, is given by

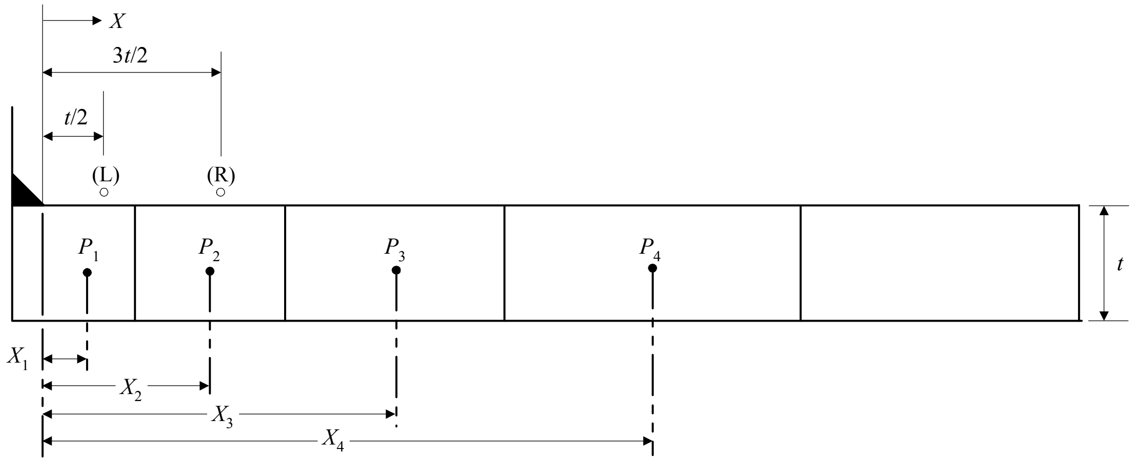
$$S_0 = (3S_L - S_R)/2$$

Notes:

The algorithm presented in the foregoing involves two types of operations. The first is to utilize the stress values at the centroid of the four elements considered to obtain estimates of stress at Points L and R by way of an interpolation algorithm known as Lagrange interpolation. The second operation is to make use of the stress estimates, S_L and S_R, to obtain the hot spot stress via linear extrapolation.

While the Lagrange interpolation is applicable to any order of polynomial, it is not advisable to go beyond the 3rd order (cubic). Also, the even order polynomials are biased, so that leaves the choice between a linear scheme and a cubic scheme. Therefore, the cubic interpolation, as described in 5C-1-A1/13.7.2, should be used. It can be observed that the coefficients, C_1 to C_4 are all cubic polynomials. It is also evident that, when $X = X_j$, which is not equal to X_i, all of the C's vanish except C_i, and if $X = X_i$, $C_i = 1$.

FIGURE 13
(1995)



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PART

5C

CHAPTER 1 **Vessels Intended to Carry Oil in Bulk (150 meters (492 feet) or more in Length)**

APPENDIX 2 **Calculation of Critical Buckling Stresses**

1 General

The critical buckling stresses for various structural elements and members may be determined in accordance with this Appendix or other recognized design practices. Critical buckling stresses derived from experimental data or analytical studies may be considered, provided that well-documented supporting data are submitted for review.

3 Rectangular Plates *(1995)*

The critical buckling stresses for rectangular plate elements, such as plate panels between stiffeners; web plates of longitudinals, girders, floors and transverses; flanges and face plates, may be obtained from the following equations, with respect to uniaxial compression, bending and edge shear, respectively.

$$f_{ci} = f_{Ei} \qquad \text{for } f_{Ei} \leq P_r f_{yi}$$

$$f_{ci} = f_{yi}[1 - P_r(1 - P_r)f_{yi}/f_{Ei}] \qquad \text{for } f_{Ei} > P_r f_{yi}$$

where

f_{ci} = critical buckling stress with respect to uniaxial compression, bending or edge shear, separately, N/cm^2 (kgf/cm^2, lbf/in^2)

f_{Ei} = $K_i\,[\pi^2 E/12(1 - \nu^2)](t_n/s)^2$, N/cm^2 (kgf/cm^2, lbf/in^2)

K_i = buckling coefficient, as given in 5C-1-A2/Table 1

E = modulus of elasticity of the material, may be taken as 2.06×10^7 N/cm^2 (2.1×10^6 kgf/cm^2, 30×10^6 lbf/in^2) for steel

ν = Poisson's ratio, may be taken as 0.3 for steel

t_n = net thickness of the plate, in cm (in.)

s = spacing of longitudinals/stiffeners, in cm (in.)

P_r	=	proportional linear elastic limit of the structure, may be taken as 0.6 for steel
f_{yi}	=	f_y, for uniaxial compression and bending
	=	$f_y/\sqrt{3}$, for edge shear
f_y	=	specified minimum yield point of the material, in N/cm² (kgf/cm², lbf/in²)

TABLE 1
Buckling Coefficient, K_i *(1995)*

For Critical Buckling Stress Corresponding to f_L, f_T, f_b or f_{LT}

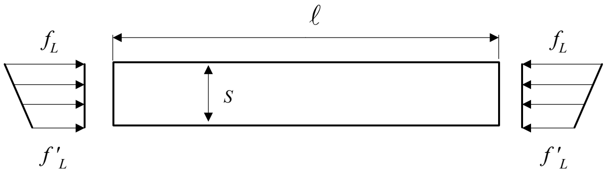
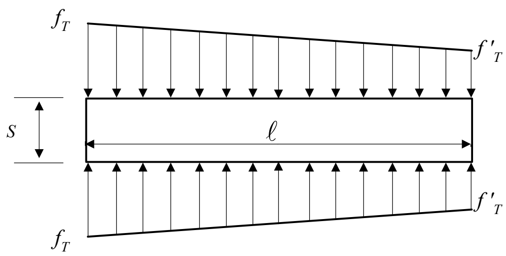
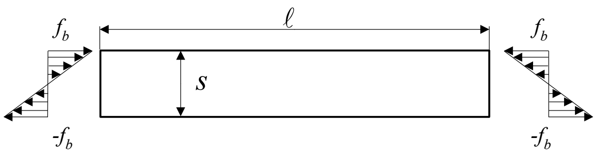
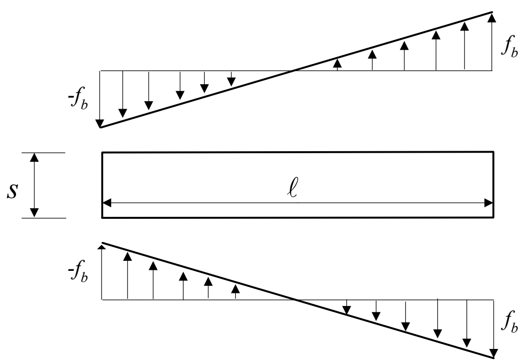
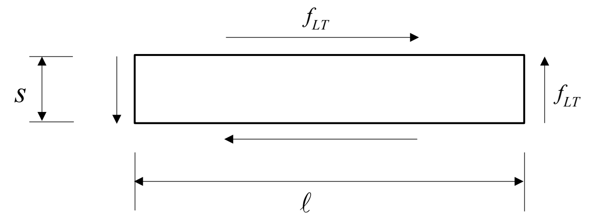
I. Plate panel between stiffeners			K_i
A Uniaxial compression 1. Long plate $\ell \geq s$		a. For f'_L, $= f_L$: b. For f'_L, $= f_L/3$: (see note)	$4C_1$, $5.8C_1$,
2. Wide plate $\ell \geq s$		a. For f'_T, $= f_T$: b. For f'_T, $= f_T/3$: (see note)	$[1 + (s/\ell)^2]^2C_2$ $1.45[1 + (s/\ell)^2]^2C_2$
B Ideal Bending 1. Long plate $\ell \geq s$			$24C_1$
2. Wide plate $\ell \geq s$		a. For $1.0 \leq \ell/s \leq 2.0$ b. For $2.0 < \ell/s$:	$24\ (s/\ell)^2C_2$ $12\ (s/\ell)C_2$

TABLE 1 (continued)
Buckling Coefficient, K_i (1995)

C Edge Shear — K_i: $[5.34 + 4\,(s/\ell)^2]C_1$



D Values of C_1 and C_2

1. For plate panels between angles or tee stiffeners

C_1 = 1.1

C_2 = 1.3 within the double bottom or double side*

C_2 = 1.2 elsewhere

2. For plate panels between flat bars or bulb plates

C_1 = 1.0

C_2 = 1.2 within the double bottom or double side*

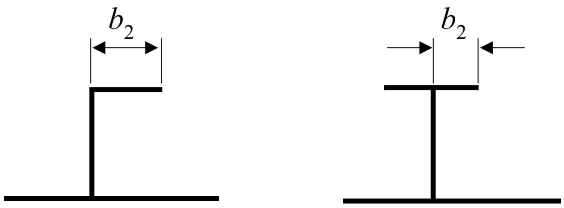
C_2 = 1.1 elsewhere

* applicable where shorter edges of a panel are supported by rigid structural members, such as bottom, inner bottom, side shell, inner skin bulkhead, double bottom floor/girder and double side web stringer.

	K_i
II. Web of Longitudinal or Stiffener	
A Axial compression	
Same as I.A.1 by replacing s with depth of the web and ℓ with unsupported span	
a. For $f'_L = f_L$:	$4C$
b. For $f'_L = f_L/2$: (see note)	$5.2C$
where	
C = 1.0 for angle or tee stiffeners	
C = 0.33 for bulb plates	
C = 0.11 for flat bars	
B Ideal Bending	
Same as I.B.1 by replacing s with depth of the web and ℓ with unsupported span	$24C$

TABLE 1 (continued) Buckling Coefficient, K_i *(1995)*

III. Flange and Face Plate	K_i
Axial Compression	0.44



$s = b_2$

ℓ = unsupported span

Note:

In I.A. (II.A), K_i for intermediate values of f'_L/f_L (f'_T/f_T) may be obtained by interpolation between a and b.

5 Longitudinals and Stiffeners

5.1 Axial Compression *(2002)*

The critical buckling stress, f_{ca}, of a beam-column, i.e., the longitudinal and the associated effective plating, with respect to axial compression may be obtained from the following equations:

$$f_{ca} = f_E \qquad \text{for } f_E \le P_r f_y$$

$$f_{ca} = f_y[1 - P_r(1 - P_r)f_y/f_E], \qquad \text{for } f_E > P_r f_y$$

where

f_E = $\pi^2 E/(\ell/r)^2$, N/cm^2 (kgf/cm^2, lbf/in^2)

ℓ = unsupported span of the longitudinal or stiffener, in cm (in.), as defined in 5C-1-4/Figure 5

r = radius of gyration of area A_e, in cm (in.)

A_e = $A_s + b_{wL} t_n$

A_s = net sectional area of the longitudinals or stiffeners, excluding the associated plating, cm^2 (in^2)

b_{wL} = effective width of the plating as given in 5C-1-5/5.3.2, in cm (in.)

t_n = net thickness of the plating, in cm (in.)

f_y = minimum specified yield point of the longitudinal or stiffener under consideration, N/cm^2 (kgf/cm^2, lbf/in^2)

P_r and E are as defined in 5C-1-A2/3.

5.3 Torsional/Flexural Buckling *(2002)*

The critical torsional/flexural buckling stress with respect to axial compression of a longitudinal, including its associated plating (effective width, b_{wL}), may be obtained from the following equations:

$$f_{ct} = f_{ET} \qquad \text{for } f_{ET} \le P_r f_y$$

$$f_{ct} = f_y[1 - P_r(1 - P_r)f_y/f_{ET}] \qquad \text{for } f_{ET} > P_r f_y$$

where

f_{ct} = critical torsional/flexural buckling stress with respect to axial compression, N/cm^2 (kgf/cm^2, lbf/in^2)

f_{ET} = $E[K/2.6 + (n\pi/\ell)^2\Gamma + C_o(\ell/n\pi)^2/E]/I_o[1 + C_o(\ell/n\pi)^2/I_o f_{cL}]$, N/cm^2 (kgf/cm^2, lbf/in^2)

K = St. Venant torsion constant for the longitudinal's cross section, excluding the associated plating.

= $[b_f t_f^3 + d_w t_w^3]/3$

I_o = polar moment of inertia of the longitudinal, excluding the associated plating, about the toe (intersection of web and plating), in cm^4 (in^4)

= $I_x + mI_y + A_s(x_o^2 + y_o^2)$

I_x, I_y = moment of inertia of the longitudinal about the x-and y-axis, respectively, through the centroid of the longitudinal, excluding the plating (x-axis perpendicular to the web), in cm^4 (in^4)

m = $1.0 - u(0.7 - 0.1d_w/b_f)$

u = unsymmetry factor

= $1 - 2b_1/b_f$

x_o = horizontal distance between centroid of stiffener, A_s, and centerline of the web plate, cm (in.)

y_o = vertical distance between the centroid of the longitudinal's cross section and its toe, cm (in.)

d_w = depth of the web, cm (in.)

t_w = net thickness of the web, cm (in.)

b_f = total width of the flange/face plate, cm (in.)

b_1 = smaller outstanding dimension of flange with respect to centerline of web (see 5C-1-A2/Figure 1), cm (in.)

t_f = net thickness of the flange/face plate, cm (in.)

C_o = $Et_n^3/3s$

Γ = warping constant

$\cong mI_{yf} d_w^2 + d_w^3 t_w^3/36$

I_{yf} = $t_f b_f^3 (1.0 + 3.0 u^2 d_w t_w/A_s)/12$, cm^4 (in^4)

f_{cL} = critical buckling stress for the associated plating, corresponding to n-half waves, N/cm^2 (kgf/cm^2, lbf/in^2)

= $\pi^2 E(n/\alpha + \alpha/n)^2 (t_n/s)^2/12(1 - \nu^2)$

α = ℓ/s

n = number of half-wave which yield a smallest f_{ET}

f_y = minimum specified yield point of the longitudinal or stiffener under consideration, N/cm^2 (kgf/cm^2, lbf/in^2)

P_r, E, s and ν are as defined in 5C-1-A2/3.

A_s, t_n and ℓ are as defined in 5C-1-A2/5.1.

5.5 Buckling Criteria for Unit Corrugation of Transverse Bulkhead *(1996)*

The critical buckling stress, which is also the ultimate bending stress, f_{cb}, for a unit corrugation, may be determined from the following equation (See 5C-1-5/5.11.2).

$f_{cb} = f_{Ec}$ for $f_{Ec} \le P_r f_y$

$f_{cb} = [1 - P_r(1 - P_r) f_y / f_{Ec}] f_y$ for $f_{Ec} > P_r f_y$

where

f_{Ec} = $k_c E(t/a)^2$

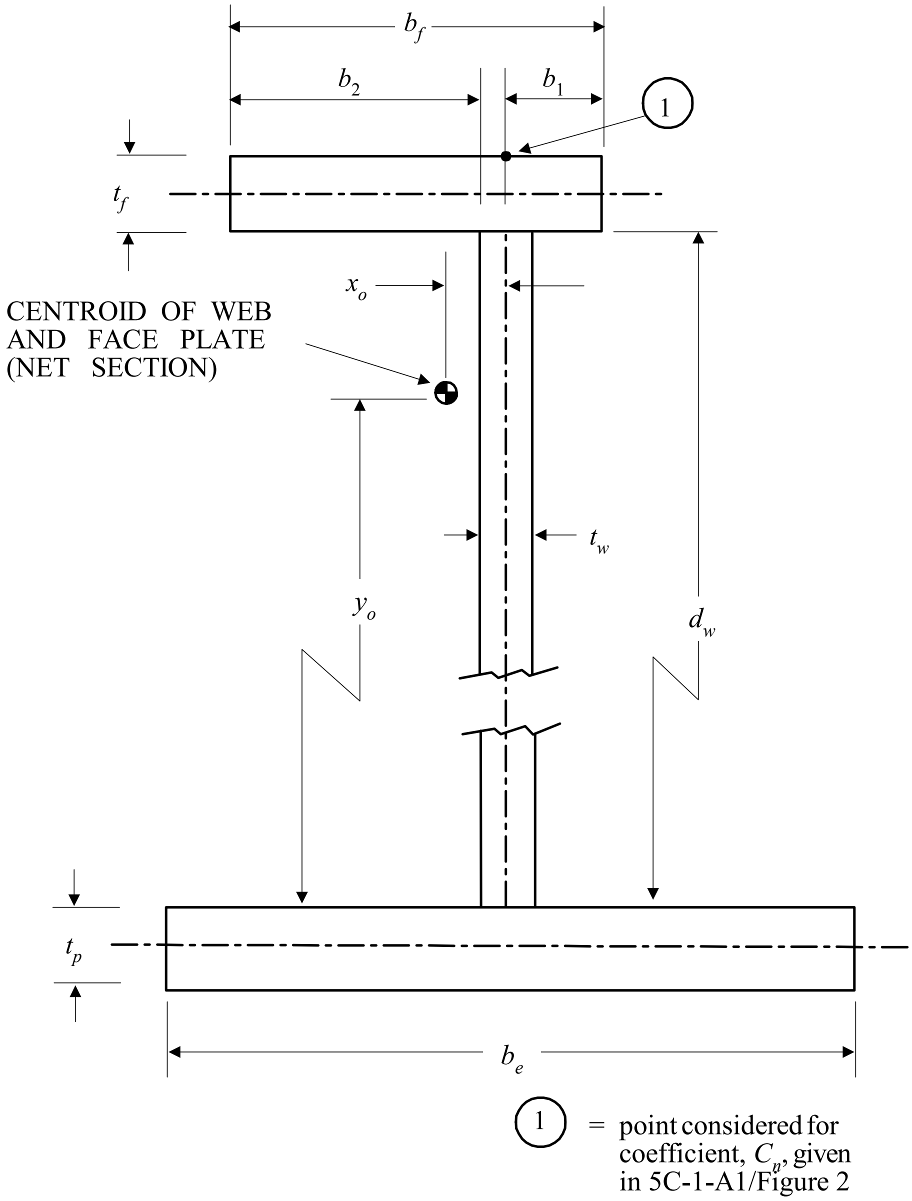
k_c = $0.09[7.65 - 0.26\,(c/a)^2]^2$

c and a are widths of the web and flange panels, respectively, in cm^2 (in^2)

t = net thickness of the flange panel, in cm (in.)

P_r, f_y and E are as defined in 5C-1-A2/3.

FIGURE 1
Net Dimensions and Properties of Stiffeners *(1995)*



7 Stiffened Panels *(1995)*

7.1 Large Stiffened Panels

For large stiffened panels between bulkheads or panels stiffened in one direction between transverses and girders, the critical buckling stresses with respect to uniaxial compression may be determined from the following equations:

$$f_{ci} = f_{Ei} \qquad \text{for } f_{Ei} \le P_r f_y$$

$$f_{ci} = f_y[1 - P_r(1 - P_r) f_y / f_{Ei}] \qquad \text{for } f_{Ei} > P_r f_y$$

where

f_{Ei} = $k_L \pi^2 (D_L D_T)^{1/2} / t_L b^2$ in the longitudinal direction, N/cm² (kgf/cm², lbf/in²)

f_{Ei} = $k_T \pi^2 (D_L D_T)^{1/2} / t_T \ell^2$ in the transverse direction, N/cm² (kgf/cm², lbf/in²)

k_L = 4 for $\ell/b \ge 1$

= $[1/\phi_L^2 + 2\eta + \phi_L^2]$ for $\ell/b < 1$

k_T = 4 for $b/\ell \ge 1$

= $[1/\phi_T^2 + 2\eta + \phi_T^2]$ for $b/\ell < 1$

D_L = $EI_L / s_L(1 - \nu^2)$

D_T = $EI_T / s_T(1 - \nu^2)$

D_T = $E t_n^3 / 12(1 - \nu^2)$ if no stiffener in the transverse direction

ℓ, b = length and width between transverse and longitudinal bulkheads, respectively, cm (in.) (See 5C-1-A2/Figure 2)

t_L, t_T = net equivalent thickness of the plating and stiffener in the longitudinal and transverse direction, respectively, cm (in.)

= $(s_L t_n + A_{sL})/s_L$ or $(s_T t_n + A_{sT})/s_T$

s_L, s_T = spacing of longitudinals and transverses, respectively, cm (in.) (See 5C-1-A2/Figure 2)

ϕ_L = $(\ell/b)\,(D_T/D_L)^{1/4}$

ϕ_T = $(b/\ell)\,(D_L/D_T)^{1/4}$

η = $[(I_{pL} I_{pT})/(I_L I_T)]^{1/2}$

A_{sL}, A_{sT} = net sectional area of the longitudinal and transverse, excluding the associated plating, respectively, cm² (in²)

I_{pL}, I_{pT} = net moment of inertia of the effective plating alone (effective breadth due to shear lag) about the neutral axis of the combined cross section, including stiffener and plating, cm⁴ (in⁴)

I_L, I_T = net moment of inertia of the stiffener (one) with effective plating in the longitudinal or transverse direction, respectively, cm⁴ (in⁴). If no stiffener, the moment of inertia is calculated for the plating only.

F_y, P_r, E and ν are as defined in 5C-1-A2/3. t_n is as defined in 5C-1-A2/5.1.

With the exception of deck panels, when the lateral load parameter, q_o, defined below, is greater than 5, reduction of the critical buckling stresses given above is to be considered.

$$q_o = p_n b^4/(\pi^4 t_T D_T)$$

$$q_o = p_n \ell^4/(\pi^4 t_L D_L)$$

where

p_n = average net lateral pressure, N/cm^2 (kgf/cm^2, lbf/in^2)

D_T, D_L, b, ℓ, t_T, t_L and s_T are as defined above.

In this regard, the critical buckling stress may be approximated by:

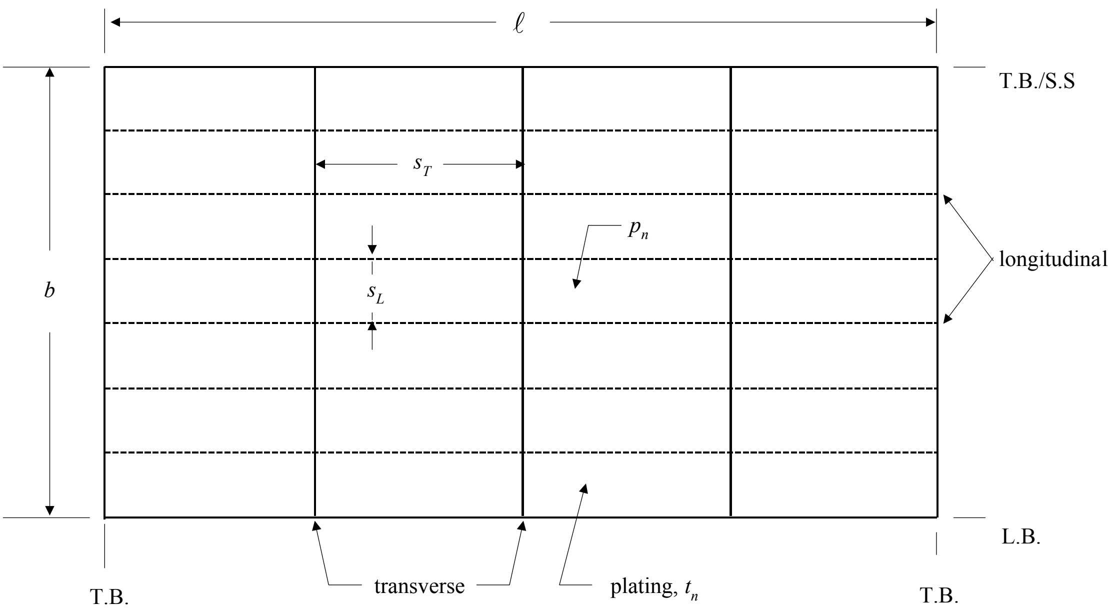
$f'_{ci} = R_o f_{ci}$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

R_o = $1 - 0.045(q_o - 5)$ for $q_o \geq 5$

For deck panels, $R_o = 1.0$ and $f'_{ci} = f_{ci}$

FIGURE 2



7.3 Corrugated Transverse Bulkheads *(1997)*

For corrugated transverse bulkheads, the critical buckling stresses with respect to uniaxial compression may be calculated from the equations given in 5C-1-A2/7.1 above by replacing the subscripts "L"and "T" with "V" and "H" for the vertical and horizontal directions, respectively, and with the following modifications. The rigidities D_V are D_H are defined as follows.

D_V = EI_v/s

D_H = $[s/(a + c)][Et^3/12(1 - \nu^2)]$

where

I_v = moment of inertia of a unit corrugation with spacing s, $s = a + c\cos\phi$

= $t/4[c\sin\phi]^2(a + c/4 + c\sin\phi/12)$, in cm^4 (in^4)

a, c = widths of the flange and web panels, respectively, in cm (in.)

t = net thickness of the corrugations, in cm (in.)

E and ν are as defined in 5C-1-A2/3.

ℓ = length of the corrugation, in cm (in.)

s_v, s_H = s

η, I_{pH}, A_{sH} = 0

A_{sV} = $tc\sin\phi$

ϕ is as defined in 5C-1-4/Figure 9 or 5C-1-4/Figure 10.

9 Deep Girders, Webs and Stiffened Brackets

9.1 Critical Buckling Stresses of Web Plates and Large Brackets *(1995)*

The critical buckling stresses of web plates and large brackets between stiffeners may be obtained from the equations given in 5C-1-A2/3 for uniaxial compression, bending and edge shear.

9.3 Effects of Cut-outs *(1995)*

The depth of cut-out, in general, is to be not greater than $d_w/3$, and the stresses in the area calculated are to account for the local increase due to the cut-out.

When cut-outs are present in the web plate, the effects of the cut-outs on reduction of the critical buckling stresses are to be considered, as outlined in the subsections below.

9.3.1 Reinforced by Stiffeners Around Boundaries of Cut-outs

When reinforcement is made by installing straight stiffeners along boundaries of the cut-outs, the critical buckling stresses of web plate between stiffeners with respect to compression and shear may be obtained from equations given in 5C-1-A2/3.

9.3.2 Reinforced by Face Plates Around Contour of Cut-outs

When reinforcement is made by adding face plates along the contour of the cut-out, the critical buckling stresses with respect to compression, bending and shear may be obtained from equations given in 5C-1-A2/3, without reduction, provided that the net sectional area of the face plate is not less than $8t_w^2$, where t_w is the net thickness of the web plate, and that depth of the cut-out is not greater than $d_w/3$, where d_w is the depth of the web.

9.3.3 No Reinforcement Provided

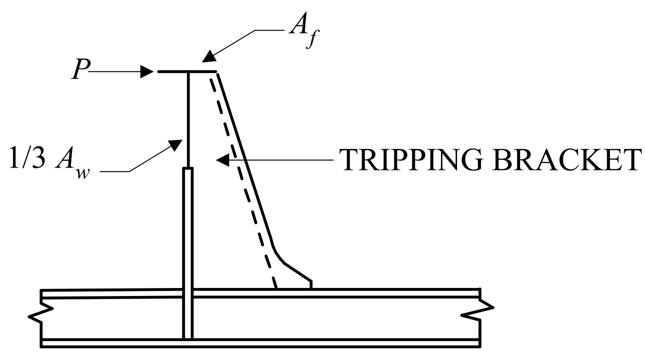
When reinforcement is not provided, the buckling strength of the web plate surrounding the cut-out may be treated as a strip of plate with one edge free and the other edge simply supported.

9.5 Tripping *(1995)*

To prevent tripping of deep girders and webs with wide flanges, tripping brackets are to be installed with a spacing generally not greater than 3 meters (9.84 ft).

Design of tripping brackets may be based on the force *P* acting on the flange, as given by the following equation:

$$P = 0.02 f_{c\ell} \left(A_f + \frac{1}{3} A_w\right)$$



where

$f_{c\ell}$	=	critical lateral buckling stress with respect to axial compression between tripping brackets, N/cm^2 (kgf/cm^2, lbf/in^2)	
$f_{c\ell}$	=	f_{ce},	for $f_{ce} \le P_r f_y$
	=	$f_y[1 - P_r(1 - P_r) f_y / f_{ce}]$,	for $f_{ce} > P_r f_y$
f_{ce}	=	$0.6E[(b_f/t_f)(t_w/d_w)^3]$,	N/cm^2 (kgf/cm^2, lbf/in^2)
A_f	=	net cross sectional area of the flange/face plate, in cm^2 (in^2)	
A_w	=	net cross sectional area of the web, in cm^2 (in^2)	

B_f, t_f, d_w, t_w are as defined in 5C-1-A2/5.3.

E, P_r and f_y are as defined in 5C-1-A2/3.

11 Stiffness and Proportions

To fully develop the intended buckling strength of the assemblies of structural members and panels, supporting elements of plate panels and longitudinals are to satisfy the following requirements for stiffness and proportion in highly stressed regions.

11.1 Stiffness of Longitudinals *(1995)*

The net moment of inertia of the longitudinals, i_o, with effective breadth of net plating, is to be not less than that given by the following equation:

$$i_o = \frac{s t_n^3}{12(1 - \nu^2)} \gamma_o \qquad \text{cm}^4 \text{ (in}^4\text{)}$$

where

γ_o = $(2.6 + 4.0\delta)\alpha^2 + 12.4\alpha - 13.2\alpha^{1/2}$

δ = A/st_n

α = ℓ/s

s = spacing of longitudinals, cm (in.)

t_n = net thickness of plating supported by the longitudinal, cm (in.)

ν = Poisson's ratio

= 0.3 for steel

A = net sectional area of the longitudinal (excluding plating), cm^2 (in^2)

ℓ = unsupported span of the longitudinal, cm (in.)

11.3 Stiffness of Web Stiffeners *(1995)*

The net moment of inertia, i, of the web stiffener, with the effective breadth of net plating not exceeding s or 0.33ℓ, whichever is less, is not to be less than obtained from the following equations:

$i = 0.17\ell t^3(\ell/s)^3$ cm^4 (in^4), for $\ell/s \le 2.0$

$i = 0.34\ell t^3(\ell/s)^2$ cm^4 (in^4), for $\ell/s > 2.0$

where

ℓ = length of stiffener between effective supports, in cm (in.)

t = required net thickness of web plating, in cm (in.)

s = spacing of stiffeners, in cm (in.)

11.5 Stiffness of Supporting Members *(1995)*

The net moment of inertia of the supporting members, such as transverses and webs, is not to be less than that obtained from the following equation:

$I_s/i_o \ge 0.2(B_s/\ell)^3(B_s/s)$

where

I_s = moment of inertia of the supporting member, including the effective plating, cm^4 (in^4)

i_o = moment of inertia of the longitudinals, including the effective plating, cm^4 (in^4)

B_s = unsupported span of the supporting member, cm (in.)

ℓ and s are as defined in 5C-1-A2/11.1.

11.7 Proportions of Flanges and Face Plates *(1995)*

The breadth-thickness ratio of flanges and face plates of longitudinals and girders is to satisfy the limits given below:

$$b_2/t_f = 0.4(E/f_y)^{1/2}$$

where

b_2 = larger outstanding dimension of flange, as given in 5C-1-A2/Figure 1, cm (in.)

t_f = net thickness of flange/face plate, cm (in.)

E and f_y are as defined in 5C-1-A2/3.

11.9 Proportions of Webs of Longitudinals and Stiffeners *(1995)*

The depth-thickness ratio of webs of longitudinals and stiffeners is to satisfy the limits given below.

$d_w/t_w \le 1.5(E/f_y)^{1/2}$ for angles and tee bars

$d_w/t_w \le 0.85(E/f_y)^{1/2}$ for bulb plates

$d_w/t_w \le 0.5(E/f_y)^{1/2}$ for flat bars

where d_w and t_w, are as defined in 5C-1-A2/5.3 and E and f_y are as defined in 5C-1-A2/3.

When these limits are complied with, the assumption on buckling control stated in 5C-1-5/5.1.2(e) is considered satisfied. If not, the buckling strength of the web is to be further investigated, as per 5C-1-A2/3.

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PART

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CHAPTER 1 Vessels Intended to Carry Oil in Bulk (150 meters (492 feet) or more in Length)

APPENDIX 3 Application to Single Hull Tankers

1 General

Where due to the nature of the cargo, single hull construction is permitted, the design criteria and evaluation procedures specified in Section 5C-1-1 may also be applied to single hull tankers with modifications as outlined in this Appendix.

1.1 Nominal Design Corrosion Values

Except as modified by the following, the nominal design corrosion values given in 5C-1-2/Table 1 are applicable to the corresponding structural elements of single hull tankers based on the proposed usage of the individual space.

For bottom plating and contiguously attached structures, the nominal design corrosion values to be used are:

Wing Ballast Tanks	
Bottom Plating	1.00 mm
Bottom Longitudinals, Transverses and Girders (Web and Flange)	1.50 mm
Center or Wing Cargo Tanks	
Bottom Plating	1.00 mm
Bottom Longitudinals, Transverses and Girders (Web and Flange)	1.00 mm

In designs which use the wing spaces for both ballast and cargo tanks, all longitudinal structural members within these spaces are to have nominal design corrosion values as for ballast spaces. The nominal design corrosion values for transverse structural members are to be based on the actual tank usage.

Consideration may be given for modifying the nominal design corrosion values, depending upon the degree of cargo corrosiveness.

1.3 Load Criteria

The load criteria and load cases specified in 5C-1-3/1 through 5C-1-3/13 are generally applicable to single hull tankers by considering the double bottom and wing ballast tanks, such as shown in 5C-1-3/Figure 1 and 5C-1-3/Figure 14, as null, except that the load patterns are specified in 5C-1-A3/Table 1 for bottom and side shell structures.

1.5 Strength Criteria

1.5.1 Hull Girder Shear Strength

For single hull tankers with two or more longitudinal bulkheads, the net thickness of side shell and longitudinal bulkhead plating is not to be less than that specified in 5C-1-4/5, wherein the shear distribution factors, D_s and D_i, and local load correction, R_i, may be derived either from direct calculations or from Appendix 5C-2-A1.

1.5.2 Plating and Longitudinals/Stiffeners

The strength requirements for plating and longitudinals/stiffeners specified in 5C-1-4/7 through 5C-1-4/17 and Section 5C-1-6 are directly applicable to single hull tankers by determining the internal pressure in accordance with the actual tank arrangement.

3 Main Supporting Structures

3.1 Bottom Transverses

3.1.1 Section Modulus of Bottom Transverses

The net section modulus of the bottom transverse, in association with the effective bottom plating, is not to be less than obtained from the following equation (see also 5C-1-4/1.3).

$$SM = M/f_b \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

$$M = 10{,}000kcps\,\ell_b^2 \qquad \text{N-cm (kgf-cm, lbf-in)}$$

where

k = 1.0 (1.0, 0.269)

c = $0.83\alpha^2$ for center tank

= 1.4 for wing tank

α = $(\ell_g/\ell_b)[(I_b/I_g)(s_g/s)]^{1/4} \le 1.0$ for tankers with bottom girder

= 1.0 for tankers without bottom girder

ℓ_b = span of the bottom transverse, in m (ft), as indicated in 5C-1-A3/Figure 1; the length is to be not less than 0.125B or one-half the breadth of the tank, whichever is the greater

ℓ_g = span of the bottom girder, in m (ft), as indicated in 5C-1-A3/Figure 1

s = spacing of the bottom transverse, in m (ft)

s_g = spacing of the bottom girder, in m (ft)

I_b and I_g = moments of inertia, in cm^4 (in^4), of the bottom transverse (I_b) and the bottom girder (I_g) with effective plating to which they are attached (clear of bracket)

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-span of the bottom transverse, as specified in 5C-1-A3/Table 1

f_b = permissible bending stress

= $0.70\ S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

B = vessel breadth, in m (ft)

3.1.2 Web Sectional Area of Bottom Transverse

The net sectional area of the web portion of the bottom transverse is not to be less than obtained from the following equation:

$A = F/f_s$ cm^2 (in^2)

The shear force, F, in N (kgf, lbf), can be obtained from the following equation (see also 5C-1-4/1.3).

$F = 1000k[ps(K_b\ell_s - h_e) + cDB_cs]$ N (kgf, lbf)

where

k = 1.0 (1.0, 2.24)

K_b = 0.5α for center tank

= 0.5 for wing tank

c = 0 for center tank

= 0.15 for wing tank without cross ties

= 0.06 for wing tank with one cross tie

= 0.03 for wing tank with two cross ties

ℓ_s = span of the bottom transverse, in m (ft), as indicated in 5C-1-A3/Figure 1

h_e = length of the bracket of bottom transverse, in m (ft), as indicated in 5C-1-A3/Figure 1

D = vessel depth, in m (ft)

B_c = breadth of the center tank, in m (ft)

P, s and α are as defined in 5C-1-A3/3.1.1.

f_s = permissible shear stress

= $0.45\ S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

3.3 Bottom Girders

3.3.1 Section Modulus of Bottom Girders

The net section modulus of the bottom girder, in association with the effective bottom plating, is not to be less than obtained from the following equation (see also 5C-1-4/1.3).

$$SM = M/f_b \qquad \text{cm}^3\ (\text{in}^3)$$

$$M = 10{,}000kcps_g\,\ell_g^2 \qquad \text{N-cm (kgf-cm, lbf-in)}$$

where

k = 1.0 (1.0, 0.269)

c = 1.0

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-span of the bottom girder, as specified in 5C-1-A3/Table 1

ℓ_g and s_g are as defined in 5C-1-A3/3.1.1.

f_b = 0.50 $S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

3.3.2 Web Sectional Area of Bottom Girder

The net sectional area of the web portion of the bottom girder is not to be less than obtained from the following equation:

$$A = F/f_s \qquad \text{cm}^2\ (\text{in}^2)$$

The shear force, F, in N (kgf, lbf), can be obtained from the following equation (see 5C-1-4/1.3).

$$F = 1000kps_g\,(0.5\ell_s - h_e)$$

where

k = 1.0 (1.0, 2.24)

ℓ_s = span of the bottom girder, in m (ft), as indicated in 5C-1-A3/Figure 1

h_e = length of bracket of bottom girder, in m (ft), as indicted in 5C-1-A3/Figure 1

s_g is as defined in 5C-1-A3/3.1.1.

p is as defined in 5C-1-A3/3.3.1.

f_s = permissible shear stress

= 0.35 $S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

TABLE 1
Design Pressure for Local and Supporting Structures

A. Plating & Longitudinals/Stiffeners.

The nominal pressure, $P = |P_i - P_e|$, is to be determined from load cases "a" & "b" below, whichever is greater, with $k_u = 1.10$ and $k_c = 1.0$, unless otherwise specified in the table

	Case "a" At fwd end of the tank				*Case "b" At mid tank/fwd end of tank*			
Structural Members/ Components	*Draft/Wave Heading Angle*	*Location and Loading Pattern*	*Coefficients* P_i	*Coefficients* P_e	*Draft/Wave Heading Angle*	*Location and Loading Pattern*	*Coefficients* P_i	*Coefficients* P_e
1. Bottom Plating & Long'l	2/3 design draft/0°	Full center and wing tanks	A_i	A_e	Design draft/0°	Midtank of empty center and wing tanks	—	B_e
2. Side Shell Plating & Long'l	2/3 design draft/60°	Starboard side of full wing tank	B_i	A_e	Design draft/60°	Midtank of empty wing tank	—	B_e

B. Main Supporting Members

The nominal pressure, $P = |P_i – P_e|$, is to be determined at the midspan of the structural member at starboard side of vessel from load cases "a" and "b" below, whichever is greater, with $k_u = 1.0$, $k_c = 1.0$, unless otherwise specified in the table

	Midtank for Transverses				*Midtank for Transverses*			
Structural Members/ Components	*Draft/Wave Heading Angle*	*Location and Loading Pattern*	*Coefficients* P_i	*Coefficients* P_e	*Draft/Wave Heading Angle*	*Location and Loading Pattern*	*Coefficients* P_i	*Coefficients* P_e
3. Bottom Transverse & Girder	2/3 design draft/0°	Full center and wing tanks	A_i	A_e	Design draft/0°	Midtank of empty center and wing tanks	—	B_e
4. Side Transverses	2/3 design draft/60°	Wing tanks full	B_i	—	Design draft/60°	Midtank of empty wing tank	—	B_e

Notes:

1 *(1 July 2005)* For calculating p_i and p_e, the necessary coefficients are to be determined based on the following designated groups:

a) For p_i

A_i: $w_v = 0.75$, w_ℓ(fwd bhd) = 0.25, w_ℓ(aft bhd) = –0.25, $w_t = 0.0$, $c_\phi = –0.35$, $c_e = 0.0$

B_i: $w_v = 0.4$, w_ℓ(fwd bhd) = 0.2, w_ℓ(aft bhd) = –0.2, w_t(starboard) = 0.4, w_t(port) = –0.4, $c_\phi = –0.3$, $c_e = 0.3$

b) For p_e

A_e: $k_{\ell o} = 1.0$, $k_u = 1.0$, $k_c = –0.5$

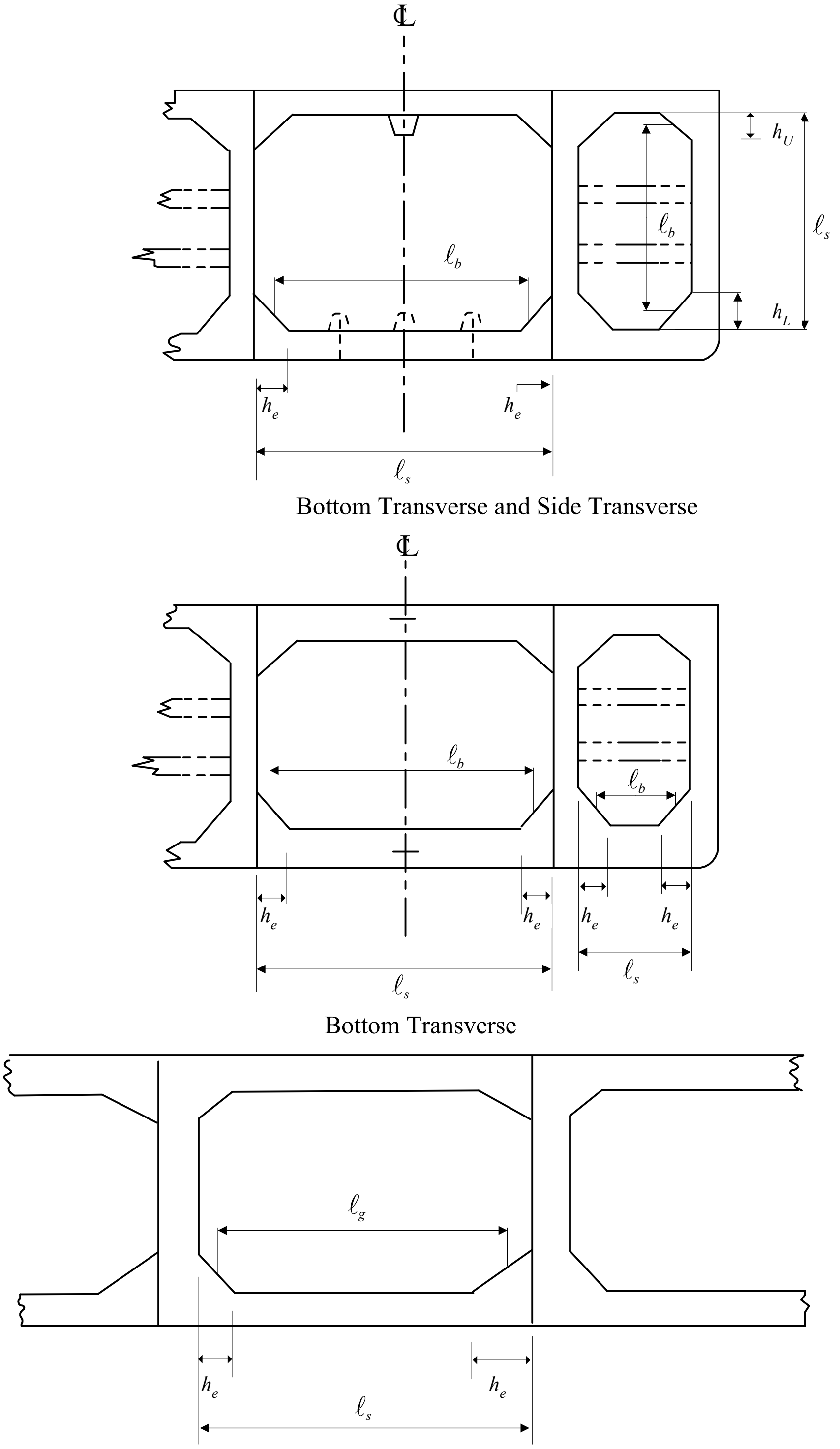
B_e: $k_{\ell o} = 1.0$

2 For structures within 0.4L amidships, the nominal pressure is to be calculated for a tank located amidships. The longest cargo and ballast tanks in the region should be considered as located amidships

3 In calculation of the nominal pressure, ρg of the liquid cargoes is not to be taken less than 0.1025 kgf/cm^2-m (0.4444 lbf/in^2-ft) for structural members 1 and 2 and is not to be taken less than 0.09 kgf/cm^2-m (0.3902 lbf/in^2-ft) for cargo tanks and 0.1025 kgf/cm^2-m (0.4444 lbf/in^2-ft) for ballast tanks for structural members 3 and 4.

4 For all other structures, 5C-1-3/Table 3 is applicable.

FIGURE 1
Spans of Transverses and Girders



Bottom Transverse and Side Transverse

Bottom Transverse

Bottom Girder

3.5 Side Transverses

3.5.1 Section Modulus of Side Transverses

The net section modulus of the side transverse, in association with the effective side plating, is not to be less than obtained from the following equation (see also 5C-1-4/1.3)

$SM = M/f_b$ cm^3 (in^3)

$M = 10{,}000kcps\,\ell_b^2$ N-cm (kgf-cm, lbf-in)

where

k = 1.0 (1.0, 0.269)

ℓ_b = span of side transverse, in m (ft), as indicated in 5C-1-A3/Figure 1

s = spacing of side transverse, in m (ft)

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-span ℓ_b of the side transverse, as specified in 5C-1-A3/Table 1

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.70\,S_m f_y$

c is given in 5C-1-A3/Table 2.

S_m and f_y are as defined in 5C-1-4/7.3.1.

For tanker without cross ties, the section modulus of the side transverse, as required above, is to extend at least up to $0.6\ell_b$ from the lower end of the span. The value of the bending moment, M, used for the calculation of the required section modulus of the remaining part of the side transverse may be reduced, but not more than 20%.

In the case of one cross tie, the section modulus of the lower (upper) side transverse, as required above, is to extend to the cross tie.

In the case of two cross ties, the section modulus of the lower (upper) side transverse, as required above, is to extend to the lower (upper) cross tie and may be linearly interpolated between the cross ties.

TABLE 2
Coefficient *c* for Side Transverse

Arrangement of Cross Ties	*For Upper Side Transverse*	*For Lower Side Transverse*
No Cross Tie	0.75	
One Cross Tie in Wing Tank	0.19	0.33
Two Cross Ties in Wing Tank	0.13	0.20

3.5.2 Web Sectional Area of Side Transverses

The net sectional area of the web portion of the side transverse is not to be less than obtained from the following equation:

$A = F/f_s$ cm^2 (in^2)

The shear force, F, in N (kgf, lbf), for the side transverse can be obtained from the following equation (see also 5C-1-4/1.3):

F = $1000ks[K_U\ell_s(P_U + P_L) - h_U P_U]$ for the upper part of the transverse

F = $1000ks[K_L\ell_s(P_U + P_L) - h_L P_L]$ or

= $350ksK_L\ell_s(P_U + P_L)$, whichever is greater, for the lower part of the transverse

In no case is the shear force for the lower part of the transverse to be less than 120% of that for the upper part of the transverse.

where

k = 1.0 (1.0, 2.24)

ℓ_s = span of the side transverse, in m (ft), as indicated in 5C-1-A3/Figure 1

s = spacing of the side transverse, in m (ft)

P_U = nominal pressure, p, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-length of the upper bracket (h_U/2), as specified in 5C-1-A3/Table 1

P_L = nominal pressure, p, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-length of the lower bracket (h_L/2), as specified in 5C-1-A3/Table 1

h_U = length of the upper bracket, in m (ft), as indicated in 5C-1-A3/Figure 1

h_L = length of the lower bracket, in m (ft), as indicated in 5C-1-A3/Figure 1

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\, S_m f_y$

K_U and K_L are given in 5C-1-A3/Table 3.

S_m and f_y are as defined in 5C-1-4/7.3.1.

For a tanker without cross ties, the sectional area of the lower side transverse, as required above, is to extend up to 0.15ℓ from the toe of the lower bracket or $0.3\ell_s$ from the lower end of the span, whichever is greater.

In the case of one cross ties, the sectional area of the lower (upper) side transverse as required above, is to extend to the cross tie.

In the case of two cross ties, the sectional area of the lower (upper) side transverse as required above, is to extend to the lower (upper) cross tie and may be linearly interpolated between the cross ties.

TABLE 3
Coefficients K_U and K_L for Side Transverses

Arrangement of Cross Ties	K_U	K_L
No Cross Tie	0.16	0.30
One Cross Tie in Wing Tank	0.09	0.21
Two Cross Ties in Wing Tank	0.075	0.16

3.7 Deck Transverses

3.7.1 Section Modulus of Deck Transverses

The net section modulus of deck transverses, in association with the effective deck plating, is not to be less than obtained from the following equation (see also 5C-1-4/1.3).

$$SM = M/f_b \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

For deck transverses in wing tanks:

$$M = k(10{,}000\, c_1 \varphi\, ps\, \ell_t^2 + \beta_s M_s) \geq M_o \qquad \text{N-cm (kgf-cm, lbf-in)}$$

For deck transverses in center tanks:

$$M = k(10{,}000\, c_1 \varphi\, ps\, \ell_t^2 + \beta_b M_b) \geq M_o \qquad \text{N-cm (kgf-cm, lbf-in)}$$

where

M_s = $10{,}000 c_2\, p_s\, s\, \ell_s^2$

M_b = $10{,}000 c_2\, p_b\, s\, \ell_b^2$

M_o = $10{,}000 k c_3 \varphi\, ps\, \ell_t^2$

k = 1.0 (1.0, 0.269)

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-span of the deck transverse under consideration, as specified in 5C-1-3/Table 3, Item 16

p_s = corresponding nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-span of the side transverse (5C-1-3/Table 3 , Item 16)

p_b = corresponding nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-span of the vertical web on longitudinal bulkhead (5C-1-3/Table 3 , Item 16)

c_1 = 0.42 for tanks without deck girder

c_1 = $0.42\alpha^2$ for tanks with deck girders, min. 0.05 and max. 0.42

α = $(\ell_g/\ell_t)[(s_g/s)\,(I_T/I_g)]^{1/4}$

ℓ_g = span of the deck girder, in m (ft), as indicated in 5C-1-4/Figure 2B-c

ℓ_t = span of the deck transverse, in m (ft), as indicated in 5C-1-4/Figure 2A, but is not to be taken as less than 60% of the breadth of the tank

I_g, I_t = moments of inertia, in cm^4 (in^4), of the deck girder and deck transverse, clear of the brackets, respectively

s_g = spacing of the deck girders, in m (ft)

s = spacing of the deck transverses, in m (ft)

When calculating α, if more than one deck girder is fitted, the average values of s_g, ℓ_g and I_g are to be used when the girders are not identical.

φ = $1 - 5(h_a/\ell_t)\alpha^{-1}$, to be not less than 0.6 for cargo tanks with deck girders

= $1 - 5(h_a/\ell_t)$, to be not less than 0.6 for cargo tanks without deck girders

h_a = distance, in m (ft), from the end of the span to the toe of the end bracket of the deck transverse, as indicated in 5C-1-4/Figure 8

β_s = $0.9[(\ell_s/\ell_t)(I_t/I_s)]$, but is not to be taken less than 0.10 and need not be greater than 0.65

β_b = $0.9[(\ell_b/\ell_t)(I_t/I_b)]$, but is not to be taken less than 0.10 and need not be greater than 0.50

ℓ_s and ℓ_b = spans, in m (ft), of side transverse and vertical web on longitudinal bulkhead, respectively, as indicated in 5C-1-4/Figure 2A

I_s and I_b = moments of inertia, in cm^4 (in^4), clear of the brackets, of side transverses and vertical web on longitudinal bulkhead, respectively

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/ in^2)

= $0.70\, S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

c_2 is given in 5C-1-A3/Table 4 below.

c_3 = 0.83 for tanks without deck girders

= $1.1c_1$ for tanks with deck girders

Where no cross ties or other effective supporting arrangements are provided for the wing tank vertical webs, the deck transverses in the wing tanks are to have section modulus not less than 70% of that required for the upper side transverse.

TABLE 4
Coefficient c_2 For Deck Transverse

Arrangement of Cross Ties	*Center Tank*	*Wing Tank*
No Cross Tie	0.4	
One Cross Tie in Wing Tank	0.13	0.37
Two Cross Ties in Wing Tank	0.05	0.12

3.7.2 Web Sectional Area of Deck Transverse

The net sectional area of the web portion of deck transverses is not to be less than obtained from the following equation:

$$A = F/f_s \qquad \text{cm}^2\ (\text{in}^2)$$

$$F = 1000k[c_1\, ps(0.50\ell - h_e) + c_2\, DB_c s] \qquad \text{N (kgf, lbf)}$$

where

k = 1.0 (1.0, 2.24)

c_1 = 1.30 for tanks without deck girder

= $0.90\alpha^{1/2}$ for tanks with deck girder, min. 0.50 and max. 1.0

c_2 = 0 for center tank

= 0.045 for wing tank

ℓ = span of the deck transverse, in m (ft), as indicated in 5C-1-4/Figure 2A

h_e = length of the bracket, in m (ft), as indicated in 5C-1-4/Figure 2A-c and d and 5C-1-4/Figure 8

D = depth of the tanker, in m (ft), as defined in 3-1-1/7

B_c = breadth of the center tank, in m (ft)

P, s and α are as defined in 5C-1-A3/3.7.1.

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\ S_m f_y$

S_m and f_y are as defined in 5C-1-4/7.3.1.

Area A is not to be less than the area obtained based on 5C-1-4/11.9 and 5C-1-4/11.11.

3.9 Longitudinal Bulkhead Vertical Webs

3.9.1 Section Modulus of Vertical Web on Longitudinal Bulkhead

The net section modulus of the vertical web, in association with the effective longitudinal bulkhead plating, is to be not less than obtained from the following equation (see also 5C-1-4/1.3):

$SM = M/f_b$ cm^3 (in^3)

$M = 10{,}000kcps\,\ell_b^2$ N-cm (kgf-cm, lbf-in)

where

k = 1.0 (1.0, 0.269)

ℓ_b = span of vertical web, in m (ft), as indicated in 5C-1-4/Figure 2B-a

s = spacing of vertical webs, in m (ft)

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2) at mid-span ℓ_b of the vertical web, as specified in 5C-1-3/Table 3

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.70\ S_m f_y$

c is given in 5C-1-A3/Table 5.

S_m and f_y are as given in 5C-1-4/7.3.1.

For tanker without cross ties, the section modulus of the vertical web, as required above, is to extend at least up to 0.6ℓ from the lower end of the span. The value of the bending moment M, used for the calculation of the required section modulus of the remaining part of vertical web, may be reduced, but not more than 20%.

In the case of one cross tie, the section modulus of the lower (upper) vertical web, as required above, is to extend to the cross tie.

In the case of two cross ties, the section modulus of lower (upper) vertical web, as required above, is to extend to the lower (upper) cross tie and may be linearly interpolated between cross ties.

TABLE 5
Coefficient c for Vertical Web on Longitudinal Bulkhead

Arrangement of Cross Ties	*For Upper Vertical Web*	*For Lower Vertical Web*
No Cross Tie	0.75	
One Cross Tie in Wing Tank	0.19	0.33
Two Cross Ties in Wing Tank	0.13	0.20

3.9.2 Web Sectional Area of Vertical Web on Longitudinal Bulkhead

The net sectional area of the web portion of the vertical web is not to be less than obtained from the following equation:

$A = F/f_s$ cm^2 (in^2)

The shear force, F, in N (kgf, lbf), for the vertical web can be obtained from the following equation (see also 5C-1-4/1.3):

$F = 1000ks[K_U\ell(P_U + P_L) - h_U P_U]$ for upper part of web

$F = 1000ks[K_L\ell(P_U + P_L) - h_L P_L]$ or

$= 350ksK_L\ell(P_U + P_L)$, whichever is greater, for lower part of web

In no case is the shear force for the lower part of the web to be less than 120% of that for the upper part of the vertical web.

where

k = 1.0 (1.0, 2.24)

ℓ = span of the vertical web, in m (ft), as indicated in 5C-1-4/Figure 2B-a

s = spacing of the vertical webs, in m (ft)

P_U = nominal pressure, p, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-length of upper bracket (h_U/2), as specified in 5C-1-3/Table 3

P_L = nominal pressure, p, in kN/m^2 (tf/m^2, Ltf/ft^2), at the mid-length of the lower bracket (h_L /2), as specified in 5C-1-3/Table 3

h_U = length of the upper bracket, in m (ft), as indicated in 5C-1-4/Figure 2B-a

h_L = length of the lower bracket, in m (ft), as indicated in 5C-1-4/Figure 2B-a

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\ S_m f_y$

K_U and K_L are given in 5C-1-A3/Table 6.

S_m and f_y are as defined in 5C-1-4/7.3.1.

For tanker without cross ties, the sectional area of lower vertical webs, as required above, is to extend up to 0.15ℓ from the toe of the lower bracket or 0.3ℓ from the lower end of the span, whichever is greater.

In the case of one cross tie, the sectional area of the lower (upper) vertical web, as required above, is to extend to the cross tie.

In the case of two cross ties, the sectional area of the lower (upper) vertical web, as required above, is to extend to the lower (upper) cross tie and may be linearly interpolated between the cross ties.

TABLE 6
Coefficients K_U and K_L for Vertical Web on Longitudinal Bulkhead

Arrangement of Cross Ties	K_U	K_L
No Cross Tie	0.16	0.30
One Cross Tie in Wing Tank	0.09	0.21
Two Cross Ties in Wing Tank	0.075	0.16

3.11 Other Main Supporting Members

The strength and stiffness requirements specified in 5C-1-4/11 and 5C-1-4/15 for deck girders, vertical webs and horizontal girders on transverse bulkheads and cross ties are applicable to single hull tankers.

3.13 Proportions

The following specifications are supplemental to 5C-1-4/11.11.

20% for bottom transverses without bottom girder

14% for bottom transverses with one girder

8% for bottom transverses with three girders

20% for bottom girders

12.5% for side transverses

5 Strength Assessment

5.1 General

The failure criteria and strength assessment procedures specified in Section 5C-1-5 are generally applicable to single hull tankers, except for the special considerations outlined in 5C-1-A3/5.3 below.

5.3 Special Considerations

For assessing buckling and fatigue strength in accordance with 5C-1-5/5 and 5C-1-5/7, due consideration is to be given to the buckling characteristics of large stiffened panels of the side shell and bottom structures, as well as the realistic boundary conditions of side and bottom longitudinals at transverse bulkheads for calculating the total stress range with respect to fatigue strength.

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PART

5C

CHAPTER 1 **Vessels Intended to Carry Oil in Bulk (150 meters (492 feet) or more in Length)**

APPENDIX 4 **Application to Mid-deck Tankers** *(1995)*

1 General

1.1 Design Concepts

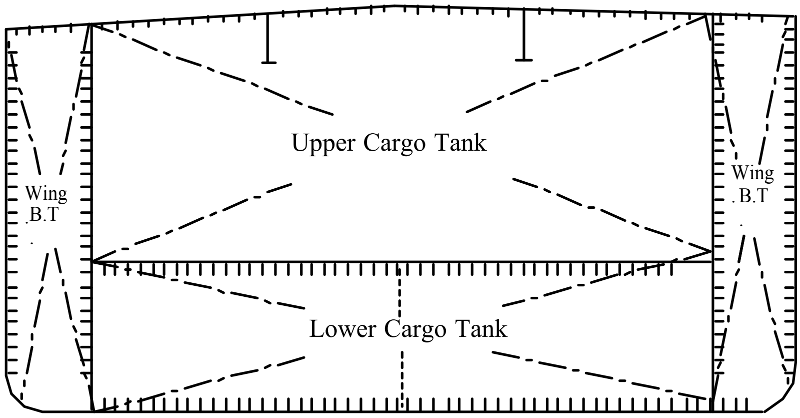
The term "mid-deck tanker" refers to a cargo tank arrangement with wing ballast tanks, single bottom and a tight deck (mid-deck) dividing the center or inboard cargo tanks into upper and lower tanks, as shown in 5C-1-A4/Figure 1. The location of the mid-deck is chosen to limit the maximum expected internal pressure at the bottom to a level less than the minimum anticipated external pressures, in accordance with Regulation 13 F(4) of Annex I to the International Convention for the Prevention of Pollution from Ships, so that the outflow of cargo oil may be prevented in grounding damage.

1.3 Design and Strength of Hull Structures

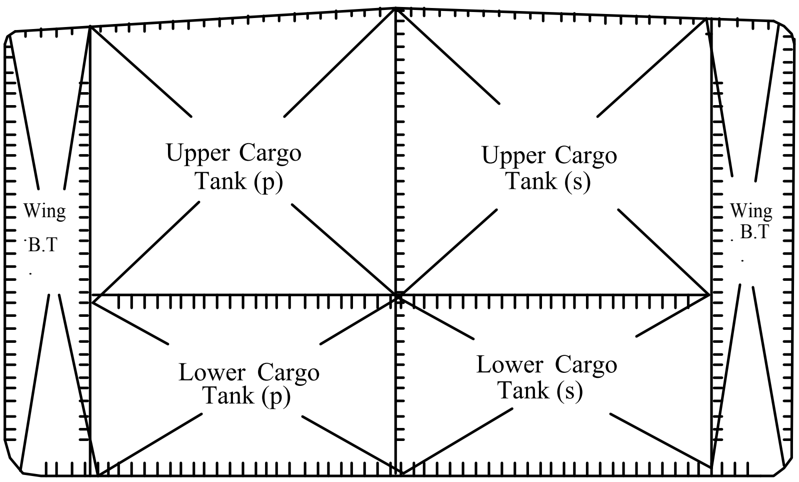
With regard to the design and strength of the hull structure, the criteria and evaluation procedures specified in Section 5C-1-1 are generally applicable to mid-deck tankers. Modifications taking the unique characteristics of this type of design into consideration are outlined in this Appendix.

The nominal design corrosion values specified in 5C-1-2/Table 1 and 5C-1-A3/1.1 may also be used for mid-deck tankers. For the bottom and mid-deck structures in cargo tanks, the nominal design corrosion values may be taken as 1.0 mm.

FIGURE 1
Typical Cross Section for Mid-deck Tankers



M D T 1



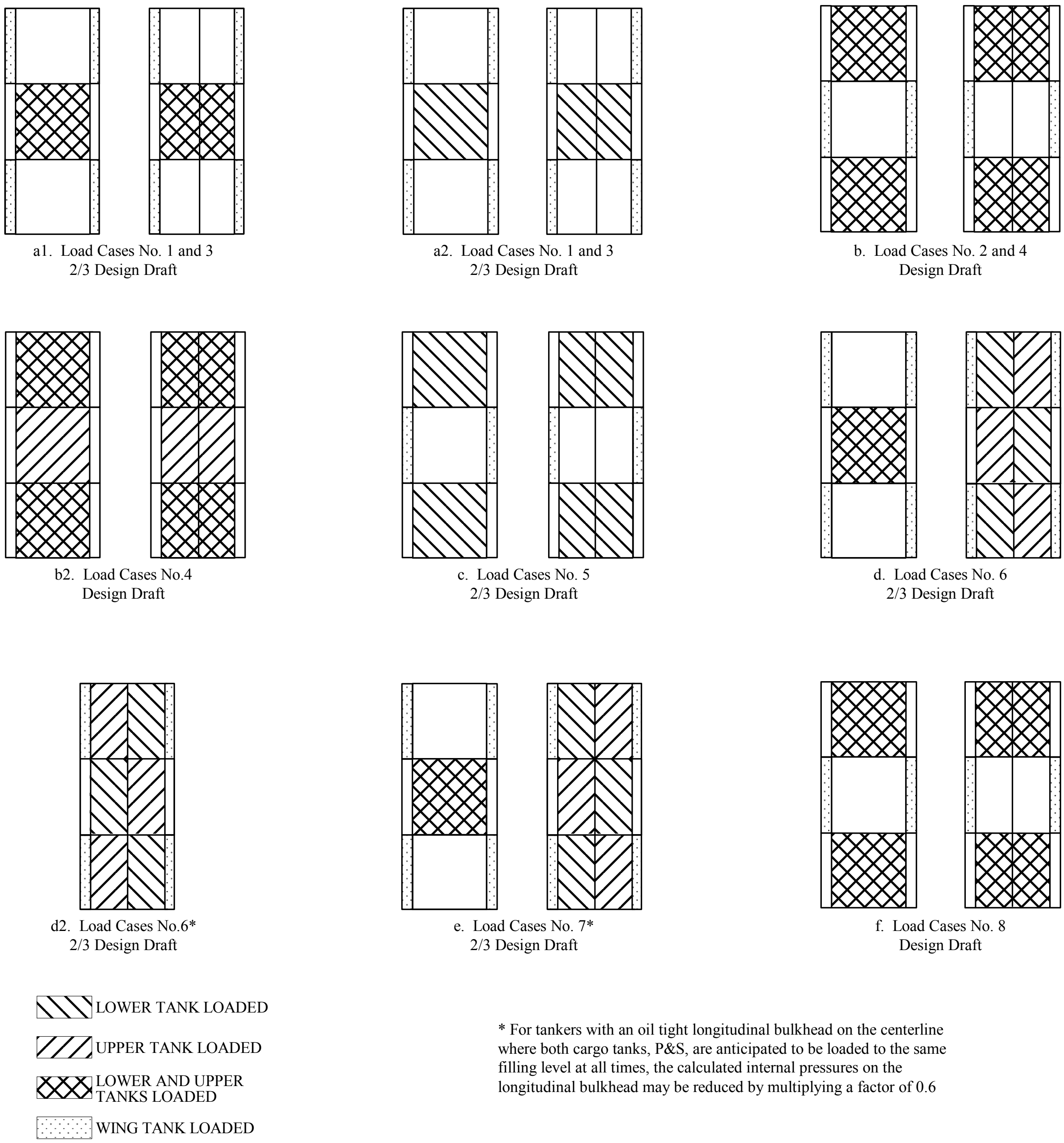
M D T 2

3 Load Criteria

3.1 Loading Patterns and Load Cases

In addition to the loading patterns shown in 5C-1-3/Figure 1a, loading patterns with respect to the upper and lower cargo tanks are also to be considered to simulate the maximum internal loads imposed on the mid-deck tanker structures. For this purpose, the cargo loading patterns given in 5C-1-A4/Figure 2 are to be considered in conjunction with 5C-1-3/Table 1, unless the pattern is proven unnecessary.

FIGURE 2
Loading Pattern



* For tankers with an oil tight longitudinal bulkhead on the centerline where both cargo tanks, P&S, are anticipated to be loaded to the same filling level at all times, the calculated internal pressures on the longitudinal bulkhead may be reduced by multiplying a factor of 0.6

3.3 Determination of Loads and Scantlings

3.3.1 Hull Girder Loads

The hull girder loads, external pressures, internal pressures and their nominal values and combined effects, specified in 5C-1-3/3, 5C-1-3/5, 5C-1-3/7 and 5C-1-3/9, are applicable to mid-deck tankers, except as outlined in 5C-1-A4/5.1 and 5C-1-A4/3.3.2 below.

3.3.2 Internal Pressure

In calculating the internal pressures in the lower cargo tanks, the tanks are to be assumed 100% full to the level of mid-deck.

In addition, the scantlings of bulkheads between lower cargo tanks are to be satisfactory for a scantling head to the upper deck with the vessel at the loading berth. Scantlings meeting the requirements in Section 5C-2-1 and Section 5C-2-2 will be acceptable for this purpose.

3.3.3 Partially Filled Tanks

For partially filled tanks, the sloshing loads specified in 5C-1-3/11 are also to be considered.

5 Strength Criteria

5.1 Hull Girder and Structural Elements

In general, the strength criteria specified in Section 5C-1-4 are directly applicable to the mid-deck tankers, with the exception of the items outlined in 5C-1-A4/5.1.1 and 5C-1-A4/5.1.2 below.

5.1.1 Hull Girder Shearing Strength

In determining the net thickness of the side shell and longitudinal bulkhead plating, the shear distribution factors, D_i, and local load corrections, R_i, given in 5C-1-4/5 are to be modified for the proposed structural configurations and loading patterns. Direct calculation results justifying the proposed modifications are to be submitted.

5.1.2 Bottom Structures

For the bottom shell plating and bottom longitudinals, the strength criteria specified in 5C-1-4/7 are directly applicable to the single bottom structures with the corresponding loading patterns given in 5C-1-A4/3.1.

For the main supporting members, bottom transverses and bottom girders, the strength formulations for the conventional single hull tankers given in Appendix 5C-1-A3 may be applied.

5.3 Mid-deck Structures

For scantling requirements for the mid-deck plating and mid-deck longitudinals, the equations given in 5C-1-4/7.3 and 5C-1-4/7.5 may be employed, by taking the permissible bending stresses $f_1 = f_2 = f_b$ = 0.85 $S_m f_y$, as defined in 5C-1-4/7.3.2 and 5C-1-4/7.5. The nominal pressure, p, is to be taken from the loaded upper tanks or lower tanks, whichever is greater.

For mid-deck transverses and mid-deck girders, the bending moments and shear forces may be determined either by a direct calculation (3D F.E. analysis) or by the equations given in 5C-1-4/11 for critical load cases and loading patterns specified in 5C-1-A4/3 above. In this case, the permissible bending and shear stresses may be taken as f_b = 0.7 $S_m f_y$ and f_s = 0.45 $S_m f_y$, as defined in 5C-1-4/11 for deck girders and deck transverses, respectively.

The sectional properties of the mid-deck transverses are also to satisfy the requirements for cross ties, given in 5C-1-4/15.

7 Strength Assessment

7.1 Failure Criteria

The failure criteria and strength assessment procedures specified in 5C-1-5/3 and 5C-1-5/9 are applicable to mid-deck tankers with the modified loading patterns and load cases outlined in 5C-1-A4/3 above.

7.3 Special Considerations

In view of the unique cargo tank arrangement for mid-deck tankers, the shear lag effects with respect to the effective hull girder section modulus and the transverse compression with respect to buckling/ultimate strength of the mid-deck plating are to be properly considered for assessing strength of the structure.

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PART

5C

CHAPTER 2 Vessels Intended to Carry Oil in Bulk (Under 150 meters (492 feet) in Length)

CONTENTS

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PART

5C

CHAPTER 2 Vessels Intended to Carry Oil in Bulk (Under 150 meters (492 feet) in Length)

SECTION 1 Introduction

1 General

1.1 Classification

In accordance with 1-1-3/3, the classification notation ✠ **A1 Oil Carrier** is to be assigned to vessels designed for the carriage of oil cargoes in bulk and built to the requirements of this section and other relevant sections of the Rules. As used in the Rules, the term "oil" refers to petroleum products having flash points at or below 60°C (140°F), closed cup test, and specific gravity of not over 1.05. Vessels intended to carry fuel oil having a flash point above 60°C (140°F), closed cup test, and to receive classification ✠ **A1 Fuel Oil Carrier** are to comply with the requirements of this section and other relevant sections of the Rules, with the exception that the requirements for cofferdams, gas-tight bulkheads and aluminum paint may be modified.

1.3 Application *(1995)*

1.3.1 Structural Arrangement

The requirements contained in this section are intended to apply to longitudinally framed, all-welded tank vessels having proportions in accordance with 3-1-2/7, machinery aft and two or more continuous longitudinal bulkheads. Where the arrangement differs from that described, the scantlings may require adjustment to provide equivalent strength.

1.3.2 Vessels of Similar Type and Arrangement

The requirements are also intended to apply to other vessels of similar type and arrangement.

Double hull tanker: A tank vessel having full depth wing water ballast tanks or other non-cargo spaces and full-breadth double bottom water ballast tanks or other non-cargo spaces within cargo area to prevent liquid cargo outflow in stranding/collision. The size and capacity of these wing/double bottom tanks or spaces are to comply with MARPOL 73/78 and national Regulations, as applicable.

Mid-deck tanker: Refer to 5C-1-A4/1.1, Design Concepts.

Single hull tanker: A tank vessel which does not fit the above definitions of *Double hull tanker and Mid-deck tanker.*

1.3.3 Engineering Analysis

It is recommended that compliance with the following requirements be accomplished through a detailed investigation of the magnitude and distribution of the imposed longitudinal and transverse forces by using an acceptable method of engineering analysis. The following paragraphs are to be used as a guide in determining scantlings. Where it can be shown that the calculated stresses using the loading conditions specified in 5C-2-2/13.5 are less than those stated to be permissible, consideration will be given to scantlings alternative to those recommended by this section.

1.5 Detail Design of Internal Members

The detail design of internals is to follow the guidance given in 3-1-2/15.

See also Appendix 5C-1-A1 entitled, "Guide for the Fatigue Strength Assessment of Tankers."

1.7 Breaks

Special care is to be taken throughout the structure to provide against local stresses at the ends of the oil spaces, superstructures, etc. The main longitudinal bulkheads are to be suitably tapered at their ends, and effective longitudinal bulkheads in the poop are to be located to provide effective continuity between the structure in way of and beyond the main cargo spaces. Where the break of a superstructure lies within the midship 0.5*L*, the required shell and deck scantlings for the midship 0.4*L* may be required to be extended to effect a gradual taper of structure, and the deck stringer plate and sheer strake are to be increased. See 5C-2-2/3.3 and 5C-2-2/5.1. Where the breaks of the forecastle or poop are appreciably beyond the midship 0.5*L*, the requirements of 5C-2-2/3.3 and 5C-2-2/5.1 may be modified.

1.9 Variations

Tankers of special type or design differing from those described in the following Rules will be specially considered on the basis of equivalent strength.

1.11 Loading Guidance

Loading guidance is to be as required by 3-2-1/7.

1.13 Higher-strength Materials

In general, applications of higher-strength materials for vessels intended to carry oil in bulk are to meet the requirements of this section, but may be modified generally as outlined in the following sections:

Section 3-2-4 for longitudinals

Section 3-2-7 for longitudinals

Section 3-2-8 for deep longitudinal members (3-2-8/9.3)

Section 3-2-10 for bulkhead plating

Section 3-2-2 for shell plating

Section 3-2-3 for deck plating

In such cases, the allowable shearing stresses will be specially considered.

1.15 Pressure-vacuum Valve Setting *(1993)*

Where pressure-vacuum valves of cargo oil tanks are set at a pressure in excess of the pressure appropriate to the length of the vessel (see 5C-1-7/11.11.2), the tank scantlings will be specially considered. Particular attention is to be given to a higher pressure setting of pressure-vacuum valves as may be required for the efficient operation of cargo vapor emission control systems, where installed.

1.17 Protection of Structure

For the protection of structure, see 3-2-18/5.

1.19 Aluminum Paint

Paint containing aluminum is not to be used in cargo tanks, on tank decks in way of cargo tanks, in pump rooms and cofferdams, or in any other area where cargo vapor may accumulate, unless it has been shown by appropriate tests that the paint to be used does not increase the fire hazard.

1.21 Tank Design Pressures *(1993)*

The requirements of this section are for tanks intended for the carriage of liquid cargoes with specific gravities not greater than 1.05. Where the specific gravity is greater than 1.05, the design heads, h, are to be increased by the ratio of specific gravity to 1.05. See also 5C-1-7/11 with regard to pressure-vacuum valve setting and liquid level control.

3 Special Requirements for Deep Loading *(2003)*

Where a vessel is intended to operate at the minimum freeboard allowed by the International Convention on Load Lines, 1966, for Type-A vessels, the conditions in 5C-2-1/3.1 through 5C-2-1/3.9 are to be complied with.

3.1 Machinery Casings

Machinery casings are normally to be protected by an enclosed poop or bridge, or by a deckhouse of equivalent strength. The height of such structure is to be at least 1.8 m (5.9 ft) for vessels up to and including 75 m (246 ft) in length, and 2.3 m (7.5 ft) for vessels 125 m (410 ft) or more in length. The minimum height at intermediate lengths is to be obtained by interpolation. The bulkheads at the forward ends of these structures are to be of not less scantlings than required for bridge-front bulkheads. (See 3-2-11/3) Machinery casings may be exposed, provided that they are specially stiffened and there are no openings giving direct access from the freeboard deck to the machinery space. A door complying with the requirements of 3-2-11/5.3 may, however, be permitted in the exposed machinery casing, provided that it leads to a space or passageway which is as strongly constructed as the casing and is separated from the engine room by a second door complying with 3-2-11/5.3. The sill of the exterior door is not to be less than 600 mm (23.5 in.), and of the second door not less than 230 mm (9 in.).

3.3 Access *(1998)*

Satisfactory arrangements are to be provided to safeguard the crew in reaching all parts used in the necessary work of the vessel. See 3-2-17/3.

3.5 Hatchways

Exposed hatchways on the freeboard and forecastle decks or on the tops of expansion trunks are to be provided with effective watertight covers of steel. The use of material other than steel will be subject to special consideration.

3.7 Freeing Arrangements

Tankers with bulwarks are to have open rails fitted for at least half the length of the exposed parts of the freeboard and superstructure deck or other effective freeing arrangements. The upper edge of the sheer strake is to be kept as low as practicable. Where superstructures are connected by trunks, open rails are to be fitted for the whole length of the exposed parts of the freeboard deck.

3.9 Flooding *(2003)*

Attention is called to the requirement of the International Convention on Load Lines, 1966, that tankers over 150 m (492 ft) in freeboard length (see 3-1-1/3.3) to which freeboards less than those based solely on Table B are assigned must be able to withstand the flooding of certain compartments.

3.11 Ventilators *(2003)*

Ventilators to spaces below the freeboard deck are to be specially stiffened or protected by superstructures or other efficient means. See also 3-2-17/9.

5 Arrangement *(1994)*

The arrangements of the vessel are to comply with the requirements in Annex 1 to International Convention for the Prevention of Pollution from Ships, with regard to segregated ballast tanks (Regulation 13), their protective locations (Regulation 13E – where the option in Regulation 13F (4) or (5) is exercised), collision or stranding considerations (Regulation 13F), hypothetical outflow of oil (Regulation 23), limitations of size and arrangement of cargo tanks (Regulation 24) and slop tanks [Regulation 15 (2)(c)]. A valid International Oil Pollution Certificate issued by the Administration maybe accepted as an evidence for compliance with these requirements.

5.1 Subdivision

The length of the tanks, location of expansion trunks, and position of longitudinal bulkheads are to be arranged to avoid excessive dynamic stresses in the hull structure.

5.3 Cofferdams

Cofferdams, thoroughly oiltight and vented, having widths as required for ready access, are to be provided for the separation of all cargo tanks from galleys and living quarters, general cargo spaces which are below the uppermost continuous deck, boiler rooms, and spaces containing propulsion machinery or other machinery where sources of ignition are normally present. Pump rooms, compartments arranged solely for ballast and fuel-oil tanks may be considered as cofferdams in compliance with this requirement.

5.5 Gastight Bulkheads

Gastight bulkheads are to be provided for the isolation of all cargo pumps and piping from spaces containing stoves, boilers, propulsion machinery, electric apparatus or machinery where sources of ignition are normally present. These bulkheads are to comply with the requirements of Section 3-2-9.

5.7 Cathodic Protection *(1996)*

5.7.1 Anode Installation Plan

Where sacrificial anodes are fitted in cargo or adjacent ballast tanks, their material, disposition and details of their attachment are to be submitted for approval.

5.7.2 Magnesium and Magnesium Alloy Anodes

Magnesium and magnesium alloy anodes are not to be used.

5.7.3 Aluminum Anodes

Aluminum anodes may be used in cargo tanks of tankers, only in locations where the potential energy does not exceed 275 N-m (28 kgf-m, 200 ft-lb). The height of the anode is to be measured from the bottom of the tank to the center of the anode, and its weight is to be taken as the weight of the anode as fitted, including the fitting devices and inserts.

Where aluminum anodes are located on horizontal surfaces, such as bulkhead girders and stringers, not less than 1 m (39 in.) wide and fitted with an upstanding flange or face flat projecting not less than 75 mm (3 in.) above the horizontal surface, the height of the anode may be measured from this surface.

Aluminum anodes are not to be located under tank hatches or Butterworth openings unless protected from falling metal objects by adjacent tank structure.

5.7.4 Anode Attachment

Anodes are to have steel cores sufficiently rigid to avoid resonance in the anode support and are to be designed to retain the anode even when it is wasted.

The steel cores are to be attached to the structure by means of continuous welds at least 75 mm (3 in.) in length. Alternatively, they may be attached to separate supports by bolting. A minimum of two bolts with locknuts are to be used.

The supports at each end of an anode are not to be attached to items of structure which are likely to move independently.

Anode inserts and supports welded directly to the structure are to be arranged so that the welds are clear of stress raisers.

5.9 Ports in Pump Room Bulkheads

Where fixed ports are fitted in the bulkheads between a pump room and the machinery or other safe space, they are to maintain the gastight and watertight integrity of the bulkhead. The ports are to be effectively protected against the possibility of mechanical damage and are to be fire resistant. Hinged port covers of steel, having non-corrosive hinge pins and secured from the safe space side, are to be provided. The covers are to provide strength and integrity equivalent to the unpierced bulkhead. Except where it may interfere with the function of the port, the covers are to be secured in the closed position. The use of material other than steel for the covers will be subject to special consideration. Lighting fixtures providing strength and integrity equivalent to that of the port covers will be accepted as an alternative.

5.11 Location of Cargo Oil Tank Openings

Cargo oil tank openings, including those for tank cleaning, which are not intended to be secured gastight at all times during the normal operation of the vessel are not to be located in enclosed spaces. For the purpose of this requirement, spaces open on one side only are to be considered enclosed. See also 5C-2-1/5.21.

5.13 Structural Fire Protection

The applicable requirements of Section 3-4-1 are to be complied with.

5.15 Allocation of Spaces *(1994)*

5.15.1 Tanks Forward of the Collision Bulkhead

Tanks forward of the collision bulkhead are not to be arranged for the carriage of oil or other liquid substances that are flammable.

5.15.2 Double Bottom Spaces and Wing Tank Spaces

For vessels of 5000 tons deadweight and above, double bottom spaces or wing tanks adjacent to cargo oil tanks are to be allocated for water ballast or spaces other than cargo and fuel oil tanks.

5.17 Access to Upper Parts of Ballast Tanks on Double Hull Tankers *(1993)*

Where the structural configuration within the ballast tank is such that it will prevent access to upper parts of tanks for required close-up examination (see 7-3-2/5.13.4) by conventional means, such as a raft on partly filled tank, permanent means of safe access is to be provided. The details of access are to be submitted for review.

Where horizontal girders or diaphragm plates are fitted, they may be considered as a part of permanent access. Alternative arrangements to the above may be considered upon submission.

5.19 Access to All Spaces in the Cargo Area *(1 October 1994)*

Access to cofferdams, ballast tanks, cargo tanks and other spaces in the cargo area is to be direct and from the open deck. Access to double bottom spaces may be through a cargo pump room, deep cofferdam, pipe tunnel or similar space, provided ventilation is suitable.

For access through horizontal openings, hatches or manholes, the access is to be of a size such as to allow a person wearing a self-contained, air-breathing apparatus and protective equipment (see 4-7-3/15.5) to ascend or descend any ladder without obstruction and also to provide a clear opening to facilitate the hoisting of an injured person from the bottom of the space. In general, the minimum clear opening is not to be less than 600 mm (24 in.) by 600 mm (24 in.).

For access through vertical openings or manholes providing passage through the length and breadth of the space, the minimum clear opening is not to be less than 600 mm (24 in.) by 800 mm (32 in.) at a height of not more than 600 mm (24 in.) from the bottom shell plating, unless gratings or other footholds are provided.

For vessels less than 5000 tons deadweight, smaller dimensions than above may be approved, provided that the ability to remove an injured person can be demonstrated to the satisfaction of the Surveyor.

5.21 Duct Keels or Pipe Tunnels in Double Bottom *(2000)*

Duct keels or pipe tunnels are not to pass into machinery spaces. Provision is to be made for at least two exits to the open deck, arranged at a maximum distance from each other. One of these exits may lead to the cargo pump room, provided that it is watertight and fitted with a watertight door complying with the requirements of 3-2-9/9.1 and in addition with the following:

i) In addition to bridge operation, the watertight door is to be capable of being closed from outside the main pump room entrance; and

ii) A notice is to be affixed at each operating position to the effect that the watertight door is to be kept closed during normal operations of the vessel, except when access to the pipe tunnel is required.

For the requirements of ventilation and gas detection in duct keels or pipe tunnels, see 5C-1-7/31.17.1.

5.23 Ventilation *(1996)*

Holes are to be cut in every part of the structure where, otherwise, there might be a chance of gases being "pocketed". Special attention is to be paid to the effective ventilation of pump rooms and other working spaces adjacent to the oil tanks. In general, floor plating is to be of an open type not to restrict the flow of air. See 5C-1-7/17.1 and 5C-1-7/17.5. Efficient means are to be provided for clearing the oil spaces of dangerous vapors by means of artificial ventilation or steam. For the venting of the cargo tanks, see 5C-1-7/11 and 5C-1-7/21.

5.25 Pumping Arrangements

See applicable requirements in Section 5C-1-7.

5.27 Electrical Equipment *(2004)*

See 5C-1-7/31 and 5C-1-7/33.

5.29 Testing

Requirements for testing are contained in Part 3, Chapter 7.

5.31 Machinery Spaces

Machinery spaces aft are to be specially stiffened transversely. Longitudinal material at the break is also to be specially considered to reduce concentrated stresses in this region. Longitudinal wing bulkheads are to be incorporated with the machinery casings or with substantial accommodation bulkheads in the tween decks and within the poop.

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PART

5C

CHAPTER **2 Vessels Intended to Carry Oil in Bulk (Under 150 meters (492 feet) in Length)**

SECTION **2 Hull Structure**

1 Hull Girder Strength

1.1 Normal-strength Standard

The longitudinal hull girder strength is to be not less than required by the equations given in 3-2-1/3.7 and 3-2-1/3.9.

1.3 Still-water Bending Moment Calculations

For still-water bending moment calculations, see 3-2-1/3.3.

3 Shell Plating

3.1 Amidships

Shell plating within the midship 0.4L is to be of not less thickness than is required for longitudinal hull girder strength, or than that obtained from 5C-2-2/3.1.1 through 5C-2-2/3.1.3.

3.1.1 Bottom Shell Thickness

The thickness t of the bottom shell plating is not to be less than obtained from 5C-2-2/3.1.1(a) and 5C-2-2/3.1.1(b).

3.1.1(a)

$$t = S(L + 8.54)/(42L + 2318) \quad \text{mm}$$

$$t = S(L + 28)/(42L + 7602) \quad \text{in.}$$

where

S = frame spacing, in mm (in.), but is not to be taken as less than 88% of that given in 3-2-5/1.7 or 864 mm (34 in.), whichever is less

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

Where the bottom hull girder section modulus SM_A is greater than required by 3-2-1/3.7.1, and still-water bending moment calculations are submitted, the thickness of bottom shell may be obtained from the above equation multiplied by the factor, R_b. Special consideration will be given to vessels constructed of higher-strength steel.

$$R_b = \sqrt{\frac{SM_R}{SM_A}} \quad \text{is not to be taken less than 0.85}$$

where

SM_R = hull girder section modulus required by 3-2-1/3.7.1, in cm^2-m (in^2-ft)

SM_A = bottom hull girder section modulus of vessel, in cm^2-m (in^2-ft), with the greater of the bottom shell plating thickness obtained when applying R_n or R_b

3.1.1(b)

$$t = 0.006s\sqrt{0.7d + 0.02(L-50)} + 2.5 \quad \text{mm}$$

$$t = 0.00331s\sqrt{0.7d + 0.02(L-164)} + 0.1 \quad \text{in.}$$

Where the bottom hull girder section modulus, SM_A, is greater than required by 3-2-1/3.7.1, and still-water bending moment calculations are submitted, the thickness of bottom shell may be obtained from the above equation multiplied by the factor, R_n. Special consideration will be given to vessels constructed of higher-strength steel.

$$R_n = \sqrt{\frac{1}{\frac{f_p}{\sigma_t}\left(1-\frac{SM_R}{SM_A}\right)+1}} \quad \text{is not to be taken less than 0.85}$$

where

f_p = nominal permissible bending stress, in kN/cm^2 (tf/cm^2, Ltf/in^2), as given in 3-2-1/3.7.1

σ_t = $KP_t(s/t)^2$, in kN/cm^2 (tf/cm^2, Ltf/in^2)

K = 0.34 for longitudinal framing

P_t = $(0.638H + d)a$ kN/cm^2 (tf/cm^2, Ltf/in^2)

a = 1.005×10^{-3} (1.025×10^{-4}, 1.984×10^{-4})

t = bottom shell plating thickness required by the equation in 5C-2-2/3.1.1(b) above, in mm (in.)

H = wave parameter defined in 3-2-2/3.13.2

SM_R and SM_A are as defined in 5C-2-2/3.1.1(a) and L, s and d are as defined in 5C-2-2/3.1.2(b).

SM_R/SM_A is not to be taken as less than 0.70.

3.1.2 Side Shell Thickness

The thickness t of the side shell plating is not to be less than obtained from 5C-2-2/3.1.2(a) and 5C-2-2/3.1.2(b).

3.1.2(a)

$t = 0.01L(6.5 + 21/D)$ mm

$t = 0.0003937L(2.0 + 21/D)$ in.

3.1.2(b)

$t = 0.0052s\sqrt{0.7d + 0.02L} + 2.5$ mm

$t = 0.00287s\sqrt{0.7d + 0.02L} + 0.1$ in.

where

L = length of vessel, as defined in 3-1-1/3.1

d = molded draft to the summer load line, as defined 3-1-1/9, in m (ft)

D = molded depth, as defined in 3-1-1/7.1, in m (ft)

s = spacing of bottom longitudinals or spacing of side longitudinals or vertical side frames, in m (ft)

3.1.3 Shell Thickness

Where a double bottom is fitted and is not to be used for the carriage of cargo oil, the bottom shell thickness may be in accordance with 3-2-2/3.13, and if a double skin is provided and is not to be used for the carriage of cargo oil, the side shell thickness may be in accordance with 3-2-2/3.9.

3.3 Sheer Strake

The thickness of the sheer strake is to be not less than the thickness of the side-shell plating, nor less than required by 5C-2-2/5.1.2. The thickness is to be increased 25% in way of breaks of superstructures, but this increase need not exceed 6.5 mm (0.25 in.). See 5C-2-1/1.7.

3.5 Keel Plate

The thickness of the flat plate keel is to be not less than that required for the bottom shell plating at that location increased by 1.5 mm (0.06 in.), except where the submitted docking plan (see 3-1-2/11) specifies all docking blocks be arranged away from the keel.

3.7 Flat of Bottom Forward *(2002)*

Where the heavy ballast draft forward is less than 0.04L, the plating on the flat of bottom forward of the location in 3-2-4/Table 1 is to be not less than required in 3-2-2/5.5. For this assessment, the heavy ballast draft forward is to be determined by using segregated ballast tanks only.

3.9 Plating Outside Midship 0.4L

The bottom and side shell, including the sheer strake beyond the midship 0.4L, is generally to be in accordance with the requirements of 3-2-2/5 and is to be gradually reduced from the midship thickness to the end thickness.

3.11 Vessels under 76 m (250 ft)

In vessels under 76 m (250 ft) in length, the thickness of the bottom shell is to be obtained from 3-2-2/3 of the *Rules for Building and Classing Steel Vessels Under 90 meters (295 feet) in Length*.

3.13 Bilge Keels

Bilge keels are to comply with 3-2-2/13.

5 Deck Plating

5.1 Amidships

The strength deck within the midship 0.4L is to be of not less thickness than is required to provide the deck area necessary for longitudinal strength in accordance with 5C-2-2/1; nor is the thickness to be less than determined by the following equations for thickness of deck plating.

5.1.1

$$t = 0.0016s\sqrt{L-53} + 0.32\frac{L}{D} - 2.5 \qquad \text{mm}$$

$$t = 0.000883s\sqrt{L-174} + 0.0126\frac{L}{D} - 0.1 \qquad \text{in.}$$

5.1.2

$$t = \frac{s(30.48+L)}{4981+40L} \qquad L < 150 \text{ m}$$

$$t = \frac{s(100+L)}{16339+40L} \qquad L < 492 \text{ ft.}$$

where

t	=	plate thickness, in mm (in.)
s	=	spacing of deck longitudinals, in mm (in.)
L	=	length of vessel, as defined in 3-1-1/3.1, in m (ft)
D	=	molded depth, as defined in 3-1-1/7.1, in m (ft)

The thickness of the stringer plate is to be increased 25% in way of breaks of superstructures, but this increase need not exceed 6.5 mm (0.25 in.). See 5C-2-1/1.7. The required deck area is to be maintained throughout the midship 0.4L of the vessel or beyond the end of a superstructure at or near the midship 0.4L point. From these locations to the ends of the vessel, the deck area may be gradually reduced in accordance with 3-2-1/11.3. Where bending moment envelope curves are used to determine the required hull girder section modulus, the foregoing requirements for strength deck area may be modified in accordance with 3-2-1/11.3. Where so modified, the strength deck area is to be maintained a suitable distance from superstructure breaks and is to be extended into the superstructure to provide adequate structural continuity.

5.3 Vessels under 76 m (250 ft)

In vessels under 76 m (250 ft) in length, the thickness of deck plating is to be obtained from 3-2-3/3 of the ABS *Rules for Building and Classing Steel Vessels Under 90 meters (295 feet) in Length*.

7 Bulkhead Plating

7.1 Plating Thickness

The plating is to be of not less thickness than is required for deep-tank bulkheads by 3-2-10/3, where *h* is measured from the lower edge of the plate to the top of the hatch or to a point located 1.22 m (4 ft) above the deck at side amidships, whichever is greater. The upper strakes are to be increased above these requirements to provide a proper margin for corrosion. It is recommended that the top strake of a complete longitudinal bulkhead be not less than 9.5 mm ($^3/_8$ in.) in vessels of 91.5 m (300 ft) length, and 12.5 mm ($^1/_2$ in.) in vessels of 150 m (492 ft) length, and that the strake below the top strake be not less than 9.5 mm ($^3/_8$ in.) in vessels of 122 m (400 ft) length and 10.5 mm ($^{13}/_{32}$ in.) in vessels of 150 m (492 ft) in length, with intermediate thicknesses for intermediate lengths. See also 5C-2-1/1.15.

9 Long or Wide Tanks

9.1 Oiltight Bulkheads

In vessels fitted with long tanks, the scantlings of oiltight transverse bulkheads in smooth-sided tanks are to be specially considered when the spacing between tight bulkheads, nontight bulkheads or partial bulkhead exceeds 12 m (40 ft) in the case of corrugated-type construction, or 15 m (50 ft) in the case of flat-plate type of construction. Special consideration is to be given to the scantlings of longitudinal oiltight bulkheads forming the boundaries of wide tanks. Where the length of the smooth-sided tanks exceeds $0.1L$ or the breadth exceeds $0.6B$, nontight bulkheads are to be fitted, unless calculations are submitted to prove that no resonance due to sloshing will occur in service.

Alternatively, reinforcements to the bulkheads and decks, without nontight bulkheads, may be determined by an acceptable method of engineering analysis.

9.3 Nontight Bulkheads

Nontight bulkheads are to be fitted in line with transverse webs, bulkheads or other structures with equivalent rigidity. They are to be suitably stiffened. Openings in the nontight bulkhead are to have generous radii and their aggregate area is not to exceed 33%, nor be less than 10% of the area of the nontight bulkhead. Plating is to be of not less thickness than that required by 5C-2-2/Table 2. Section moduli of stiffeners and webs may be one half of the requirements for watertight bulkheads in 3-2-9/5.3 and 3-2-9/5.7. Alternatively, the opening ratio and scantlings may be determined by an acceptable method of engineering analysis.

11 Double Bottom Structure

11.1 General

Where a double bottom is fitted, it is generally to be arranged with a centerline girder, or equivalent, and, where necessary, with full depth side girders similar to Section 3-2-4. The arrangements and scantlings of the double bottom structure as given in Section 3-2-4 may be used, except where modified by this section. Increases in scantlings may be required where tanks other than double bottom tanks are designed to be empty with the vessel in a loaded condition. Alternatively, consideration will be given to arrangements and scantlings determined by an acceptable method of engineering analysis, provided that the stresses are in compliance with 5C-2-2/13. Where ducts forming a part of the double bottom structure are used as a part of the piping system for transferring cargo oil or ballast, the structural integrity of the duct is to be safeguarded by suitable relief valves or other arrangement to limit the pressure in the system to the value for which it is designed.

11.3 Floors and Girders

In general, the thickness of floors and girders is to be as required by Section 3-2-4. Where tanks adjacent to the double bottom are designed to be empty with the vessel in a loaded condition, the floors and girders in the double bottom are to be specially considered. Where the heavy ballast draft forward is less than 0.04*L* the fore-end arrangement of floors and side girders is to comply with 3-2-4/13.1 and 3-2-4/13.3.

11.5 Inner Bottom

The thickness of the inner-bottom plating is to be not less than required by Section 3-2-10, with a head to 1.22 m (4 ft) above the deck at side amidships or to the top of the hatch, whichever is greater.

11.7 Inner-bottom Longitudinals

Scantlings for inner-bottom longitudinals are to be not less than required in 5C-2-2/15.3, using $c = 1.00$. Where effective struts are fitted between inner-bottom and bottom longitudinals, the inner-bottom longitudinals are not to be less than required in 5C-2-2/15.3, using $c = 0.55$, or 85% of the requirement in 3-2-4/11.3 for bottom longitudinals, using $c = 0.715$, whichever is greater.

11.9 Bottom Longitudinals

Scantlings for bottom longitudinals are to be not less than required by 3-2-4/11.3. Where effective struts are fitted between bottom and inner-bottom longitudinals, the bottom longitudinals are to be not less than 90% of the inner-bottom longitudinal requirement in 5C-2-2/15.3, using $c = 0.55$, or the requirement in 3-2-4/11.3, using $c = 0.715$, whichever is greater. Where the heavy ballast draft forward is less than 0.04*L*, the flat of bottom-forward longitudinals are to be not less than required by 3-2-4/13.5.

13 Deep Supporting Members

13.1 General

Webs, girders and transverses which support longitudinal frames, beams or bulkhead stiffeners, generally are to be in accordance with the following paragraphs. It is recommended that deep girders be arranged in line with webs and stringers to provide complete planes of stiffness. In vessels without a longitudinal centerline bulkhead or effective centerline supporting member, a center vertical keel having sufficient strength to serve as one line of support is to be provided where centerline keel blocks are used in drydocking operations.

13.3 Section Modulus

Each member is to have a section modulus, *SM*, in cm^3 (in^3), not less than that obtained from the following equation:

$$SM = M/f \quad \text{cm}^3\ (\text{in}^3)$$

where

M = maximum bending moment along the member between the toes of the end brackets as computed by an acceptable method of engineering analysis, in kN-cm (kgf-cm, Ltf-in.)

f = permissible maximum bending stress, as determined from the following table.

Values of f (Ordinary-strength Steel)

	kN/cm²	*kgf/cm²*	*Ltf/in²*
Transverse members	13.9	1420	9
Longitudinal members	9.3	947	6

Note: Local axial loads on webs, girders or transverses are to be accounted for by reducing the maximum permissible bending stress.

In addition, the following equation is to be used in obtaining the required section modulus *SM*.

$SM = 4.74chs\,\ell_b^2$ cm³ $\qquad SM = 0.0025chs\,\ell_b^2$ in³

c for bottom and deck transverses as shown in 5C-2-2/Figure 1.

= 2.00 for bottom girders, vertical webs on transverse bulkheads, horizontal girders and stringers

= 2.50 for deck girders

c for side transverses and vertical webs on longitudinal bulkheads

= 1.50 without struts

= 0.85 with one horizontal strut

= 0.65 with two horizontal struts

= 0.55 with three horizontal struts

= Where a centerline longitudinal bulkhead is fitted, the value of c for side-shell transverses and vertical webs on longitudinal wing bulkheads will be subject to special consideration.

Where no struts or other effective supporting arrangements are provided for the wing-tank vertical transverses, the deck transverses in the wing tanks are to have section modulus values not less than 70% of that for the vertical side transverses. In no case are the deck transverses in the wing tank to have less than 70% of the section modulus for the corresponding members in the center tanks.

s = spacing of transverses, or width of area supported, in m (ft)

h = bottom transverses and girders of the depth of the vessel, D, in m (ft). See also 5C-2-1/1.15.

= side transverses and vertical webs on longitudinal bulkheads, vertical webs on transverse bulkheads and horizontal girders and stringers, the vertical distance, in m (ft) from the center of the area supported to a point located 1.22 m (4 ft) above the deck at side amidships in vessels 61 m (200 ft) in length, and to a point located 2.44 m (8 ft) above the deck at side amidships in vessels 122 m (400 ft) in length and above; for intermediate lengths, intermediate points may be used. The value of h is to be not less than the vertical distance from the center of the area supported to the tops of the hatches, in m (ft). See also 5C-2-1/1.15.

= deck transverses and girders, in m (ft), is to be measured as indicated above for side transverses, etc., except that in no case is it to be less than 15% of the depth of vessel.

ℓ_b = span of the member, in m (ft), measured between the points of support as indicated in 5C-2-2/Figure 1. Where effective brackets are fitted, the length ℓ_b is to be measured as indicated in 5C-2-2/Figure 2a and 5C-2-2/Figure 2b; nor is the length for deck and bottom transverses in wing tanks to be less than 0.125*B* or one-half the breadth of the wing tank, whichever is the greater. Where a centerline longitudinal bulkhead is also fitted, this minimum length will be specially considered.

13.5 Local Loading Conditions

In addition to withstanding the loads imposed by longitudinal hull girder shearing and bending action, the structure is to be capable of withstanding the following local loading conditions without exceeding the permissible bending and average shearing stresses stated in 5C-2-2/13.3 and 5C-2-2/13.7.

- Center tank loaded; wing tanks empty; $^1/_3$ summer load line draft
- Center tank empty; wing tanks loaded; $^1/_3$ summer load line draft
- Center and wing tanks loaded; $^1/_3$ summer load line draft

Note: For loaded tanks, the head h is to be measured to a point located 2.44 m (8 ft) above the deck at side, except in the case of vessels less than 122 m (400 ft) in length, as explained in 5C-2-2/13.3. See also 5C-2-1/1.15.

In addition, where the arrangement of the vessel involves tanks of relatively short length, or tanks designated as permanent ballast tanks, it is recommended that the following appropriate loading conditions also be investigated:

- Center tank loaded; wing tanks empty; summer load line draft
- Center tank empty; wing tank loaded; summer load line draft

In all cases, the structure is to be reviewed for other realistic loading conditions associated with the vessel's intended service.

13.7 Web Portion of Members

The net sectional area of the web portion of the member, including effective brackets where applicable, is not to be less than that obtained from the following equation.

$A = F/q$ cm^2 (in^2)

where

F = shearing force at the point under consideration, kN (kgf, Ltf)

q = allowable average shearing stress in the web of the supporting member, as determined from 5C-2-2/Table 1.

For longitudinal supporting members, the value of q is to be 80% of the value shown in 5C-2-2/Table 1.

Where individual panels exceed the limits given in 5C-2-2/Table 1, detailed calculations are to be submitted in support of adequate strength against buckling.

The thickness of the web portions of the members is not to be less than given in 5C-2-2/Table 2 for minimum thickness. Reduced thickness may be considered for higher strength materials if the buckling and fatigue strength is proven adequate.

It is recommended that compliance with the foregoing requirement be accomplished through a detailed investigation of the magnitude and distribution of the imposed shearing forces by means of an acceptable method of engineering analysis. Where this is not practicable, the following equations may be used as guides in approximating the shearing forces.

$F = csD(K\ell_s - h_e)$ for bottom transverses

$F = cs[K_L\, \ell_s h - h_e(h + \frac{\ell_s}{2} - \frac{h_e}{2})]$ for lower side transverses or vertical transverses on longitudinal bulkheads

$F = cs[K_U\, \ell_s h - h_e(h - \frac{\ell_s}{2} + \frac{h_e}{2})]$ for upper side transverses or vertical transverses on longitudinal bulkheads

where

c = 10.05 (1025, 0.0285)

s = spacing of transverses, in m (ft)

D = depth of vessel, as defined in 3-1-1/7, in m (ft)

B = breadth of vessel as defined in 3-1-1/5, in m (ft)

ℓ_s = span of transverse, in m (ft), as indicated in 5C-2-2/Figure 3

h_e = effective length or height of bracket, in m (ft), as indicated in 5C-2-2/Figure 3. In no case is h_e to be greater than $0.33\ell_s$

h = vertical distance, in m (ft), as defined in 5C-2-2/13.3, for the particular member in question. See also 5C-2-1/1.15.

K = bottom members, K is as shown in 5C-2-2/Figure 3 for the point under consideration

K_L = lower side transverses or vertical transverses on longitudinal bulkheads

= 0.65 without struts

= 0.55 with one strut

= 0.43 with two struts

= 0.38 with three or more struts

K_U = upper side transverses or vertical transverses on longitudinal bulkheads

= 0.35 without struts

= 0.25 with one strut

= 0.20 with two struts

= 0.17 with three or more struts

Where a centerline longitudinal bulkhead is fitted, the tabulated values of K_L and K_U will be specially considered.

The net sectional area of the lower side transverse, as required by the foregoing paragraphs, should be extended up to the lowest strut, or to $0.33\ell_s$, whichever point is the higher. The required sectional area of the upper side transverse may be extended over the upper $0.33\ell_s$ of the member.

13.9 Proportions

Webs, girders and transverses are to be not less in depth than required by the following, where the required depth of member is expressed as a percentage of the span.

12.5% for side and deck transverses, for webs and horizontal girders of longitudinal bulkheads, and for stringers.

20% for deck and bottom centerline girders, bottom transverses, and webs and horizontal girders of transverse bulkheads.

The depth of side transverses and vertical webs is to be measured at the middle of ℓ_b, as defined in 5C-2-2/13.3, and the depth may be tapered from bottom to top by an amount not exceeding 8 mm per 100 mm (1 in. per ft). In no case are the depths of members to be less than three (3) times the depth of the slots for longitudinals. The thickness of webs is to be not less than required by 5C-2-2/13.7, nor is it to be less than the minimum thickness given in 5C-2-2/Table 2.

13.11 Brackets

Brackets are generally to be of the same thickness as the member supported, are to be flanged at their edges and are to be suitably stiffened.

13.13 Stiffeners and Tripping Brackets

13.13.1 Web Stiffeners

Stiffeners are to be fitted for the full depth of the deep supporting member at the following intervals, unless specially approved based on the structural stability of deep supporting members:

Location	*Interval*
Bottom	every longitudinal
Side	every second longitudinal
Bulkhead	every second stiffener
Deck	every third longitudinal

Special attention is to be given to the stiffening of web plate panels close to change in contour of web or where higher strength steel is used.

The moment of inertia, I, of the above stiffener, with the effective width of plating not exceeding s or 0.33ℓ, whichever is less, is not to be less than the following equations:

$$I = 0.19\ell t^3 (\ell/s)^3 \quad \text{cm}^4 \text{ (in}^4\text{)} \quad \text{for } \ell/s \le 2.0$$

$$I = 0.38\ell t^3 (\ell/s)^2 \quad \text{cm}^4 \text{ (in}^4\text{)} \quad \text{for } \ell/s > 2.0$$

where

ℓ = length of stiffener between effective supports, in cm (in.)

t = required thickness of web plating, in cm (in.), but need not be greater than $s/80$

s = spacing of stiffeners, in cm (in.)

Web stiffeners are to be attached to the deep webs, longitudinals and stiffeners by continuous fillet welds.

Where depth/thickness ratio of the web plating exceeds 200, a stiffener is to be fitted parallel to the flange at approximately one-quarter depth of the web from the face plate. Special attention is to be given to providing for compressive loads.

13.13.2 Tripping Bracket

Tripping brackets, arranged to support the flanges, are to be fitted at intervals of about 3 m (10 ft), close to change of section, and in line with or as near as practicable to the flanges of struts.

13.15 Slots and Lightening Holes

Slots and lightening holes, where cut in webs, are to be kept well clear of other openings. The slots are to be neatly cut and well rounded. Lightening holes are to be located midway between the slots and at about one-third of the depth of the web from the shell, deck or bulkhead. Their diameters are not to exceed one-fourth the depth of the web. In general, lightening holes are not to be cut in those areas of webs, girders and transverses where the shear stresses are high. Similarly, slots for longitudinals are to be provided with filler plates or other reinforcement in these same areas. Where openings are required in high shear stress areas, they are to be effectively compensated. Continuous fillet welds are to be provided at the connection of the filler plates to the web and of the filler plate to the longitudinals.

13.17 Struts *(1994)*

Where one or more struts are fitted as an effective supporting system for the wing-tank members, they are to be spaced so as to divide the supported members into spans of approximately equal length. The value of W for struts is obtained from the following equation:

$W = nbhs$ kN (tf, Ltf)

where

n = 10.5 (1.07, 0.03)

b = mean breadth, in m (ft), of the area supported

h = vertical distance, in m (ft), from the center of the area supported to a point located 1.22 m (4 ft) above the deck at side amidships in vessels 61 m (200 ft) in length and to a point located 2.44 m (8 ft) above the deck at side amidships in vessels 122 m (400 ft) in length and above; for intermediate lengths, intermediate points may be used. The value of h is not to be less than the vertical distance, in m (ft), from the center of the area supported to the tops of the hatches.

The permissible load of struts, W_a, is to be determined by the following equation and is to be equal to or greater than the calculated W as determined above.

$W_a = (k - n\ell/r)A$ kN (tf, Ltf)

where

k = 12.09 (1.232, 7.83) ordinary strength steel

= 16.11 (1.643, 10.43) HT32

= 18.12 (1.848, 11.73) HT36

ℓ = unsupported span of the strut, in cm (ft)

r = least radius of gyration, in cm (in.)

A = cross sectional area of the strut, in cm (in.)

n = 0.0444 (0.00452, 0.345) ordinary strength steel

= 0.0747 (0.00762, 0.581) HT32

= 0.0900 (0.00918, 0.699) HT36

Special attention is to be paid to the end connections for tension members, as well as to the stiffening arrangements at their ends, to provide effective means for transmission of the compressive forces into the webs. In addition, horizontal stiffeners are to be located in line with and attached to the first longitudinal above and below the ends of the struts.

15 Frames, Beams and Bulkhead Stiffeners

15.1 Arrangement

The sizes of the longitudinals or stiffeners as given in this paragraph are based on the transverses or webs being regularly spaced. Longitudinals or horizontal stiffeners are to be continuous or attached at their ends to effectively develop their sectional area. This requirement may be modified in the case of stiffeners on transverse bulkheads. Longitudinals and stiffeners are to be attached to the transverses or webs to effectively transmit the loads onto these members. Consideration is to be given to the effective support of the plating in compression when selecting the size and spacing of longitudinals.

15.3 Structural Sections

15.3.1 Section Modulus

Each structural section for longitudinal frames, beams or bulkhead stiffeners, in association with the plating to which it is attached, is to have a section modulus SM not less than obtained from the following equation:

$$SM = 7.8chs\ell^2 \quad \text{cm}^3 \qquad\qquad SM = 0.0041chs\ell^2 \quad \text{in}^3$$

where

c = 1.40 for bottom longitudinals

= 0.95 for side longitudinals

= 1.25 for deck longitudinals

= 1.00 for vertical frames

= 1.00 for horizontal or vertical stiffeners on transverse bulkheads and vertical stiffeners on longitudinal bulkheads

= 0.90 for horizontal stiffeners on longitudinal bulkheads.

h = distance, in m (ft), from the longitudinals, or from the middle of ℓ for vertical stiffeners, to a point located 1.22 m (4 ft) above the deck at side amidships in vessels of 61 m (200 ft) length, and to a point located 2.44 m (8 ft) above the deck at side amidships in vessels of 122 m (400 ft) length and above; at intermediate lengths, h is to be measured to intermediate heights above the side of the vessel. The value of h for bulkhead stiffeners and deck longitudinals is not to be less than the distance, in m (ft), from the longitudinal, or stiffener to the top of the hatch. See also 5C-2-1/1.15.

s = spacing of longitudinals or stiffeners, in m (ft)

ℓ = length between supporting points, in m (ft)

The section modulus SM of the bottom longitudinals may be obtained from the above equation multiplied by R_1 where,

15.3.1(a) The bottom hull girder section modulus, SM_A, is greater than required by 3-2-1/3.7.1, at least throughout 0.4L amidships,

15.3.1(b) Still-water bending moment calculations are submitted, and

15.3.1(c) Adequate buckling strength is maintained.

The bottom longitudinals with this modified section modulus are to meet all other Rule requirements.

$R_1 = n/[n + f_p(1 - SM_R/SM_A)]$ but is not to be taken less than 0.69

where

n = 7.69 (0.784, 4.978)

f_p = nominal permissible bending stress, as given in 3-2-1/3.7.1

SM_R = hull girder section modulus required by 3-2-1/3.7.1, in cm^2-m (in^2-ft)

SM_A = bottom hull girder section modulus, cm^2-m (in^2-ft), with the longitudinals modified as permitted above.

Where the heavy ballast draft forward is less than 0.04L, the flat of bottom forward longitudinals are not to be less than required by 3-2-4/13.5.

15.3.2 Web Thickness *(1993)*

In addition to the requirements in 3-1-2/13.5.2, the thickness of web portion is to be not less than the thickness given in 5C-2-2/Table 2, reduced by 1.0 mm (0.04 in.).

15.5 Bilge Longitudinals

Longitudinals around the bilge are to be graded in size from that required for the lowest side longitudinals to that required for the bottom longitudinals.

15.7 Vessels under 76 m (250 ft)

In vessels under 76 m (250 ft) in length, the coefficient c for use in the above equation for bottom longitudinals may be reduced to 1.30.

17 Structure at Ends

Beyond the cargo spaces, the scantlings of the structure may be as required in way of the oil spaces, in association with the values of h in the various equations measured to the upper deck, except that in way of deep tanks, h is to be not less than the distance, in m (ft), measured to the top of the overflow. In way of dry spaces, the deck beams and longitudinals are to be as required in Section 3-2-7. The value of h for deck transverses in way of dry spaces is to be obtained from Section 3-2-7 and the section modulus SM is to be obtained from the following equation:

$SM = 4.74chs\ell^2$ cm^3 $SM = 0.0025chs\ell^2$ in^3

where

c = 1.23

s = spacing of transverses, in m (ft)

ℓ = span, in m (ft)

The transition from longitudinal framing to transverse framing is to be effected in as gradual a manner as possible, and it is recommended that a system of closely spaced transverse floors be adopted in way of the main machinery.

FIGURE 1
Coefficients and Lengths for Transverses

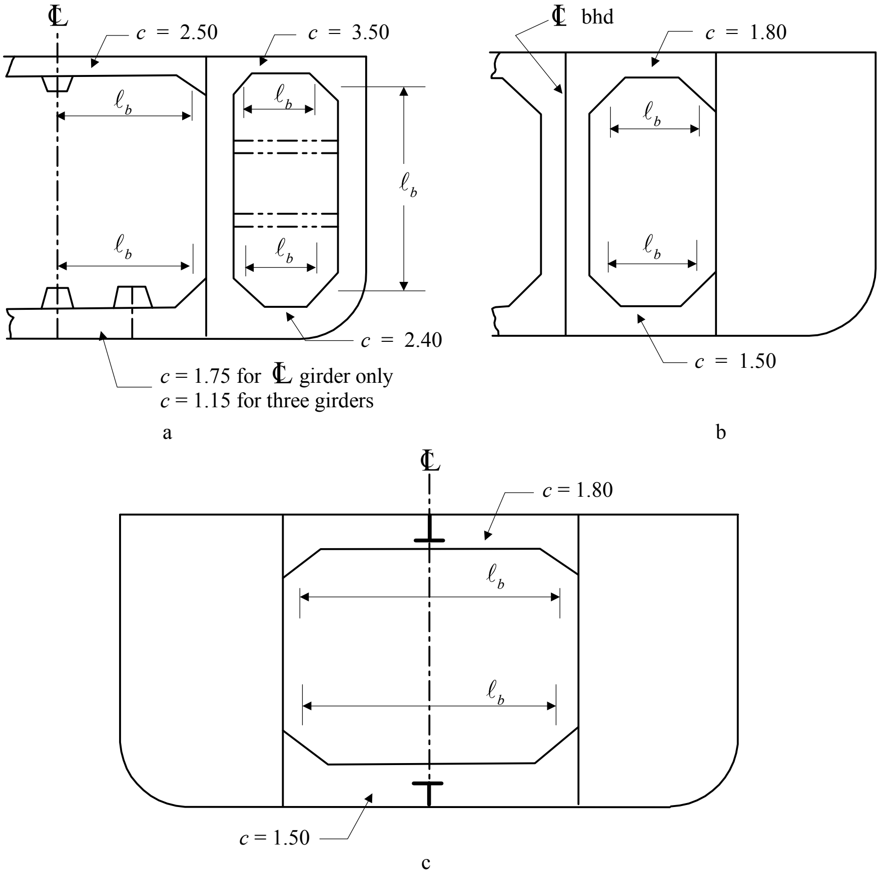
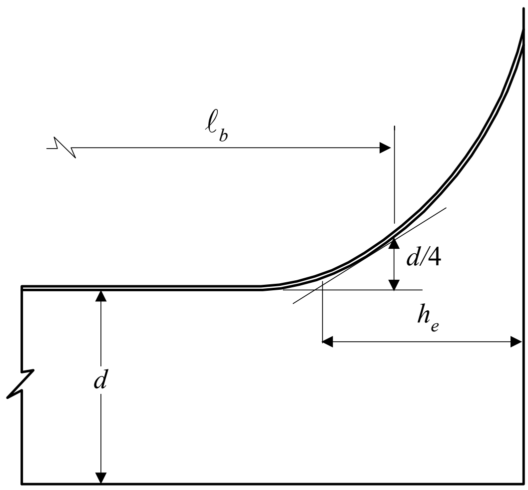
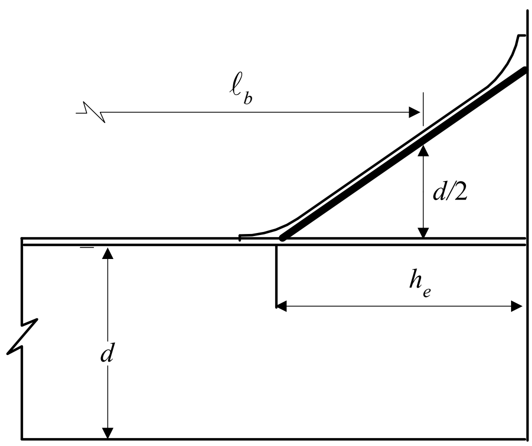


FIGURE 2
Lengths with Brackets



Where face plate area on the member is carried along the face of the bracket

a



Where face plate area on the member is not carried along the face of the bracket, and where face plate area on the bracket is at least one-half the face plate area on the member

b

FIGURE 3
Spans of Members and Effective Lengths or Heights of Brackets

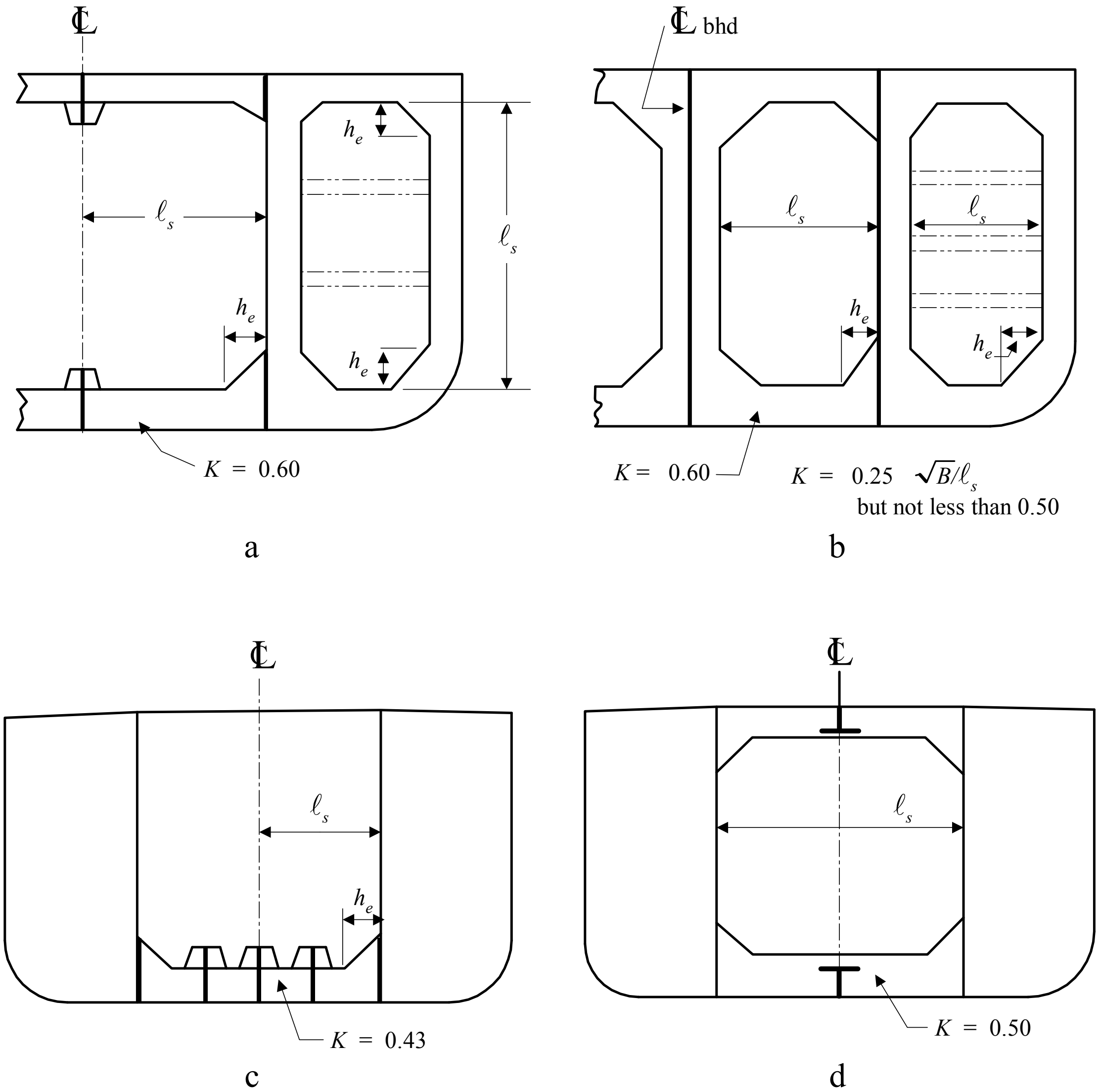


TABLE 1
Values of q for Ordinary Strength Steel

s = spacing of stiffeners or depth of web plate, whichever is the lesser, in cm (in.)

t = thickness of web plate, in cm (in.)

s/t	kN/cm^2	kgf/cm^2	Ltf/in^2
80 and less	8.5	870	5.5
160 maximum	5.4	550	3.5

TABLE 2
Minimum Thickness for Web Portions of Members

L is the length of the vessel, in m (ft), as defined in 3-1-1/3. For vessels of lengths intermediate to those shown in the table, the thickness is to be obtained by interpolation.

L meters	t mm	L feet	t in.
61	8.5	200	0.34
82	9	270	0.36
118	10	390	0.40
150	11	492	0.44

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PART

5C

CHAPTER 2 Vessels Intended to Carry Oil in Bulk (Under 150 meters (492 feet) in Length)

SECTION 3 Cargo Oil and Associated Systems

See Section 5C-1-7.

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PART

5C

CHAPTER 2 Vessels Intended to Carry Oil in Bulk (Under 150 meters (492 feet) in Length)

APPENDIX 1 Guide for Hull Girder Shear Strength for Tankers

1 Introduction

This Guide is a supplement to 3-2-1/3.5 of the Rules and is intended to provide a simplified method for determining the allowable still-water shearing forces, in accordance with the Rule requirements, for tankers having two or three longitudinal oil-tight bulkheads, where the wing bulkheads are located no closer than 20% of the breadth from the side shell.

The computational method presented in this Guide is deduced from shear flow and three-dimensional finite element calculation results and is applicable to tankers having single bottom construction with deep bottom transverses and swash transverse bulkheads. For tankers having either double bottom, double skin or deep bottom girders, the allowable still-water shearing force will be subject to special consideration.

With the present Rule side shell thickness, local load effects are not considered for the side shell, as the longitudinal bulkhead generally governs the permissible shear force at any particular location.

3 Allowable Still-water Shearing Force

The allowable still-water shearing force, in kN (tf, Ltf), at any transverse section of the vessel is the lesser of the *SWSF* obtained from 5C-2-A1/3.1 and 5C-2-A1/3.3 with any applicable modification as specified in 5C-2-A1/3.5.

3.1 Considering the Side Shell Plating

$$SWSF = \frac{0.935 f_s t_s D_s}{N_s} - F_w$$

3.3 Considering Various Longitudinal Bulkhead Plating

$$SWSF = \frac{1.05 f_s t_b D_b}{K_1 N_b} - F_w$$

In general, in the absence of a local load, two locations need be checked for each bulkhead: the lower edge of the thinnest strake and at the neutral axis of the section. When a local load is present, the *SWSF* should be computed at the base of each longitudinal bulkhead strake for use with 5C-2-A1/3.5. For vessels having three longitudinal bulkheads, the *SWSF* should be calculated considering both the centerline and wing bulkheads.

F_w = wave induced shear force, as specified by 3-2-1/3.5.2 of the Rules, in kN (tf, Ltf)

f_s = permissible total shear stress, as specified in 3-2-1/3.9.1 of the Rules, in kN/cm^2 (tf/cm^2, Ltf/in^2)

t_s = thickness of the side shell plating at the neutral axis of the section in, cm (in.)

t_b = thickness of the centerline or wing longitudinal bulkhead plating at the location under consideration, in cm (in.)

D_s = depth of the hull girder at the section under consideration, in cm (in.)

D_b = depth of the longitudinal bulkhead at the section under consideration, in cm (in.)

N_s, N_b = shear distribution factors for side shell and longitudinal bulkheads, respectively, and may be determined by 5C-2-A1/5.

K_1 = $1 + y/(8\bar{y})$

y = distance measured from the deck or bottom (depending on whether the strake considered is above or below the neutral axis of the section) to the lower edge of the bulkhead strake under consideration, in cm (in.)

$\bar{y}$ = distance measured from the deck (bottom) to the neutral axis of the section, when the strake under consideration is above (below) the neutral axis, in cm (in.)

3.5 Reduction for Local Loads

When the loading head in the center tank is different from that in an adjacent wing tank, then the allowable *SWSF* computed at the various bulkhead locations in 5C-2-A1/3.3 may have to be reduced, as follows.

3.5.1

For the case of a two longitudinal bulkhead vessel, when the center tank head is less than that in any adjacent wing tank, no reduction need be made.

3.5.2

For two and three bulkhead vessels, when the center tank head exceeds that in a wing tank, within the center tank region, a hull girder shear force reduction, *R*, should be computed at the corresponding locations on the bulkheads used in 5C-2-A1/3.3. These reductions should be determined for both wing and centerline bulkheads, and may be calculated as follows.

$$R = W_c\left(\frac{2.1K_2N_w}{3K_1N_b} - 1\right) \text{ kN (tf, Ltf)}$$

If $2.1K_2N_w$ is less than or equal to $3K_1N_b$, *R* should be taken as zero.

K_1, N_b = as previously defined

N_w = distribution factor for local loads, as specified in 5C-2-A1/5

K_2 = $1 + (A/A_b)$

A = total area of the longitudinal bulkhead plating above the lower edge of the strake under consideration, in cm^2 (in^2)

A_b = total area of the longitudinal bulkhead plating under consideration, in cm^2 (in^2)

W_c = effective local load which may be denoted by W_{c1} and W_{c2}, at the fore and aft ends of the center tank, respectively

$$W_{c1} = \frac{wb_c}{\ell_c}\left[h_{c1}\ell_1\left(\ell_2 + \frac{\ell_1}{2}\right) + h_{c2}\frac{\ell_2^2}{2}\right]$$

$$W_{c2} = \frac{wb_c}{\ell_c}\left[h_{c1}\frac{\ell_1^2}{2} + h_{c2}\ell_2\left(\ell_1 + \frac{\ell_2}{2}\right)\right]$$

w = density of the cargo (ballast), in kgf/m^3 (tf/m^3, Ltf/ft^3)

ℓ_c, b_c = length and breadth, respectively, of the center tank, in m (ft)

h_{c1}, h_{c2} = excess fluid heads in the center tank. Should the head in a wing tank exceed that in the center tank, see 5C-2-A1/3.5.3 below.

ℓ_1, ℓ_2 = longitudinal distances from the respective center tank ends to the succeeding wing tank transverse bulkheads

3.5.3

When the head in wing tanks exceeds that in the center tank, within the center tank region, h_c should be taken as zero for two longitudinal bulkhead vessels. However, a reduction should be applied only to the *SWSF* computed while considering the centerline bulkhead in 5C-2-A1/3.3. This reduction may be computed by the equations in 5C-2-A1/3.5.2, except that b_c is to be taken as the combined breadth of both wing tanks ($b_c = 2b_w$), and h_c is the excess head in the wing tank above that in the center tank.

3.5.4

Where adjacent tanks are loaded with cargoes of different densities, the heads in 5C-2-A1/3.5 are to be corrected to account for the difference in density.

5 Distribution Factors

The distribution factors N_s, N_b and N_w may be determined by the following equations.

5.1 For Vessels Having Two Longitudinal Bulkheads

$$N_b = 0.32 - 0.06(A_s/A_b)$$

$$N_s = 0.5 - N_b$$

$$N_w = 0.31(n - 1)/n$$

where

A_s = total projected area of the side shell plating, in cm^2 (in^2)

A_b = as previously defined

n = total number of transverse frame spaces in the center tank

5.3 For Vessels Having Three Longitudinal Bulkheads

N_b (center) = $0.26 - 0.044(A_s/A_b) + C_1$

N_b (wing) = $0.25 - 0.044(A_s/A_b) - C_2$

N_s = $0.5 - 0.5N_b$ (center) $- N_b$ (wing)

N_w (center) = $(0.7N_b + 0.15)(n - 1)/n$

N_w (wing) = $(1.5N_b - 0.1)(n - 1)/n$

A_s, A_b, n are as previously defined, however, A_b should be either the center or wing bulkhead area, depending on which is being considered.

C_1 = 0 for $K > 0.9$

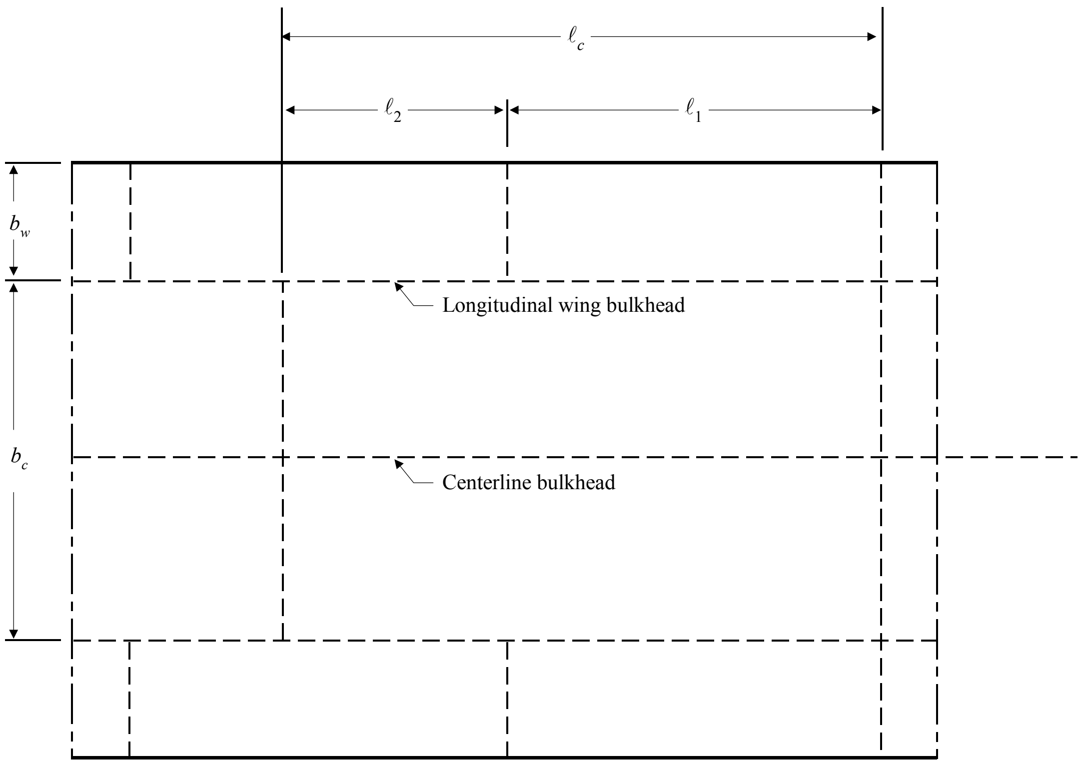
C_1 = $0.1(1 - K) - 0.005$ for $K \le 0.9$

K = A_b (wing)/A_b (center)

C_2 = 0 for $K > 0.9$

C_2 = $0.04(1 - K)$ for $K \le 0.9$

FIGURE 1
Center Tank Region



PART

5C

CHAPTER **3 Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)**

CONTENTS

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PART

5C

CHAPTER 3 Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)

SECTION 1 Introduction

1 General

1.1 Classification *(1 July 2003)*

In accordance with 1-1-3/3 and 1-1-3/25, the classification notations ✠ **A1 Bulk Carrier, BC-A,** (or **BC-B** or **BC-C), SH, SHCM**; ✠ **A1 Ore Carrier, SH, SHCM**; ✠ **A1 Ore or Oil Carrier, SH, SHCM**; or ✠ **A1 Oil or Bulk/Ore (OBO) Carrier, SH, SHCM** are to be assigned, as applicable, to vessels designed for the carriage of bulk cargoes, or ore cargoes, and built to the requirements of this Chapter and other relevant Parts/Chapters of the Rules. The bulk carrier notation **BC-A** or **BC-B** denotes that_a vessel has been designed for the carriage of dry bulk cargoes of cargo density of 1.0 tonne/m^3 (62.4 lbs/ft^3) and above and may or may not have special loading arrangements. Where a **BC-A** or **BC-B** bulk carrier is not designed to carry 3.0 tonnes/m^3 (187 lbs/ft^3) or higher density cargoes, it will be distinguished by the maximum cargo density in tonnes/m^3 following the bulk carrier notation, e.g., **BC-B (maximum cargo density: 1.90 tonnes/m^3)**. A **BC-A** bulk carrier designed to carry heavy cargo with specified holds empty will be distinguished by a supplementary note, "(holds, x, y,… may be empty)" followed by **(maximum cargo density: ρ tonnes/m^3)**, e.g., **BC-A (holds 2, 4, 6 and 8 may be empty with maximum cargo density: 2.50 tonnes/m^3)**. The bulk carrier notation **BC-C** denotes that a vessel has been designed for the carriage of cargo density of less than 1.0 tonne/m^3 (62.4 lbs/ft^3). Additionally, the above bulk carrier notations will be followed by the **(no MP)** notation where a bulk carrier has not been designed for loading and unloading in multiple ports, e.g., **BC-B (maximum cargo density: 1.70 tonnes/m^3)(no MP)**. Full particulars of the loading conditions and the maximum density of the cargoes to be carried are to be identified on the basic design drawings.

1.2 Optional Class Notation for Design Fatigue Life *(2003)*

Vessels designed and built to the requirements in this Chapter are intended to have a structural fatigue life of not less than 20 years. Where a vessel's design calls for a fatigue life in excess of the minimum design fatigue life of 20 years, the optional class notation **FL (year)** will be assigned at the request of the applicant. This optional notation is eligible, provided the excess design fatigue life is verified to be in compliance with the criteria in Appendix 1 of this Chapter, "Guide for Fatigue Strength Assessment of Bulk Carriers." Only one design fatigue life value is published for the entire structural system. Where differing design fatigue life values are intended for different structural elements within the vessel, the **(year)** refers to the least of the varying target lives. The 'design fatigue life' refers to the target value set by the applicant, not the value calculated in the analysis.

The notation **FL (year)** denotes that the design fatigue life assessed according to Appendix 1 of this Chapter is greater than the minimum design fatigue life of 20 years. The **(year)** refers to the fatigue life equal to 25 years or more (in 5-year increments) as specified by the applicant. The fatigue life will be identified in the *Record* by the notation **FL (year)**; e.g., **FL(30)** if the minimum design fatigue life assessed is 30 years.

1.3 Application *(1996)*

1.3.1 Size and Proportions

The requirements contained in this Chapter are applicable to vessels of 150 meters (492 feet) or more in length, having proportions within the range specified in 3-2-1/1, and are intended for unrestricted service.

1.3.2 Vessel Types

The equations and formulae for determining design load and strength requirements, as specified in 5C-3-3 and 5C-3-4, are applicable to double hull or single hull bulk carriers and also to ore or ore/oil carriers with modifications and additions as specified in Appendix 5C-3-A3. In general, the strength assessment procedure and failure criteria as specified in Section 5C-3-5 are applicable to all types of bulk carriers.

1.3.3 Direct Calculations

Direct calculations with respect to the determination of design loads and the establishment of alternative strength criteria based on first principles will be accepted for consideration, provided that all supporting data, analysis procedures and calculated results are fully documented and submitted for review. In this regard, due consideration is to be given to the environmental conditions, probability of occurrence, uncertainties in load and response predictions, and reliability of the structure in service. For long term prediction of wave loads, realistic wave spectra covering the North Atlantic Ocean and a probability level of 10^{-8} are to be employed.

1.3.4 SafeHull Construction Monitoring Program *(1 July 2001)*

For the class notation **SH, SHCM,** a Construction Monitoring Plan for critical areas, prepared in accordance with the requirements of Part 5C, Appendix 1, is to be submitted for approval, prior to comencement of fabrication. See Part 5C, Appendix 1 "Guide for SafeHull Construction Monitoring Program."

1.3.5 Additional Design Loading Conditions for Bulk Carrier Notation, BC-A, BC-B or BC-C *(1 July 2003)*

The corresponding design loading conditions in respect to strength and stability for a harmonized system of bulk carrier notations, **BC-A**, **BC-B** or **BC-C**, are to comply with the requirements of Appendix 5C-3-A6.

1.5 Definitions *(2001)*

1.5.1 Bulk Carrier *(1 July 2003)*

The class notation **Bulk Carrier** indicates a sea going self-propelled single deck vessel with a double bottom and lower and upper wing tanks (hopper and topside tanks) intended for carriage of dry cargoes in bulk. Typical midship sections are shown in 5C-3-1/Figure 1. The bulk carrier notations as introduced in 5C-3-1/1.1 are as follows:

BC-A: Bulk carriers designed to carry dry bulk cargoes of cargo density 1.0 tonne/m^3 (62.4 lbs/ft^3) and above with specified holds empty in addition to **BC-B** conditions.

BC-B: Bulk carriers designed to carry dry bulk cargoes of cargo density of 1.0 tonne/m^3 (62.4 lbs/ft^3) and above with all cargo holds loaded in addition to **BC-C** conditions.

BC-C: Bulk carriers designed to carry dry bulk cargoes of cargo density less than 1.0 tonne/m^3 (62.4 lbs/ft^3).

1.5.1(a) Double Side Skin Construction is the construction of a hold in which both sides of the hold are bounded by two watertight boundaries, one of which is the side shell, which are not less than 1000 mm (39.4 in.) apart measured perpendicular from the outer surface of the inner watertight boundary to the inner surface of the side shell. This structural configuration will be identified in column 5 of the *Record* with the abbreviation "DS".

1.5.1(b) Double Side Skin Bulk Carrier is a bulk carrier with all cargo holds of double side skin construction.

Where the Rules refer to *Single Side Skin Bulk Carrier*, the following interpretations apply to vessel's keel laid or at a similar stage of construction on or after 1 January 2000.

1.5.1(c) Single Side Skin Construction is the construction of a hold in which one or both sides of the hold are bounded by the side shell only, or by two watertight boundaries, one of which is the side shell, which are less than 1000 mm (39.4 in.) apart measured perpendicular from the outer surface of the inner watertight boundary to the inner surface of the side shell.

1.5.1(d) Single Side Skin Bulk Carrier is a bulk carrier with one or more cargo holds of single side skin construction.

1.5.2 Ore Carrier

The class notation **Ore Carrier** indicates a seagoing self-propelled vessel having two longitudinal bulkheads and a double bottom throughout the cargo region intended for the carriage of ore cargoes in the center holds only. A typical midship section is shown in 5C-3-1/Figure 2.

1.5.3 Ore or Oil Carrier

The class notation **Ore or Oil Carrier** indicates a seagoing self-propelled single deck vessel having two longitudinal bulkheads and a double bottom throughout the cargo region intended for the carriage of ore cargoes in the center holds, or for the carriage of oil cargoes in the center holds and wing tanks. Typical midship sections are shown in 5C-3-1/Figure 4.

1.5.4 Oil or Bulk/Ore (OBO) Carrier

The class notation **Oil or Bulk/Ore (OBO) Carrier** indicates a seagoing self-propelled single deck vessel of double skin construction with a double bottom and lower and upper wing tanks (hopper and topside tanks) intended for carriage of oil or dry cargoes including ore in bulk. A typical midship section is shown in 5C-3-1/Figure 3.

FIGURE 1 *(1998)*

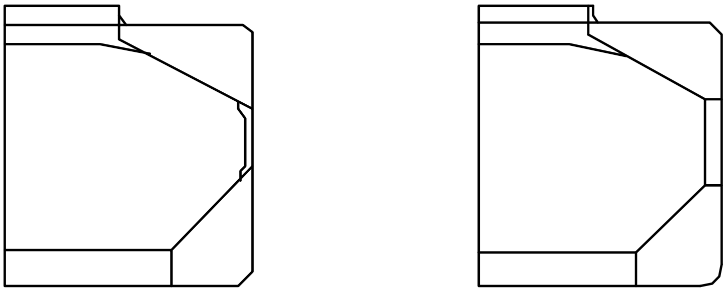


FIGURE 2 *(1998)*

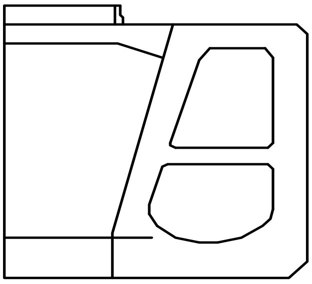


FIGURE 3 *(1998)*

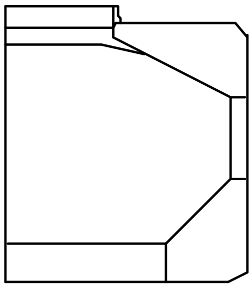
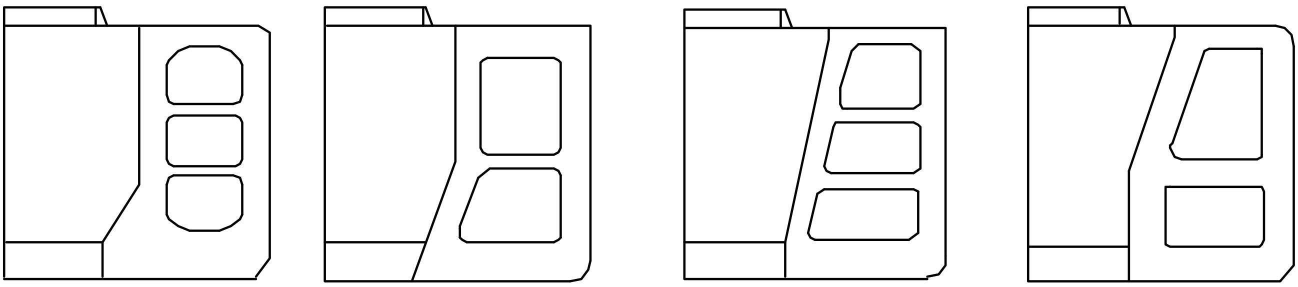


FIGURE 4 *(1998)*



1.5.5 Combination Carrier

A general term applied to vessels intended for carriage of either oil or dry cargoes in bulk; these cargoes are not carried simultaneously, with the exception of oil retained in the slop tanks. Vessels described in 5C-3-1/1.5.3 and 5C-3-1/1.5.4 are examples of *Combination Carriers*.

1.7 Section Properties of Structural Members *(1 July 2008)*

The geometric properties of structural members may be calculated directly from the dimensions of the section and the associated effective plating (see 3-1-2/13.3 or 5C-3-4/Figure 4, as applicable). For structural members with angle θ (see 5C-3-1/Figure 5) between web and associated plating not less than 75 degrees, the section modulus, web sectional area and moment of inertia of the "standard" (θ = 90 degrees) section may be used without modification. Where the angle θ is less than 75 degrees, the sectional properties are to be directly calculated about an axis parallel to the associated plating. (see 5C-3-1/Figure 5).

For longitudinals, frames and stiffeners, the section modulus may be obtained from the following equation:

$$SM = \alpha_\theta SM_{90}$$

where

α_θ = $1.45 - 40.5/\theta$

SM_{90} = the section modulus at θ = 90 degrees

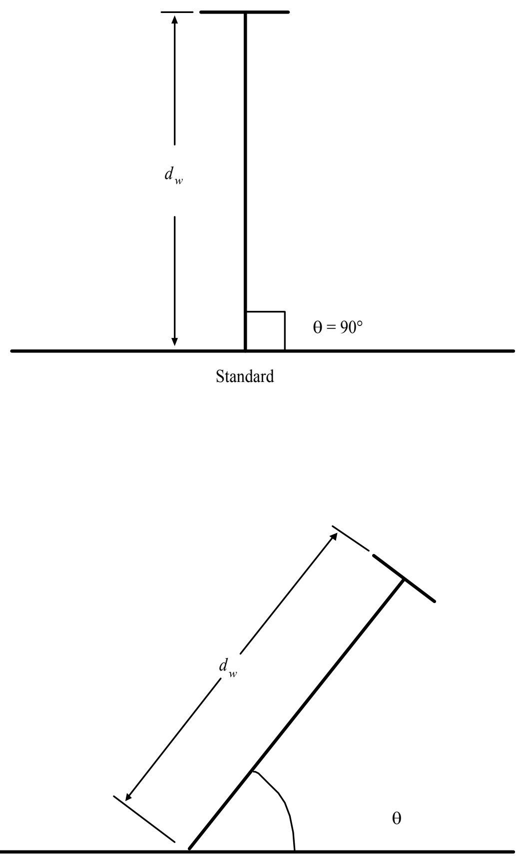
The effective section area may be obtained from the following equation:

$$A = A_{90} \sin \theta$$

where

A_{90} = effective shear area at θ = 90 degrees

FIGURE 5



1.9 Protection of Structure

For the protection of structure, see 3-2-18/5

3 Arrangement

3.1 General

Watertight and strength bulkheads in accordance with Section 3-2-9 are to be provided. Where this is impracticable, the transverse strength and stiffness of the hull is to be effectively maintained by deep webs or partial bulkheads. Where it is intended to carry liquid in any of the spaces, additional bulkheads or swash bulkheads may be required. Tank bulkheads are to be in accordance with the requirements of Part 5C, Chapter 1. The depth of double bottom at the centerline is not to be less than the height for center girder, as obtained from Section 3-2-4. Tanks forward of the collision bulkhead are not to be arranged for the carriage of oil or other liquid substances that are flammable.

3.3 Subdivision and Damage Stability *(1 July 1998)*

Single side skin bulk carriers of 150 m (492 ft) in length (L_f) and above, intended to carry solid bulk cargoes having a density of 1.0 t/m^3 (62.4 lb/ft^3) or more, are to be able to withstand flooding for compliance with Appendix 3-3-A2, "Subdivision and Damage Stability Requirements for Bulk Carriers". (See 3-3-1/3.3 and Appendix 3-3-A2.). The review procedures for the information and calculations are to be in accordance with 3-3-1/5.

3.5 Special Requirements for Deep Loading

Bulk carriers or ore carriers having freeboards assigned based on the subdivision requirements of the International Convention on Load Lines, 1966, are to comply with those regulations.

5 Carriage of Oil Cargoes

5.1 General

Ore carriers and bulk carriers, which are also intended to carry oil cargoes as defined in Section 5C-1-1, are to comply with the applicable Sections of Part 5C, Chapter 1, and Part 5C, Chapter 2, in addition to the requirements of this Chapter.

5.3 Gas Freeing

Prior to and during the handling of bulk or ore cargoes, all spaces are to be free of cargo oil vapors.

5.5 Slop Tanks

Slop tanks are to be separated from spaces that may contain sources of vapor ignition by adequately vented oiltight cofferdams, as defined in 5C-1-1/5.5, or by cargo oil tanks which are maintained gas free.

7 Forecastle *(2004)*

7.1 General

These requirements apply to all bulk carriers, ore carriers and combination carriers. These vessels are to be fitted with an enclosed forecastle on the freeboard deck, in accordance with the requirements in this section.

7.3 Arrangements *(2007)*

The forecastle is to be located on the freeboard deck with its aft bulkhead fitted in way or aft of the forward bulkhead of the foremost hold, as shown in 5C-3-1/Figure 6. However, if this requirement hinders hatch cover operation, the aft bulkhead of the forecastle may be fitted forward of the forward bulkhead of the foremost cargo hold provided the forecastle length is not less than $0.07L_f$ (L_f: see 3-1-1/3.3) abaft the forward perpendicular.

A breakwater is not to be fitted on the forecastle deck with the purpose of protecting the hatch coaming or hatch covers. If fitted for other purposes, it is to be located such that its upper edge at center line is not less than H_B/tan 20° forward of the aft edge of the forecastle deck, where H_B is the height of the breakwater above the forecastle (see 5C-3-1/Figure 6).

7.5 Dimensions

7.5.1 Heights

The forecastle height, H_F, above the main deck at side is to be not less than:

- the standard height of a superstructure as specified in the International Convention on Load Lines 1966 and its Protocol of 1988, or
- H_C + 0.5 m, where H_C is the height of the forward transverse hatch coaming of cargo hold No. 1,

whichever is the greater.

7.5.2 Location of Aft Edge of Forecastle Deck

All points of the aft edge of the forecastle deck are to be located at a distance ℓ_F:

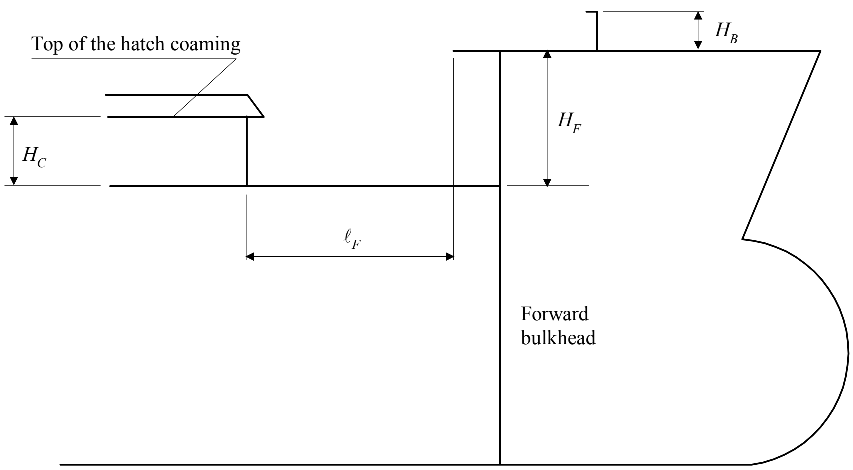
$$\ell_F \leq 5\sqrt{H_F - H_C}$$

from the No.1 hatch forward coaming plate in order to apply the reduced loading to the No. 1 forward transverse hatch coaming and No. 1 hatch cover in applying 5C-3-4/19.

7.7 Structural Arrangements and Scantlings

The structural arrangements and scantlings of the forecastle are to comply with the applicable requirements of 3-2-2/5.7, 3-2-5/5, 3-2-7/3, 3-2-11/1.3 and 3-2-11/9.

FIGURE 6



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PART

5C

CHAPTER **3 Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)**

SECTION **2 Design Considerations and General Requirements**

1 General Requirements *(1996)*

1.1 General *(1 July 1998)*

The strength requirements specified in this Chapter are based on a "net" ship approach. In determining the required scantlings, and performing structural analyses and strength assessments, the nominal design corrosion values given in 5C-3-2/Table 1 are to be deducted, except for the application of 5C-3-4/19 and Appendices 5C-3-A5a, 5C-3-A5b and 5C-3-A5c, where the corrosion additions are specified within the Section and Appendices themselves.

1.3 Initial Scantling Requirements *(1996)*

The initial plating thicknesses, section moduli of longitudinals/stiffeners and the scantlings of the main supporting structures are to be determined in accordance with Section 5C-3-4 for the "net"ship for further assessment as required in the following subsection. The relevant nominal design corrosion values are then added to obtain the full scantling requirements.

1.5 Strength Assessment – Failure Modes *(1996)*

A total assessment of the structures determined on the basis of the initial strength criteria in Section 5C-3-4 is to be carried out against the following three failure modes.

1.5.1 Material Yielding

The calculated stress intensities are not to be greater than the yielding state limit given in 5C-3-5/3 for all load cases specified in 5C-3-3/9.

1.5.2 Buckling and Ultimate Strength

For each individual member, plate or stiffened panel, the buckling and ultimate strength are to be in compliance with the requirements specified in 5C-3-5/5. In addition, the hull-girder ultimate strength is to be in accordance with 5C-3-5/5.13.

1.5.3 Fatigue

The fatigue strength of structural details and welded joints in highly stressed regions is to be in accordance with 5C-3-5/7.

1.7 Structural Redundancy and Residual Strength *(1996)*

In the early design stages, consideration should be given to structural redundancy and hull-girder residual strength.

Vessels which have been built in accordance with the procedures and criteria for calculating and evaluating the residual strength of hull structures in the ABS *Guide for Assessing Hull-Girder Residual Strength*, in addition to other requirements of these Rules, will be classed and distinguished in the *Record* by the symbol **RES** placed after the appropriate hull classification notation.

1.9 Strength Assessment in the Flooded Condition *(1 July 1998)*

For single or double side skin bulk carriers intended to carry solid bulk cargoes having a density of 1.0 t/m^3 (62.4 lb/ft^3) or greater, assessments are to be carried out on the structural adequacy of the following items in the flooded condition, in accordance with Appendices 5C-3-A5a, 5C-3-A5b and 5C-3-A5c:

i) Longitudinal Strength of the Hull Girder

ii) Water Tight Corrugated Transverse Bulkheads in Dry Cargo Holds

iii) Double Bottom Floors and Girders in Cargo Holds

3 Nominal Design Corrosion Values (NDCV) *(1996)*

3.1 General

As indicated in 5C-3-2/1.1, the strength criteria specified in this Chapter are based on a “net” ship approach, wherein the nominal design corrosion values are deducted.

The “net” thickness or scantlings correspond to the minimum strength requirements acceptable for classification, regardless of the design service life of the vessel. In addition to the coating protection specified in the Rules, minimum corrosion values for plating and structural members as given in 5C-3-2/Table 1 and 5C-3-2/Figure 1 are to be applied. These minimum corrosion values are being introduced solely for the above purpose, and are not to be construed as renewal standards.

In view of the anticipated higher corrosion rates for structural members in some regions, such as highly stressed areas, it is advisable to consider additional design margins for the primary and critical structural members in order to minimize repairs and maintenance costs. The beneficial effects of these design margins on reduction of stresses and increase of the effective hull-girder section modulus can be appropriately accounted for in the design evaluation.

FIGURE 1
Nominal Design Corrosion Values (NDCV) *(1996)*

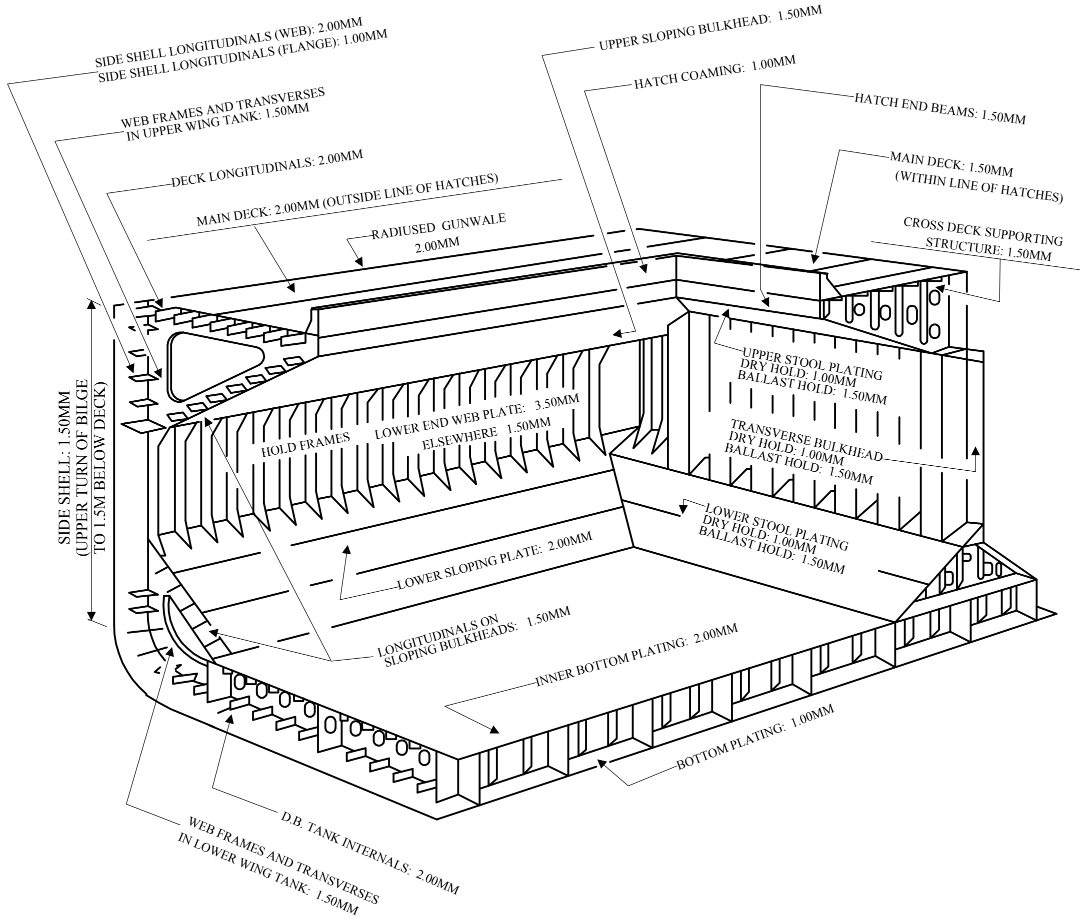


TABLE 1
Nominal Design Corrosion Values (NDCV) for Bulk Carriers *(2002)* (1, 2)

Group		Structural Item	NDCV in mm (in.)
1. Outer Skin	a.	Bottom Shell Plating (including keel and bilge plating)	1.0 (0.04)
	b1.	Side Shell Plating (above upper turn of bilge to 1.5 m (5 ft) below deck)	1.5 (0.06)
	b2.	Side Shell Plating (within 1.5 m (5 ft) from deck)	2.0 (0.08)
	c.	Upper Deck Plating (outside the lines of opening)	2.0 (0.08) (3)
	d.	Upper Deck Plating (within the lines of opening)	1.5 (0.06)
2. Double Bottom	a.	Inner Bottom Plating	2.0 (0.08)
	b.	Inner Bottom Longitudinals	2.0 (0.08) (7)
	c.	Floors and Girders	2.0 (0.08) (7)
	d1.	Miscellaneous Internal Members (in Tank)	2.0 (0.08) (7)
	d2.	Miscellaneous Internal Members, including CL Girder (in Dry Ducts)	1.5 (0.06)
3. Lower Wing Tank	a.	Top (Sloping Bulkhead) Plating	2.0 (0.08)
	b.	Transverses	1.5 (0.06)
	c.	Bottom and Bilge Longitudinals	2.0 (0.08) (7)
	d1.	Side longitudinals (Web)	2.0 (0.08) (7)
	d2.	Side Longitudinals (Flange)	1.0 (0.04)
	e.	Top (Sloping Bulkhead) Longitudinals	1.5 (0.06)
4. Upper Wing Tank	a.	Bottom (Sloping Bulkhead) Plating	1.5 (0.06) (4)
	b.	Inboard (Vertical) Bulkhead Plating	2.0 (0.08)
	c.	Transverses	1.5 (0.06) (4)
	d.	Deck Longitudinals	2.0 (0.08) (5)
	e1.	Side and Diaphragm Longitudinals (Web)	2.0 (0.08)
	e2.	Side and Diaphragm Longitudinals (Flange)	1.0 (0.04) (4)
	f1.	Bottom (Sloping Bulkhead) Longitudinals (in Tank)	1.5 (0.06) (4)
	f2.	Bottom (Sloping Bulkhead) Longitudinals (in Dry Hold)	1.0 (1.14)
	g.	Diaphragm Plating	1.5 (0.06) (4)
5. Side Frame	a.	Side Shell Frames in Hold	1.5 (0.06) (6)
	b.	Web Plates of Lower Bracket or Web Plates of Lower End of Built-Up Frames	3.5 (0.14) (6)
	c.	Face Plates of Lower Bracket or Web Plates of Lower End of Built-Up Frames	1.5 (0.06) (6)
6. Double Side	a.	Inner Bulkhead Plating	1.5 (0.06)
	b1.	Diaphragm Plates and Non-tight Stringers	1.5 (0.06)
	b2.	Tight Stringers	2.0 (0.08)
	c1.	Inner Bulkhead Longitudinals (Web)	2.0 (0.08)
	c2.	Inner Bulkhead Longitudinals (Flange)	1.0 (0.04)
	d.	Inner Bulkhead Vertical Stiffeners	1.5 (0.06)
7. Transverse Bulkheads	a1.	In Hold (including Stools), Plating & Stiffeners (Dry Hold)	1.0 (0.04) (8)
	a2.	In Hold (including Stools), Plating & Stiffeners (Ballast Hold)	1.5 (0.06) (8)
	b.	In Upper or Lower Wing Tanks, Plating	1.5 (0.06) (4)
	c.	In Upper or Lower Wing Tanks, Vertical Stiffeners	1.5 (0.06)
	d1.	Horizontal Stiffeners (Web)	2.0 (0.08)
	d2.	Horizontal Stiffeners (Flange)	1.0 (0.04)
	e.	Internals of Upper and Lower Stool (Dry)	1.0 (0.04)
8. Cross Deck		Beams, Girders and other Structures	1.5 (0.06)
9. Other Members	a.	Hatch Coaming	1.0 (0.04)
	b.	Hatch End Beams, Hatch Side Girders (outside Tank)	1.5 (0.06)
	c.	Internals of void spaces (outside Double Bottom)	1.0 (0.04)

Notes

1 It is recognized that corrosion depends on many factors, including coating properties, and that actual wastage rates observed may be appreciably different from those given here.

2 Pitting and grooving are regarded as localized phenomena and are not covered in this table.

3 Includes horizontal and curved portion of round gunwale.

4 To be not less than 2.0 mm (0.08 in.) within 1.5 m (5 ft) from the deck plating.

5 May be reduced to 1.5 mm (0.06 in.) if located outside tank.

6 Including frames in ballast hold.

7 May be reduced to 1.5 mm (0.06 in.) if located inside fuel oil tank.

8 When plating forms a boundary between a hold and a void space, the plating NDCV is determined by the hold type (dry/ballast).

PART

5C

CHAPTER 3 Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)

SECTION 3 Load Criteria

1 General

1.1 Load Components *(1996)*

In the design of the hull structure of bulk carriers, all load components with respect to the hull girder and local structure as specified in this Chapter and Section 3-2-1 are to be taken into account. These include static loads in still water, wave-induced motions and loads, slamming, dynamic, thermal and ice loads, where applicable.

3 Static Loads *(1996)*

3.1 Still-water Bending Moments and Shear Forces *(1 July 1998)*

For still-water bending moment and shear force calculations for intact conditions, see 3-2-1/3.3

When a direct calculation of wave-induced loads [i.e., longitudinal bending moments and shear forces, hydrodynamic pressures (external) and inertial forces and added pressure heads (internal)] is not anticipated, envelope curves are to be provided for the still-water bending moments (hogging and sagging) and shear forces (positive and negative).

Except for special loading cases, the loading patterns shown in 5C-3-3/Figure 1 are to be considered in determining local static loads.

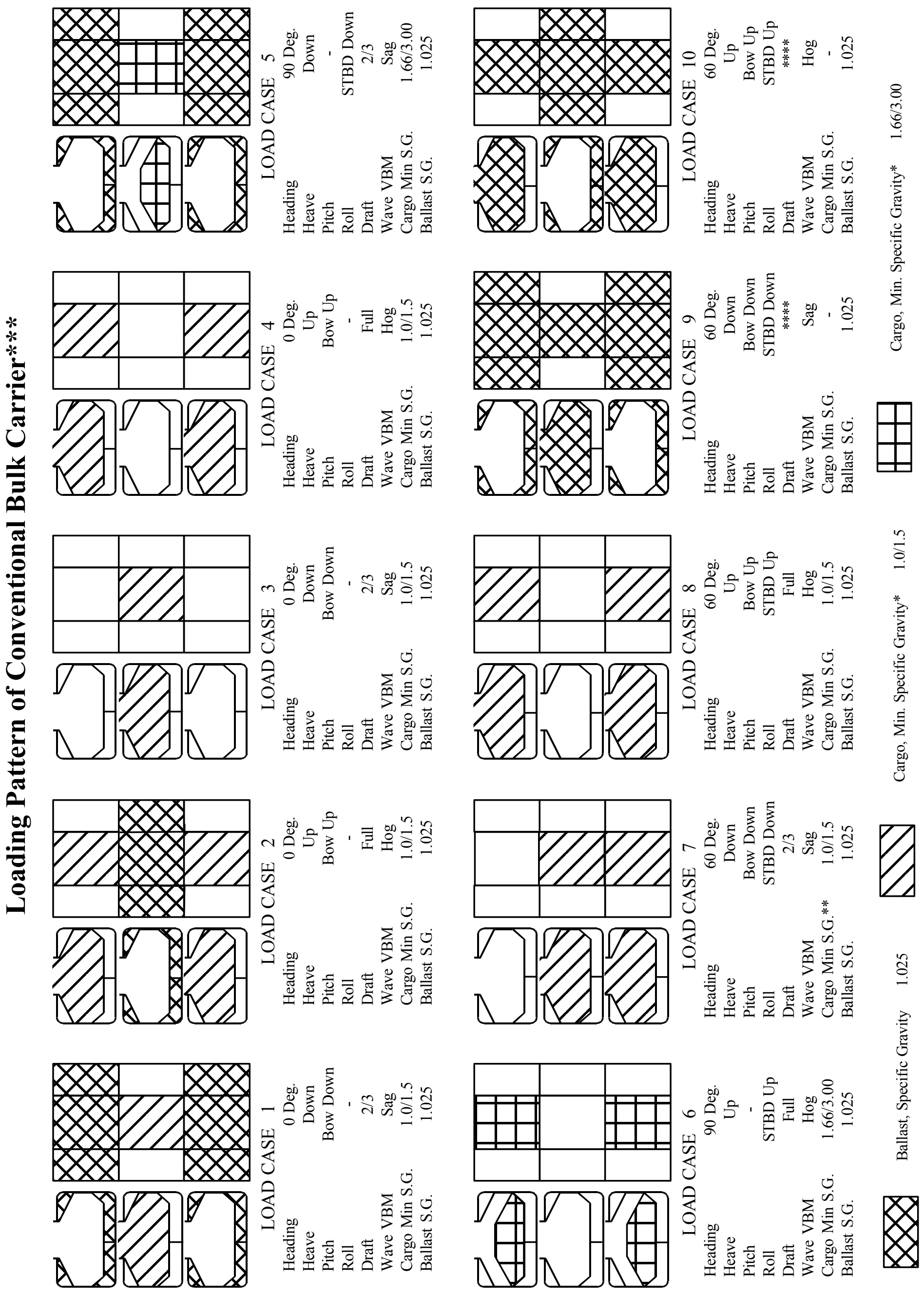
For alternate cargo hold loading conditions, modification for the hull girder shear forces may be applied in accordance with 3-2-1/3.9.3.

For single or double side skin bulk carriers intended to carry solid bulk cargoes having a density of 1.0 t/m^3 (62.4 lb/ft^3) or greater, still-water bending moment and shear force calculations in the hold flooded condition are to be submitted for each of the at-sea cargo and ballast loading conditions shown in the intact longitudinal strength calculations. See Appendix 5C-3-A5a.

3.3 Bulk Cargo Pressures

The bulk cargo pressures acting on the internal surfaces of the cargo holds, in still water, may be determined based on the equations given in 5C-3-3/5.7.2 for static cargo pressure components, P_{sn} and P_{st}, normal and parallel to the wall surface, respectively. For vessels carrying cargoes on deck, the specific weight of the cargoes, maximum stowage height and the intended cargo distribution are to be submitted for review and to be appropriately accounted for in the loading manual.

FIGURE 1
Loading Pattern of Conventional Bulk Carrier *(2003)*



* The maximum value of cargo specific gravity (relative density) calculated as the maximum cargo weight divided by cargo volume of each load case is to be used. The specific gravity is not to be taken as less than the higher value of two minimum specific gravities for all vessels designed for alternate hold loading with certain holds empty and for those designed for heavy cargo. The lower value of two minimum specific gravities is applicable to all other vessels designed for homogeneous loading only.

** All vessels are to be checked for the lower specific gravity with minimum 1.0. The higher specific gravity with minimum 1.5 is to be used as special block load case on ship by ship basis.

*** Loading pattern may be subject to special consideration where a vessel is designed for homogeneous loading only.

**** *(2003)* For Load Cases 9 and 10, draft $d = [47 - 0.11(L - 150)]L/1000$ m (ft).

5 Wave-Induced Loads

5.1 General *(1996)*

Where a direct calculation of the wave-induced loads is not available, the approximation equations given below and specified in 3-2-1/3.5 may be used to calculate the design loads.

When a direct calculation is performed, envelope curves for the combined wave and still-water bending moments and shear forces covering all the anticipated loading conditions are to be submitted for review.

5.3 Additional Wave Induced Moments and Shear Force *(1996)*

5.3.1 Horizontal Wave Bending Moment

The horizontal wave bending moment, expressed in kN-m (tf-m, Ltf-ft), positive (tension port) or negative (tension starboard), may be obtained from the following equation:

$$M_H = \pm\, m_h K_3 C_1 L^2 D C_b \times 10^{-3}$$

where

m_h = distribution factor, as given by 5C-3-3/Figure 2

K_3 = 180 (18.34, 1.68)

C_1 and C_b are as given in 3-2-1/3.5.

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

D = depth of vessel, as defined in 3-1-1/7.3, in m (ft)

5.3.2 Horizontal Wave Shear Force

The envelope of horizontal wave shearing force, F_H, expressed in kN (tf, Ltf), positive (toward port forward) or negative (toward starboard aft), may be obtained from the following equation:

$$F_H = \pm f_h\, k\, C_1 L D (C_b + 0.7) \times 10^{-2}$$

where

f_h = distribution factor as given in 5C-3-3/Figure 3

k = 36 (3.67, 0.34)

C_1 and C_b are as defined in 3-2-1/3.5.

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

D = depth of vessel, as defined in 3-1-1/7.3, in m (ft)

5.3.3 Torsional Moment

5.3.3(a) Nominal Torsional Moment. The nominal torsional moment amidships, in kN-m (tf-m, Ltf-ft), positive clockwise looking forward, may be determined as follows:

$$T_M = kLB^2 d_1 [(C_w - 0.5)^2 + 0.1][0.13 - (e/D)(c_o/d_1)^{1/2}]$$

where

k = 2.7 (0.276, 0.077)

c_o = 0.14 (0.14, 0.459)

d_1 = draft, as defined in 3-1-1/9, but not less than 12.5 m (41 ft)

e = the vertical distance, in m (ft), of the effective shear center of the hull girder within cargo space, measured from the baseline of the vessel, positive upward.

For simplification, the effective shear center of a typical cargo hold may be estimated by considering a closed cargo hold, of which the original hatch opening is considered to be closed by a thin plate of equivalent thickness. This thin plate should be made up by "stretching" lengthwise the cross deck plating and, if applicable, the upwardly projected upper box stool plating at vessel centerline between hatch openings to cover the whole length of the cargo hold. This plate's volume should be equivalent to the original plate volume of the cross deck plating plus, if applicable, that of the projected upper box stool plating.

C_w = waterplane coefficient for the scantling draft, if not available, it may be approximated by 1.09 C_b. C_w, but need not be taken greater than 0.98 for typical bulk carriers.

C_b is as defined in 3-2-1/3.5.

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

B = breadth of vessel, as defined in 3-1-1/5, in m (ft)

D = depth of vessel, as defined in 3-1-1/7.3, in m (ft)

5.3.3(b) Distribution of Torsional Moment. The nominal torsional moment along the length of the vessel L may be obtained by multiplying the midship value by the distribution factor m_T given by 5C-3-3/Figure 6.

5.5 External Pressures *(1996)*

5.5.1 Pressure Distribution

The external pressures, P_e, positive toward inboard, imposed on the hull in seaways can be expressed by the following equation at a given location.

$$p_e = \rho g\,(h_s + k_u h_{de}) \geq 0 \qquad \text{in N/cm}^2\ (\text{kgf/cm}^2,\ \text{lbf/in}^2)$$

where

ρg = specific weight of sea water

= 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf/in^2-ft)

h_s = hydrostatic pressure head in still water, in m (ft)

k_u = load factor, and may be taken as unity unless otherwise specified.

h_{de} = hydrodynamic pressure head induced by the wave, in m (ft), may be calculated as follows:

h_{de} = $k_c h_{di}$

where

k_c = correlation factor for a specific combined load case, as given in 5C-3-3/7 and 5C-3-3/9

h_{di}	=	hydrodynamic pressure head, in m (ft), at location i, (i = 1, 2, 3, 4 or 5; see 5C-3-3/Figure 4)
	=	$k_\ell \alpha_i h_{do}$ in m (ft)
k_ℓ	=	distribution factor along the length of the vessel
	=	$1 + (k_{\ell o} - 1) \cos \mu$, $k_{\ell o}$ is as given in 5C-3-3/Figure 5
h_{do}	=	$1.36\, kC_1$ in m (ft)
C_1	=	as defined in 3-2-1/3.5
k	=	1 (1, 3.281)
α_i	=	distribution factor around the girth of vessel at location i. Intermediate location may be obtained by linear interpolation.
	=	$1.00 - 0.25 \cos \mu$, for i = 1, at WL, starboard
	=	$0.40 - 0.10 \cos \mu$, for i = 2, at bilge, starboard
	=	$0.30 - 0.20 \sin \mu$, for i = 3, at bottom centerline
	=	$2\alpha_3 - \alpha_2$, for i = 4, at bilge, port
	=	$0.75 - 1.25 \sin \mu$, for i = 5, at WL, port
μ	=	wave heading angle to be taken from 0° to 90° (0° for head sea, 90° for beam sea for wave coming from starboard)

The distribution of the total external pressure, including static and hydrodynamic pressure, is illustrated in 5C-3-3/Figure 14.

5.5.2 Extreme Pressures

In determining the required scantlings of local structural members, the extreme external pressure, p_e, as defined in 5C-3-3-/5.5.1 with k_u given in 5C-3-3/7 and 5C-3-3/9 is to be used.

5.5.3 Simultaneous Pressures

For performing 3D structural analysis, the simultaneous pressure along any portion of the hull girder may be obtained from:

$$p_{es} = \rho\, g\, (h_s + k_f k_u h_{de}) \geq 0 \text{ in N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

k_f is the distribution function of h_{de}, corresponding to a designated wave profile along the vessel's length, and may be determined as follows:

5.5.3(a) For the combined load cases, L.C.1 through L.C.6 specified in 5C-3-3/Table 1

$$k_f = k_{fo} \{1 - [1 - \cos 2\pi (x/L - x_o/L)] \cos \mu\}$$

5.5.3(b) For the combined load cases, L.C.7 and L.C.8 specified in 5C-3-3/Table 1

$$k_f = k_{fo} \cos\{4\pi (x/L - x_o/L - 0.25) \cos \mu\}$$

5.5.3(c) For the combined load cases, L.C.9 and L.C.10 specified in 5C-3-3/Table 1

$$k_f = k_{fo} \cos\{4\pi (x/L - x_o/L) \cos \mu\}$$

where

x = distance from A.P. to the station considered, in m (ft)

x_o = distance from A.P. to the reference station, in m (ft)

The reference station is the point along the vessel's length where the wave trough or crest is located in head seas and may be taken as the mid-point of the mid-hold of the three hold model.

L = the vessel length, as defined in 3-1-1/3.1, in m (ft)

μ = the wave heading angle, to be taken from 0° to 90°

k_{fo} = ±1.0, as specified in 5C-3-3/Table 1

The simultaneous pressure distribution around the girth of the vessel is to be determined based on the wave heading angles specified in 5C-3-3/Table 1.

5.5.4 Impact Loads on Bow and Deck

5.5.4(a) Bow Pressures. When experimental data or direct calculation are not available, nominal wave-induced bow pressures above *LWL* in the region from the forward end to the collision bulkhead may be obtained from the following equation:

$$p_{bij} = kC_kC_{ij}V_{ij}^2 \sin \gamma_{ij} \quad \text{kN/m}^2 \text{ (tf/m}^2\text{, Ltf/ft}^2\text{)}$$

where

k = 1.025 (0.1045, 0.000888)

C_{ij} = $\{1 + \cos^2 [90(F_{bi} - 2a_{ij})/F_{bi}]\}^{1/2}$

V_{ij} = $\omega_1 V \sin \alpha_{ij} + \omega_2(L)^{1/2}$

ω_1 = 0.515 (0.515, 1.68)

ω_2 = 1.0 (1.0, 1.8)

V = 75% of the design speed, V_d, in knots. V is not to be taken less than 10 knots. V_d is defined in 3-2-14/3.

γ_{ij} = local bow angle measured from the horizontal, not to be taken less than 50°

= $\tan^{-1} (\tan \beta_{ij}/\cos \alpha_{ij})$

α_{ij} = local waterline angle measured from the centerline, see 5C-3-3/Figure 7, not to be taken less than 35°

β_{ij} = local body plan angle measure from the horizontal, see 5C-3-3/Figure 7, not to be taken less than 35°

F_{bi} = freeboard from the highest deck at side to the load waterline (*LWL*) at station *i,* see 5C-3-3/Figure 7

a_{ij} = vertical distance from the *LWL* to WL_j, see 5C-3-3/Figure 7

C_k = 0.7 at collision bulkhead and 0.9 at 0.0125L, linear interpolation for in between

= 0.9 between 0.0125L and the FP

= 1.0 at and forward of the FP

i, j = station and waterline, to be taken to correspond to the locations as required by 5C-3-6/1.1

5.5.4(b) Green Water. When experimental data or direct calculation is not available, nominal green water pressures imposed on deck in the region from the FP to 0.25L aft, including the extension beyond the FP, may be obtained from the following equations. P_{gi} is not to be taken less than 20.6 kN/m^2 (2.1 tf/m^2, 0.192 Ltf/ft^2).

$$p_{gi} = k\,(M_{Ri} - k_1 F_{bi})^{1/2} \qquad \text{kN/m}^2 \text{ (tf/m}^2\text{, Ltf/ft}^2\text{)}$$

where

k = 19.614 (2.0, 0.0557)

k_1 = 1.0 (1.0, 3.28)

M_{Ri} = $0.44\, A_i\,(VL/C_b)^{1/2}$ for L in meters

= $2.615\, A_i\,(VL/C_b)^{1/2}$ for L in feet

V = 75% of the design speed, V_d, in knots. V is not to be taken less than 10 knots.

V_d = as defined in 3-2-14/3

F_{bi} = as defined in 5C-3-3/5.5.4(a)

A_i = as shown in 5C-3-3/Table 2

C_b = as defined in 3-2-1/3.5

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

5.7 Internal Pressures – Inertia Forces and Added Pressure Heads *(1996)*

5.7.1 Ship Motions and Accelerations

In determining cargo pressures and ballast pressures, the dominating ship motions, pitch and roll, and the resultant accelerations induced by the wave are required. When a direct calculation is not available, the equations given below may be used.

5.7.1(a) Pitch. (1997) The pitch amplitude: (positive bow up)

$$\phi = k_1 (V/C_b)^{1/4}/L, \qquad \text{in deg.}$$

but need not to be taken more than 10 deg.

The pitch natural period:

$$T_p = k_2 \sqrt{C_b d_i} \qquad \text{in sec.}$$

where

k_1 = 1030 (3378) for L in m (ft)

k_2 = 3.5 (1.932) for d_i in m (ft)

V = 75% of the design speed, V_d, in knots. V is not to be taken less than 10 knots. V_d is defined in 3-2-14/3.

d_i = draft amidships for the relevant loading conditions

L and C_b are as defined in 3-1-1/3.1 and 3-1-1/11.3, respectively.

5.7.1(b) Roll. The roll amplitude: (positive starboard down)

$\theta = C_R(35 - k_\theta C_{di} \Delta/1000)$ if $T_r > 20$ sec.

$\theta = C_R(35 - k_\theta C_{di}\Delta/1000)(1.5375 - 0.027T_r)$ if $12.5 \le T_r \le 20$ sec

$\theta = C_R(35 - k_\theta C_{di}\Delta/1000)(0.8625 + 0.027T_r)$ if $T_r \le 12.5$ sec

k_θ = 0.005 (0.05, 0.051)

θ in degrees, need not be taken more than 30 deg.

$C_R = 1.3 - 0.025V$

$C_{di} = 1.06\,(d_i/d) - 0.06$

d_i = draft amidships for the relevant loading conditions, m (ft)

d = draft as defined in 3-1-1/9, in m (ft)

$\Delta = k_d L B d C_b$ kN (tf, Ltf)

k_d = 10.05 (1.025, 0.0286)

L and B are as defined in 3-1-1/3.1 and 3-1-1/5, respectively, in m (ft).

The roll natural motion period:

$T_r = k_4 k_r / GM^{1/2}$ in sec.

where

k_4 = 2 (1.104) for k_r, GM in m (ft)

k_r = roll radius of gyration, in m (ft), and may be taken as $0.35B$ for full load conditions and $0.40B$ for ballast conditions.

GM = metacentric height, to be taken as:

= GM (full) for $d_i = d$

= 1.5 GM (full) for $d_i = 2d/3$

= 2.0 GM (full) for $d_i = d/2$

GM (full) = metacentric height for fully loaded condition. If GM (full) is not available, GM (full) may be taken as $0.12B$ for the purpose of estimation.

5.7.1(c) Accelerations. The vertical, longitudinal and transverse accelerations of tank contents (cargo or ballast), a_v, a_ℓ and a_t may be obtained from the following formulae:

$a_v = C_v k_v a_o g$ m/sec² (ft/sec²) positive downward

$a_\ell = C_\ell k_\ell a_o g$ m/sec² (ft/sec²) positive forward

$a_t = C_t k_t a_o g$ m/sec² (ft/sec²) positive starboard

where

$a_o = k_o(2.4/L^{1/2} + 34/L - 600/L^2)$ for L in m

$= k_o(4.347/L^{1/2} + 111.55/L - 6458/L^2)$ for L in ft

$k_o = 0.86 + 0.048V - 0.47\,C_b$

C_v = $\cos\mu + (1 + 2.4\,z/B)(\sin\mu)/k_v$

μ = wave heading angle in degrees, 0° for head sea, and 90° for beam sea for wave coming from starboard

k_v = $[1 + 0.65(5.3 - 45/L)^2(x/L - 0.45)^2]^{1/2}$ for L in m

= $[1 + 0.65(5.3 - 147.6/L)^2(x/L - 0.45)^2]^{1/2}$ for L in ft

C_ℓ = $0.35 - 0.0005(L - 200)$ for L in m

= $0.35 - 0.00015(L - 656)$ for L in ft

k_ℓ = $0.5 + 8y/L$

C_t = $1.27[1 + 1.52(x/L - 0.45)^2]^{1/2}$

k_t = $0.35 + y/B$

L, B are the length and breadth of vessel, as defined in 3-1-1/3.1 and 3-1-1/5, respectively, in m (ft).

x = longitudinal distance from the AP to the station considered, in m (ft)

y = vertical distance from the waterline to the point considered, in m (ft), positive upward

z = transverse distance from the centerline to the point considered, in m (ft), positive starboard

g = acceleration of gravity = 9.8 m/sec^2 (32.2 ft/sec^2)

5.7.2 Bulk Cargo Pressures

5.7.2(a) Bulk Cargo Pressures on Inner Bottom and Side Wall within 0.4L Amidships. The bulk cargo pressures, acting on the inner bottom, side wall and sloped bottom of a cargo hold may be expressed by pressure components, p_{cn}, $p_{ct(t)}$ and $p_{ct(\ell)}$, in directions normal, parallel to the wall surface in transverse direction, and parallel to the wall surface in longitudinal direction, respectively. These components can be determined by the following equations:

$p_{cn} = p_{sn} + k_u p_{dn}$ N/cm^2 (kgf/cm^2, lbf/in^2)

$p_{ct(t)} = p_{st(t)} + k_u p_{dt(t)}$ N/cm^2 (kgf/cm^2, lbf/in^2)

$p_{ct(\ell)} = p_{st(\ell)} + k_u p_{dt(\ell)}$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

p_{sn} = nominal static pressure component due to gravity

= $\rho g h_c\{\cos^2\alpha + (1 - \sin\alpha_o)\sin^2\alpha\}$

$p_{st(t)}$ = tangential static pressure component due to gravity in transverse direction (positive shown in 5C-3-3/Figure 8)

= $\rho g h_c(\sin\alpha_o \sin\alpha \cos\alpha)$

$p_{st(\ell)}$ = tangential static pressure component due to gravity in longitudinal direction (positive shown in 5C-3-3/Figure 8)

= 0

p_{dn} = dynamic pressure component due to vessel's roll, pitch, vertical and transverse accelerations

= $k_c[p_{qn} + \rho g h_c \{(a_{ve}/g) \cos^2\alpha + k_n (a_{te}/g) (b/2h_c) \sin^2\alpha\}]$

p_{qn} = additional normal pressure component due to roll and pitch

= $\rho g h^* \cos \phi_e [\cos^2 (\alpha - \theta_e) + (1 - \sin \alpha_o) \sin^2(\alpha - \theta_e)] - p_{sn}$

$p_{dt(t)}$ = tangential dynamic pressure component due to vessel's roll, pitch, vertical and transverse accelerations in transverse direction (positive shown in 5C-3-3/Figure 8)

= $k_c [p_{qt(t)} + \rho g h_c \{(a_{ve}/g) \sin \alpha \cos \alpha - k_n(a_{te}/g)(b/2h_c) \sin \alpha \cos \alpha\}]$

$p_{qt(t)}$ = $\rho g h^* \cos \phi_e \sin \alpha_o \sin(\alpha - \theta_e) \cos(\alpha - \theta_e) - p_{st(t)}$

$p_{dt(\ell)}$ = tangential dynamic pressure component due to vessel's roll, pitch, vertical and transverse accelerations in longitudinal direction (positive shown in 5C-3-3/Figure 8)

= $k_c[-\rho g h^* \cos \phi_e \sin \alpha_o \cos(\alpha - \theta_e) \sin \phi_e]$

k_c = correlation coefficient and may be taken as unity unless otherwise specified

k_u = dynamic load factor and may be taken as unity unless otherwise specified

where

ρg = specific weight of the bulk cargo considered, in N/cm^2-m (kgf/cm^2-m, lbf/in^2-ft)

α = slope of wall measured from horizontal plane, in degrees (see 5C-3-3/Figure 9)

α_o = angle of repose for the bulk cargo considered, normally 30 degrees (Re: "Code of Safe Practice for Solid Bulk Cargoes" published by IMO)

θ_e = effective angle of roll = 0.71 $C_\theta\theta$, in degrees

ϕ_e = effective angle of pitch = 0.71 $C_\phi\phi$, in degrees

h_c = vertical distance from the top cargo surface to the wall point considered in upright condition, in m (ft), as shown in 5C-3-3/Figure 10

h^* = vertical distance from the top of cargo surface to the wall point considered in heeled condition, in m (ft), as shown in 5C-3-3/Figure 10

b = width of the cargo hold at the level of the wall point considered, in m (ft)

a_{ve} = effective vertical acceleration

= 0.71 $c_v a_v$, in m/sec^2 (ft/sec^2)

a_{te} = effective transverse acceleration

= 0.71 $c_T a_t$, in m/sec^2 (ft/sec^2)

c_v, c_T, C_θ and C_ϕ are as specified in 5C-3-3/Table 1.

k_n = 0.33 unless otherwise specified

a_v and a_t are as specified in 5C-3-3/5.7.1(c).

If the direction of gravity is away from the wall at the point considered, the following equation can be used:

$$p_{qn} = \rho g h_c \cos \phi_e [\cos \theta_e (1 - \sin \alpha_o) \sin^2(\alpha - \theta_e)] - p_{sn}$$

$$p_{qt(t)} = \rho g h_c \cos \phi_e \cos \theta_e (1 - \sin \alpha_o) \sin(\alpha - \theta_e) \cos(\alpha - \theta_e) - p_{st}$$

$$p_{dt(t)} = -\rho g h_c \sin \phi_e \cos \theta_e (1 - \sin \alpha_o) \sin(\alpha - \theta_e) \cos(\alpha - \theta_e)$$

5.7.2(b) Bulk Cargo Pressures on Transverse Bulkhead within 0.4L Amidships. The bulk cargo pressures acting on transverse bulkheads and stools can be similarly obtained when the wall angle is defined as β.

$p_{cn} = p_{sn} + k_u p_{dn}$ N/cm^2 (kgf/cm^2, lbf/in^2)

$p_{ct(t)} = p_{st(t)} + k_u p_{dt(t)}$ N/cm^2 (kgf/cm^2, lbf/in^2)

$p_{ct(\ell)} = p_{st(\ell)} + k_u p_{dt(\ell)}$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

p_{sn} = nominal static pressure component due to gravity

= $\rho g h_c \{\cos^2 \beta + (1 - \sin \alpha_o) \sin^2 \beta\}$

$p_{st(t)}$ = tangential static pressure component due to gravity in transverse direction (positive shown in 5C-3-3/Figure 8)

= 0

$p_{st(\ell)}$ = tangential static pressure component due to gravity in longitudinal direction (positive shown in 5C-3-3/Figure 8)

= $-\rho g h_c (\sin \alpha_o \sin \beta \cos \beta)$

p_{dn} = dynamic pressure component due to vessel's roll, pitch, vertical and longitudinal accelerations

= $k_c[p_{qn} + \rho g h_c\{(a_{ve}/g) \cos^2\beta + k_n(a_{\ell e}/g)(\ell/2h_c) \sin^2\beta\}]$

p_{qn} = additional normal pressure component due to roll and pitch

= $\rho g h^* \cos \theta_e[\cos^2(\beta + \phi_e) + (1 - \sin \alpha_o) \sin^2(\beta + \phi_e)] - p_{sn}$

$p_{dt(t)}$ = tangential dynamic pressure component due to vessel's roll, pitch, vertical and longitudinal accelerations in transverse direction (positive shown in 5C-3-3/Figure 8)

= $k_c[-\rho g h^* \sin \alpha_o \cos(\beta + \phi_e) \sin \theta_e]$

$p_{dt(\ell)}$ = tangential dynamic pressure component due to vessel's roll, pitch, vertical and longitudinal accelerations in longitudinal direction (positive shown in 5C-3-3/Figure 8)

= $k_c[p_{qt(\ell)} - \rho g h_c\{(a_{ve}/g) \sin \beta \cos \beta + k_n(a_{\ell e}/g)(\ell/2h_c) \sin \beta \cos \beta\}]$

$p_{qt(\ell)}$ = $-\rho g h^* \sin \alpha_o \sin(\beta + \phi_e) \cos(\beta + \phi_e) - p_{st(\ell)}$

β = slope of wall measured from horizontal plane, in degrees, as shown in 5C-3-3/Figure 11

ℓ = length of the cargo hold at the level of the wall point considered, in m (ft)

$a_{\ell e}$ = effective longitudinal acceleration

= $0.71\, c_L\, a_\ell$, m/sec^2 (ft/sec^2)

c_v, c_L, C_θ and C_ϕ are as specified in 5C-3-3/Table 1.

k_n = 0.33 unless otherwise specified

a_ℓ is as specified in 5C-3-3/5.7.1(c).

5.7.2(c) Cargo Pressure Outside of 0.4L Amidships. Where the vessel form changes significantly outside 0.4L amidships, the cargo pressures on the side shell may be obtained based on the vector sum of the normal and tangential components considering the orientation of the plates.

5.7.2(d) Extreme Cargo Pressure. For assessing local structures at a cargo hold boundary, the extreme cargo pressure determined based on a specified dynamic load factor, k_u (equal or greater than unity), in 5C-3-3/7 is to be considered.

5.7.2(e) Simultaneous Cargo Pressures. In performing a 3D structural analysis, the internal cargo pressures may be calculated in accordance with 5C-3-3/5.7.2(a), 5C-3-3/5.7.2(b) and 5C-3-3/5.7.2(c) above for cargo holds in the midbody region. For cargo holds in the fore or aft body regions, the pressures are to be determined based on linear distributions of acceleration and ship motions along the length of the vessel.

5.7.3 Internal Ballast Liquid Pressures

For wing and ballast tanks, the internal liquid pressures may be determined in accordance with 5C-3-3/5.7.2 with consideration of overflows.

5.7.3(a) Distribution of Internal Pressures. The internal ballast pressures, p_i, positive toward tank boundaries for a fully filled ballast tank, may be obtained from the following formula:

$$p_i = \rho g(\eta + k_u h_d) \geq 0 \qquad \text{in N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

ρg = specific weight of the liquid, in N/cm^2-m (kgf/cm^2-m, lbf/in^2-ft)

η = local vertical coordinate for tank boundaries measuring, as shown in 5C-3-3/Figure 12, in m (ft)

k_u = load factor and may be taken as unity unless otherwise specified

h_d = wave induced pressure head, including inertial force and added pressure head

= $k_c(\eta_i a_i/g + \Delta h_i)$, in m (ft)

η_i = local coordinate in vertical direction for tank boundaries measuring from the top of the tank

k_c = correlation factor and may be taken as unity unless otherwise specified

a_i = effective resultant acceleration, in m/sec^2 (ft/sec^2), at the point considered and may be approximated by

a_i = $0.71\, C_{dp}\, [w_v a_v + w_\ell (\ell/h) a_\ell + w_t (b/h) a_t]$

C_{dp} = 1.0 for rectangular tank, upper wing tank, lower wing tank

= 0.7 for J-shaped ballast tanks of double hull type bulk carrier

a_v, a_ℓ and a_t are as given in 5C-3-3/5.7.1(c).

w_v, w_ℓ and w_t are weighted coefficients and showing directions as specified in 5C-3-3/Table 1.

Δh_i = added pressure head due to pitch and roll motions at the point considered, in m (ft), may be calculated as follows

i) for bow down and starboard down ($\phi_e < 0$, $\theta_e > 0$)

Δh_i = $\xi \sin(-\phi_e) + (\zeta_e \sin \theta_e \cos \phi_e + \eta_e \cos \theta_e \cos \phi_e - \eta)$ for tank without overflows

Δh_i = $(\xi - \ell/2) \sin(-\phi_e) + (\zeta_e \sin \theta_e \cos \phi_e + \eta_e \cos \theta_e \cos \phi_e - \eta)$ for tank with overflows

ζ_e = $b - \zeta$

η_e = η

ii) for bow up and starboard up ($\phi_e > 0$, $\theta_e < 0$)

Δh_i = $(\ell - \xi) \sin \phi_e + (\zeta_e \sin(-\theta_e) \cos \phi_e + \eta_e \cos \theta_e \cos \phi_e - \eta)$ for tank without overflows

Δh_i = $(\ell/2 - \xi) \sin \phi_e + (\zeta_e \sin(-\theta_e) \cos \phi_e + \eta_e \cos \theta_e \cos \phi_e - \eta)$ for tank with overflows

ζ_e = $\zeta - \zeta_b$

η_e = $\eta - \delta_h$

ξ, ζ, η are the local coordinates, in m (ft), for the point considered with respect to the origin shown in 5C-3-3/Figure 12.

δ_b and δ_h are the local coordinate adjustments, in m (ft), for a rounded tank corner, as shown in 5C-3-3/Figure 12.

where

θ_e = $0.71\ C_\theta\ \theta$

ϕ_e = $0.71\ C_\phi\ \phi$

ℓ = length of the tank, in m (ft)

b = breadth of the tank considered, in m (ft)

h = height of the tank considered, in m (ft)

ϕ and θ are pitch and roll amplitude as given in 5C-3-3/5.7.1(a) and (b).

C_ϕ and C_θ are weighted coefficients and showing directions as given in 5C-3-3/Table 1.

5.7.3(b) Extreme Internal Ballast Pressure. For assessing local structures at a tank boundary, the extreme internal ballast pressure with k_u as specified in 5C-3-3/7, is to be considered.

5.7.3(c) Simultaneous Internal Ballast Pressures. In performing a 3D structural analysis, the internal ballast pressures may be calculated in accordance with 5C-3-3/5.7.3(a) and 5C-3-3/5.7.3(b) above for tanks in the midbody. For tanks in the fore or aft body, the pressures are to be determined based on linear distributions of accelerations and ship motions along the length of the vessel.

5.7.4 Deck Cargo Loads

In addition to the static load components of deck cargoes, the inertial forces with respect to the vertical accelerations, a_v, are to be considered.

FIGURE 2
Distribution Factor m_h (1996)

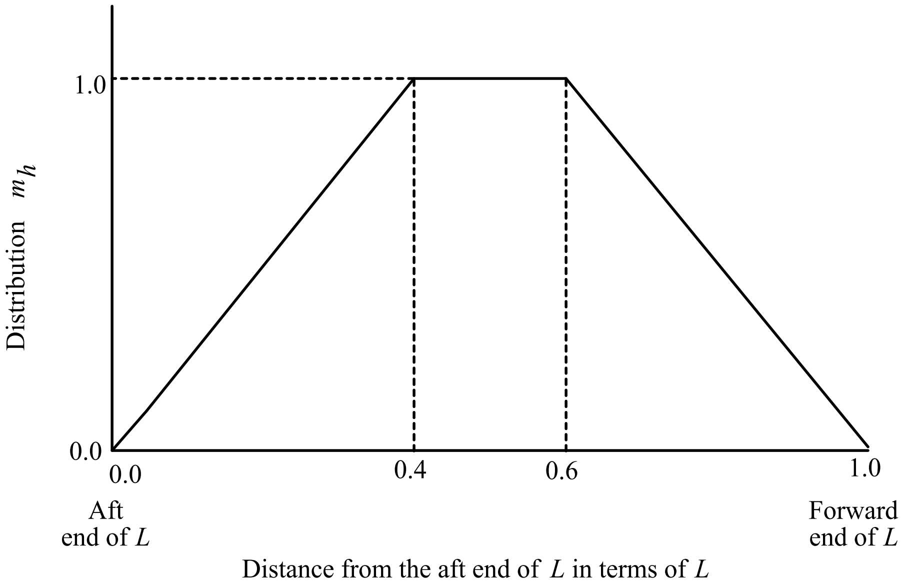


FIGURE 3
Distribution Factor f_h (1996)

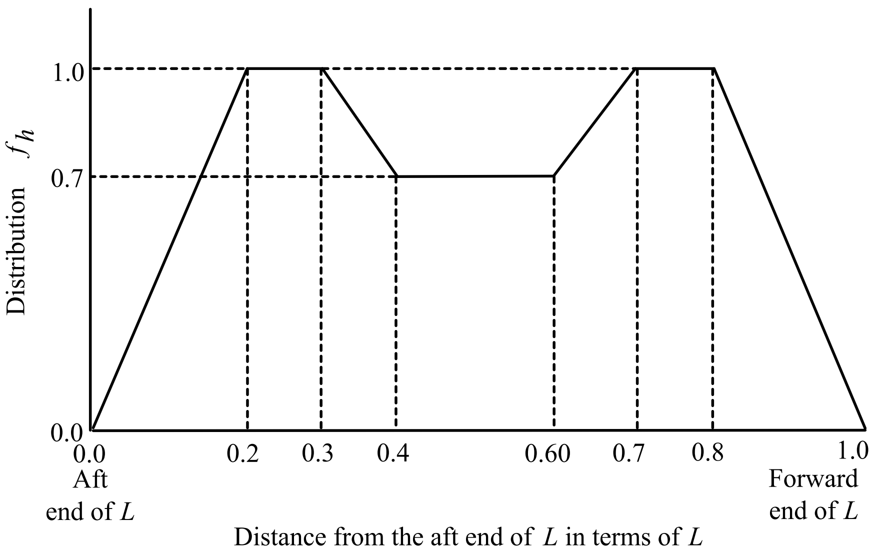
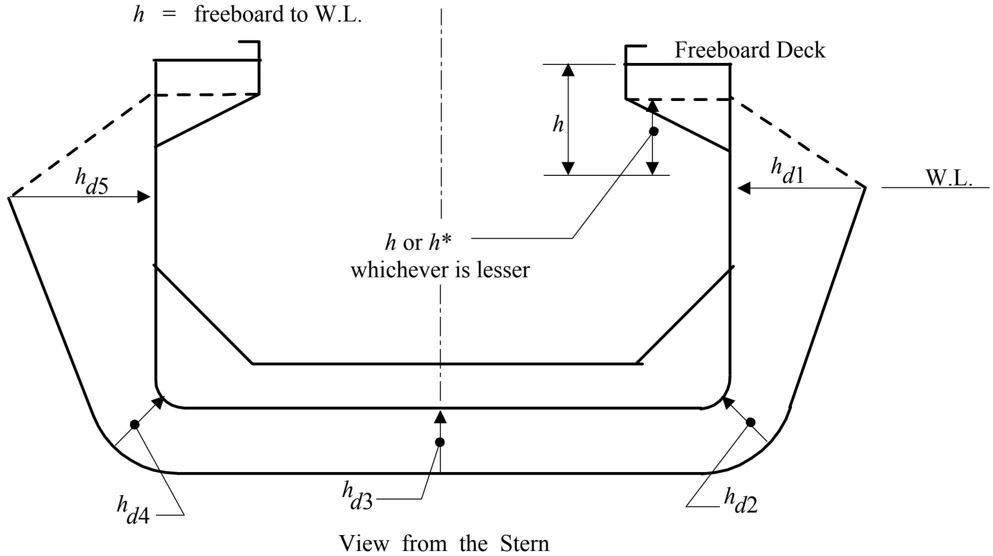


FIGURE 4
Distribution of h_{di} (1996)



Note: $h^* = k_u k_c h_{d1}$ for nominal pressure
$h^* = k_f k_u h_{d1}$ for simultaneous pressure

FIGURE 5
Pressure Distribution Function $k_{\ell o}$ (1996)

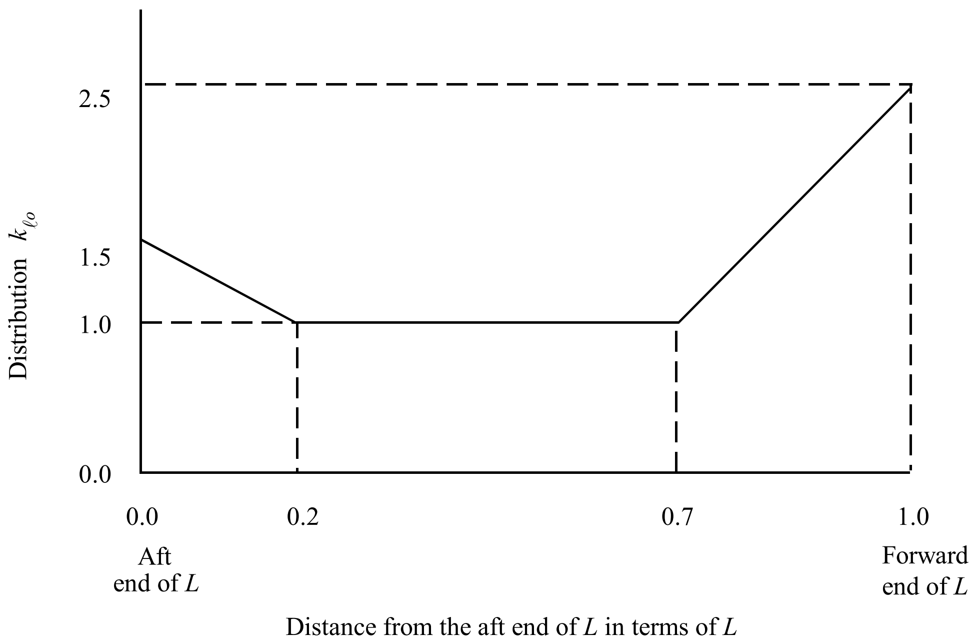


FIGURE 6
Distribution Factor m_T *(1996)*

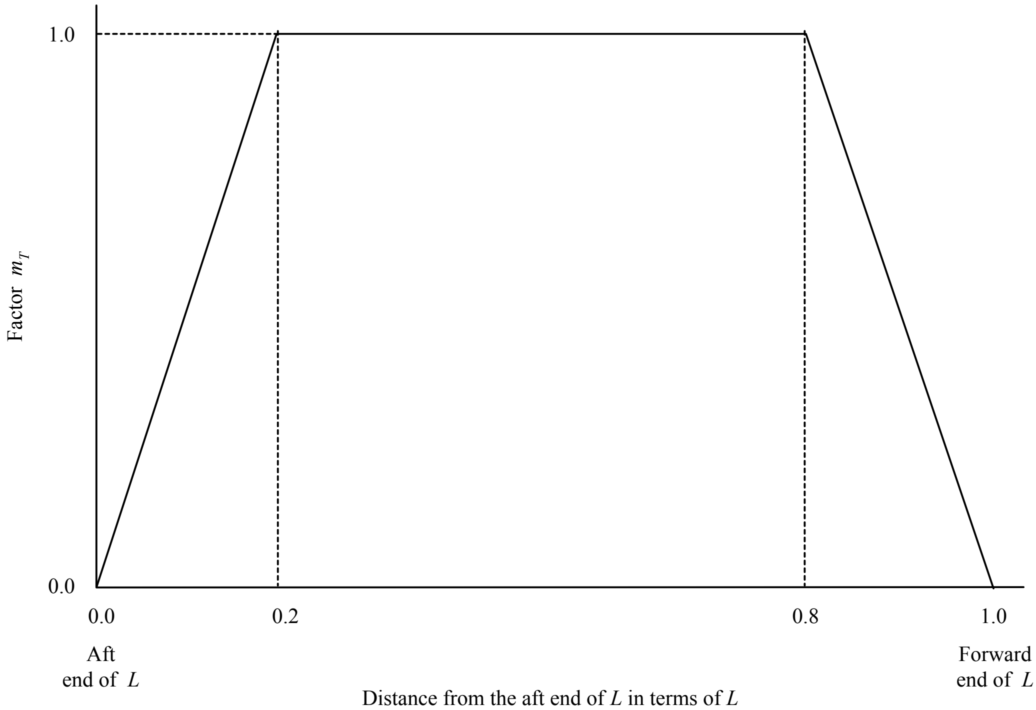


FIGURE 7
Definition of Bow Geometry *(1 July 2008)*

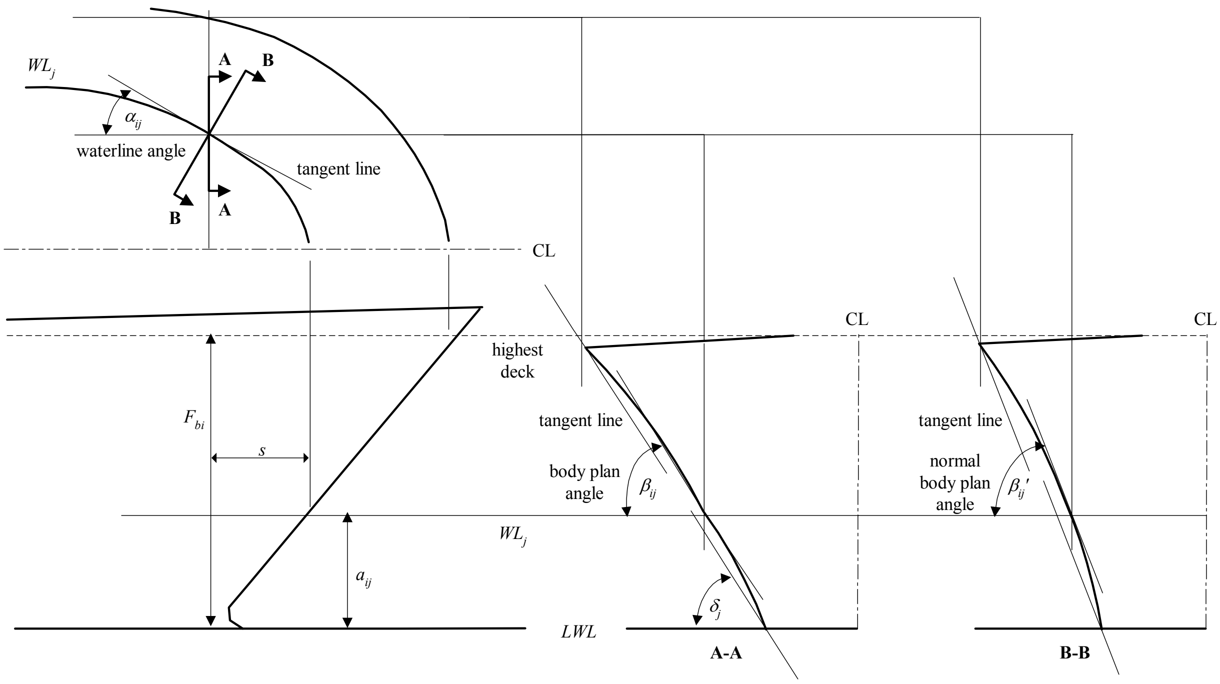


FIGURE 8
Direction of Positive Tangential Force *(1996)*

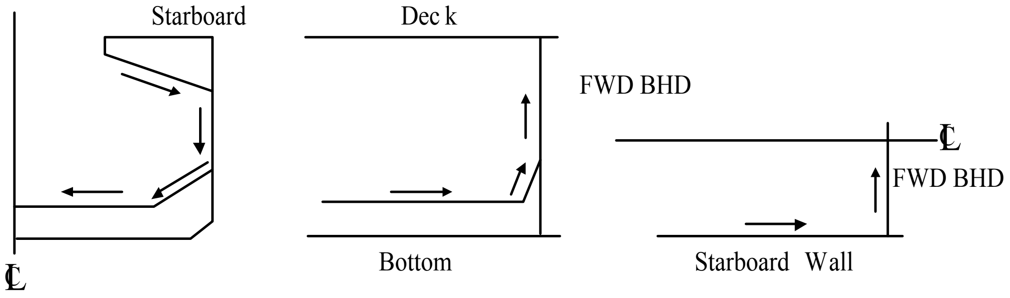


FIGURE 9
Definition of Wall Angle *(1996)*

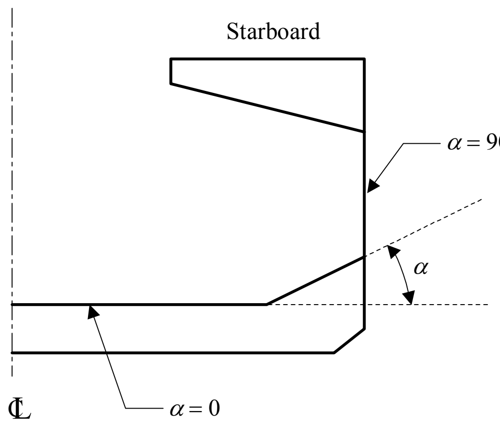
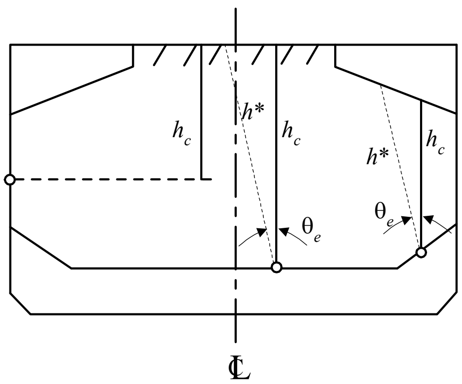
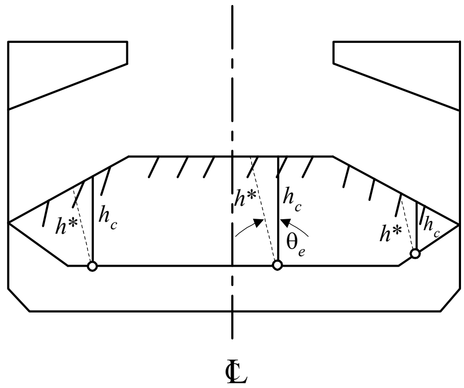


FIGURE 10
Definition of Cargo Height at Various Locations *(1996)*



Light Cargo (See 5C-3-3/Figure 1)
To be filled up to the deck line.



Heavy Cargo (See 5C-3-3/Figure 1)
Top of the cargo surface inclined 30 degrees from the horizontal at the top of the lower hopper wing tank, and intersects a vertical line drawn from the side of the hatch coaming.

FIGURE 11
Definition of Wall Angle for Transverse Bulkhead *(1996)*

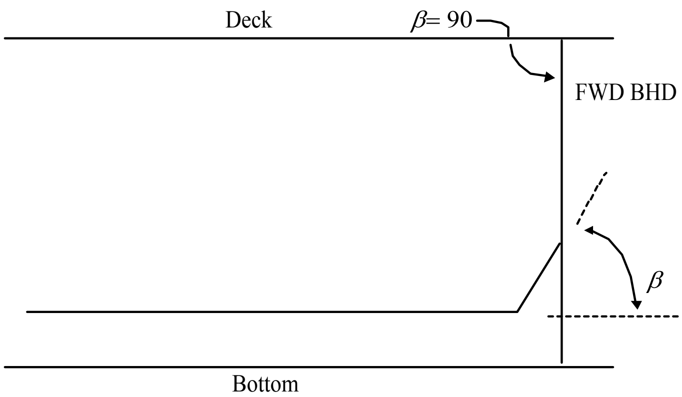
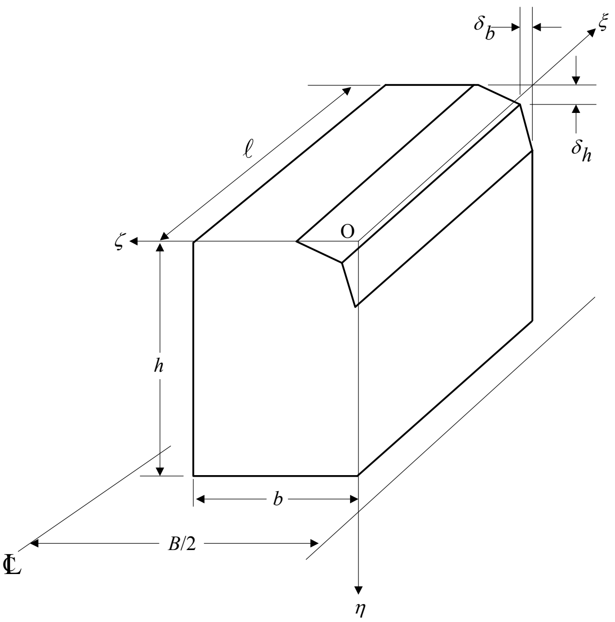
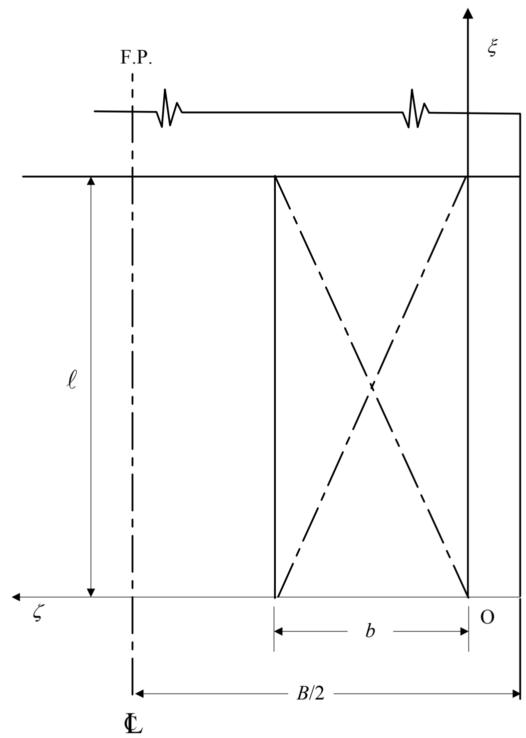
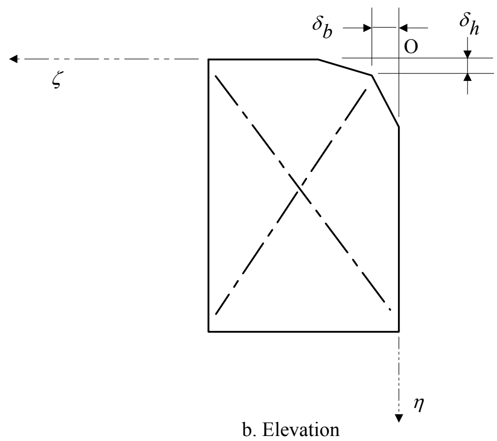


FIGURE 12
Definition of Tank Geometry *(1996)*





a. Plan View



b. Elevation

For the lower ballast tanks, η is to be measured from a point located at $^2/_3$ the distance from the top of the tank to the top of the overflow (minimum 760 mm above deck).

TABLE 1
Combined Load Cases for Bulk, Ore/Bulk/Oil and Ore/Oil Carriers* *(2003)*

	L.C. 1	*L.C. 2*	*L.C. 3*	*L.C. 4*	*L.C. 5*	*L.C. 6*	*L.C. 7*	*L.C. 8*	*L.C. 9*	*L.C. 10*
A. HULL GIRDER LOADS**										
Vertical B.M.***	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)
k_c	1.0	1.0	0.7	0.7	0.3	0.3	0.4	0.4	0.4	0.4
Vertical S.F.	(+)	(–)	(+)	(–)	(+)	(–)	(+)	(–)	(+)	(–)
k_c	0.5	0.5	1.0	1.0	0.3	0.3	0.4	0.4	0.4	0.4
Horizontal B.M.					Stbd Tens (–)	Port Tens (+)	Stbd Tens (–)	Port Tens (+)	Stbd Tens (–)	Port Tens (+)
k_c	0.0	0.0	0.0	0.0	0.3	0.3	0.5	0.5	1.0	1.0
Horizontal S.F.					(+)	(–)	(+)	(–)	(+)	(–)
k_c	0.0	0.0	0.0	0.0	1.0	1.0	0.5	0.5	1.0	1.0
Torsional Mt.					(–)	(+)	(–)	(+)	(–)	(+)
k_c	0.0	0.0	0.0	0.0	0.6	0.6	1.0	1.0	0.6	0.6
B. EXTERNAL PRESSURE										
k_c	0.5	0.5	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0
k_{f0}	–1.0	1.0	–1.0	1.0	–1.0	1.0	–1.0	1.0	–1.0	1.0
C. INTERNAL BULK CARGO PRESSURE										
k_c	0.4	0.4	1.0	0.5	1.0	0.5	1.0	0.5	—	—
c_V	0.8	–0.8	0.8	–0.8	0.4	–0.4	0.7	–0.7	—	—
c_L	Fwd Bhd 0.6	Fwd Bhd –0.6	Fwd Bhd 0.6	Fwd Bhd –0.6	—	—	Fwd Bhd 0.7	Fwd Bhd –0.7	—	—
	Aft Bhd –0.6	Aft Bhd 0.6	Aft Bhd –0.6	Aft Bhd 0.6	—	—	Aft Bhd –0.7	Aft Bhd 0.7	—	—
c_T	—	—	—	—	Port Wall –0.9	Port Wall 0.9	Port Wall –0.7	Port Wall 0.7	—	—
	—	—	—	—	Stbd Wall 0.9	Stbd Wall –0.9	Stbd Wall 0.7	Stbd Wall –0.7	—	—
c_ϕ, Pitch	–1.0	1.0	–1.0	1.0	0.0	0.0	–0.7	0.7	—	—
c_θ, Roll	0.0	0.0	0.0	0.0	1.0	–1.0	0.7	–0.7	—	—

TABLE 1 (continued)
Combined Load Cases for Bulk, Ore/Bulk/Oil and Ore/Oil Carriers* *(2003)*

	L.C. 1	*L.C. 2*	*L.C. 3*	*L.C. 4*	*L.C. 5*	*L.C. 6*	*L.C. 7*	*L.C. 8*	*L.C. 9*	*L.C. 10*
D. INTERNAL BALLAST TANK PRESSURE										
k_c	0.4	0.4	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5
w_v	0.75	–0.75	0.75	–0.75	0.25	–0.25	0.4	–0.4	0.4	–0.4
w_ℓ	Fwd Bhd 0.25	Fwd Bhd - 0.25	Fwd Bhd 0.25	Fwd Bhd –0.25	—	—	Fwd Bhd 0.2	Fwd Bhd –0.2	Fwd Bhd 0.2	Fwd Bhd –0.2
	Aft Bhd –0.25	Aft Bhd 0.25	Aft Bhd –0.25	Aft Bhd 0.25	—	—	Aft Bhd –0.2	Aft Bhd 0.2	Aft Bhd –0.2	Aft Bhd 0.2
w_t	—	—	—	—	Port Wall –0.75	Port Wall 0.75	Port Wall –0.4	Port Wall 0.4	Port Wall –0.4	Port Wall 0.4
	—	—	—	—	Stbd Wall 0.75	Stbd Wall –0.75	Stbd Wall 0.4	Stbd Wall –0.4	Stbd Wall 0.4	Stbd Wall -0.4
c_ϕ, Pitch	–1.0	1.0	–1.0	1.0	0.0	0.0	–0.7	0.7	–0.7	0.7
c_θ, Roll	0.0	0.0	0.0	0.0	1.0	–1.0	0.7	–0.7	0.7	–0.7
E. REFERENCE WAVE HEADING AND POSITION										
Heading Angle	0	0	0	0	90	90	60	60	60	60
Heave	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up
Pitch	Bow Down	Bow Up	Bow Down	Bow Up	—	—	Bow Down	Bow Up	Bow Down	Bow Up
Roll	—	—	—	—	Stbd Down	Stbd Up	Stbd Down	Stbd Up	Stbd down	Stbd Up
Draft	2/3	1	2/3	1	2/3	1	2/3	1	****	****

* k_u = 1.0 for all load components.

** Boundary forces are to be applied to produce the above specified hull girder bending moment at the middle of the structural model, and specified hull girder shear force at one end of the middle hold of the model. The sign convention for the shear force corresponds to the forward end of middle hold. The specified torsional moment is to be produced at the aft bulkhead of the middle hold.

*** The following still water bending moment (SWBM) is to be used for structural analysis.

L.C. 1, 3 and 5: Maximum sagging SWBM among alternate hold loading conditions only, but not to be taken less than 20% of the maximum sagging SWBM among all loading conditions.

L.C. 2, 4 and 6: Maximum hogging SWBM among alternate hold loading conditions only, but not to be taken less than 20% of the maximum hogging SWBM among all loading conditions.

L.C. 7: Maximum sagging SWBM among all loading conditions other than ballast conditions, but not to be taken less than 20% of the maximum sagging SWBM among all loading conditions.

L.C. 8: Maximum hogging SWBM among all loading conditions other than ballast conditions, but not to be taken less than 20% of the maximum hogging SWBM among all loading conditions.

L.C. 9: Maximum sagging SWBM among ballast conditions only, but not to be taken less than 20% of the maximum sagging SWBM among all loading conditions.

L.C. 10: Maximum hogging SWBM among ballast conditions only, but not to be taken less than 20% of the maximum hogging SWBM among all loading conditions.

**** *(2003)* For Load Cases 9 and 10, draft $d = [47 - 0.11(L - 150)]L/1000$ m (ft).

TABLE 2
Values of A_i and B_i *

	A_i	B_i
–0.05L	1.25	0.3600
FP	1.00	0.4000
0.05L	0.80	0.4375
0.10L	0.62	0.4838
0.15L	0.47	0.5532
0.20L	0.33	0.6666
0.25L	0.22	0.8182
0.30L	0.22	0.8182

* Linear interpolation may be used for intermediate values.

7 Nominal Design Loads *(1996)*

7.1 General

The nominal design loads specified below are to be used for determining the required scantlings of hull structures in conjunction with the specified permissible stresses given in Section 5C-3-4.

7.3 Hull Girder Loads – Longitudinal Bending Moments and Shear Forces *(1996)*

7.3.1 Total Vertical Bending Moment and Shear Force

The total longitudinal vertical bending moments and shear forces may be obtained from the following equations:

$$M_t = M_{sw} + k_u k_c M_w \qquad \text{kN-m (tf-m, Ltf-ft)}$$

$$F_t = F_{sw} + k_u k_c F_w \qquad \text{kN (tf, Ltf)}$$

where

M_{sw} and M_w are the still-water bending moment and wave-induced bending moment, respectively, as specified in 3-2-1/3.7, for either hogging or sagging conditions.

F_{sw} and F_w are the still-water and wave-induced shear forces, respectively, as specified in 3-2-1/3.9, for either positive or negative shear.

k_u is a load factor and may be taken as unity unless otherwise specified.

k_c is a correlation factor and may be taken as unity unless otherwise specified.

For determining the hull girder section modulus for 0.4L amidships as specified in 5C-3-4/3, the maximum still water bending moments, either hogging or sagging, are to be added to the hogging or sagging wave bending moments, respectively. Elsewhere, the total bending moment may be directly obtained based on the envelope curves as specified in 5C-3-3/3 and 5C-3-3/5.

For this purpose, k_u = 1.0, and k_c = 1.0

7.3.2 Horizontal Wave Bending Moment and Shear Force

For non-head sea conditions, the horizontal wave bending moment and the horizontal shear force as specified in 5C-3-3/5.3 are to be considered as additional hull girder loads, especially for the design of the side shell and inner skin structures. The effective horizontal bending moment and shear force, M_{HE} and F_{HE}, may be determined by the following equations:

$$M_{HE} = k_u k_c M_H \qquad \text{kN-m (tf-m, Ltf-ft)}$$

$$F_{HE} = k_u k_c F_H \qquad \text{kN (tf, Ltf)}$$

where k_u and k_c are a load factor and a correlation factor, respectively, which may be taken as unity unless otherwise specified.

7.3.3 Torsional Moment

The effective torsional moments for non-head sea conditions are to be considered in addition to the hull girder loads specified in 5C-3-3/7.3.1 and 5C-3-3/7.3.2 above.

$$T_{ME} = k_u k_c T_M \qquad \text{kN-m (tf-m, Ltf-ft)}$$

where

k_u and k_c are as defined above.

T_M is as specified in 5C-3-3/5.3.3.

7.5 Local Loads for Design of Supporting Structures *(1996)*

In determining the required scantlings of the main supporting structures, such as girders, transverses, stringers, floors and deep webs, the nominal loads induced by the external and cargo or ballast pressures distributed over both sides of the structural panel within the cargo hold boundaries are to be considered for the worst possible load combinations. In general, considerations are to be given to the following two loading cases accounting for the worst effects of the dynamic load components.

i) Maximum internal cargo pressures for a fully loaded cargo hold with the adjacent holds empty and minimum external pressures, where applicable.

ii) Empty cargo hold with the fore and aft holds full and maximum external pressures where applicable.

The specified design loads for main supporting structures are given in 5C-3-3/Table 3.

7.7 Local Pressures for Design of Plating and Longitudinals *(1996)*

In calculating the required scantlings of plating, longitudinals and stiffeners, the nominal pressures are to be considered for the two load cases given in 5C-3-3/7.5, using k_u = 1.1 instead of k_u = 1.0 as shown above.

The necessary details for calculating the nominal pressures are given in 5C-3-3/Table 3.

FIGURE 13
Location of Hold for Nominal Pressure Calculation *(1997)*

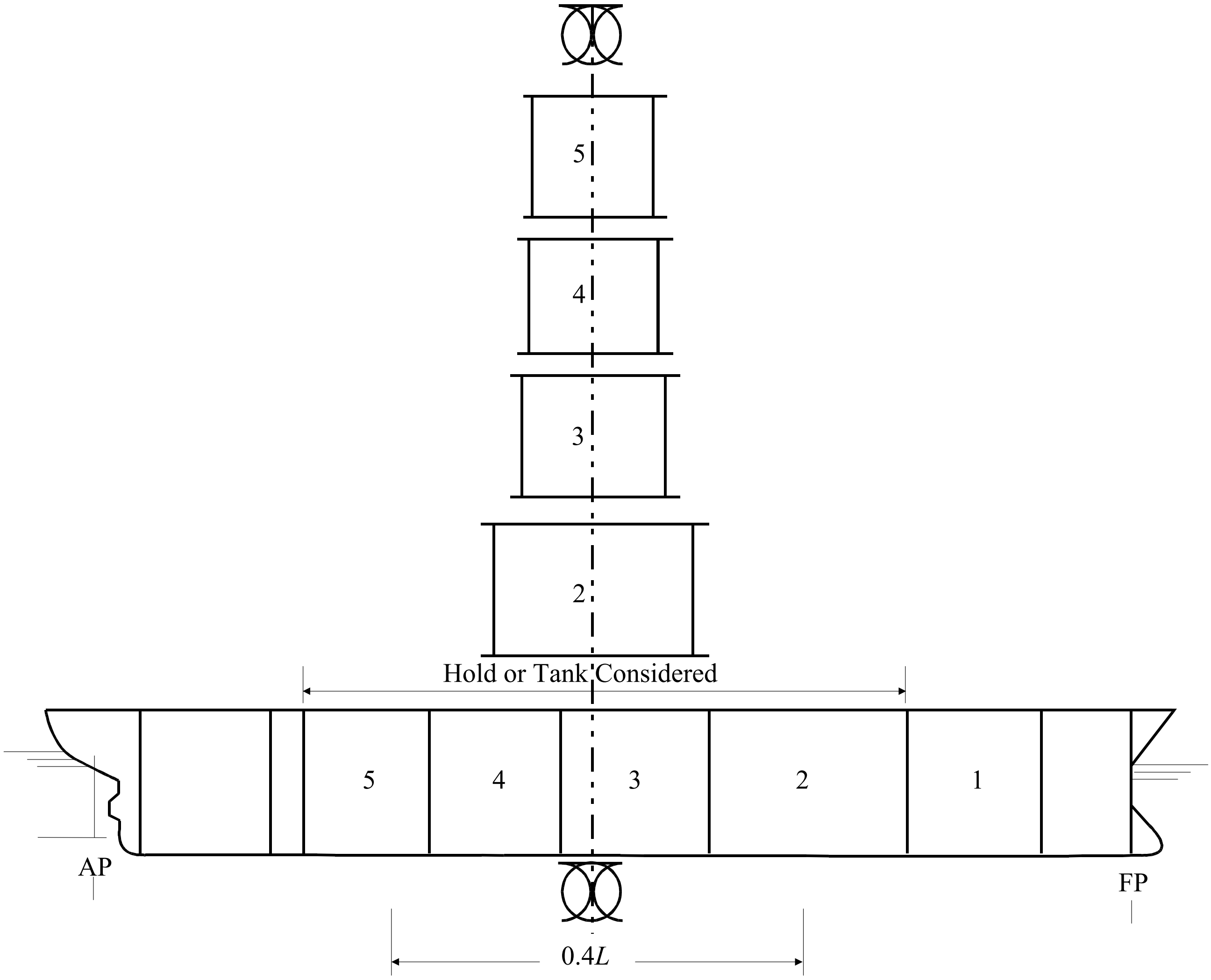


TABLE 3
Design Pressure for Local and Supporting Members *(2003)*

A. Local Structures—Plating & Long'ls/Stiffeners.

The nominal pressure, $p = |p_i - p_e|$, is to be determined from load cases "a" & "b" below, whichever is greater, with k_u = 1.1 and k_c = 1.0, unless otherwise specified in the table.

	Case "a" *At Forward end of the tank or hold*				*Case "b"* *At Mid-Tank/Forward end of tank or hold*			
Structural Members/ Components	Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients		Draft/Wave Heading Angle	Location and LoadingPattern	Coefficients	
			p_i	p_e			p_i	p_e
1. Bottom Plating and Long'l	2/3 scantling draft/0°	Full double bottom ballast tank	A_{ti}	A_e	Scantling draft/0°	Midtank of empty double bottom ballast tanks	—	B_e
2. Inner Bottom Plating & Long'l (dry cargo holds)	2/3 scantling draft/0°	Full double bottom ballast tank cargo holds empty	A_{ti}	—	Scantling draft/0°	Fwd end of full cargo hold, ballast tanks empty	A_{bi}	—
Inner Bottom Plating & Long'l (ballast or liquid cargo holds)	2/3 scantling draft/0°	Full ballast hold, double bottom ballast tanks empty	A_{ti}	—				
3. Side Shell Plating & Long'l	2/3 scantling draft/60°	Starboard side of full ballast tank	B_{ti}	A_e	Scantling draft/60°	Midtank of empty ballast tanks	—	B_e
Side Shell Plating (ballast or liquid cargo holds)	2/3 scantling draft/60°	Starboard side of full ballast or liquid cargo holds, adjacent tanks empty	B_{ti}	—				
4. Hold Frame (dry cargo holds)	Scantling draft/0°	Empty cargo hold	—	B_e	2/3 scantling draft/0°	Empty cargo hold	—	B_e
Hold Frame (ballast or liquid cargo holds)	2/3 scantling draft/60°	Starboard side of full ballast or liquid cargo holds	B_{ti}	A_e				
5. Side Frame in double hull side spaces (void)	Scantling draft/0°	Empty cargo hold	—	B_e	2/3 scantling draft/0°	Empty cargo hold	—	B_e
Side Frame in double hull side spaces (ballast tank)	2/3 scantling draft/60°	Starboard side of full ballast	B_{ti}	A_e				
6. Deck Plating & Long'l (ballast tank)	2/3 scantling draft/0°	Full ballast tank	C_{ti}	—				
Cross Deck Structure (ballast hold)	2/3 scantling draft/0°	Full ballast hold	C_{ti}	—				
7. Lower Wing Tank Sloping Bulkhead Plating & Long'l (dry cargo holds)	Scantling draft/60°	Full cargo hold, ballast tanks empty	B_{bi}	—	2/3 scantling draft/60°	Fwd end and full port and starboard ballast tanks cargo hold empty	B_{ti}	—
Lower Wing Tank Sloping Bulkhead Plating & Long'l (ballast or liquid cargo holds)	2/3 scantling draft/60°	Starboard side of full ballast or liquid cargo holds, adjacent tanks empty	B_{ti}	—				

TABLE 3 (continued)
Design Pressure for Local and Supporting Members *(2003)*

A. Local Structures—Plating & Long'ls/Stiffeners.

The nominal pressure, $p = |p_i - p_e|$, is to be determined from load cases "a"& "b" below, whichever is greater, with k_u = 1.1 and k_c = 1.0, unless otherwise specified in the table

	Case "a" At Forward end of the tank or hold				*Case "b" At Mid-Tank/Forward end of tank or hold*			
Structural Members/ Components	Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients		Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients	
			p_i	p_e			p_i	p_e
8. Upper Wing Tank Sloping Bulkhead Plating & Long'l (dry cargo holds)	2/3 scantling draft/60°	Starboard side of full ballast tanks, cargo hold empty	B_{ti}	—	2/3 scantling draft/60°	Port side of full ballast tanks, cargo hold empty	B_{ti}	—
Upper Wing Tank Sloping Bulkhead Plating & Long'l (ballast or liquid cargo holds)	2/3 scantling draft/60°	Starboard side of full ballast or liquid cargo holds, adjacent tanks empty	B_{ti}	—				
9. All Other Long'l Bulkhead Plating (dry cargo holds)	Scantling draft/60°	Full cargo hold, ballast tanks or double hull void spaces empty	B_{bi}	—	2/3 scantling draft/60°	Forward end and full port and starboard ballast tanks, double hull void spaces and cargo hold empty	B_{ti}	—
All Other Long'l Bulkhead Plating (ballast or liquid cargo holds)	2/3 scantling draft/0°	Starboard side of full ballast or liquid cargo holds, adjacent tanks or double hull void spaces empty	B_{ti}	—				
10. Transverse Bulkhead Plating & Stiffeners (dry cargo holds)	2/3 scantling draft/0°	Forward bulkhead of full cargo hold, adjacent holds empty	A_{bi}	—	Flooded Condition (see note 7)			
Transverse Bulkhead Plating & Stiffeners (ballast or liquid cargo holds)	2/3 scantling draft/60°	B/4 off vessel's centerline of full ballast hold, adjacent holds empty	B_{ti}	—				
Transverse Bulkhead Plating & Stiffeners (all other tanks)	2/3 scantling draft/0°	Forward bulkhead of full ballast tank, adjacent tanks empty	A_{ti}	—				

TABLE 3 (continued)
Design Pressure for Local and Supporting Members *(2003)*

B. Main Supporting Members

The nominal pressure, $p = |p_i - p_e|$, is to be determined at the mid span of the structural members at starboard side of vessel from load cases "a"& "b" below, whichever is greater, with k_u = 1.0 and k_c = 1.0, unless otherwise specified in the table.

	Case "a" At Mid-tank or Mid-hold for Transverses				*Case "b" At Mid-tank or Mid-hold for Transverses*			
Structural Members/ Components	Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients		Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients	
			p_i	p_e			p_i	p_e
11. Double Bottom Floor & Girder	2/3 scantling draft/0°	Full cargo hold, ballast tanks empty	A_{bi}	A_e	Scantling draft/90°	Mid-tank, cargo holds and ballast tanks empty	—	B_e
12. Bottom Transverse in Lower Wing Tank	2/3 scantling draft/0°	Full lower wing tank	A_{ti}	A_e	Scantling draft/90°	Empty lower wing tank	—	B_e
13. Side Transverse in Lower Wing Tank	2/3 scantling draft/60°	Full lower wing tank	B_{ti}	A_e	Scantling draft/90°	Empty lower wing tank	—	B_e
14. Side Transverse in Upper Wing Tank	2/3 scantling draft/60°	Full upper wing tank	B_{ti}	—	Scantling draft/90°	Empty upper wing tank	—	B_e
15. Deck Transverse in Upper Wing Tank	2/3 scantling draft/60°	Full upper wing tank	B_{ti}	—				
16. Sloping Bulkhead Transverse in Lower wing Tank (dry cargo holds)	Scantling draft/60°	Full cargo hold, lower wing tank empty	B_{bi}	—	2/3 scantling draft/60°	Full lower wing tank, cargo hold empty	B_{ti}	—
Sloping Bulkhead Transverse in Lower wing Tank (ballast and liquid cargo holds)	2/3 scantling draft/60°	Full ballast or liquid cargo holds, lower wing tank empty	B_{ti}	—				
17. Sloping Bulkhead Transverse in Upper Wing Tank (dry cargo holds)	2/3 scantling draft/60°	Full upper wing tank	B_{ti}	—				
Sloping Bulkhead Transverse in Upper Wing Tank (ballast or liquid cargo holds)	2/3 scantling draft/60°	Full hold with ballast or liquid cargo, upper wing tank empty	B_{ti}	—				
18. Horizontal Girder and Vertical Web on Transverse Bulkhead (dry cargo holds)	2/3 scantling draft/0°	Forward bulkhead of full cargo hold, adjacent holds empty	A_{bi}	—	2/3 scantling draft/0°	Aft bulkhead of full cargo hold, adjacent holds empty	C_{bi}	—
Horizontal Girder and Vertical Web on Transverse Bulkhead (ballast or liquid cargo holds and fore peak tank)	2/3 scantling draft/60°	Forward bulkhead of full ballast hold, adjacent holds empty	B_{ti}	—	2/3 scantling draft/60°	Aft bulkhead of full forepeak tank, adjacent hold empty	D_{ti}	—

TABLE 3 (continued) Design Pressure for Local and Supporting Members *(2003)*

B. Main Supporting Members

The nominal pressure, $p = |p_i - p_e|$, is to be determined at the mid span of the structural members at starboard side of vessel from load cases "a"& "b" below, whichever is greater, with $k_u = 1.0$ and $k_c = 1.0$, unless otherwise specified in the table.

	Case "a" At Mid-tank or Mid-hold for Transverses				*Case "b" At Mid-tank or Mid-hold for Transverses*			
Structural Members/ Components	Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients		Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients	
			p_i	p_e			p_i	p_e
19. Diaphragms and Stringers in double hull side tanks or void spaces (dry cargo holds)	Scantling draft/0°	Empty cargo hold, double hull side tanks or void spaces empty	—	B_e	Scantling draft/0°	Empty cargo hold, double hull side tanks or void spaces empty	—	B_e
Diaphragms and Stringers in double hull side tanks or void spaces (ballast or liquid cargo holds)	2/3 scantling draft/60°	Starboard side of full ballast or liquid cargo holds, double hull side tanks full	B_{ti}	A_e				
20. Deck Girder and Hatch-End Beam	2/3 scantling draft/60°	Full hold with ballast or liquid cargo	B_{ti}	—				

Notes:

1 For calculating p_i and p_e, the necessary coefficients are to be determined based on the following designated groups:

a) For p_{ti} (ballast or liquid cargo pressure):

A_{ti}: $w_v = 0.75$, w_ℓ(forward bulkhead) = 0.25, w_ℓ(aft bulkhead) = –0.25, $w_t = 0.0$, $C_\phi = -1.0$, $C_\theta = 0.0$

B_{ti}: $w_v = 0.4$, w_ℓ(forward bulkhead) = 0.2, w_ℓ(aft bulkhead) = –0.2, w_t(starboard) = 0.4, w_t(port) = –0.4, $C_\phi = -0.7$, $C_\theta = 0.7$

C_{ti}: $w_v = -0.75$, w_ℓ(forward bulkhead) = 0.25, $w_t = 0.0$, $C_\phi = -1.0$, $C_\theta = 0.0$

D_{ti}: $w_v = 0.4$, w_ℓ(forward bulkhead) = –0.2, w_ℓ(aft bulkhead) = 0.2, w_t(starboard) = 0.4, w_t(port) = –0.4, $C_\phi = 0.7$, $C_\theta = 0.7$

b) For p_{bi} (dry cargo pressure):

A_{bi}: $c_V = 0.8$, c_L(forward bulkhead) = 0.6, c_L(aft bulkhead) = –0.6, $c_T = 0$, $C_\phi = -1.0$, $C_\theta = 0.0$

B_{bi}: $c_V = 0.7$, c_L(forward bulkhead) = 0.7, c_L(aft bulkhead) = –0.7, c_T(starboard) = 0.7, c_T(port) = –0.7, $C_\phi = -0.7$, $C_\theta = 0.7$

C_{bi}: $c_V = 0.8$, c_L(forward bulkhead) = –0.6, c_L(aft bulkhead) = 0.6, $c_T = 0$, $C_\phi = 1.0$, $C_\theta = 0.0$

TABLE 3 (continued)
Design Pressure for Local and Supporting Members *(2003)*

c) For p_e:

A_e: $k_{\ell o} = 1.0$, $k_u = 1.0$, $k_c = -0.5$

B_e: $k_{\ell o} = 1.0$

2 *(1997)* For structures within 0.4L amidships, the nominal pressure is to be calculated for a hold located amidships. Each cargo hold or ballast hold in the region should be considered as located amidships as shown in 5C-3-3/Figure 13.

3 For structures outside 0.4L amidships, the nominal pressure is to be calculated for members in a tank under consideration.

4 In calculation of the nominal pressure, ρg of the liquid or ballast is not to be taken less than 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf/in^2-ft)

5 The cargo specific weight of dry cargoes is defined as cargo weight divided by hold volumes for each cargo hold. In calculation of the nominal pressure, ρg of bulk cargo and ore cargo is not to be taken less than 0.9807 N/cm^2-m (0.1 kgf/cm^2-m, 0.4336 lbf/in^2-ft) and 1.471 N/cm^2-m (0.15 kgf/cm^2-m, 0.6503 lbf/in^2-ft), respectively.

6 Dry cargoes are to be considered to be stored up to the level of the upper deck at centerline. The design angle of repose of bulk and ore cargoes may be taken as 30 degrees, unless otherwise specified by designers.

7 *(1 July 1998)* The nominal pressure in the flooded holds may be approximated by taking 70% of the nominal ballast pressure as specified for transverse bulkhead plating and stiffeners (ballast or liquid cargo holds), except for single or double side skin vessels intended to carry solid bulk cargoes having a density of 1.0 t/m^3 (62.4 lb/ft^3) or above. For these vessels, the flooding loads and the strength assessment are to be carried out in accordance with 5C-3-A5b/1.

8 Where cargo is carried on deck, the nominal pressure of deck structures is not to be taken less than the specified cargo pressure.

9 Combined Load Cases *(1996)*

9.1 Combined Load Cases for Structural Analysis *(1996)*

For assessing the strength of the hull girder structures and in performing a structural analysis as outlined in Section 5C-3-5, the ten combined load cases specified in 5C-3-3/Table 1 are to be considered. 5C-3-5/9.9 specifies the load cases to be investigated in assessing the adequacy of structure in each designated hold. Additional combined load cases may be required as warranted. The loading patterns are shown in 5C-3-3/Figure 1 for three cargo hold lengths. The necessary factors and coefficients for calculating hull girder and local loads are given in 5C-3-3/Table 1. The total external pressure distribution including static and hydrodynamic pressure is illustrated in 5C-3-3/Figure 14.

9.3 Combined Load Cases for Total Strength Assessment *(1996)*

For assessing the failure modes with respect to material yielding, buckling and ultimate strength, the following combined load cases shall be considered.

9.3.1 Ultimate Strength of Hull Girder

For assessing ultimate strength of the hull girder, the combined effects of the following primary and local loads are to be considered.

9.3.1(a) Primary Loads, Longitudinal Bending Moments and Shear Forces in Head Sea Conditions

$(M_H = 0, F_H = 0, T_M = 0)$

$M_t = M_{sw} + k_u k_c M_w$, $k_c = 1.0$ hogging and sagging

$F_t = F_{sw} + k_u k_c F_w$, $k_c = 1.0$ positive and negative

where

k_u = 1.15. For vessels with heavy ballast draft forward less than $0.04L$ or with flare parameter A_r exceeding 21 m (68.9 ft), k_u is to be increased as may be required by 5C-3-3-/11.1.3 or 5C-3-3/11.3.3, whichever is greater

M_{sw}, M_w, F_{sw} and F_w are as defined in 3-2-1/3.

A_r is as defined in 5C-3-3/11.3.3.

9.3.1(b) Local Loads for Large Stiffened Panels. Internal and external pressure loads as given in Note 1 of 5C-3-3/Table 3 are to be considered.

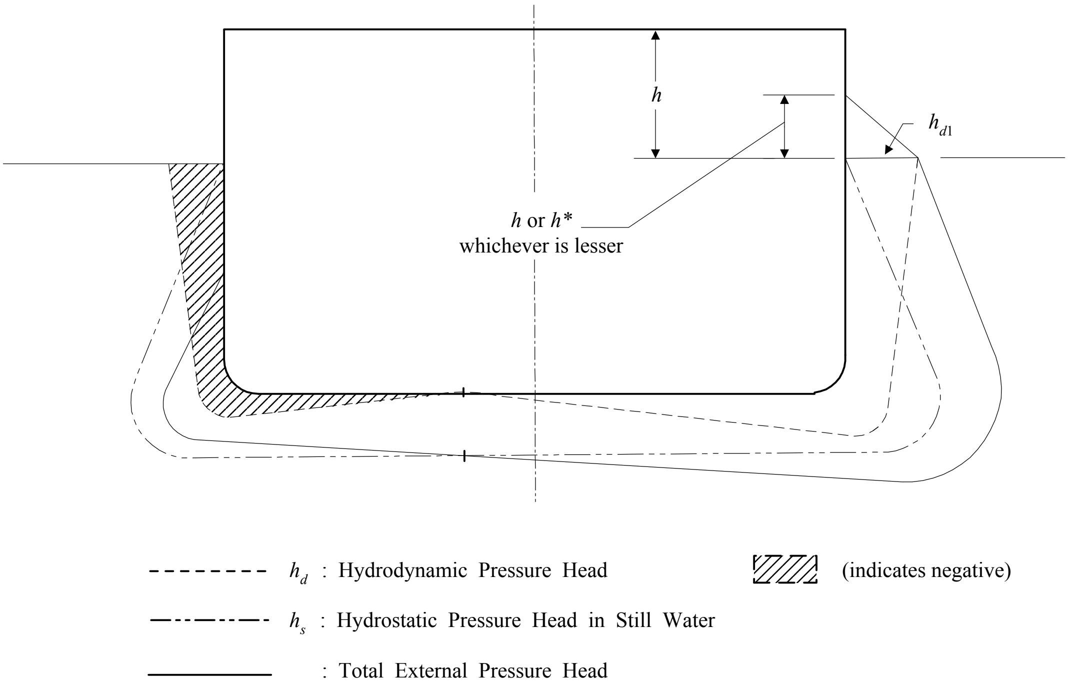
9.3.2 Yielding, Buckling and Ultimate Strength of Local Structures

For assessing the yielding, buckling and ultimate strength of local structure, the ten combined load cases as given in 5C-3-3/Table 1 are to be considered.

9.3.3 Fatigue Strength

For assessing the fatigue strength of structural joints, the ten combined load cases given in 5C-3-3/9.1 are to be used for a first level fatigue strength assessment as outlined in Appendix 5C-3-A1 "Guide for the Fatigue Assessment of Bulk Carriers."

FIGURE 14
Illustration of Determining Total External Pressure *(1996)*



Note: $h^* = k_u k_c h_{d1}$ for nominal pressure
$h^* = k_f k_u h_{d1}$ for simultaneous pressure

11 Impact Loads *(1996)*

11.1 Bottom Slamming

For bulk carriers with a heavy ballast draft forward less than 0.04L but greater than 0.025L, bottom slamming loads are to be considered for assessing strength of the flat of bottom plating forward and the associated stiffening system in the fore body region. For this assessment, the heavy ballast draft forward may be determined with one cargo hold, adapted for carriage of water ballast at sea, full. In addition, the effects of the slamming loads on the hull girder bending moments are also to be considered for assessing strength of the fore body structures

11.1.1 Bottom Slamming Pressure *(2001)*

The equivalent bottom slamming pressure for strength formulation and assessment should be determined based on well-documented experimental data or analytical studies. When these direct calculations are not available, nominal bottom slamming pressures may be determined by the following equations:

$$P_{si} = kk_i\,[v_o^2 + M_{Vi}E_{ni}]E_f \qquad \text{kN/m}^2\ (\text{tf/m}^2,\ \text{Ltf/ft}^2)$$

where

P_{si} = equivalent bottom slamming pressure for section i

k = 1.025 (0.1045, 0.000888)

k_i = $2.2\, b^*/d_o + \alpha \leq 40$

b^* = half width of flat of bottom at the i-th ship station, see 5C-3-3/Figure 15

d_o = $^1/_{10}$ of the section draft at the heavy ballast condition, see 5C-3-3/Figure 15

α = a constant as given in 5C-3-3/Table 4

where b represents the half breadth at the $^1/_{10}$ draft of the section, see 5C-3-3/Figure 15. Linear interpolation may be used for intermediate values.

E_f = $f_1\, \omega_1\, (L)^{1/2}$, ω_1 is defined in 5C-3-3/11.1.3

f_1 = 0.004 (0.0022) for m (ft)

E_f need not be taken greater than $0.1(11 - 0.01L)^{1/2}$ for SI or MKS Units $[0.0175(360 - 0.1L)^{1/2}$ for U.S. Units].

V = 75% of the design speed V_d in knots. V is not to be taken less than 10 knots.

v_o = $c_o(L)^{1/2}$, in m/s (ft/s)

c_o = 0.29 (0.525) for m (ft)

L = vessel length, as defined in 3-1-1/3.1

M_{Ri} = $c_1 A_i (VL/C_b)^{1/2}$

c_1 = 0.44 (2.615) for m (ft)

M_{Vi} = $B_i M_{Ri}$

A_i and B_i are as given in 5C-3-3/Table 2.

G_{ei} = $e^{[-(v_o^2/M_{Vi} + d_i^2/M_{Ri})]}$

d_i = local section draft, in m (ft)

E_{ni} = natural log of n_i

n_i = $5730(M_{Vi}/M_{Ri})^{1/2}\, G_{ei}$, if $n_i < 1$ then $P_{si} = 0$

TABLE 4
Values of α

b/d_o	α	b/d_o	α
1.00	0.00	4.00	20.25
1.50	9.00	5.00	22.00
2.00	11.75	6.00	23.75
2.50	14.25	7.00	24.50
3.00	16.50	7.50	24.75
3.50	18.50	25.0	24.75

11.1.2 Simultaneous Slamming Pressures

For performing structural analyses to determine overall responses of bottom structures of the first two cargo holds from the FP, the spatial distributions of instantaneous bottom slamming pressures on the forward bottom region are shown in 5C-3-3/Figure 15 and 5C-3-3/Figure 16. The instantaneous girth-wise distribution at station *i*, as shown in 5C-3-3/Figure 15, may be assumed to be uniformly distributed over the flat portion of the bottom structures. The largest value of P_{si}, determined within the bound of each of the two cargo holds, is to be used as the respective peak value of the bottom pressure distribution in the longitudinal direction, 5C-3-3/Figure 16, for each cargo hold. This peak value may cover 0.01L portion of the ship bottom and it may be placed at the mid-section of the cargo hold considered. The base of this distribution may cover 0.15L of the ship bottom on either side of this mid-section of the cargo hold, but need not go beyond 0.05L aft of the FP.

11.1.3 Effects of Bottom Slamming on Vertical Hull Girder Bending Moment

In addition to the effects of bottom slamming on the bottom structures, the vibratory responses induced by bottom slamming on the hull girder in terms of vertical bending moment are also to be considered in the strength assessment as given below.

The load factor, k_u, for hull girder ultimate strength assessment in association with wave induced hogging moment is not to be less than 1.15 or the following, whichever is greater.

$$k_u = (1 + M_{si}^2 / M_{wi}^2)^{1/2}$$

where

M_{wi}	=	wave induced hogging bending moment, as specified in 3-2-1/3.5.1, for ship station *i*.
M_{si}	=	$k\,\Gamma_i \times 10^8\,[b/(\omega_1 d_m)]^3\,[F_n/L^4] \times M_{w10}$. Bottom slamming induced vertical bending moment of ship station *i* – station 10 being the midship, and station 0, the FP.
k	=	1.0 (115.74) for m (ft)
Γ_i	=	envelope curve factors: 2.05, 2.50, 2.35, 2.21, 1.84, 1.84, 2.16, 1.56, corresponding to ship stations at 0.2, 0.3, 0.35, 0.4, 0.5, 0.6, 0.7 and 0.8 L, respectively, measured from the FP. Linear interpolation may be used for intermediate values.
b	=	average value of the half breadths at the $^1/_{10}$ draft of the 6 forward stations, starting from station 0, the FP, to station 5, the forward quarter length of the vessel.
d_m	=	average value of $^1/_{10}$ drafts at the heavy ballast condition of 6 forward stations, starting from station 0, the FP, to station 5, the quarter length of the vessel.
F_n	=	0.514 $V_d/(gL)^{1/2}$ for SI and MKS units (1.688 $V_d/(gL)^{1/2}$ for US units), V_d is the design speed in knots, g is the acceleration due to gravity (9.807 m/sec^2, 32.2 ft/sec^2). F_n need not be taken greater than 0.17.
ω_1	=	natural angular frequency of the hull girder 2-node vertical vibration of the vessel in the wet mode and the heavy ballast draft condition, in rad/second. If not known, the following equation may be used.
	=	$\mu[B\,D^3/(\Delta_S C_b^3 L^3)]^{1/2} + c_o \quad \geq 3.7$

where

μ = 23400 (7475, 4094)

Δ_S = $\Delta_b[1.2 + B/(3d_b)]$

Δ_b = vessel displacement at the heavy ballast condition, in kN (tf, Ltf)

d_b = mean draft of vessel at the heavy ballast condition, in m (ft)

c_o = 1.0 for heavy ballast draft

L, *B* and *D* are as defined in Section 3-1-1.

C_b is as defined in 3-2-1/3.5.1.

For vessels with conventional ship forms and cargo hold arrangements, and a forward draft less than 0.04*L* but greater than or equal to 0.03*L*, k_u may be approximated from the envelope curves given in 5C-3-3/Figure 17. Linear interpolation may be used for determining intermediate values.

11.3 Bowflare Slamming

For vessels possessing bowflare and having a shape parameter A_r (defined in 5C-3-3/11.3.3) greater than 21 m (68.9 ft) in the forebody region, bowflare slamming loads are to be considered for assessing the strength of the side plating and the associated stiffening system in the forebody region of the vessel at its scantling draft.

11.3.1 Nominal Bowflare Slamming *(1 July 2008)*

When experimental data or direct calculation is not available, nominal bowflare slamming pressures may be determined by the following equations:

$P_{ij} = P_{oij}$ or P_{bij} as defined below, whichever is greater

$P_{oij} = k_1(9M_{Ri} - h_{ij}^2)^{1/2}$ kN/m² (tf/m², Ltf/ft²)

$P_{bij} = k_2\, k_3\{C_2 + K_{ij}M_{Vi}[1 + E_{ni}]\}$ kN/m² (tf/m², Ltf/ft²)

where

k_1 = 9.807 (1, 0.0278)

k_2 = 1.025 (0.1045, 0.000888)

k_3 = 1 for $h_{ij} \le h_b^*$

= $1 + (h_{ij}/h_b^* - 1)^2$ for $h_b^* < h_{ij} < 2h_b^*$

= 2 for $h_{ij} \ge 2h_b^*$

h_{ij} = vertical distance measured from the load waterline (*LWL*) at station *i* to WL_j on the bowflare. The value of h_{ij} is not to be taken less than h_b^*. P_{bij} at a location between *LWL* and h_b^* above *LWL* need not be taken greater than p_{bij}^*.

h_b^* = $0.005(L - 130) + 3.0$ (m) for $L < 230$ m

= $0.005(L - 426.4) + 9.84$ (ft) for $L < 754$ ft

= $7.143 \times 10^{-3}(L - 230) + 3.5$ (m) for 230 m $\le L <$ 300 m

= $7.143 \times 10^{-3}(L - 754.4) + 11.48$ (ft) for 754 ft $\le L <$ 984 ft

= 4.0 m (13.12 ft) for $L \ge$ 300 m (984 ft)

p^*_{bij} = $P^*_{bi}\sqrt{\beta^*_i/\beta'_{ij}}$

P^*_{bi} = P_{bij} at h^*_b above LWL

C_2 = 39.2 (422.46) for m (ft)

n_{ij} = $5730(M_{Vi}/M_{Ri})^{1/2}\,G_{ij} \geq 1.0$

E_{ni} = natural log of n_{ij}

G_{ij} = $e^{(-h^2_{ij}/M_{Ri})}$

M_{Ri} = see 5C-3-3/11.1.1

M_{Vi} = B_iM_{Ri}, where B_i is given in 5C-3-3/Table 2.

K_{ij} = $f_{ij}\,[r_j/(bb_{ij} + 0.5h_{ij})]^{3/2}\,[\ell_{ij}/r_j]\,[1.09 + 0.029V - 0.47C_b]^2$

r_j = $(M_{Ri})^{1/2}$

bb_{ij} = $b_{ij} - b_{i0} > 2.0$ m (6.56 ft)

b_{ij} = local half beam of WL_j at station i. The value of b_{ij} is not to be taken less than 2.0 (6.56) m (ft).

b_{i0} = load waterline half beam at station i

ℓ_{ij} = longitudinal distance of WL_j at station i measured from amidships.

f_{ij} = $[90/\beta'_{ij} - 1]^2\,[\tan^2(\beta'_{ij})/9.86]\cos\gamma$

β'_{ij} = normal local body plan angle

= $\tan^{-1}[\tan(\beta_{ij})/\cos(\alpha_{ij})]$

α_{ij} = waterline angle as in 5C-3-3/Figure 7

β_{ij} = local body plan angle measured from the horizontal, in degrees, need not be taken greater than 75 degrees, see 5C-3-3/Figure 18

β^*_i = β'_{ij} at h^*_b above LWL

V = as defined in 5C-3-3/11.1

L = as defined in 3-1-1/3.1, in m (ft)

C_b = as defined in 3-2-1/3.5.1 and not to be less than 0.6.

γ = ship stem angle at the centerline measured from the horizontal, 5C-3-3/Figure 19, in degrees, not to be taken greater than 75 degrees.

11.3.2 Simultaneous Bowflare Slamming Pressure

For performing structural analyses to determine overall responses of the hull structures, the spatial distribution of instantaneous bowflare slamming pressures on the fore body region of the hull may be expressed by multiplying the calculated maximum bowflare slamming pressures, P_{ij}, at forward ship stations by a factor of 0.71 for the region between the stem and 0.3L from the FP.

11.3.3 Effects of Bowflare Slamming on Vertical Hull Girder Bending Moment and Shear Force *(2002)*

The ultimate strength of the hull girder in the forward half-length is to be evaluated as follows.

The load factor, k_u, for hull girder ultimate strength assessment in association with wave induced sagging moment is not to be less than 1.15 or the following, whichever is greater.

$$k_u = k\{\alpha_i(\Delta\, B\, d/L^3)\, A_r\, F_n^{1/3}/\omega_1\}/|M_{wi}|$$

where

$|M_{wi}|$ = absolute value of the wave-induced bending moment at the station i, as specified in 3-2-1/3.5 for sagging conditions, where station 10 denotes the midship.

k = 9.81 (1.0, 3.28) for m (ft)

α_i = envelope curve factors: 9516, 19032, 28382, 32054, 32722, and 31387, corresponding to stations at 0.1, 0.2, 0.3, 0.35, 0.4, and 0.5L from the FP, respectively. Linear interpolation may be used for intermediate values.

Δ = vessel displacement at the scantling draft in kN (tf, Ltf)

F_n = $0.514\, V_d/(gL)^{1/2}$ for SI and MKS units (for US units, $1.688\, V_d/(gL)^{1/2}$), V_d is the design speed in knots, g is the acceleration due to gravity (9.807 m/sec^2, 32.2 ft/sec^2). F_n need not be taken greater than 0.17.

A_r = the maximum value of A_{ri} in the forebody region

A_{ri} = bowflare shape parameter at a station i forward of the quarter length, up to the FP of the vessel, to be determined between the LWL and the upper deck/forecastle, as follows:

$(b_T/H)^2\ \sum b_j[1 + (s_j/b_j)^2]^{1/2},\quad j = 1, n;\ n \geq 3$

where

n = number of segments

b_T = $\sum b_j$

H = $\sum s_j$

b_j = local change (increase) in beam for the j-th segment at station i (see 5C-3-3/Figure 18)

s_j = local change (increase) in freeboard up to the highest deck for the j-th segment at station i forward (see 5C-3-3/Figure 18)

ω_1 = natural frequency of the 2-node hull girder vibration of the vessel in the wet mode, in rad/second. If not known, the following equation may be used.

= $\mu[BD^3/(\Delta_s C_b{}^3 L^3)]^{1/2} + 0.7 \geq 3.7$

μ = 23400 (7475, 4094)

Δ_s = $\Delta[1.2 + B/(3d)]$

L, B and d are as defined in Section 3-1-1.

The load factor, k_u, for hull girder ultimate strength assessment in association with the positive wave-induced shear force is not to be less than 1.15 or the following, whichever is greater.

$$k_u = K_{si}N_4$$

where

F_{wi} = positive wave-induced shear force (see 3-2-1/3.5.3) at station i, where station 10 denotes the midship, kN (tf, Ltf)

N_4 = $[c_2(\Delta\, B\, d/L^4)\, A_r\, F_n^{1/3}\, /\omega_1]/F_{w4}$

= ratio of total wave-induced and wave-induced vertical shear force for ship station 4 or 0.2L from the FP.

c_2 = $9.8k \times 10^4$

K_{si} = shear envelope curve factor at station i

= 0.95 for station 2 and forward

= 1.0 for stations 3 to 6

= $1.05/N_4$ for station 10

Linear interpolation may be used for intermediate values.

For vessels with a shape parameter, A_r, less than or equal to 27 m (88.6 ft), the total wave induced vertical bending moments and shear forces may be determined from the envelope curves given in 5C-3-3/Figure 20 and 5C-3-3/Figure 21, respectively. Linear interpolation may be used for determining intermediate values.

11.5 Load Cases for Structural Analysis with Respect to Slamming

When structural analysis for bottom and bowflare slamming is preferable, the load cases given in Appendix 5C-3-A4 may be used as reference.

13 Other Loads *(1996)*

13.1 Thermal and Ice Loads

For vessels intended for special services such as carrying hot cargoes or navigating in cold regions, consideration is to be given to the effects of thermal and ice loads in assessing the strength of the hull structure.

In this case, the limits of the thermal and ice loads are to be furnished and analyzed by the designer.

13.3 Accidental Loads

It is advisable to give due consideration to the effects of possible accidental loads on the stiffening systems in the design of the main supporting members of the side and bottom shell structures. The pressures for flooded condition, as specified in 5C-3-4/25.7, for corrugated cargo hold bulkheads and nominal magnitudes of the accidental loads with respect to collision or grounding as outlined in the *Guide for Assessing Hull-girder Residual Strength* may be regarded as appropriate in this regard.

FIGURE 15
Distribution of Bottom Slamming Pressure Along the Section Girth *(1996)*

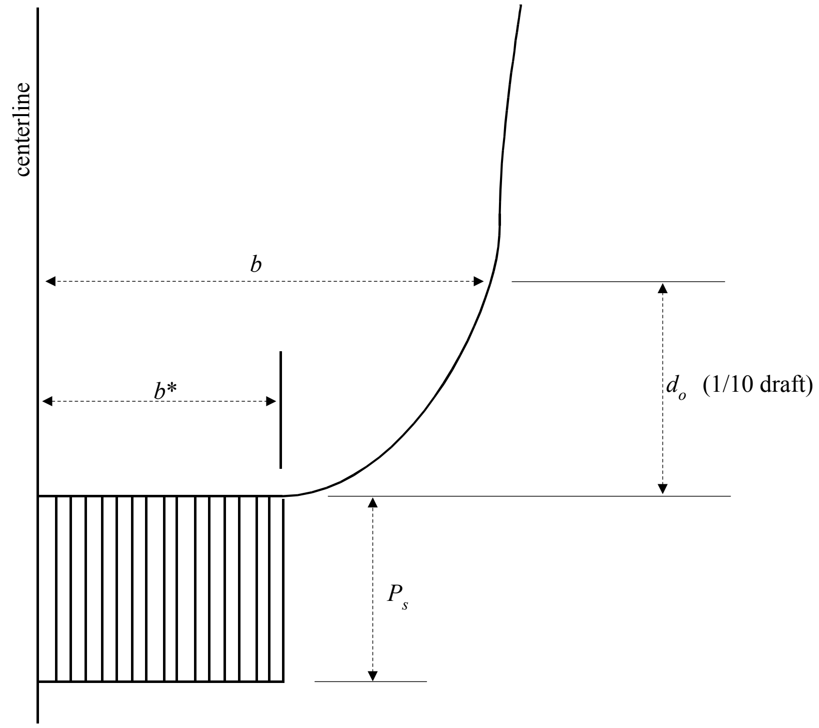


FIGURE 16
Distribution of Bottom Slamming Pressure Along the Ship Bottom *(1996)*

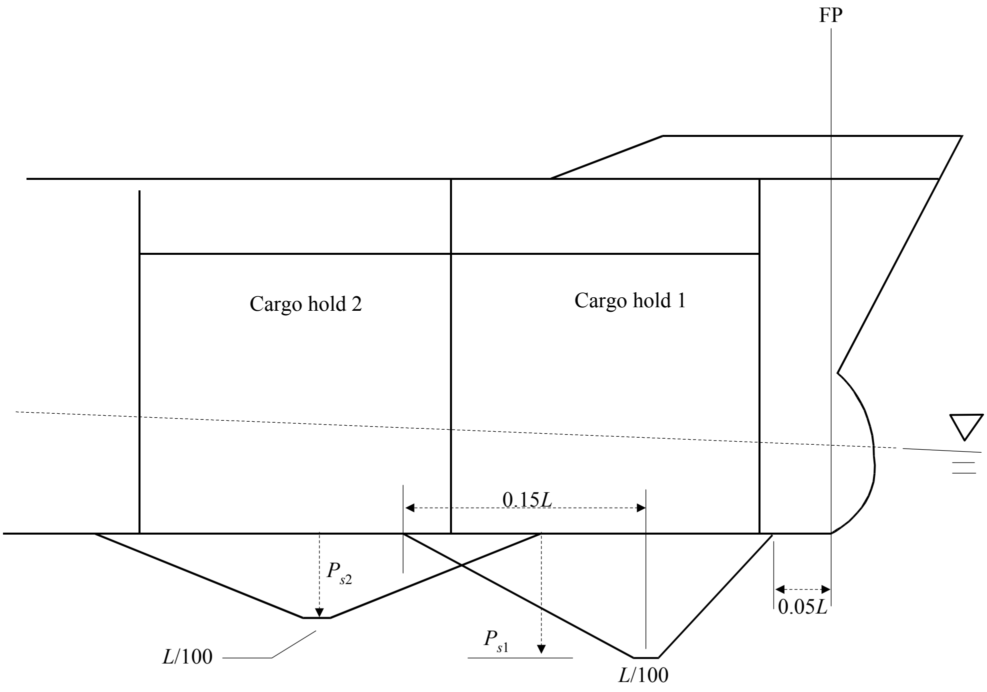


FIGURE 17
Total Vertical Bending Moment Distribution (Wave and Bottom Slamming) *(1996)*

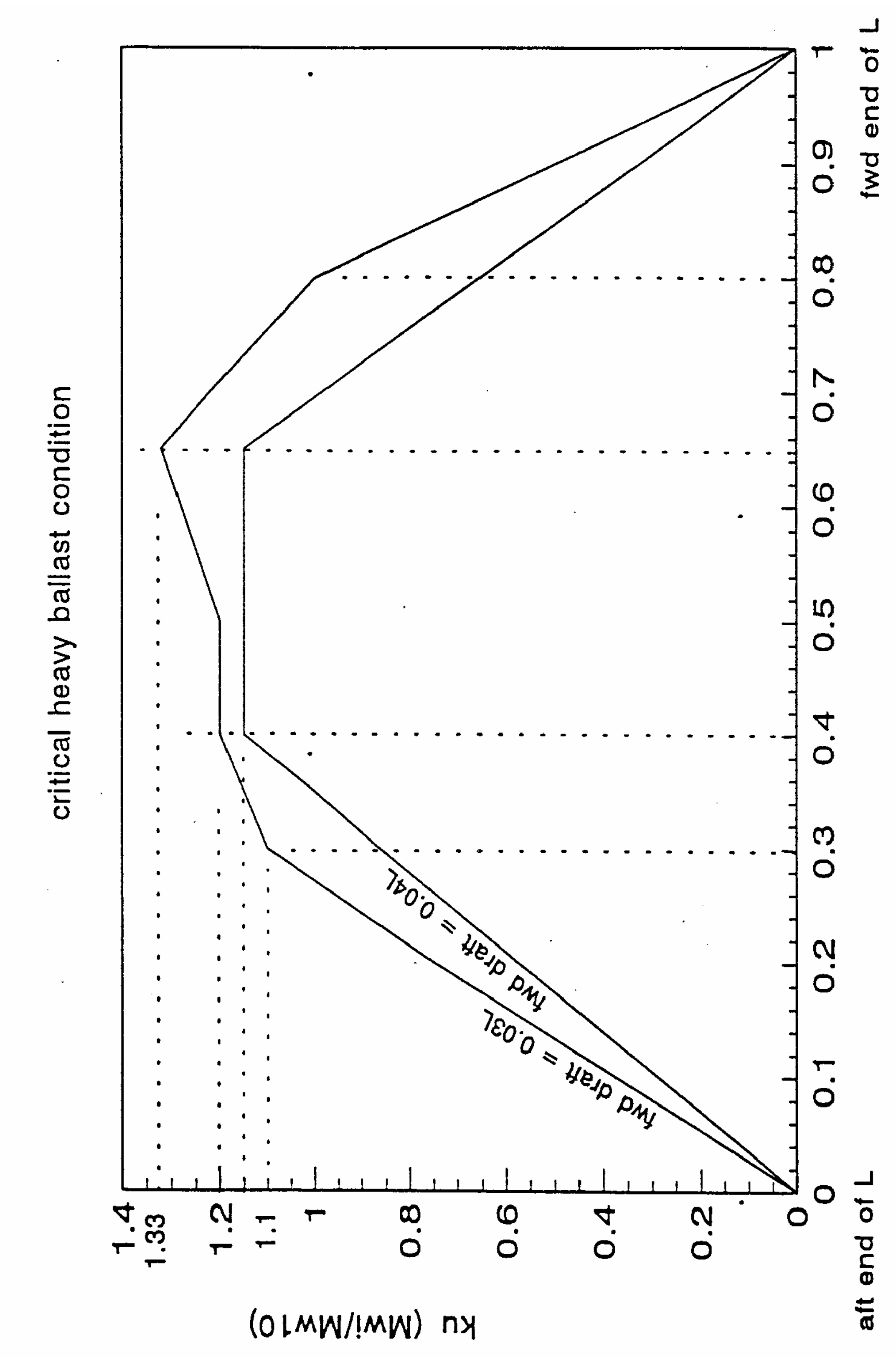


FIGURE 18
Definition of Bowflare Geometry for Bowflare Shape Parameter *(1996)*

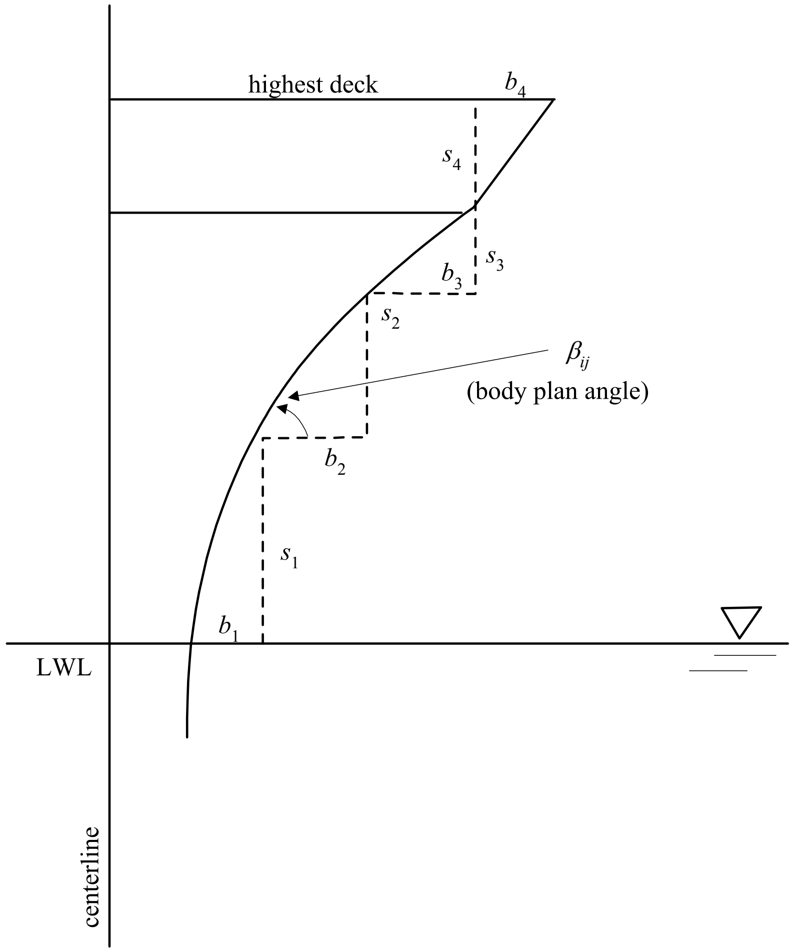


FIGURE 19
Ship Stem Angle, γ *(1996)*

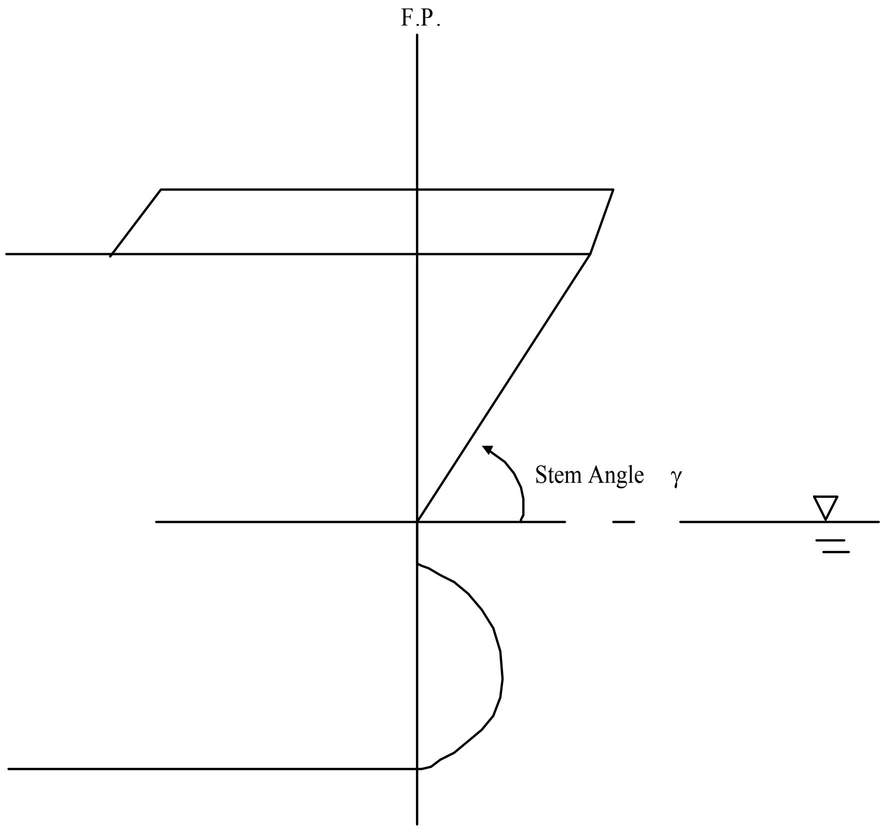


FIGURE 20
Total Vertical Bending Moment Distribution (Wave and Bowflare Slamming) *(1996)*

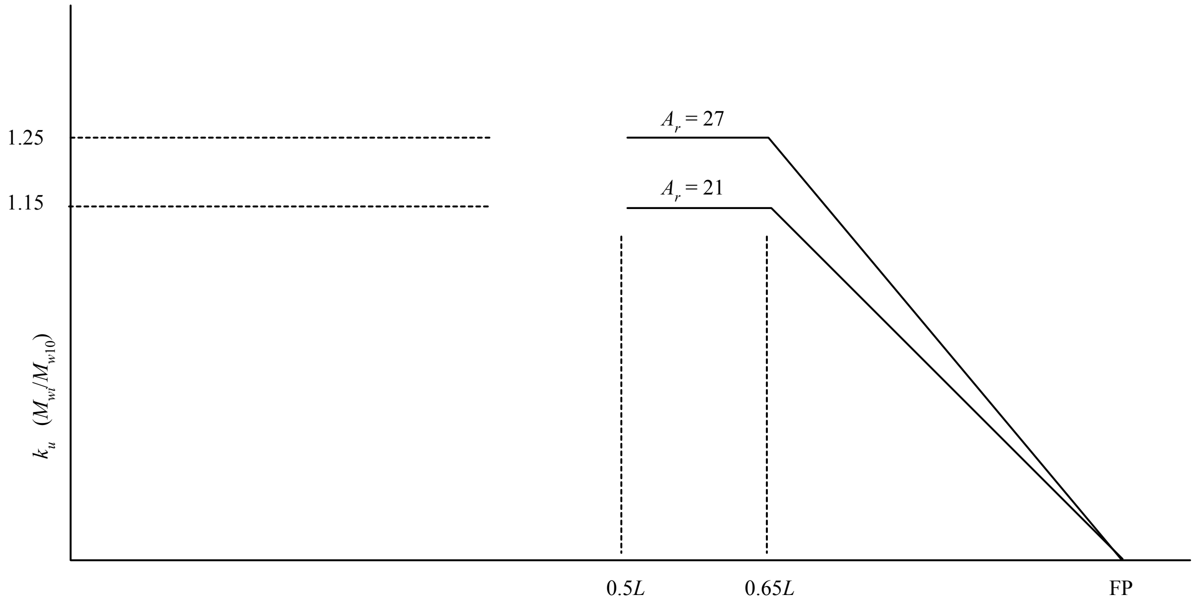
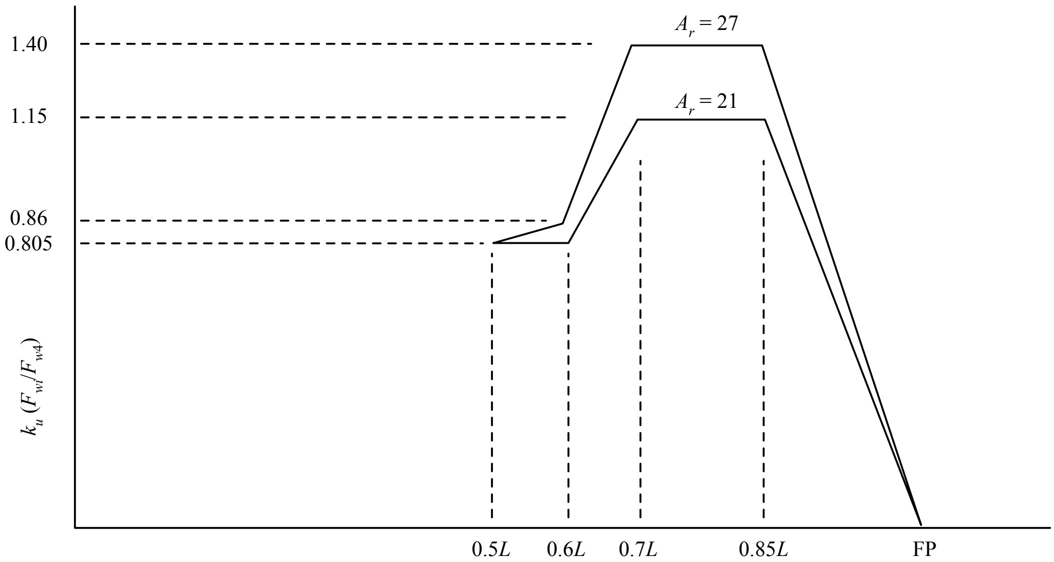


FIGURE 21
Total Vertical Shear Force Distribution (Wave and Bowflare Slamming) *(1996)*



PART

5C

CHAPTER 3 Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)

SECTION 4 Initial Scantling Criteria

1 General

1.1 Strength Requirement *(1996)*

This section specifies the minimum strength requirements for the hull structure with respect to the determination of the initial scantlings, including the hull girder, shell and bulkhead plating, frames/stiffeners and main supporting members. Once the minimum scantlings are determined, the strength of the resulting design is to be assessed in accordance with Section 5C-3-5. The assessment is to be carried out by means of an appropriate structural analysis as per 5C-3-5/9 in order to establish compliance with the failure criteria in 5C-3-5/3. Structural details are to comply with 5C-3-4/1.5 below.

The requirements for the hull girder strength are specified in 5C-3-4/3. The required scantlings of double bottom structures, side shell, deck, and longitudinal and transverse bulkheads are specified in 5C-3-4/7, 5C-3-4/9, 5C-3-4/15, 5C-3-4/21 and 5C-3-4/23, respectively. 5C-3-4/Figure 1 shows the appropriate subsections giving scantling requirements for the various structural components of typical bulk carriers. For hull structures beyond 0.4*L* amidships, the initial scantlings are determined in accordance with Section 5C-3-6.

In general, webs, girders and transverses are not to be less in depth than specified in 5C-3-4/9 and 5C-3-4/15 as a percentage of the span. Alternative designs with stiffness equivalent to the specified depth/length ratio and the required section modulus may be considered, provided that the calculated results are submitted for review.

For ore carriers and ore/oil carriers, the strength requirements are given in Appendix 5C-3-A3.

1.3 Calculation of Load Effects *(1996)*

Approximation equations are given in 5C-3-4/7 through 5C-3-4/25 and Section 5C-3-6 for calculating the maximum bending moments and shear forces for hold frames and main supporting members clear of the end brackets for typical structural arrangements and configurations. For designs with different structural configurations, these local load effects may be determined from a 3D structural analysis at the early design stages, as outlined in 5C-3-5/9 for the combined load cases specified in 5C-3-3/9, excluding the hull girder load components. In this regard, the detailed analysis results are to be submitted for review.

1.5 Structural Details *(1996)*

The strength criteria specified in 5C-3-4/3 through 5C-3-4/25 are based on assumptions that all structural joints and welded details are properly designed and fabricated and are compatible with the anticipated working stress levels at the locations considered. It is critical to closely examine the loading patterns, stress concentrations and potential failure modes of structural joints and details during the design of highly stressed regions. In this exercise, failure criteria specified in 5C-3-5/3 may be used to assess the adequacy of structural details.

To enhance the structural integrity and to prevent possible damage to the side shell, special consideration is to be given to the structural details in critical areas. These include the connections of the wing tanks, the hold frame and its end brackets to the side shell, also the connections of extended brackets for continuous longitudinal members and webs to the side shell in the transition zone between forepeak and No. 1 cargo hold as shown in 5C-3-6/Figure 5. Additional sample improvements are illustrated in 5C-3-4/Figure 2.

FIGURE 1
Scantling Requirement Reference by Subsection *(1996)*

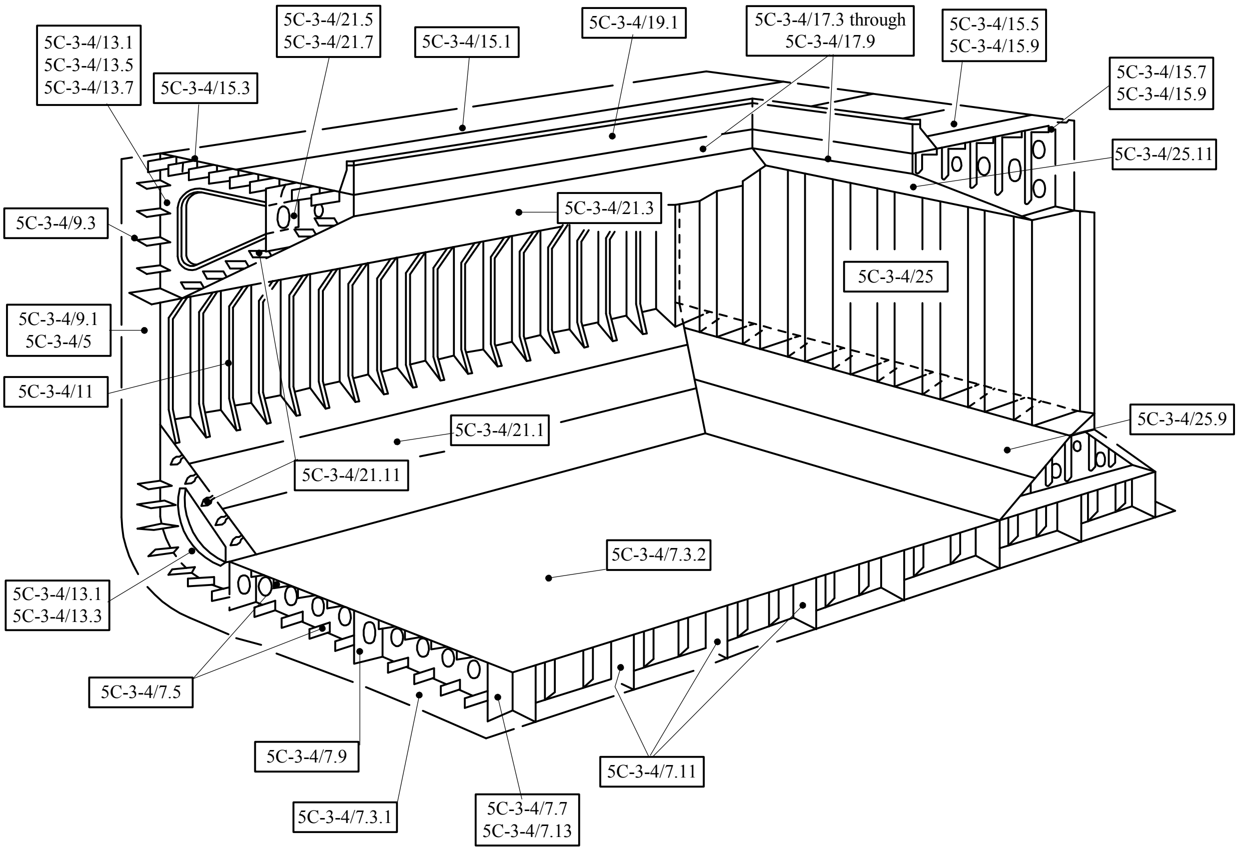
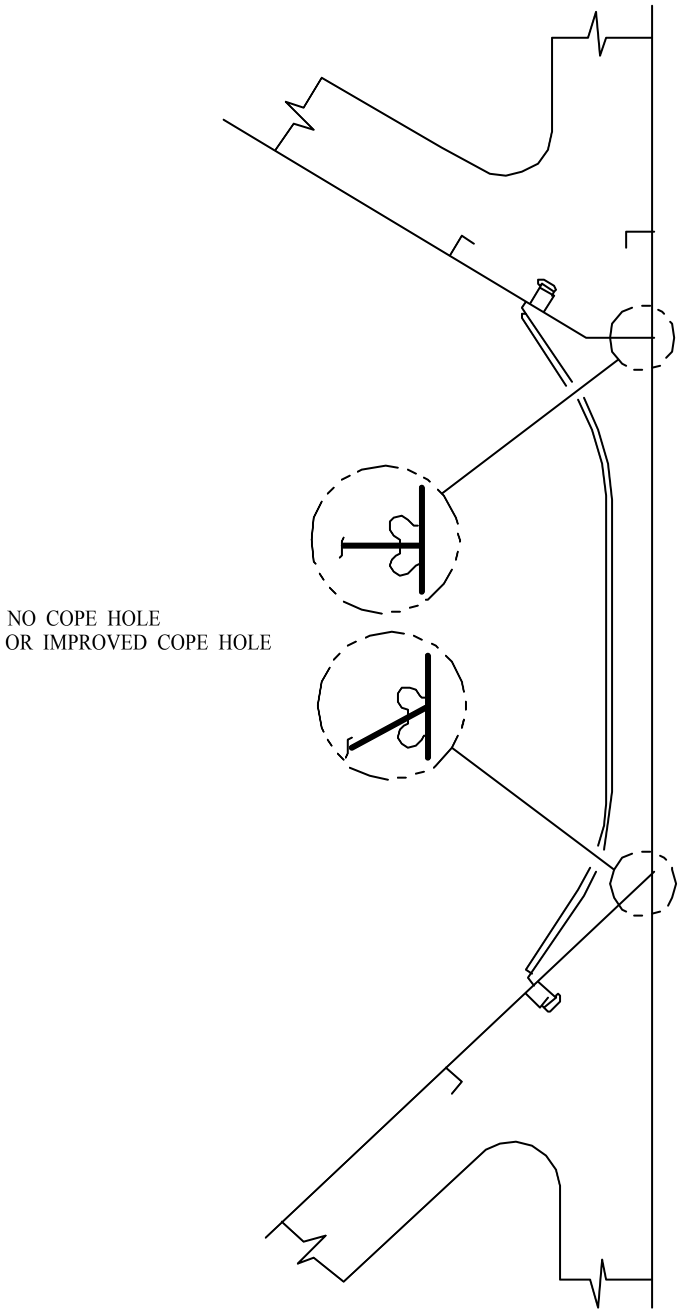


FIGURE 2
Improved Structural Connection to Side Shell



3 Hull Girder Strength

3.1 Hull Girder Section Modulus *(1996)*

3.1.1 Hull Girder Section Modulus Amidships

The required hull girder section modulus amidships is to be calculated in accordance with 3-2-1/3.7, 3-2-1/5 and 3-2-1/9. For the assessment of ultimate strength as specified in Section 5C-3-5 and the determination of initial net structural scantlings, the net hull girder section modulus amidships, SM_n, is to be calculated in accordance with 5C-3-4/3.1.2 below.

3.1.2 Effective Longitudinal Members

The hull girder section modulus calculation is to be carried out in accordance with 3-2-1/9, as modified below. To suit the strength criteria based on a "net" ship concept, the nominal design corrosion values specified in 5C-3-2/Table 1 are to be deducted in calculating the net section modulus, SM_n.

3.3 Hull Girder Moment of Inertia *(1996)*

The hull girder moment of inertia is to be not less than required by 3-2-1/3.7.2.

5 Shearing Strength *(1997)*

5.1 General

The net thicknesses of the side shell and longitudinal bulkhead plating are to be determined based on the total vertical shear force, F_t, and the permissible shear stress, f_s, given below.

$F_t = F_S + K_u K_c F_w$ kN (tf, Ltf)

$f_s = 11.957/Q$ kN/cm^2 (1.220/Q tf/cm^2, 7.741/Q Ltf/in^2) at Sea

$= 10.87/Q$ kN/cm^2 (1.114/Q tf/cm^2, 7.065/Q Ltf/in^2) in Port

where

F_S = still water shear force based on the envelope curve required by 5C-3-3/3.1 for all anticipated loading conditions at location considered, in kN (tf, Ltf). Where cargo is carried in alternate holds, F_S may be modified based on 3-2-1/3.9.3.

F_w = vertical wave shear force as given in 3-2-1/3.5.3, in kN (tf, Ltf). F_w for in port condition may be taken as zero.

Q = material conversion factor

= 1.0 for ordinary strength steel

= 0.78 for Grade H32 steel

= 0.72 for Grade H36 steel

= 0.68 for Grade H40 steel

K_u and K_c may be taken as unity unless otherwise specified.

When a direct calculation is not available, the net thickness of the side shell, inner skin and wing tank sloping bulkhead plating may be obtained from the equations given in 5C-3-4/5.3, 5C-3-4/5.5 and 5C-3-4/5.7 below, where the inner skin is located no further than 0.075B from the side shell.

The nominal design corrosion values as given in 5C-3-2/Table 1 for the side shell, inner hull and wing tank sloping bulkhead plating are to be added to the "net" thickness.

5.3 Net Thickness of Side Shell Plating

$t_s \geq F_t D_s \, m/2 \, I f_s$ cm (in.)

where

I = moment of inertia of the "net" hull girder section at the position considered, in cm^4 (in^4)

m = first moment of the "net" hull girder section, in cm^3 (in^3), about the neutral axis, of the area between the vertical level at which the shear stress is being determined and the vertical extremity of the section under consideration.

F_t and f_s are as defined in 5C-3-4/5.1 above.

D_s = shear distribution factors for side shell are as defined in 5C-3-4/5.3.1, 5C-3-4/5.3.2 and 5C-3-4/5.3.3 below, respectively.

5.3.1 Side Shell in way of the Upper Wing Tank

$D_s = 0.912 - 0.35(A_{USB}/A_{SU})$

where

A_{USB} = total projected net area of the upper wing tank sloping bulkhead plating, in cm^2 (in^2)

A_{SU} = projected net area of the side shell plating in way of the upper wing tank, in cm^2 (in^2)

5.3.2 Side Shell between the Upper and Lower Wing Tanks

5.3.2(a) Single skin:

$D_s = 1.0$

5.3.2(b) Double skin (including vessels whose inner skin is less than 1000 mm (39.4 in.) from the side shell):

$D_s = 1 - \{A_{IH}/(A_{IH} + A_{SM})\}\ (1 + b_s/B)$

where

A_{IH} = total projected net area of the inner hull between the upper and lower wing tanks, in cm^2 (in^2)

A_{SM} = projected net area of the side shell between the upper and lower wing tanks, in cm^2 (in^2)

b_s = distance between the inner hull and the side shell, in m (ft)

B = breadth of the vessel, in m (ft), as defined in 3-1-1/5

5.3.3 Side Shell in Way of the Lower Wing Tank

$D_s = 0.74 - 0.3(A_{LSB}/A_{SL})$

where

A_{LSB} = total projected net area of the lower wing tank sloping bulkhead plating, in cm^2 (in^2)

A_{SL} = projected net area of the side shell plating in way of the lower wing tank above the inner bottom level, in cm^2 (in^2)

5.5 Net Thickness of the Sloping Bulkhead Plating of Upper and Lower Wing Tanks

$$t_b \geq F_t D_{SB} m/2\, I f_s$$

where

D_{SB} = shear distribution factors for the projected sloping bulkhead plating of the upper and lower wing tanks, depending on the locations are defined in 5C-3-4/5.5.1 and 5C-3-4/5.5.2 below, respectively.

F_t, m, I and f_s are as defined above.

5.5.1 Upper Wing Tank Sloping Bulkhead

$$D_{SB} = 0.4(A_{USB}/A_{SU}) + 0.1$$

where

A_{USB} = total projected net area of the upper wing tank sloping bulkhead plating, in cm^2 (in^2)

A_{SU} = projected net area of the side shell plating in way of the upper wing tank, in cm^2 (in^2)

5.5.2 Lower Wing Tank Sloping Bulkhead

$$D_{SB} = 0.3(A_{LSB}/A_{SL}) + 0.26$$

where

A_{LSB} = total projected net area of the lower wing tank sloping bulkhead plating, in cm^2 (in^2)

A_{SL} = projected net area of the side shell plating in way of the lower wing tank, above the inner bottom level, in cm^2 (in^2)

5.7 Net Thickness of the Inner Hull Plating

$$t_{IH} \geq F_t D_{IH}\, m/2\, I f_s$$

where

D_{IH} = shear distribution factor for the inner hull

= $[A_{IH}/(A_{IH} + A_{SM})](1 + b_s/B)$

All other parameters are as defined in 5C-3-4/5.3 above.

5.9 Three Dimensional Analysis *(1996)*

The total shear stress in the side shell, inner hull (on double hull vessels) and wing tank sloping bulkhead plating (net thickness) may be calculated using a 3D structural analysis to determine the general shear distribution.

7 Double Bottom Structures

7.1 General *(1996)*

7.1.1

The depth of the double bottom and arrangement of access openings are to be in compliance with 5C-3-1/1.5 and Section 3-2-4. Centerline and side girders are to be fitted as necessary to provide sufficient stiffness and strength for docking loads as well as those specified in Section 5C-3-3. The side girders are to be spaced approximately 3 m (10 ft).

Struts connecting the bottom and inner bottom longitudinals are not to be fitted in the double bottom of vessels engaged in trade where cargoes are handled by grabs or similar mechanical appliances.

7.1.2

The net thickness of the flat plate keel is to be not less than that required for the bottom shell plating at that location by 5C-3-4/7.3.1, increased by 1.5 mm (0.06 in.), except where the submitted docking plan (see 3-1-2/11) specifies all docking blocks be arranged away from the keel.

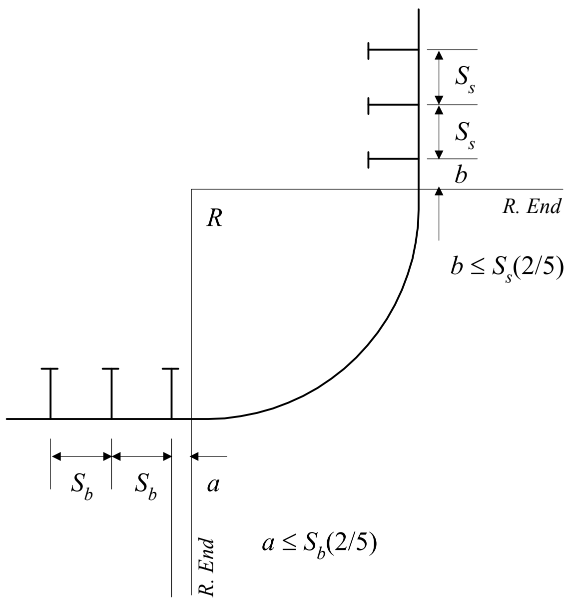
7.1.3

The term "bottom shell plating" refers to the plating from the keel to the upper turn of the bilge for 0.4*L* amidships.

7.1.4 *(2004)*

Longitudinals around the bilge are to be graded in size from that required for the lowest side longitudinal to that required for the bottom longitudinals. Where longitudinals are omitted in way of the bilge, the bottom and side longitudinals are to be arranged so that the distance between the nearest longitudinal and the turn of the bilge is not more than 0.4*s* (*s* is the spacing of bottom or side longitudinals), as applicable (see-5C-3-4/Figure 2A).

FIGURE 2A



7.1.5

Where a hold is to carry special cargoes such as steel coils and containers, double bottom structures are to be reinforced to withstand the anticipated load. An engineering analysis may be required.

7.1.6

Where ducts forming a part of the double bottom structure are used as a part of the piping system for transferring cargo oil or ballast, the structural integrity of the duct is to be safeguarded by suitable relief valves or other arrangement to limit the pressure in the system to the value for which it is designed.

7.3 Bottom Shell and Inner Bottom Plating *(1996)*

The net thickness of the bottom shell and inner bottom plating over the midship $0.4L$ is to satisfy the hull girder section modulus requirements in 5C-3-4/3.1. The buckling and ultimate strength are to be in accordance with the requirements in 5C-3-5/5. In addition, the net thickness of the bottom shell and inner bottom plating are to be not less than the following:

7.3.1 Bottom Shell Plating *(1999)*

The net thickness of the bottom shell plating, t_n, is to be not less than t_1, t_2 and t_3, specified as follows:

$t_1 = 0.73s(k_1 p/f_1)^{1/2}$ mm (in.)

$t_2 = 0.73s(k_2 p/f_2)^{1/2}$ mm (in.)

$t_3 = cs(S_m f_y/E)^{1/2}$ mm (in.)

where

s = spacing of bottom longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.500

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2) as specified in 5C-3-3/Table 3

Where upper and lower wing tanks are connected by trunks or double sides, the nominal pressure, p, in the lower wing tank for load case "a" may be modified by the following equation:

$p = p_a - p_{uh}$

$p_{uh} = 0.32\gamma(h\ell_{wt}\tan\phi_e)^{1/2}$ where $\ell_{wt} \geq 0.20L$

$= 0$ where $\ell_{wt} \leq 0.10L$

Linear interpolation is to be used for intermediate values of ℓ_{wt}.

p_a is nominal pressure in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in load case "a" in 5C-3-3/Table 3 for bottom plating.

γ = specific weight of the ballast water, 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf/in^2-ft)

h = height of upper wing tank at vessel's side, in m (ft)

ℓ_{wt} = length of the upper wing tank, in m (ft)

L = vessel length, as defined in 3-1-1/3, in m (ft)

ϕ_e = effective pitch amplitude, as defined in 5C-3-3/5.7.3 with $C_\phi = 1.0$

f_1 = permissible bending stress, in the longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $(0.95 - 0.67\alpha_1 SM_{RB}/SM_B)S_m f_y \leq k_3\, S_m f_y$

α_1 = $S_{m1} f_{y1}/S_m f_y$

k_3 = 0.40 for load case 1 – "a" in 5C-3-3/Table 3

= 0.36 for load case 1 – "b" in 5C-3-3/Table 3

SM_{RB} = reference net hull girder section modulus based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

= $0.9\, SM$

SM = required gross hull girder section modulus at the location under consideration in accordance with 3-2-1/3.7 and 3-2-1/5.5, based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

SM_B = design (actual) net hull girder section modulus to the bottom at the location under consideration, in cm^2-m (in^2-ft)

f_2 = permissible bending stress, in the transverse direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.80\, S_m f_y$

S_m = strength reduction factor

= 1 for Ordinary Strength Steel, as specified in 2-1-2/Table 2

= 0.95 for Grade H32, as specified in 2-1-3/Table 2

= 0.908 for Grade H36, as specified in 2-1-3/Table 2

= 0.875 for Grade H40, as specified in 2-1-3/Table 2

S_{m1} = strength reduction factor for the bottom flange of the hull girder

f_y = minimum specified yield point of the bottom shell plating, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{y1} = minimum specified yield point of the bottom flange of the hull girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

E = modulus of elasticity of the material, may be taken as 2.06×10^7 N/cm^2 (2.1×10^6 kgf/cm^2, 30×10^6 lbf/in^2) for steel

c = $0.7N^2 - 0.2$, not to be less than $0.4Q^{1/2}$ or $0.5N$, whichever is less

N = $R_b\,(Q/Q_b)^{1/2}$

R_b = $(SM_{RBH}/SM_B)^{1/2}$

SM_{RBH} = reference net hull girder section modulus for hogging bending moment based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

= $0.9SM_H$

SM_H = required gross hull girder section modulus in accordance with 3-2-1/3.7.1and 3-2-1/5.5 for hogging total bending moment at the location under consideration, based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

Q, Q_b = material conversion factor in 5C-3-4/5 for the bottom plating and the bottom flange of the hull girder, respectively.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

Bottom shell plating may be transversely framed in pipe tunnels, provided that the net thickness of the bottom shell plating, t_n, is not less than t_4, obtained from the following equation:

$$t_4 = 0.73\, sk(k_2\, p/f_1)^{1/2} \quad \text{mm (in.)}$$

where

s = spacing of the bottom transverse frames, in mm (in.)

k_2 = 0.5

k = $(3.075\,(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

All other parameters are as defined above.

In addition to the foregoing, the net thickness of the bottom shell plating, outboard of 0.3B from the centerline of the vessel, is to be not less than that of the lowest side shell plating required by 5C-3-4/9.1, adjusted for the spacing of the longitudinals and the material factors.

7.3.2 Inner Bottom Plating *(1999)*

The net thickness of the inner bottom plating, t_n, is to be not less than t_1, t_2 and t_3, specified as follows:

$$t_1 = 0.73s(k_1\, p/f_1)^{1/2} \quad \text{mm (in.)}$$

$$t_2 = 0.73s(k_2\, p/f_2)^{1/2} \quad \text{mm (in.)}$$

$$t_3 = cs(S_m f_y/E)^{1/2} \quad \text{mm (in.)}$$

where

s = spacing of inner bottom longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.50

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-3-3/Table 3

Where upper and lower wing tanks are connected by trunks or double sides, the nominal pressure, p, in load case "a" for dry cargo holds may be modified by the following equation:

$$p = p_a - p_{uh}$$

p_a is nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in load case "a" of 5C-3-3/Table 3 for inner bottom plating in dry cargo holds.

p_{uh} is as defined in 5C-3-4/7.3.1.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

The net thickness of the inner bottom plating, outboard of $0.3B$ from the centerline of the vessel, is also not to be less than that of the adjacent strake on the lower wing tank sloping bulkhead required by 5C-3-4/21.1, adjusted for the spacing of the longitudinals and the material factors.

f_1 = permissible bending stress, in the longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $(0.95 - 0.50\alpha_1\ SM_{RB}/SM_B)S_m f_y \le 0.55S_m f_y$, where SM_B/SM_{RB} is not to be taken more than 1.4

f_2 = permissible bending stress, in the transverse direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.85\ S_m f_y$

α_1 = $S_{m1}f_{y1}/S_m f_y$

S_m = strength reduction factor obtained from 5C-3-4/7.3.1 for the steel grade of the inner bottom plating

S_{m1} = strength reduction factor obtained from 5C-3-4/7.3.1 for the steel grade of the bottom flange of the hull girder

f_y = minimum specified yield point of the inner bottom plating, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{y1} = minimum specified yield point of the bottom flange of the hull girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

c = $0.7N^2 - 0.2$, not to be less than $0.4Q^{1/2}$

N = $R_b[(Q/Q_b)(y/y_n)]^{1/2}$

Q = material conversion factor in 5C-3-4/5.1 for the inner bottom plating

y = vertical distance, in m (ft), measured from the inner bottom to the neutral axis of the hull girder section

y_n = vertical distance, in m (ft), measured from the bottom to the neutral axis of the hull girder section

SM_{RB}, SM_B, R_b, Q_b and E are as defined in 5C-3-4/7.3.1.

Inner bottom plating may be transversely framed in pipe tunnels, provided the net thickness of the inner bottom plating, t_n, is not less than t_4, obtained from the following equation:

$$t_4 = 0.73sk(k_2\,p/f_1)^{1/2} \quad \text{mm (in.)}$$

where

s = spacing of inner bottom transverse frame, in mm (in.)

k_2 = 0.5

k = $(3.075\,(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

All other parameters are as defined above.

7.3.2(a) Inner Bottom Plating for Vessels Intended to Use Grabs (1999). Where the vessel is regularly engaged in trades where the cargoes are handled by grabs, or similar mechanical appliances, it is recommended that flush inner-bottom plating be adopted throughout the cargo space. The net thickness of the inner bottom plating is, in addition to that specified above, also not to be taken less than t_5, obtained from the following equation:

$$t_5 = (0.037L + 0.009s)\sqrt{R} + 3.5 \quad \text{mm}$$

$$= (0.000444L + 0.009s)\sqrt{R} + 0.138 \quad \text{in.}$$

where

R	=	1.0	for ordinary mild steel
	=	$f_{ym}/S_m f_{yh}$	for higher strength material
f_{ym}	=	specified minimum yield point for mild steel, in N/cm^2 (kgf/cm^2, lbf/in^2)	
f_{yh}	=	specified minimum yield point for higher tensile steel, in N/cm^2 (kgf/cm^2, lbf/in^2)	
L	=	length of vessel, in m (ft), as defined in 3-1-1/3.1	

s is as defined above.

It is also required that the net thickness of sloping bulkhead plating of lower wing tanks and lower stool plating of transverse bulkheads within a vertical extent of 1.5 m above the inner bottom is not to be taken less than t_5 with the actual spacing of the sloping bulkhead and stool stiffeners.

If the vessel is designed to discharge its cargo by a means other than by grabs, or similar mechanical appliances, which would negate the t_5 inner bottom thickness requirement, it is to be recorded in the vessel's Loading Manual that grabs, or similar mechanical appliances are not to be used to discharge cargo.

7.3.2(b) Optional Supplementary Requirement for Vessels Intended to Use Grabs (2001). Where the vessel is intended to use a specific weight of grab, the net thickness of inner bottom plating may be obtained from the following equation:

$$t_6 = k_3\sqrt{Wg \cdot s \cdot R / s_e} \quad \text{mm (in.)}$$

where

k_3	=	4.56 (0.181) where Wg is in tonnes (L tons)	
Wg	=	unladen grab weight (mass), in tonnes (L tons)	
s	=	spacing of inner bottom longitudinals, in mm (in.)	
R	=	1.0 for ordinary mild steel	
	=	$f_{ym}/S_m f_{yh}$ for higher strength material	
s_e	=	1000 mm (39.37 in.)	where $Wg \le 20$ tonnes (19.684 Ltons)
	=	$1000 + \sqrt{(k_4 Wg - 31.2)10^3 - Wg^2/k_5}$ mm	where $Wg > 20$ tonnes
	=	$39.37[1 + (\sqrt{(k_4 Wg - 31.2)10^3 - Wg^2/k_5})/1000]$ in.	where $Wg > 19.684$ Ltons

k_4 = 1.58 (1.605), where Wg is in tonnes (Ltons)

k_5 = 1.0 (0.969)

f_{ym} = specified minimum yield point for mild steel, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{yh} = specified minimum yield point for higher tensile steel, in N/cm^2 (kgf/cm^2, lbf/in^2)

S_m = strength reduction factor

= 1.0 for mild steel

= 0.95 for HT32 steel

= 0.908 for HT36 steel

The unladen grab weight (mass) used in determining the inner bottom thickness, t_6, is to be recorded in the vessel's Loading Manual. It should be noted, however, that this does not negate the use of heavier grabs, but the owner and operators are to be made aware of the increased risk of local damage and possible early renewal of inner bottom plating if heavier grabs are used regularly to discharge cargo. The notation **GRAB** placed after the appropriate classification notation in the *Record* will signify that the vessel's inner-bottom has been designed for a specific grab weight.

7.3.2(c) Inner Bottom Plating for Vessels Intended to Carry Steel Coils (2001). Where the vessel is intended to carry steel coils in holds, the net thickness of the inner bottom plating is not to be less than t_7, obtained from the following equation:

$$t_7 = \sqrt{\frac{a\varphi W_1}{f_y S_m}} \quad \text{mm (in.)}$$

where

a = 1.25 (within 0.4L amidships)

= 1.25 or 1 + 0.568$k_v a_o$, whichever is greater, (beyond 0.4L amidships)

k_v = acceleration factor, determined as defined in 5C-3-3/5.7.1(c), at the center of the supported panel under consideration.

a_o = acceleration factor, as defined in 5C-3-3/5.7.1(c), with L in m (ft)

W_1 = weight, in kN (tf, Ltf), of steel coils on one inner bottom plating panel

= $k_6 W\, m\, n_1/n$

k_6 = 9.8 (1.0, 1.0)

W = weight (mass) of one steel coil, in tonnes (L tons)

n_1 = number of tiers of steel coils

n = number of dunnages supporting one steel coil

m = parameter as given in 5C-3-4/Table 1, as a function of n and ℓ/s_f

ℓ = length of one steel coil, in m (ft)

s_f = floor spacing at the location being consideration, in m (ft)

$$\varphi = \frac{\alpha\delta - \delta^2 - 0.25\alpha^2(1-\beta)^2}{\alpha\beta(1+2\alpha\delta)}$$

δ = $0.5[\sqrt{1+2\alpha^2+\alpha^4(1-\beta)^2}-1]/\alpha$

α = aspect ratio of the inner bottom plating panel, (between floors and longitudinal stiffeners); α is not to be taken more than 3.0

β = parameter, as given in 5C-3-4/Table 1 as a function of n and ℓ/s_f

f_y = specified minimum yield point of the inner bottom plating, in kN/mm^2 (tf/mm^2, Ltf/in^2)

S_m = strength reduction factor for the steel of the inner bottom plating, as defined in 5C-3-4/7.3.1

The above equation is applicable for normal loading arrangements where steel coils are stowed on dunnage laid athwartships, with the steel coils' axes in fore-and-aft direction. Other loading arrangements of steel coils will be specially considered. The normal corrosion value is to be added to the net thickness to obtain the gross required inner bottom thickness. This corrosion value is in 5C-3-2/Table 1 for bulk carriers. The corrosion value for multipurpose vessels can be taken from 5C-3-2/Table 1.

TABLE 1
Parameters m and β as functions of n and ℓ/s_f

n	ℓ/s_f	m	β
2	$0.83 \le \ell/s_f$	2	$0.5\ \ell/s_f$
2	$0.60 \le \ell/s_f < 0.83$	3	$1.2\ \ell/s_f$
2	$0.42 \le \ell/s_f < 0.60$	4	$1.65\ \ell/s_f$
2	$0.30 \le \ell/s_f < 0.42$	5	$2.35\ \ell/s_f$
3	$0.83 \le \ell/s_f$	3	$0.65\ \ell/s_f$
3	$0.65 \le \ell/s_f < 0.83$	4	$1.2\ \ell/s_f$
3	$0.52 \le \ell/s_f < 0.65$	5	$1.53\ \ell/s_f$
4	$0.83 \le \ell/s_f$	4	$0.75\ \ell/s_f$
4	$0.65 \le \ell/s_f < 0.83$	5	$1.2\ \ell/s_f$

The special comment, "Designed for the carriage of steel coil" will be entered in column 5 of the *Record* where the scantlings of double bottom are in compliance with the requirements of the above and 5C-3-4/7.5, as applicable.

7.5 Bottom and Inner Bottom Longitudinals *(2001)*

The net section modulus of each bottom or inner bottom longitudinal, or each transverse frame in the pipe tunnels, in association with the effective plating to which it is attached, is to be not less than obtained from the following equations:

$SM = M/f_b$ cm^3 (in^3)

$M = 1000ps\ell^2/k$ N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 83.33)

s = spacing of longitudinals or transverse frames, in mm (in.)

ℓ = span of longitudinals or transverse frames between effective supports as shown in 5C-3-4/Figure 3, in m (ft)

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-3-4/7.3.1 and 5C-3-4/7.3.2 for bottom and inner bottom longitudinals or transverse frame, respectively.

f_b = permissible bending stresses, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $1.2\,[1.0 - 0.65\,\alpha_1\,SM_{RB}/SM_B]S_m f_y \leq 0.55 S_m f_y$ for bottom longitudinals

f_b = $1.3\,[1.0 - 0.50\,\alpha_1\,SM_{RB}/SM_B]S_m f_y \leq 0.65 S_m f_y$ for inner bottom longitudinals

= $0.65\,S_m f_y$ for inner bottom longitudinals of vessels intended to carry steel coils (within 0.4L amidships)

= $0.75\,S_m f_y$ for inner bottom longitudinals of vessels intended to carry steel coils (within 0.2L and the ends of L)

between 0.3L and 0.2L from the ends of L of vessels intended to carry steel coils, f_b for inner bottom longitudinals is to be obtained by linear interpolation

= $0.70\,S_m f_y$ for transverse frames in pipe tunnels

α_1 = $S_{m1} f_{y1}/S_m f_y$

S_m = strength reduction factor obtained from 5C-3-4/7.3.1 for the steel grade of the longitudinals considered

S_{m1} = strength reduction factor obtained from 5C-3-4/7.3.1 for the steel grade of the bottom flange of the hull girder

f_y = minimum specified yield point of the longitudinals considered, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{y1} = minimum specified yield point of the bottom flange of the hull girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

SM_{RB} and SM_B are as defined in 5C-3-4/7.3.1.

The net section modulus of the bottom longitudinals, outboard of 0.3B from the centerline of the vessel, is also to be not less than that of the lowest side longitudinal required by 5C-3-4/9.3, adjusted for the span and spacing of the longitudinals and the material factors.

The net section modulus of the inner bottom longitudinals, outboard of 0.3B from the centerline of the vessel, is also to be not less than that of the lowest longitudinal on the lower wing tank sloping bulkhead required by 5C-3-4/21.11, adjusted for the span and spacing of the longitudinals and the material factors.

In determining compliance with the foregoing, an effective breadth, b_e, of the attached plating is to be used in the calculation of the section modulus of the design longitudinal. b_e is to be obtained from line b) of 5C-3-4/Figure 4, or alternatively, b_e may be approximated as being 10% of the span ℓ, defined above.

The net section modulus of inner bottom longitudinals in association with the effective inner bottom plating is to be not less than obtained from the following equation:

$$SM = M/f_b \qquad \text{cm}^3\ (\text{in}^3)$$

where

M = maximum bending moment at the longitudinal, in N-cm (kgf-cm, lbf-in), obtained with the assumption that the longitudinal is a fixed-fixed beam at floors. The longitudinal should be loaded with concentrated loads $P = 0.8aWn_1/n$ at the position of dunnages, where W, a, n_1, n are as defined in 5C-3-4/7.3.2(c). The span of the longitudinal is to be defined as shown in 5C-3-4/Figure 3.

f_b = permissible bending stress, as defined in 5C-3-4/7.5 for inner bottom longitudinals

Strength and buckling of floors are also to be checked for loading of steel coils.

7.7 Bottom Centerline Girder *(2004)*

The net thickness of the centerline girder amidships is to be not less than t_1 and t_2, as defined below:

$t_1 = (0.045L + 4.5)R$ mm

$= (0.00054L + 0.177)R$ in.

$t_2 = 10F_1/(d_b f_s)$ mm

$= F_1/(d_b f_s)$ in.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

$t_3 = cs(S_m f_y/E)^{1/2}$ mm (in.)

where F_1 is the maximum shear force at the centerline girder, as obtained from the equations given below (see also 5C-3-4/1.3). Alternatively, F_1 may be determined from finite element analyses, as specified in 5C-3-5/9 with the combined load cases in 5C-3-5/9.9. However, in no case should F_1 be taken less than 85% of that determined from the equations below:

$F_1 = 1000k\alpha_1\gamma_1 n_1 n_2\, p\ell_s s_1$ N (kgf, lbf), for $\lambda \le 1.5$

$F_1 = 345\, k\gamma_1 n_1 n_2\, pb_s s_1$ N (kgf, lbf), for $\lambda > 1.5$

where

c = $0.7N^2 - 0.2$, not to be less than $0.4Q^{1/2}$, but need not be greater than $0.45(Q/Q_b)^{1/2}$

N = $R_b[(Q/Q_b)(y/y_n)]^{1/2}$

k = 1.0 (1.0, 2.24)

α_1 = $0.505 - 0.183\lambda$

λ = ℓ_s/b_s

γ_1 = $2x/(\ell_s - s_f) \le 1.0$

n_1 = $0.0374\,(s_1/s_f)^2 - 0.326(s_1/s_f) + 1.289$

n_2 = $1.3 - (s_f/12)$ for SI or MKS Units

= $1.3 - (s_f/39.37)$ for U.S. Units

ℓ_s = unsupported length of the double bottom structure under consideration, in m (ft), as shown in 5C-3-4/Figure 5.

b_s = unsupported width of the double bottom structures under consideration, in m (ft), as shown in 5C-3-4/Figure 5.

s_1 = sum of one-half of girder spacings on both sides of the centerline girder, in m (ft)

s_f = average spacing of floors, in m (ft)

x = longitudinal distance from the mid-span of unsupported length (ℓ_s) of the double bottom to the location of the girder under consideration, in m (ft).

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), as specified in 5C-3-3/Table 3

d_b = depth of double bottom, in cm (in.)

f_s = permissible shear stresses, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.50\, S_m f_y$

R = 1.0 for ordinary mild steel

= $f_{ym}/S_m f_{yh}$ for higher strength steel

f_{ym} = specified minimum yield point for mild steel, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{yh} = specified minimum yield point for higher tensile steel, in N/cm^2 (kgf/cm^2, lbf/in^2)

L = length of vessel, in m (ft), as defined in 3-1-1/3.1

R_b, Q, Q_b, S_m and f_y are as defined in 5C-3-4/7.3.1.

y and y_n are as defined in 5C-3-4/7.3.2.

Pipe tunnels may be substituted for centerline girders, provided the tunnel is suitably stiffened by fitting vertical webs, as may be required. The thickness of each girder forming the pipe tunnel and center girder within the pipe tunnel, if any, is to be not less than that required for the bottom side girder (see 5C-3-4/7.9 and 5C-3-4/7.13) and for docking (see 3-2-4/3.7), as appropriate.

7.9 Bottom Side Girders *(1999)*

The net thickness of the bottom side girders is to be not less than t_1 and t_2, as defined below:

$t_1 = (0.026L + 4.5)R$ mm

$= (0.00031L + 0.177)R$ in.

$t_2 = 10F_2/(d_b f_s)$ mm

$= F_2/(d_b f_s)$ in.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

$t_3 = cs(S_m f_y/E)^{1/2}$ mm (in.)

where F_2 is the maximum shear force at the side girders under consideration, as obtained from the equations given below (see also 5C-3-4/1.3). Alternatively, F_2 may be determined from finite element analyses, as specified in 5C-3-5/9 with the combined load cases in 5C-3-5/9.9. However, in no case should F_2 be taken less than 85% of that determined from the equations below.

$F_2 = 1000k\alpha_2\beta_1\gamma_1 n_3 n_4 p\ell_s s_2$ N (kgf, lbf), for $\lambda \le 1.5$

$F_2 = 285k\beta_1\gamma_1 n_3 n_4 p b_s s_2$ N (kgf, lbf), for $\lambda > 1.5$

where

c	=	$0.7N^2 - 0.2$, not to be less than $0.4Q^{1/2}$, but need not be greater than $0.45(Q/Q_b)^{1/2}$	
k	=	1.0 (1.0, 2.24)	
α_2	=	$0.445 - 0.17\lambda$	
β_1	=	$1 - (1.2z_1/b_s) \geq 0.6$	for loaded holds under alternate loading conditions
	=	$1.25 - (2z_1/b_s) \geq 0.6$	for all holds or tanks under all other loading conditions
n_3	=	$1.072 - 0.0715\,(s_2/s_f)$	
n_4	=	$1.2 - (s_f/18)$	for SI or MKS Units
	=	$1.2 - (s_f/59.1)$	for U.S. Units
s_2	=	sum of one-half of girder spacings on both sides of each side girder, in m (ft)	
z_1	=	transverse distance from the centerline of the unsupported width (b_s) of the double bottom to the location of the girder under consideration, in m (ft)	

γ_1, N, ℓ_s, b_s, λ, s_f, p, d_b, f_s, L and R are as defined in 5C-3-4/7.7.

7.11 Bottom Floors *(1997)*

The net thickness of the floors is to be not less than t_1 and t_2, as specified below:

$t_1 = (0.026L + 4.5)R$ mm

$= (0.0031L + 0.177)R$ in.

$t_2 = 10F_3/(d_b f_s)$ mm

$= F_3/(d_b f_s)$ in.

where F_3 is the maximum shear force at the floors under consideration, as obtained from the equation given below (see also 5C-3-4/1.3). Alternatively, F_3 may be determined from finite element analyses, as specified in 5C-3-5/9 with the combined load cases in 5C-3-5/9.9. However, in no case should F_3 be taken less than 85% of that determined from the equation below.

$F_3 = 1000\, k\alpha_3\beta_2\beta_3\gamma_2\, p\, b_s\, s_f$ N (kgf, lbf)

where

k	=	1.0 (1.0, 2.24)	
α_3	=	$0.5\rho_o$	
ρ_o	=	$\eta(0.66 - 0.08\eta)$,	for $\eta \leq 2.0$
	=	1.0	for $\eta > 2.0$
β_2	=	$2\,z_2/b_s$	
β_3	=	$1 - 0.4\,(z_2/b_s)$	for loaded holds under alternate loading conditions
	=	1.0	for all holds or tanks under all other loading conditions
γ_2	=	$1 - (x/\ell_s)(1.245\lambda + 0.044)$	
η	=	$(\ell_s/b_s)(s_g/s_f)^{1/4}$	

s_g = average spacing of girders, in m (ft)

s_f = sum of one-half of floor spacings on both sides of each floor, in m (ft)

x = longitudinal distance from the mid-span of unsupported length (ℓ_s) of the double bottom to the location of the floor under consideration, in m (ft)

z_2 = transverse distance from the centerline of the unsupported width (b_s) of the double bottom to the location of floor under consideration, in m (ft)

f_s = $0.50\ S_m f_y$ in N/cm^2 (kgf/cm^2, lbf/in^2)

ℓ_s, b_s, s_f, λ, R, p, d_b, L, S_m and f_y are as defined in 5C-3-4/7.7 above.

7.13 Deep Tank Double Bottom Girder *(1999)*

The net thickness of the double bottom girders forming boundaries of deep tanks, in addition to complying with 5C-3-4/7.7, 5C-3-4/7.9 and 5C-3-4/7.11, is to be not less than t, obtained from the following equation:

$$t = 0.73s(k_1 p/f_1)^{1/2} \qquad \text{mm (in.)}$$

where

s = spacing of longitudinals or vertical stiffeners

k_1 = 0.342, for longitudinally stiffened plating

= $0.50k^2$, for vertically stiffened plating

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha < 2)$

= 1.0, $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as specified in 5C-3-3/Table 3

Where the lower bottom tank is connected to the upper wing tank by trunks or double sides, the nominal pressure, p, in load case "b" may be modified by the following equation:

$$p = p_b - p_{uo}$$

p_b is nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as defined in load case "b" of 5C-3-3/Table 3 for other longitudinal bulkhead plating.

p_{uo} is as defined in 5C-3-4/9.1.

f_1 = permissible bending stress in N/cm^2 (kgf/cm^2, lbf/in^2)

= $1.2[1 - 0.4(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]\ S_m f_y \le 0.70 S_m f_y$

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the lower edge of each plate where the plating is longitudinally stiffened

= vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the mid-depth of the double bottom height where the plating is vertically stiffened

B = vessel's breadth, in m (ft), as defined in 3-1-1/5

SM_{RB} and SM_B are as defined in 5C-3-4/7.3.1.

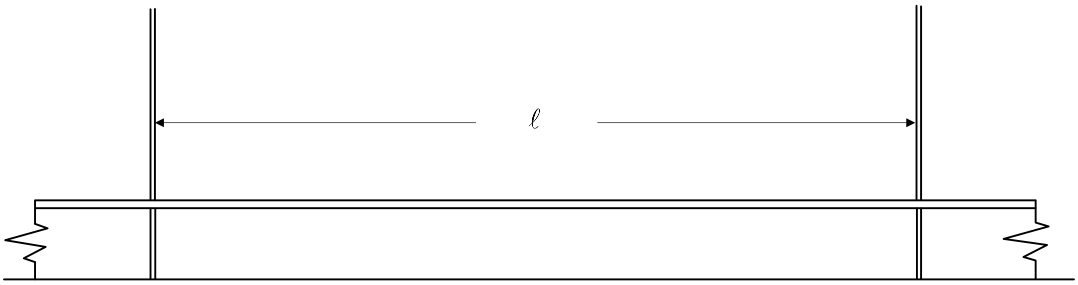
S_m, f_y and α_1 are as defined in 5C-3-4/7.5.

Z and y_n are as defined in 5C-3-4/21.1.

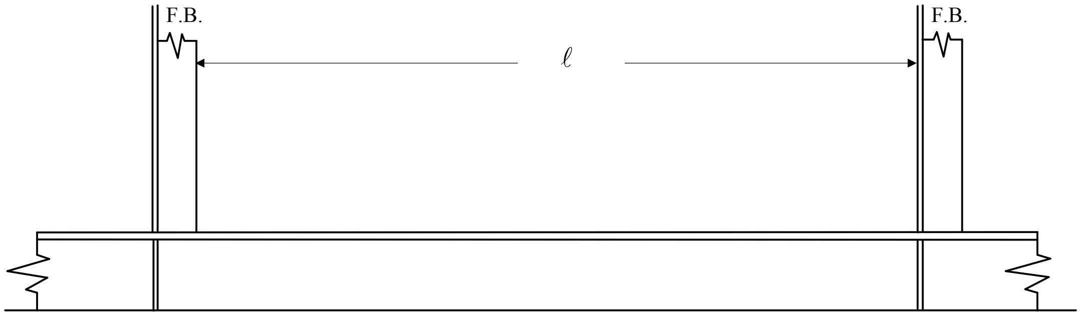
7.15 Double Bottom Shear Capacity in Flooded Condition *(1 July 1998)*

In addition to the requirements of 5C-3-4/7.7, 5C-3-4/7.9 and 5C-3-4/7.11 for single or double side skin bulk carriers intended to carry solid bulk cargoes having a density of 1.0 t/m^3 (62.4 lb/ft^3) or greater, the shear strength of the floors and girders under loads caused by hold flooding are to meet the requirements in Appendix 5C-3-A5c.

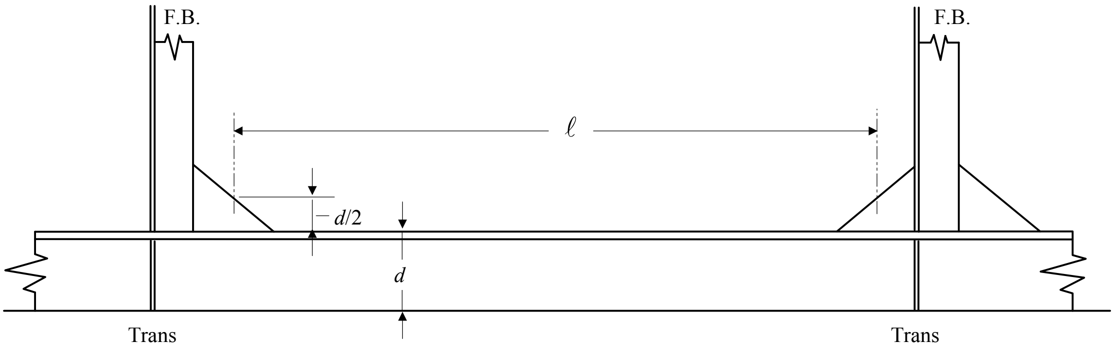
FIGURE 3
Unsupported Span of Longitudinal



a) Supported by transverses

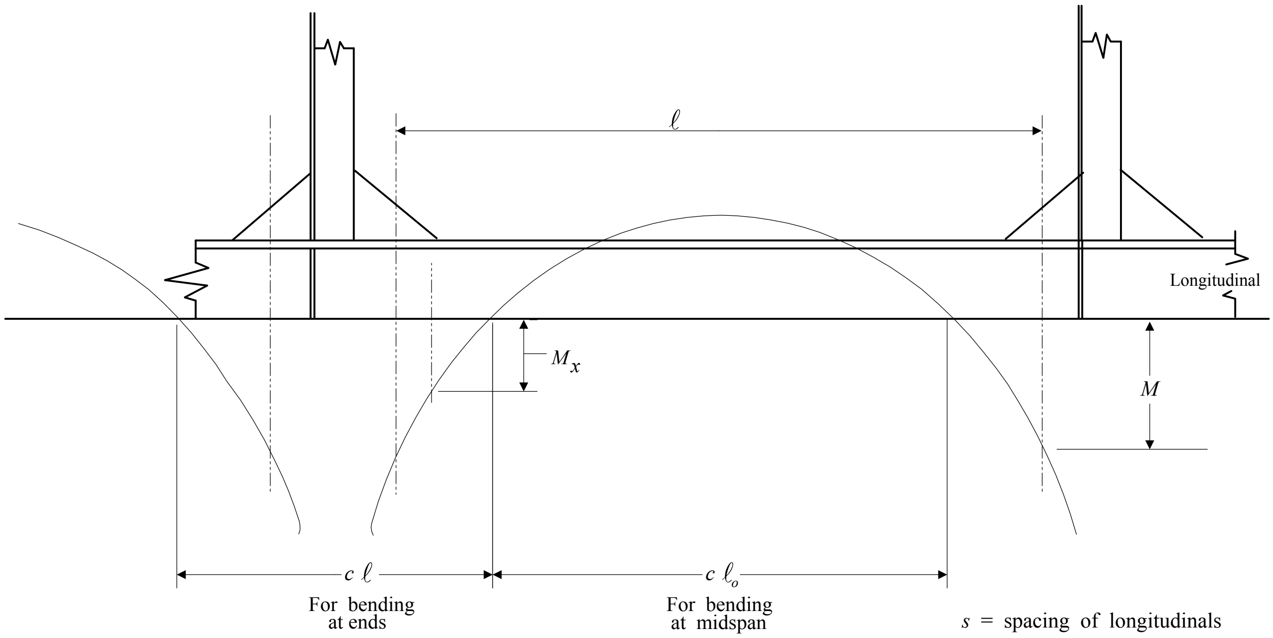


b) Supported by transverses and flat bar stiffeners



c) Supported by transverses, flat bar stiffeners and brackets

FIGURE 4
Effective Breadth of Plating b_e



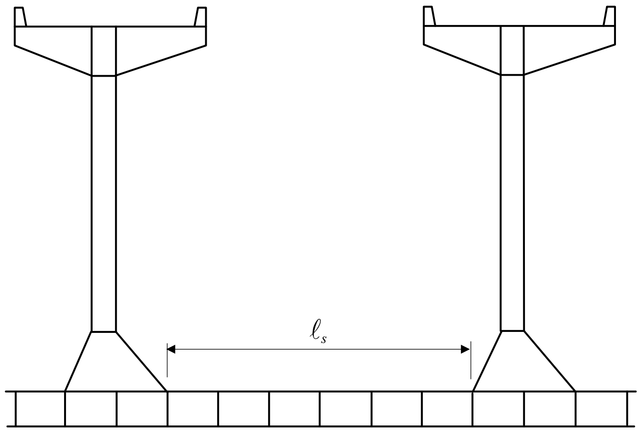
a) For bending at midspan

$c\ell_o/s$	1.5	2	2.5	3	3.5	4	4.5 and greater
b_e/s	0.58	0.73	0.83	0.90	0.95	0.98	1.0

b) For bending at ends [$b_e/s = (0.124c\ell/s - 0.062)^{1/2}$]

$c\ell/s$	1	1.5	2	2.5	3	3.5	4.0
b_e/s	0.25	0.35	0.43	0.5	0.55	0.6	0.67

FIGURE 5
Definition of ℓ_s and b_s



9 Side Shell Plating and Longitudinals

9.1 Side Shell Plating *(2001)*

The net thickness of the side shell plating, in addition to complying with 5C-3-4/5.3, is to be not less than t_1, t_2 and t_3, obtained from the following equations for the midship 0.4L:

$t_1 = 0.73s(k_1 p/f_1)^{1/2}$ mm (in.)

$t_2 = 0.73s(k_2 p/f_2)^{1/2}$ mm (in.)

$t_3 = cs(S_m f_y/E)^{1/2}$ mm (in.)

where

s = spacing of side longitudinals/frames, in mm (in.)

k_1 = 0.342

k_2 = 0.50

p = nominal pressure at the upper turn of bilge, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-3-3/Table 3

Where upper and lower wing tanks are connected by trunks or double sides, the nominal pressure in load case "a" may be modified by the following equation:

$p = p_a - p_{uo}$

$p_{uo} = 0.23\gamma(h\ell_{wt}b_{wt}\tan\phi_e \tan\theta_e)^{1/3}$ where $\ell_{wt} \geq 0.2L$

$= 0$ where $\ell_{wt} \leq 0.1L$

Linear interpolation is to be used for intermediate values of ℓ_{wt}.

However, the nominal pressure at the upper turn of bilge may be taken as if the upper and lower wing tanks were not connected, for calculation of the required thickness of side shell in way of the upper wing tank. p_a is nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in load case "a" at the upper turn of bilge in 5C-3-3/Table 3 for side shell plating.

b_{wt} = breadth at tank top of upper wing tank, in m (ft)

ϕ_e = effective pitch amplitude, as defined in 5C-3-3/5.7.3 with $C_\phi = 0.7$

θ_e = effective roll amplitude, as defined in 5C-3-3/5.7.3 with $C_\theta = 0.7$

L is vessel length, as defined in 3-1-1/3.1.

γ, h and ℓ_{wt} are as defined in 5C-3-4/7.3.1.

f_1 = permissible bending stress, in the longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $[0.80 - 0.50\,\alpha_1\,(SM_{RB}/SM_B)(y/y_b)]\,S_m f_y, \leq 0.40 S_m f_y$, where SM_B/SM_{RB} is not to be taken more than 1.4, below the neutral axis

= $0.40\,S_m f_y$, above neutral axis

f_2 = permissible bending stress, in the vertical direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.80\,S_m f_y$

α_1 = $S_{m1}f_{y1}/S_m f_y$

S_m = strength reduction factor, obtained from 5C-3-4/7.3.1 for the steel grade of the side shell plating

S_{m1} = strength reduction factor, obtained from 5C-3-4/7.3.1 for the steel grade of the bottom flange of the hull girder

f_y = minimum specified yield point of the side shell material, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{y1} = minimum specified yield point of the bottom flange material of the hull girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

y_b = vertical distance, in m (ft), measured from the upper turn of bilge to the neutral axis of the section

c = $0.7N^2 - 0.2$, not to be less than $0.4Q^{1/2}$

N = $R_d\,(Q/Q_d)^{1/2}$ for the sheer strake

= $R_d\,[(Q/Q_d)(y/y_n)]^{1/2}$ for other locations above neutral axis

= $R_b\,[(Q/Q_b)(y/y_n)]^{1/2}$ for locations below neutral axis

R_d = $(SM_{RDS}/SM_D)^{1/2}$

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the lower edge (upper edge) of the side shell strake, when the strake under consideration is below (above) the neutral axis for N.

= vertical distance, in m(ft), measured from the neutral axis of the hull girder transverse section to the lower edge of the side shell strake under consideration for f_1.

SM_{RDS} = reference net hull girder section modulus for sagging bending moment based on the material factor of the deck flange of the hull girder in cm^2-m (in^2-ft)

= $0.9SM_S$

SM_S = required gross hull girder section modulus at the location under consideration in accordance with 3-2-1/3.7.1 and 3-2-1/5.5 for sagging total bending moment based on the material factor of the deck flange of the hull girder in cm^2-m (in^2-ft)

Q, Q_d = material conversion factor in 5C-3-4/5.1 for the side shell plating under consideration and the deck flange of the hull girder, respectively.

y_n = vertical distance, in m (ft), measured from the bottom (deck) to the neutral axis of the section, when the strake under consideration is below (above) the neutral axis.

SM_{RB}, SM_B, R_b, Q_b and E are as defined in 5C-3-4/7.3.1.

SM_D is as defined in 5C-3-4/9.3.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

The side shell is to be longitudinally framed in the lower and upper wing tanks, except the upper part of lower wing tank and the lower part of upper wing tank where the limited access makes this impractical. These parts of the side shell may be transversely framed with efficient brackets arranged in line with the side frames, provided the net thickness of the side shell plating in this area is not less than that of the adjacent longitudinally framed shell and is also not less than t_4, obtained from the following equation:

$t_4 = 0.73sk(k_2\, p/f)^{1/2}$ mm (in.)

where

s = spacing of side transverse brackets, in mm (in.)

k = $(3.075\sqrt{\alpha} - 2.077)/(\alpha + 0.272)$ $(1 \le \alpha \le 2)$

k = 1.0 $(\alpha > 2)$

k_2 = 0.5

α = aspect ratio of the panel (longer edge/shorter edge)

p = nominal pressure at the side shell under consideration, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-3-3/Table 3, but need not be greater than that at the upper turn of bilge

In the upper wing tank and lower wing tank which is connected to the upper wing tank by trunks or double sides, the nominal pressure, p, in load case "a" may be modified by the following equation:

$p = p_a - p_{uo}$

In no case is p to be taken less than 2.06 N/cm^2 (0.21 kgf/cm^2, 2.987 lbf/in^2).

p_a is nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in load case "a" at the lower edge of each plate in 5C-3-3/Table3 for side shell plating.

p_{uo} is as defined above.

f = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $1.1\,[0.80 - 0.50\,\alpha_1\,(SM_{RB}/SM_B)(y/y_b)]\,S_m f_y \le 0.60 S_m f_y$, where SM_B/SM_{RB} is not to be taken more than 1.4 below neutral axis

= $0.60\,S_m f_y$, above neutral axis

All other parameters are as defined above.

For vessels intended to carry highly corrosive cargoes, additional corrosion margins are recommended for the side shell plating between the upper and the lower wing tanks.

The net thickness of the side shell plating, where transversely framed between the upper and lower wing tanks, is not to be less than t_4, as specified above, with the nominal pressure calculated at the top of the lower wing tank. The thickness is also not to be less than that of the adjacent side shell. Where upper and lower wing tanks are connected by trunk, the required thickness of the adjacent side shell may be calculated for this purpose as if the upper and lower wing tanks were not connected.

Where a cargo hold is intended to be used for the carriage of water ballast or liquid cargoes, the net thickness of the side shell plating in the hold between the upper and lower wing tanks is also not to be taken less than t_5, obtained from the following equation.

$t_5 = 0.73s(kp/f)^{1/2}$ mm (in.)

where

s = spacing of side frames, in mm (in.)

k = 0.5

p = nominal pressure at the top of the lower wing tank, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-3-3/Table 3 for side structural members (ballast or liquid cargo holds)

f = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.75\,S_m f_y$

In no case is the net thickness of shell plating in way of the cargo holds the side of which is bounded only by side shell to be less than t_6, given by the equation below:

$t_6 = (L)^{1/2} - 1.5$ mm $\qquad$ $t_6 = 0.02175\,(L)^{1/2} - 0.06$ in.

L = length of the vessel, as defined in 3-1-1/3.1, in m (ft)

The minimum width of the sheerstrake for the midship 0.4L is to be obtained from the following equations:

$b = 5L + 800$	mm	for $L \leq 200$ m
$= 0.06L + 31.5$	in.	for $L \leq 656$ ft
$b = 1800$	mm	for $200 < L \leq 500$ m
$= 70.87$	in.	for $656 < L \leq 1640$ ft

where

L = length of the vessel, as defined in 3-1-1/3.1, in m (ft)

b = width of the sheer strake, in mm (in.)

The thickness of the sheer strake is to be increased 25% in way of breaks of superstructures, but this increase need not exceed 6.5 mm (0.26 in.).

The thickness of a radiused gunwale is not to be less than that of the adjacent side shell or deck plating, whichever is greater. When a radiused gunwale is fitted, the requirement for the minimum width of sheer strake need not be considered applicable.

9.3 Side Longitudinals *(1999)*

The net section modulus of each side longitudinal, in association with the effective plating to which it is attached, is to be not less than obtained from the following equation:

$SM = M/f_b$ $\qquad$ cm^3 (in^3)

$M = 1000\,ps\ell^2/k$ $\qquad$ N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 83.33)

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the side longitudinal considered, as specified in 5C-3-3/Table 3

In the upper wing tank and lower wing tank which is connected to the upper wing tank by trunks or double sides, the nominal pressure, p, in load case "a" may be modified by the following equation:

$p = p_a - p_{uo}$

In no case is p to be taken less than 2.06 N/cm^2 (0.21 kgf/cm^2, 2.987 lbf/in^2).

p_a is nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in load case "a" at the lower edge of each plate in 5C-3-3/Table 3 for side shell plating.

p_{uo} is as defined in 5C-3-4/9.1.

s and ℓ are as defined in 5C-3-4/7.5.

f_b = permissible bending stresses, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $1.4\ [0.80 - 0.52\ \alpha_1\ (SM_{RB}/SM_B)\ (y/y_n)]\ S_m f_y \le 0.80 S_m f_y$, for side longitudinals below neutral axis

= $2.2\ [0.80 - 0.52\ \alpha_2\ (SM_{RD}/SM_D)\ (y/y_n)]\ S_m f_y \le 0.80 S_m f_y$, for side longitudinals above neutral axis

α_2 = $S_{m2} f_{y2}/S_m f_y$

S_m, f_y and α_1 are as defined in 5C-3-4/7.5.

S_{m2} = strength reduction factor for the steel grade of the top flange material of the hull girder, obtained from 5C-3-4/7.3.1.

f_{y2} = minimum specified yield point of the top flange material of the hull girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

SM_{RD} = reference net hull girder section modulus based on the material factor of the top flange of the hull girder, in cm^2-m (in^2-ft)

= 0.9 SM

SM = required gross hull girder section modulus at the location under consideration in accordance with 3-2-1/3.7 and 3-2-1/5.5 based on the material factor of the deck flange of the hull girder, in cm^2-m (in^2-ft)

SM_D = design (actual) net hull girder section modulus to the deck at the location under consideration, in cm^2-m (in^2-ft)

SM_{RB} and SM_B are as defined in 5C-3-4/7.3.1.

y = vertical distance, in m (ft), measured from the neutral axis of the section to the longitudinal under consideration at its connection to the associated plate

y_n = vertical distance, in m (ft), measured from the deck (bottom) to the neutral axis of the section, when the longitudinal under consideration is above (below) the neutral axis.

The effective breadth of plating, b_e, is as defined in 5C-3-4/7.5.

The net moment of inertia of each side longitudinal within the region of 0.1D from the deck at side, in association with the effective plating ($b_{wL} \cdot t_n$), is to be not less than obtained from the following equation:

$i_o = k\, A_e\, \ell^2 f_y / E$ cm^4 (in^4)

where

k = 1220 (1220, 17.57)

A_e = net sectional area of the longitudinal with the associated effective plating ($b_{wL} \cdot t_n$), in cm^2 (in^2)

b_{wL} = $c_e s$

c_e = $2.25/\beta - 1.25/\beta^2$ for $\beta \ge 1.25$

= 1.0 for $\beta < 1.25$

β = $(f_y/E)^{1/2}\ s/t_n$

t_n = net thickness of the plate, in mm (in.)

D = depth of the vessel, in m (ft), as defined in 3-1-1/7

ℓ, s and f_y are as defined in 5C-3-4/7.5.

E is as defined in 5C-3-4/7.3.1.

11 Side Frames and Supporting Structures *(1 July 1998)*

11.1 General *(2003)*

The hold frames of the configuration shown in 5C-3-4/Figure 6, and their supporting structures are to be designed in compliance with Section 3-2-5, except when otherwise specified in Part 5C, Chapter 3, to provide sufficient transverse strength for the hull girder and proper load transmission between the upper and lower wing tank structures. In addition to the section modulus and the minimum thickness requirements specified below, the stiffness of the structural elements and the design of end brackets are to be in compliance with the buckling and fatigue criteria given in 5C-3-5/5. For double side skin construction, transverse side frames in association with vertical diaphragms and side stringers are to be provided in ballast tanks or void spaces. The scantlings of transverse side frames in double hull side tanks or void spaces are to comply with 5C-3-4/11.3. Where side longitudinals are provided in lieu of transverse side frames in side ballast tanks or void spaces, the scantlings of the longitudinals are to comply with 5C-3-4/9.3. Vertical diaphragms are to be properly arranged in line with the transverse webs in the topside tank or lower wing tank.

11.3 Frame Section Modulus *(2003)*

The net section modulus of the hold frame in association with effective shell plating to which it is attached is not to be less than obtained from the following equations, whichever is greater.

$SM_F = M/f_b$ in cm^3 (in^3)

$M = 1000\ c_1 p_1 s\ell^2/k_1$ or

$= 1000\ c_1 p_2 s\ell^2/k_2 + k_3 wb$ N-cm (kgf-cm, lbf-in)

$= 1000\ c_1 p_1 s\ell^2/k_1$ N-cm (kgf-cm, lbf-in) for side frames in double hull side tanks or void spaces

where

k_1 = 12 (12, 83.33)

k_2 = 16 (16, 111.11)

k_3 = 5 (5, 0.6)

c_1 = $1 - 4(d/\ell) \geq 0.65$

= $1 + \gamma\ell/10p_1$ for side frames in double hull side tanks or void spaces

γ = specific weight of sea water, 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.444 lbf/in^2-ft)

p_1, p_2 = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the middle of the unsupported span of the hold frame (dry cargo holds), as specified in 5C-3-3/Table 3 case "a" and case "b", respectively

s = spacing of hold frames, in mm (in.)

d = depth of hold frames, in m (ft)

ℓ = unsupported span of the hold frame, in m (ft) (see 5C-3-4/Figure 6)

w = weight of the ballast water in upper wing tank per frame spacing for one side (port or starboard), in N (kgf, lbf), and may be approximated as follows:

= $k_4(h_1 + h_2)bs$

k_4 = 5.026 (0.5125, 0.032)

h_1, h_2, b = dimensions of the upper wing tank, in m (ft), as shown in 5C-3-4/Figure 6

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $S_m f_y - F/A$

= $0.8\ S_m f_y$ for side frames in double hull side tanks or void spaces

F = axial force, in N (kgf, lbf)

= $(0.5 + 2\ell_H/b_w)Bsp_b\ k_5$

k_5 = 1 (1, 1.2)

ℓ_H = length of the cargo hold, in m (ft)

b_w = breadth of the double bottom structure, in m (ft). For vessels having lower wing tanks with sloping tops, making an angle of about 45 degrees with the horizontal, the breadth may be measured between the midpoints of the sloping plating

B = breadth of the vessel, in m (ft), as defined in 3-1-1/5

p_b = corresponding net nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), of the double bottom structure at its centerline (5C-3-3/Table 3., item 4, case "a" and case "b" for p_1 and p_2 above, respectively)

A = net sectional area of the frame and the associated effective plating (st_n), in cm^2 (in^2)

S_m and f_y are as defined in 5C-3-4/7.3.1.

The effective breadth of plating, b_e, is as defined in 5C-3-4/7.5.

Where a cargo hold is also intended to be a water ballast or liquid cargo tank, the net section modulus of the hold frame is also not to be less than obtained from the following equation:

$SM_F = M/f_b$ in cm^3 (in^3)

$M = 1000c_1p_3s\ell^2/k$ N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 83.33)

p_3 = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the middle of the unsupported span of hold frames, as specified in 5C-3-3/Table 3 for hold frame (ballast or liquid cargo holds)

p_b = corresponding net nominal pressure, N/cm^2 (kgf/cm^2, lbf/in^2) of the double bottom structure at B/4 off its centerline [5C-3-3/Table 3 for hold frame (ballast or liquid cargo holds)]

All other parameters are as defined above.

11.5 Frame Sections

In vessels of 190 m (623 ft) or more in length, frames are to be fabricated symmetrical sections with integral upper and lower brackets. Their brackets are to be soft toed. The side frame flange is to be curved (not knuckled) at the transition to integral brackets. The radius of curvature is not to be less than r, in mm (in.), given by:

$$r = \frac{0.4 \cdot b_f^2}{t_f + c}$$

where b_f and t_f are the flange width and net flange thickness of the brackets, respectively, in mm (in.). c = 1.5 mm (0.06 in.). The end of the flange is to be sniped.

In vessels less than 190 m (623 ft) in length, frames of ordinary strength steel may be asymmetric sections (fabricated or rolled) and fitted with separate brackets. The face plate or flange of the bracket is to be sniped at both ends. Brackets are to be soft toed.

For vessels of all lengths, the web depth to thickness ratio of frames is to comply with the proportion limits given in 5C-3-A2/11.9. The ratio of outstanding flange breadth to gross thickness is not to exceed $10\sqrt{Q}$, where Q is as defined in 3-2-1/5.5.

11.7 Brackets

11.7.1 Section Modulus

The net section modulus of the lower and upper brackets at the top of the lower wing tank and the bottom of the upper wing tank, as indicated in 5C-3-4/Figure 6, in association with the effective shell plating to which they are attached, is not to be less than obtained from the following equation:

$$SM_E = c_2 h_3^2 SM_F/(c_1 \ell^2) \qquad \text{in cm}^3 \text{ (in}^3\text{)}$$

where

c_2 = 1.2 for upper bracket

= 1.1 for lower bracket

h_3 = vertical distance, in m (ft), between the top of lower wing tank and the bottom of upper wing tank (see 5C-3-4/Figure 6)

SM_F = required net section modulus of the hold frame in 5C-3-4/11.3

c_1 and ℓ are as defined in 5C-3-4/11.3.

In no case is SM_E to be less than 2.0(SM_F).

When the section modulus is calculated in way of the brackets, any bracket flange or face plate which is sniped at both ends may be considered effective for this purpose only if the location as indicated in 5C-3-4/Figure 6 is clear of the snipe and lies within the middle two-thirds of the flange length.

11.7.2 Arm Lengths

Integral or separate frame brackets are to extend at least for a length of $0.125h_3$ onto the frame and the depth of the bracket plus frame, measured at the heels of the frame, is generally to be at least 1.5 times that of the frame. Where the hull form renders this impracticable, equivalent strength in shear and bending is to be provided. The brackets are to be arranged with “soft” toes. See 5C-3-4/Figure 7 and 5C-3-4/Figure 8).

11.7.3 Minimum Thickness

The net thickness of the brackets and the web portions of the frames is not to be less than obtained from the following equation:

$$t_n = 0.03L + 5.5 \quad \text{mm}$$

$$= (0.036L + 21.7)10^{-2} \quad \text{in.}$$

but need not to be greater than 11.5 mm (0.45 in.)

where

L = length of vessel, in m (ft), as defined in 3-1-1/3.1

The net thickness of the upper bracket is to be not less than t_n above or the proposed net thickness of web of the frame being supported, whichever is greater.

The net thickness of the lower bracket is to be not less than t_n above or the proposed net thickness of web of the frame being supported reduced by 2.0 mm (0.08 in.), whichever is greater.

11.7.4 Supporting Bracket

Brackets are to be fitted in the lower and upper wing tanks, in line with every side frame.

11.9 Longitudinals at the Toe of Brackets

The section modulus of side longitudinals and sloping bulkhead longitudinals at the toes of brackets is to be determined based on 5C-3-4/9.3 and 5C-3-4/21.11 with the unsupported span, ℓ, measured between transverses and spacing, s, taken equal to dimension "b", as shown in 5C-3-4/Figure 8.

13 Side Transverses/Web Frames and Transverse Webs in Lower and Upper Wing Tanks *(1996)*

13.1 General *(1997)*

The main supporting members such as the transverse webs and girders are to be arranged and designed with sufficient stiffness to provide support to the vessel's hull structure. In general, deep beams, web frames and bottom floors are to be arranged in one plane to form continuous transverse rings. Deck girders and continuous hatch coamings, where fitted, are to be extended throughout the cargo hold spaces and are to be effectively supported at the transverse bulkheads.

Generous transitions are to be provided at the intersections of the main supporting members to provide for smooth transmission of loads and to minimize stress concentrations. Abrupt changes in sectional properties and sharp re-entrant corners are to be avoided. In general, stool structures, where fitted, are to have sloping bulkheads on both sides.

The net section modulus and sectional area of the main supporting members required by this Chapter apply to those parts of the member clear of the end brackets. They are considered as the requirements of initial scantlings for transverses in lower and upper wing tanks, and may be reduced, provided the strength of the resultant design is verified with the subsequent total strength assessment in Section 5C-3-5. However, in no case should they be taken less than 85% of those determined from this section. (See also 5C-3-5/9.9.) The structural properties of the main supporting members and end brackets are to comply with failure criteria specified in 5C-3-5/3, 5C-3-5/5 and 5C-3-5/7.

The required section modulus of the main supporting members in association with the effective plating to which they are attached is to be determined as specified in 3-1-2/13.

13.3 Transverses in Lower Wing Tank

13.3.1 Section Modulus

The net section modulus of the transverses in the lower wing tank in association with the effective plating is not to be less than obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

$M = M_1 + M_2$

$M_1 = 1000 ps \ell_b^2 / k_1$ N-cm (kgf-cm, lbf-in)

$M_2 = 0$ for sloping bulkhead transverse

$= 0.5\, M_{sL}$ for side transverse

$= M_{1s}$ for bottom transverse

where

k_1 = 0.12 (0.12, 0.446)

M_{sL} = bending moment for sloping bulkhead transverse, in N-cm (kgf-cm, lbf-in)

M_{1s} = bending moment M_1 for side transverse, in N-cm (kgf-cm, lbf-in)

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the midspan of ℓ_b of the transverse under consideration, as specified in 5C-3-3/Table 3

s = spacing of the webs in the lower wing tank, in m (ft)

ℓ_b = span of the transverse under consideration, in m (ft)

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

$= 0.7\, S_m f_y$

For the calculation of the section modulus, ℓ_b is to be taken not less than $c_1 \ell_o$.

where

ℓ_o = b_{SL} for sloping bulkhead transverse

= b_S for side transverse

= b_B for bottom transverse

c_1 = 0.4 for sloping bulkhead transverse and side transverse

= 0.5 for bottom transverse

b_{SL}, b_S and b_B are as shown in 5C-3-4/Figure 9.

The bending moment M for the bottom transverse is not to be less than 80% of the bending moment M for the sloping bulkhead transverse.

13.3.2 Web Sectional Area

The net sectional area of the web of the transverses in the lower wing tank is not to be less than obtained from the following equation:

$A = F_s/f_s$ cm^2 (in^2)

$F_s = 1000k_2\,ps(0.5\ell - h_e)$ N (kgf, lbf)

where

k_2 = 1 (1, 2.24)

ℓ = span, in m (ft), of the transverse under consideration as shown in 5C-3-4/Figure 9

h_e = length, in m (ft), of the end bracket as shown in 5C-3-4/Figure 9

For the calculation of the web sectional area, ℓ is to be taken not less than $c_1\ell_o$.

c_1, ℓ_o, p and s are as defined in 5C-3-4/13.3.1 above.

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.5\,S_m f_y$

13.3.3 Depth of Transverses in Lower Wing Tank *(1997)*

The depth of the transverses in the lower wing tank is not to be less than $c_2\ell_o$

where

c_2 = 0.12 for sloping bulkhead and side transverses

= 0.16 for the bottom transverse

ℓ_o is as defined in 5C-3-4/13.3.1 above.

In general, the depth of the transverse is to be not less than 2.5 times the depth of the slots.

13.5 Transverses in Upper Wing Tank in Way of Dry Cargo Holds

13.5.1 Section Modulus

The net section modulus of the transverses in the upper wing tank in association with the effective plating is not to be less than obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

$M = c_1(M_1 + M_2)$ for deck and sloping bulkhead transverses

$M = 2000k_1c_1p_s s b_{ss}(b)^2/(b_1 + 0.5\ell_s)$ N-cm (kgf-cm, lbf-in) for side transverse

$M_1 = 1000c_2\,p_s s(\ell_s)^2/k_2$ N-cm (kgf-cm, lbf-in)

$M_2 = 1000c_3\,p_d\,s(\ell_d)^2/k_2$ N-cm (kgf-cm, lbf-in)

where

k_1 = 1 (1, 0.269)

k_2 = 0.12 (0.12, 0.446)

c_1 = 1.0 for deck, sloping bulkhead and side transverses in the upper wing tank without longitudinal bulkhead

= 0.7 for deck and side transverses in the upper wing tank with longitudinal bulkhead

= 0.65 for sloping bulkhead transverse in the upper wing tank with longitudinal bulkhead

c_2 = $1.5/(1 + \beta)$ for deck transverse

= 1.0 for sloping bulkhead transverse

c_2 is not to be taken less than 0.5 for deck transverse.

c_3 = $1.5\beta/(1 + \beta)$ for deck transverse

= 0.50 for sloping bulkhead transverse

c_3 is not to be taken less than 0.8 for deck transverse.

β = $(\ell_d/\ell_s)(i_s/i_d)$

i_d, i_s = moments of inertia of the deck transverse and the sloping bulkhead transverse with effective plating, clear of end brackets

p_s = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2) at the midspan of ℓ_b of the sloping bulkhead transverse, as specified in 5C-3-3/Table 3

p_d = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2) at the midspan of ℓ_b of the deck transverse, as specified in 5C-3-3/Table 3

s = spacing of the webs in the upper wing tank, in m (ft)

ℓ_d, ℓ_s = span ℓ_b of the deck and sloping bulkhead transverses under consideration, in m (ft)

To obtain M for the deck and sloping bulkhead transverses, span ℓ_d is not to be taken less than $0.4b$ and span ℓ_b is not to be taken less than $0.4b_{su}$.

b, b_{su} = widths of the upper wing tank, in m (ft), as shown in 5C-3-4/Figure 9

b_1 = distance from the longitudinal hatch side girder to the side of the opening in the web, in m (ft), as shown in 5C-3-4/Figure 9

b_{ss} = height of the upper wing tank, in m (ft), as shown in 5C-3-4/Figure 9

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.85\, S_m f_y$

13.5.2 Web Sectional Area

The net sectional area of the web of the transverses in the upper wing tank is not to be less than obtained from the following equation.

$A = F/f_s$ cm^2 (in^2)

$F = 1000 k_3 c_1 c_2 c_3\, p_s s (b_1 + \ell_s)^2/(b_1 + 0.5\ell_s)$ N (kgf, lbf) for deck and side transverses

$F = 1000 c_2 c_3 (F_1 + F_2)$ N (kgf, lbf) for sloping bulkhead transverses

where

$F_1 = k_3 p_s s(0.5\ell - h_e)$

$F_2 = 0.8k_3 p_s s b_1^2/(b_1 + 0.5\ell_s)$

k_3 = 1 (1, 2.24)

c_1 = 0.38 for deck transverse

= 0.16 for side transverse

c_2 = $A_d/(A_d + A_s)$ for deck transverse

= $A_s/(A_d + A_s)$ for sloping bulkhead transverse

= 1.0 for side transverse

c_2 is not to be taken less than 0.42

A_d, A_s = web sectional areas of the deck and sloping bulkhead transverses, clear of the end brackets

c_3 = 1.0 for transverses in upper wing tank without longitudinal bulkhead

= 0.7 for transverses in upper wing tank with longitudinal bulkhead

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.5\, S_m f_y$

ℓ = span, in m (ft), of sloping bulkhead transverse, as shown in 5C-3-4/Figure 9

h_e = length, in m (ft), of the lower end bracket of the sloping bulkhead transverse, as shown in 5C-3-4/Figure 9

p_s, s, b, b_1 and ℓ are as defined in 5C-3-4/13.5.1 above.

13.5.3 Depth of Transverses in Upper Wing Tank

The depth of the transverses in the upper wing tank is not to be less than as specified below, respectively.

$0.15b_{ss}$ for side transverse

$0.085b$ for deck transverse

$0.085b_{su}$ for sloping bulkhead transverse

where

b, b_{ss} and b_{su} are as shown in 5C-3-4/Figure 9.

In general, the depth of the transverse is to be not less than 2.5 times the depth of the slots.

13.7 Transverses in Upper Wing Tank in Way of Ballast or Liquid Cargo Holds

Where a cargo hold is intended to be used for the carriage of water ballast or liquid cargoes, the net section modulus and the web sectional area of the transverses are also not to be less than obtained from the following requirements, respectively.

13.7.1 Section Modulus

The net section modulus of the side, deck and sloping bulkhead transverses in the upper wing tank in association with the effective plating is not to be less than obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

$M = 15k_1c_1psb_{su}b_{ss}(2B - b)/(B - b + 0.5\ell_s + b_1)$ N-cm (kgf-cm, lbf-in) for side transverse

$M = c_1(M_1 + M_2)$ for deck and sloping bulkhead transverse

$M_1 = 1000c_2ps(\ell_s)^2/k_2$ N-cm (kgf-cm, lbf-in)

$M_2 = 1000k_1c_3c_4psb_1\ell_b(2B - 2b + b_1)/(B - b + 0.5\ell_s + b_1)$ N-cm (kgf-cm, lbf-in)

where

k_1	=	100 (100, 26.9)	
k_2	=	0.12 (0.12, 0.446)	
c_1	=	1.0	for deck, sloping bulkhead and side transverses in upper wing tank without longitudinal bulkhead
	=	0.50	for sloping bulkhead transverse in upper wing tank with longitudinal bulkhead
	=	0.70	for deck and side transverses in upper wing tank with longitudinal bulkhead
c_2	=	1.0	for sloping bulkhead transverse
	=	$1.5/(1 + \beta)$	for deck transverse

c_2 is not to be taken less than 0.54 for the deck transverse.

c_3	=	0.095	for sloping bulkhead transverse
	=	0.035	for deck transverse
c_4	=	$0.233\beta + 0.034$	for sloping bulkhead transverse, if $\beta \le 2.0$
	=	$0.7\beta - 0.9$	for sloping bulkhead transverse if $\beta > 2.0$

c_4 is not to be taken less than 0.15 and need not be greater than 1.0 for sloping bulkhead transverse.

c_4 = $1.343 - 0.0714\beta$ for deck transverse

c_4 is not to be taken less than 1.0 for deck transverse.

β is as defined in 5C-3-4/13.5.1.

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the midspan of ℓ_b of the sloping bulkhead transverse, as specified in 5C-3-3/Table 3

ℓ_b = span of the transverse under consideration, in m (ft), as shown in 5C-3-4/Figure 9

ℓ_s = span of ℓ_b of the sloping bulkhead transverse, in m (ft), as shown in 5C-3-4/Figure 9

To obtain moment M_1, span ℓ_s is to be taken not less than $0.33b_{su}$.

s, B, b, b_1, b_{su} and b_{ss} are as defined in 5C-3-4/13.5.1.

f_b = permissible bending stress, in N/cm² (kgf/cm², lbf/in²)

= $0.85\ S_m f_y$

13.7.2 Web Sectional Area

The net sectional area of the web of the transverses in the upper wing tank is not to be less than obtained from the following equation:

$A = F/f_s$ cm² (in²)

$F = 1000k_3c_1c_2c_3psb_{su}(2B - b)/(B - b + 0.5\ell_s + b_1)$, N (kgf, lbf) for deck and side transverses

$= 1000c_1c_3(F_1 + F_2)$ N (kgf, lbf) for sloping bulkhead transverse

$F_1 = k_3\ 2.38ps(0.5\ell - h_e)$ N (kgf, lbf)

$F_2 = k_3\ 0.117psb_1(2B - 2b + b_1)/(B - b + 0.5\ell_s + b_1)$ N (kgf, lbf)

where

k_3 = 1.0 (1.0, 2.24)

c_2 = 0.16 for deck transverse

= 0.105 for side transverse

c_3 = $A_d/(A_d + A_s)$ for deck transverse

= $A_s/(A_d + A_s)$ for sloping bulkhead transverse

= 1.0 for side transverse

A_d, A_s, ℓ and h_e are as defined in 5C-3-4/13.5.2.

p, ℓ_s and c_1 are as defined in 5C-3-4/13.7.1.

B, s, b and b_1 are as defined in 5C-3-4/13.5.1.

ℓ = span, in m (ft), of sloping bulkhead transverse, as shown in 5C-3-4/Figure 9

h_e = length, in m (ft), of the lower end bracket of the sloping bulkhead transverse, as shown in 5C-3-4/Figure 9

f_s = permissible shear stress, in N/cm² (kgf/cm², lbf/in²)

= $0.5\ S_m f_y$

13.7.3 Depth of Transverses in Upper Wing Tank

The depth of transverses is to be as specified in 5C-3-4/13.5.3.

13.9 Minimum Thickness for Web Portion of Main Supporting Members

The net thickness of the web of the main supporting members is not to be less than 9.5 mm (0.374 in.)

13.11 Vertical Diaphragms and Side Stringers in Double Hull Side Tanks or Void Spaces *(2003)*

The net thickness of vertical diaphragms and side stringers is not to be less than 9.5 mm (0.374 in.).

13.11.1 Vertical Diaphragms

The net section modulus of vertical diaphragms in association with effective shell/inner skin plating to which they are attached is, in general, not to be less than obtained from the following.

$SM_{DP} = M/f_b$ in cm^3 (in^3)

where

$M = 1000\, c_1 p s \ell^2/k_2 + k_3 w b$ N-cm (kgf-cm, lbf-in)

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the middle of the unsupported span, ℓ, as specified in 5C-3-3/Table 3B case "a" and case "b", respectively

s = spacing of vertical diaphragms in mm (in.)

ℓ = unsupported span between the top side tank and the lower wing tank

w = weight of the ballast water in upper wing tank per spacing of vertical diaphragm for one side (port or starboard), in N (kgf, lbf)

f_b = $0.85 S_m f_y$

c_1, k_2, k_3, b, S_m and f_y are defined in 5C-3-4/11.3.

Where the cargo hold is intended to be used for the carriage of water ballast or liquid cargoes, the net section modulus of the diaphragms is, in general, not to be less than obtained from the following equation:

$SM_{DP} = M/f_b$ in cm^3 (in^3)

$M = 1000\, c_1 p s \ell^2/k_2$ N-cm (kgf-cm, lbf-in)

where

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the middle of the unsupported span, ℓ, as specified in 5C-3-3/Table 3B for vertical diaphragms (ballast or liquid cargo holds)

All other parameters are as defined above.

13.11.2 Side Stringers

The net thickness of a side stringer is also to be not less than t, obtained from the following equation:

$t = cs(S_m f_y/E)^{1/2}$ mm (in.)

where

c = $0.7N^2 - 0.2$, not to be less than 0.33

s = spacing of longitudinals, in mm (in.)

S_m = strength reduction factor, obtained from 5C-3-4/7.3.1, for the steel grade of the stringer

f_y = minimum specified yield point of the stringer material, in N/cm^2 (kgf/cm^2, lbf/in^2)

N = $R_d[(Q/Q_d)(y/y_n)]^{1/2}$ for stringers above neutral axis

= $R_b[(Q/Q_b)(y/y_n)]^{1/2}$ for stringers below neutral axis

Q = material conversion factor in 5C-3-4/5.1 for the side stringer under consideration

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the side stringer under consideration

E, R_b and Q_b are as defined in 5C-3-4/7.3.1. R_d, Q_d and y_n are as defined in 5C-3-4/9.1.

The net thickness, t, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

13.11.3 Grillage Analysis

The net scantlings of vertical diaphragms and associated side stringers may be determined based on a grillage analysis, provided that the calculated stresses for the nominal pressure as specified in 5C-3-3/Table 3B for vertical diaphragms and side stringers do not exceed the following permissible values:

Permissible Bending Stress, f_b:	$0.85S_mf_y$	for vertical diaphragms
	$0.75S_mf_y$	for horizontal stringers
Permissible Shear Stress, f_s:	$0.50S_mf_y$	for vertical diaphragms
	$0.45S_mf_y$	for horizontal stringers

FIGURE 6
Definitions of Parameters for Hold Frame *(2003)*

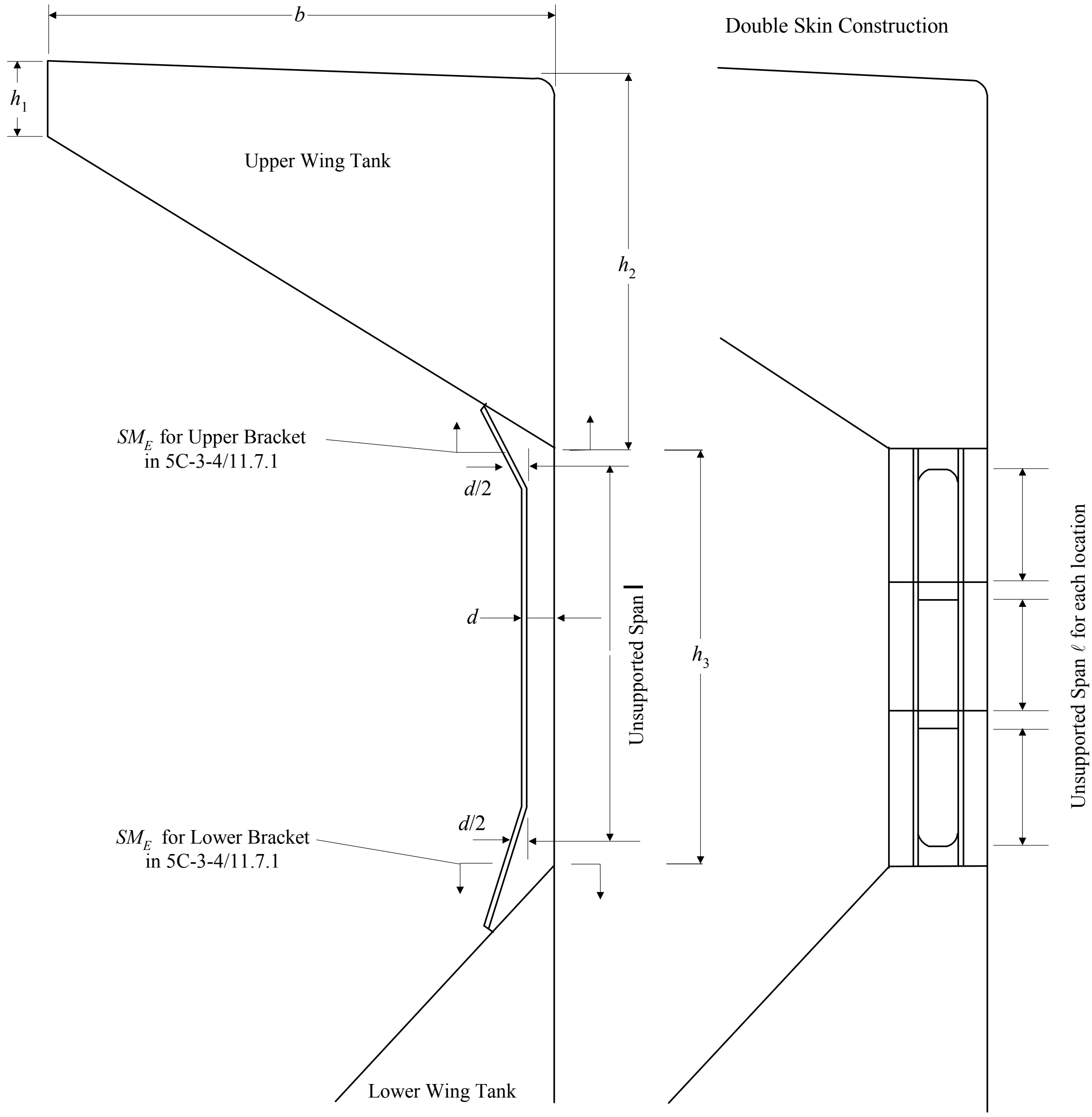


FIGURE 7
(1 July 1998)

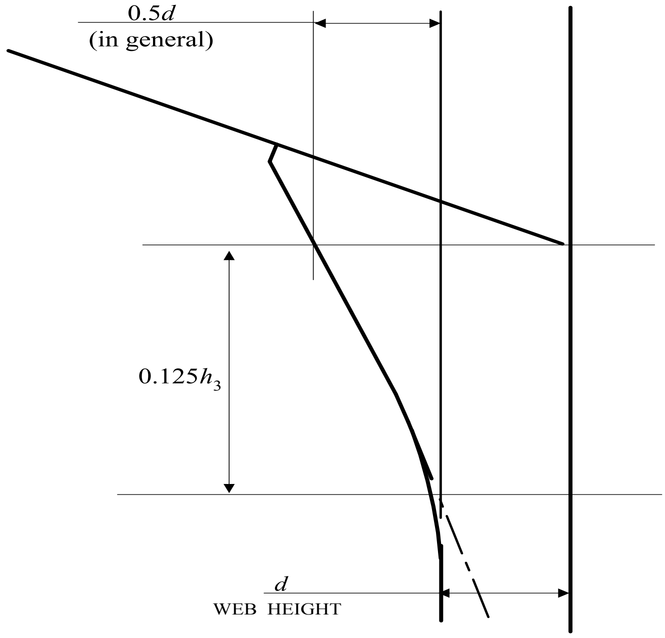


FIGURE 8
(1 July 1998)

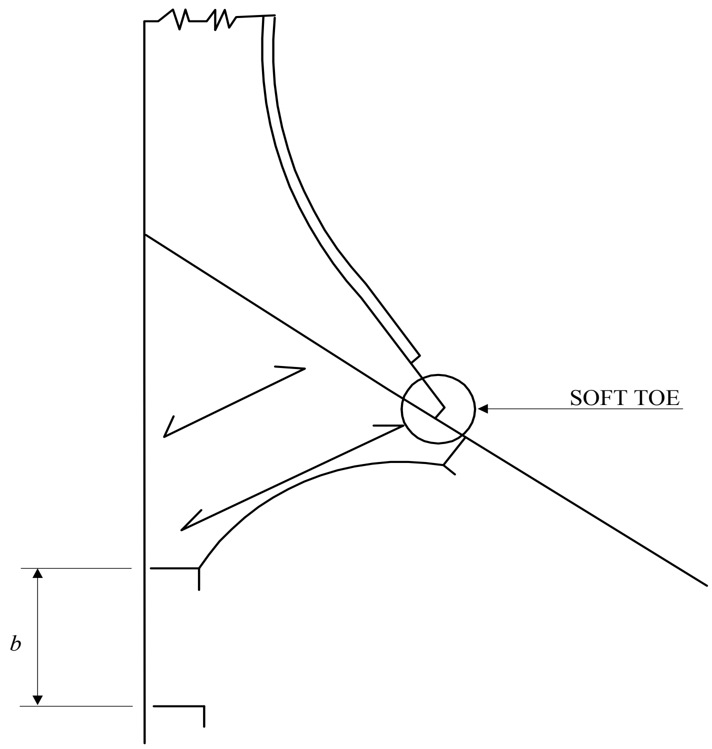
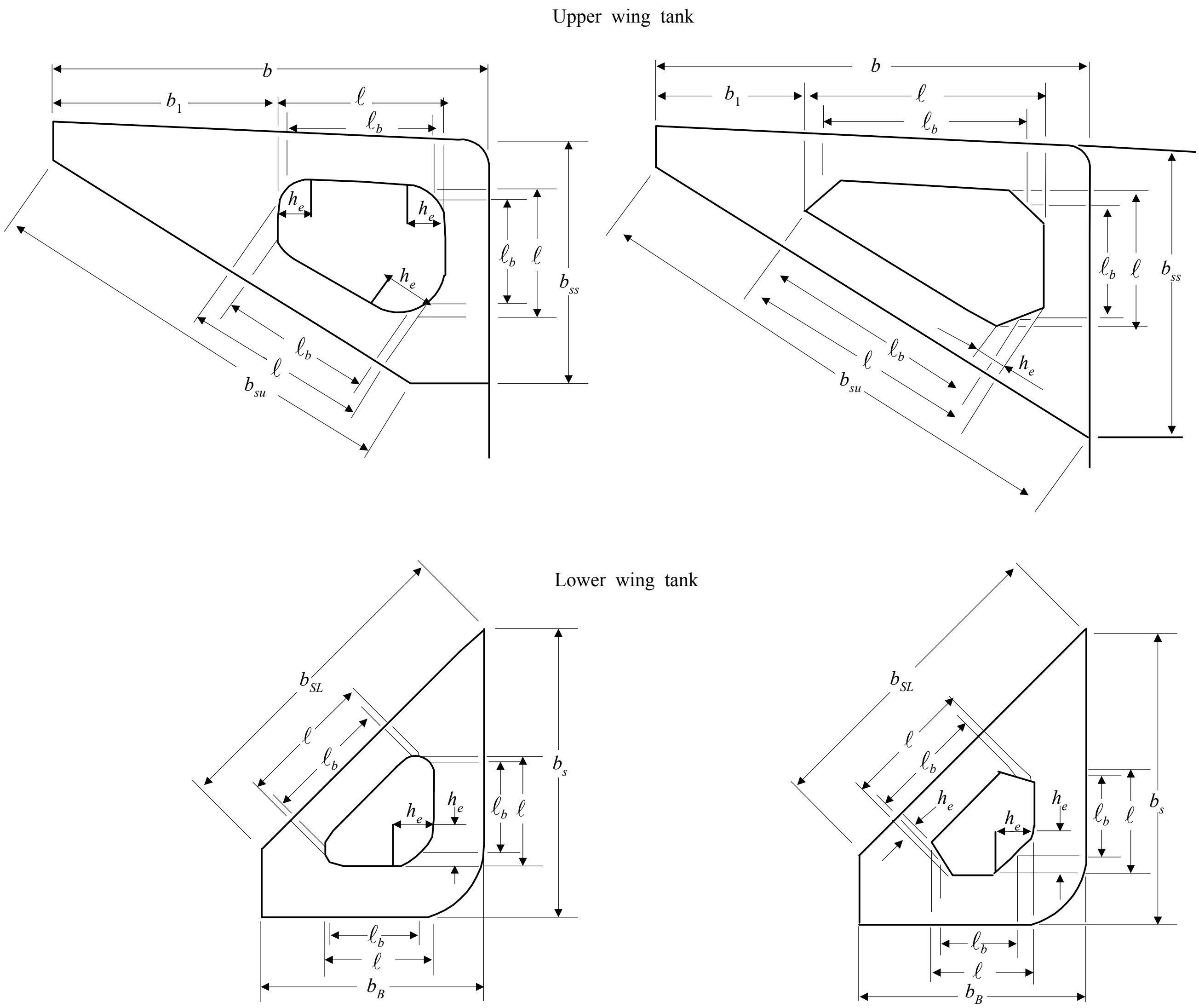


FIGURE 9
Transverses in Wing Tanks Definition of Span



15 Deck Plating and Longitudinals/Beams

15.1 Main Deck Plating *(1999)*

The net thickness of the strength deck plating is to be not less than that needed to meet the hull girder section modulus requirement in 3-2-1/3.7 and the buckling and ultimate strength requirements in 5C-3-5/5. In addition, the net thickness of deck plating is to be not less than t_1, t_2 and t_3, as specified below for the midship 0.4*L*:

$t_1 = 0.73s(k_1 p/f_1)^{1/2}$ mm (in.)

$t_2 = 0.73s(k_2 p/f_2)^{1/2}$ mm (in.)

$t_3 = cs(S_m f_y/E)^{1/2}$ mm (in.)

where

s = spacing of deck longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.50

p = $p_n - p_{uh}$

In no case is p to be taken less than 2.06 N/cm² (0.21 kgf/cm², 2.987 lbf/in²)

p_n is nominal pressure, in N/cm² (kgf/cm², lbf/in²), as defined in 5C-3-3/Table 3, for deck plating.

p_{uh} is as defined in 5C-3-4/7.3.1.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

f_1 = permissible bending stress, in the longitudinal direction

= $0.15\, S_m f_y$, in N/cm² (kgf/cm², lbf/in²)

f_2 = permissible bending stress, in the transverse direction

= $0.80\, S_m f_y$, in N/cm² (kgf/cm², lbf/in²)

c = $0.5\,(0.6 + 0.0015L)$ for SI or MKS Units

= $0.5\,(0.6 + 0.0046L)$ for U.S. Units

c is not to be taken less than $0.7N^2 - 0.2$ for vessels less than 267 m (876 ft) in length.

L = length of vessel, in m (ft), as defined in 3-1-1/3.1

N = $R_d\,(Q/Q_d)^{1/2}$

R_d = $(SM_{RDS}/SM_D)^{1/2}$

Q = material conversion factor in 5C-3-4/5 for the deck plating

S_m, f_y and E are as defined in 5C-3-4/7.3.1.

SM_{RDS} and Q_d are as defined in 5C-3-4/9.1.

SM_D is as defined in 5C-3-4/9.3.

15.3 Main Deck Longitudinals *(1999)*

The net section modulus of each deck longitudinal, in association with the effective plating to which it is attached, is to be not less than obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

$M = 1000ps\ell^2/k$ N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 83.33)

p = nominal deck pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-3-4/15.1

s, ℓ are as defined in 5C-3-4/7.5

f_b = permissible bending stresses, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $(1.0 - 0.60\alpha_2 SM_{RD}/SM_D)S_m f_y$

α_2 = $S_{m2}\, f_{y2}/S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.5.

S_{m2} = strength reduction factor for the steel grade of the top flange material of the hull girder, obtained from 5C-3-4/7.3.1

f_{y2} = minimum specified yield point of the top flange material of the hull girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

SM_{RD} and SM_D are as defined in 5C-3-4/9.3.

The effective breadth of plating, b_e, is as defined in 5C-3-47.5.

The net moment of inertia of each deck longitudinal in association with the effective plating ($b_{wL} \cdot t_n$), is to be not less than i_o, as specified in 5C-3-4/9.3.

15.5 Cross Deck Plating

The net thickness of the cross deck plating is to satisfy the buckling requirements in Section 5C-3-5 and is not to be less than t_1, t_2 and t_3, as obtained from the following equations:

$t_1 = 0.02L + 4.5$ mm

$= 0.00024L + 0.18$ in.

$t_2 = s/90$ mm (in.)

$t_3 = k_1F/(wf_s)$ mm (in.)

but not to be less than 8.5 mm (0.33 in.)

where

L = length of the vessel, as defined in 3-1-1/3.1, in m (ft)

s = spacing of deck beams, in mm (in.)

k_1 = 0.1 (0.1, 0.083)

F = $k_2(1 + 0.74b_o/w)T_M(L_H)^2wn^2/(DB^3)$ N (kgf, lbf)

k_2 = 24 (24, 53.76)

L_H	=	length of the longest hold within the midship 0.4L, in m (ft)
T_M	=	torsional moment, in kN-m (tf-m, Ltf-ft), as defined in 5C-3-3/5.3.3
b_o	=	width of the hatch opening, in m (ft)
w	=	width of the cross deck structure, in m (ft), as indicated in 5C-3-4/Figure 10
n	=	total number of holds
B	=	breadth of the vessel, as defined in 3-1-1/5, in m (ft)
D	=	depth of the vessel, as defined in 3-1-1/7.3, in m (ft)
f_s	=	permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)
	=	0.45 $S_m f_y$

15.7 Cross Deck Beams

15.7.1 Section Modulus *(1997)*

The net section modulus of the deck beam inside the lines of hatch openings, in association with the effective deck plating, is not to be less than obtained from the following equation.

$$SM = M/f_b \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

M is equal to M_1 or M_2, whichever is larger.

$$M_1 = 100 c_1 p s b_o^2 / k \qquad \text{N-cm (kgf-cm, lbf-in)}$$

$$M_2 = 100 p s \ell^2 / k \qquad \text{N-cm (kgf-cm, lbf-in)}$$

where

k	=	12 (12, 0.536)
c_1	=	$1/(n + 1)^2$, not to be taken less than 0.02 and need not be greater than 0.05
p	=	nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), as specified in 5C-3-3/Table 3 for deck at centerline, not to be less than 20.6 kN/m^2 (2.1 tf/m^2, 0.192 Ltf/ft^2)
s	=	spacing of the deck beams, in mm (in.)
b_o	=	width of the hatch opening, in m (ft)
ℓ	=	maximum unsupported span of the deck beam, in m (ft)
n	=	number of deck girders inside the lines of hatch openings
f_b	=	permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)
	=	0.4 $S_m f_y$

The effective breadth of plating, b_e, is as defined in 5C-3-4/7.5.

15.7.2 Moment of Inertia

The net moment of inertia of the deck beam inside the lines of hatch openings, in association with the effective plating ($b_{wL} \cdot t_n$), is to be not less than that obtained from the following equation:

$$i_o = kA_e \ell^2 f_y / E \qquad \text{cm}^4 \text{ (in}^4\text{)}$$

where

k = 2440 (2440, 35.14)

A_e = net sectional area of the beam with the associated effective plating (b_{wL} t_n), in cm^2 (in^2)

b_{wL} = $c_e s$

c_e = $2.25/\beta - 1.25/\beta^2$ for $\beta \geq 1.25$

= 1.0 for $\beta < 1.25$

β = $(f_y/E)^{1/2}\, s/t_n$

t_n = net thickness of the plate, in mm (in.)

ℓ = unsupported span of the beam, in m (ft)

s and f_y are as defined in 5C-3-4/7.5.

E is as defined in 5C-3-4/7.3.1.

15.9 Stiffness of Cross Deck Structures *(1996)*

15.9.1 Minimum Sectional Area

The total net sectional area of the cross deck structure at vessel's centerline, inside the lines of hatch openings (see 5C-3-4/Figure 10), between two adjacent hatch openings is not to be less than that obtained from the following equation:

$$A = F/f_c \qquad \text{cm}^2 \text{ (in}^2\text{)}$$

$$F = F_1 + F_2$$

$$F_1 = kc(Q - 0.544P)B/D \qquad \text{N (kgf, lbf)}$$

$$F_2 = kpDL_H \qquad \text{N (kgf, lbf)}$$

where

k = 250 (250, 560)

Q = total cargo weight, in kN (tf, Ltf), with full cargo loads in the two adjacent holds considered

P = $2L_H B d\gamma$, in kN (tf, Ltf)

γ = 10.05 (1.025, 0.0286), in kN/m^3 (tf/m^3, Ltf/ft^3)

c = $0.312 - 0.0688 L_H/B$ if $L_H/B \geq 0.9$

= $0.3625 - 0.125\, L_H/B$ if $L_H/B < 0.9$

L_H = $0.5(L_{H1} + L_{H2})$

L_{H1}, L_{H2} = length of the adjacent holds, in m (ft)

B = breadth of the vessel, as defined in 3-1-1/5, in m (ft)

D = depth of the vessel, as defined in 3-1-1/7.3, in m (ft)

d = design draft of the vessel, as defined in 3-1-1/9, in m (ft)

p = $1.02k_1C_1$, in kN/m^2 (tf/m^2, Ltf/ft^2)

k_1 = 9.8 (1.00, 0.0914)

C_1 is as defined in 3-2-1/3.5.

f_c = permissible compressive stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.7\,S_m f_y$

The following items may be included in the calculation of the sectional area A:

- Deck plating and continuous beams
- Upper stool or box structure on top of bulkhead corrugation
- Hatch-end beams below the deck

15.9.2 Section Modulus

The total net section modulus of the cross deck structure at any section with respect to the vertical axis (z axis shown in 5C-3-4/Figure 10) is not to be less than that obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

$M = Fb_1$ N-cm (kgf-cm, lbf-in)

where

F = shear force, in N (kgf, lbf), as defined in 5C-3-4/15.5

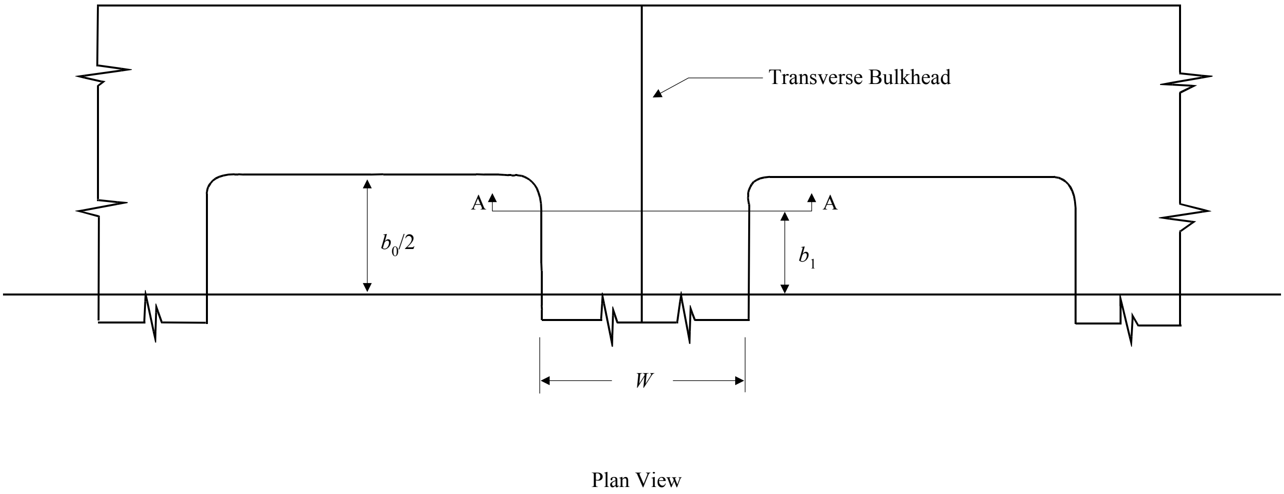
b_1 = transverse distance, in cm (in.), from centerline of the vessel to the section of the cross deck structure under consideration, as indicated in 5C-3-4/Figure 10, b_1 is not to be more than $0.5b_o$, where b_o = width of hatch opening

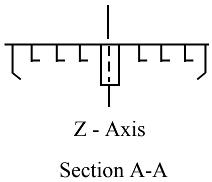
f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.70\,S_m f_y$

The items included in the calculation of the section modulus are as specified in 5C-3-4/15.9.1.

FIGURE 10
Cross Deck Structure





17 Deck Girders and Main Supporting Members *(1996)*

17.1 General

The main supporting members such as the transverse webs and girders are to be arranged and designed as indicated in 5C-3-4/13.1.

17.3 Hatch Side Girders

The depth of the hatch-side girder below the deck is not to be less than obtained from the following equation:

$$d_w = c_1 c_2 \ell_o / 25 \qquad \text{m (ft)}$$

where

ℓ_o = length of the hatch opening, in m (ft)

c_1 = 0.85 if $n = 2$

= 0.75 if $n \geq 3$

n = number of transverse webs in the upper wing tank between two ends of the hatch opening

c_2 = 1 for upper wing tank without longitudinal bulkhead

= 0.9 for upper wing tank with longitudinal bulkhead

17.5 Hatch-End Beams

17.5.1 Section Modulus

The least net section modulus of the hatch-end beam including hatch coaming in association with effective deck plating is not to be less than obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

M is $\overline{M_1}$ or $\overline{M_2}$, whichever is greater, as obtained from the following equations:

$\overline{M_1} = M_1 + 0.75M_2$

$\overline{M_2} = M_2 + 0.80M_1$

$M_1 = C_1(0.25q\ell_0 b_0^2 + 0.375p\ell_1 b_0^2)\ 10^5/k_1$ N-cm (kgf-cm, lbf-in)

$M_2 = 0.08 b_0^2\ (M_c + 0.5F_c h)/[sw(n + 1)]$ N-cm (kgf-cm, lbf-in)

if transverse bulkhead connected with hatch-end beam under consideration has upper stool.

$M_2 = 0.5M_{c1} b_0^2/[sw(n + 1)]$ N-cm (kgf-cm, lbf-in)

if transverse bulkhead connected with hatch-end beam under consideration does not have upper stool.

where

k_1 = 12 (12, 44.64)

C_1 = $1/(1 + \beta^3)$

M_c, M_{c1} = bending moment M, in N-cm (kgf-cm, lbf-in), as defined in 5C-3-4/25.5, at the upper end of corrugation span for transverse bulkhead with upper stool (M_c) and without upper stool (M_{c1}), loaded with dry cargo, ballast or liquid cargo

F_c = shear force, in N (kgf, lbf), at the upper end of corrugation span for transverse bulkhead with upper stool, loaded with dry cargo, ballast or liquid cargo

= $k_2 s\ell\ (0.125p_\ell + 0.375p_u)10^4$

k_2 = 1 (1, 0.0144)

β = $0.45\ [(I/i)\ (b_0/w)^3\ (n + 1)]^{1/4}$

I = net moment of inertia, in m^4 (ft^4), of cross deck girder or supporting bracket closest to vessel's centerline at the midspan of ℓ_1 (with effective deck plating)

i = net moment of inertia, in m^4 (ft^4), of hatch-end beam including hatch coaming at vessel's centerline (with effective deck plating)

b_0 = width, in m (ft), of the hatch opening

ℓ_0 = length, in m (ft), of the hatch opening

ℓ_1 = distance in m (ft) between the hatch-end beam and the adjacent transverse bulkhead or upper stool. ℓ_1 is not to be less than $0.5w$ to obtain M_1.

w = width of the cross deck structure, in m (ft), as shown in 5C-3-4/Figure 10

s = spacing of corrugation, in m (ft), as shown in 5C-3-4/Figure 11

h = height of the upper stool at vessel's centerline, in cm (in.)

n = number of deck girders or supporting brackets between lines of hatch openings

q = hatch cover load, in kN/m^2 (tf/m^2, Ltf/ft^2), at the center of hatch opening, mimimum 20.6 kN/m^2 (2.1 tf/m^2, 0.192 Ltf/ft^2); design hatch cover load, green water (see 5C-3-3/5.5.4) or internal pressure for ballast or liquid cargo tanks as specified in 5C-3-3/Table 3, whichever is greater

p = deck load, in kN/m^2 (tf/m^2, Ltf/ft^2), at the midspan of ℓ_1, minimum 20.6 kN/m^2 (2.1 tf/m^2, 0.192 Ltf/ft^2); design deck load, green water (see 5C-3-3/5.5.4) or internal pressure for ballast or liquid cargo tanks as specified in 5C-3-3/Table 3, whichever is greater

p_ℓ, p_u, ℓ are as defined in 5C-3-4/25.3.

f_b = permissible bending stress in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.95\, S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.3.1.

17.5.2 Depth

The depth of the hatch-end beam below the deck is not to be less than that obtained from the following equation:

$d_w = c_1 b_o/20$ m (ft)

where

c_1 = $1.2 - 0.05n$, not to be less than 0.75 and need not be greater than 1.0

n = number of the deck girders or supporting brackets inside the lines of hatch openings

b_o = width of the hatch opening, in m (ft). For calculation of d_w, b_o is not to be taken less than $0.46B$

B = breadth of the vessel, in m (ft), as defined in 3-1-1/5

17.7 Deck Girders Inside the Lines of Hatch Openings

17.7.1 Section Modulus *(1997)*

The least net section modulus of the deck girder or supporting bracket, clear of end brackets in association with effective deck plating, is not to be less than that obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

M is not to be less than $\overline{M_1}$, $\overline{M_2}$ and $\overline{M_3}$, as obtained from the following equations:

$$\overline{M_1} = M_1 + 0.75M_2$$

$$\overline{M_2} = M_2 + 0.80M_1$$

$\overline{M_3} = M_3 + 0.70M_1$

$M_1 = 0.7k_1\phi_1(0.25q\gamma_1 b_0\ell_0\ell_1 + p\gamma_2 b_0\ell_1^2)\,10^5/(n+1)$ N-cm (kgf-cm, lbf-in)

$M_2 = 0.5c_1\phi_2 b_0(M_c + 0.5F_c h)/[s(n+1)]$ N-cm (kgf-cm, lbf-in)

if transverse bulkhead, connected with deck girder or supporting bracket under consideration, has upper stool.

$M_2 = 0.5\phi_2 M_{c1} b_0/[s(n+1)]$ N-cm (kgf-cm, lbf-in)

if transverse bulkhead, connected with deck girder or supporting bracket under consideration, does not have upper stool.

$M_3 = 0.15k_1k_v cQ_1\phi_2 B^3 I\,10^5/(w^2AD^2)$ N-cm (kgf-cm, lbf-in)

where

k_1 = 1.0 (1.0, 0.269)

C_1 = $0.3\alpha^{1.5}$, not to be less than 0.05 and need not be greater than 0.25

γ_1 = $1.03\beta - 0.356$, not to be less than 0.05 and need not be greater than 1.0

γ_2 = $0.39\beta - 0.0085$, not to be less than 0.13 and need not be greater than 0.5

F_c, M_c and M_{c1} are as defined in 5C-3-4/17.5.1 above.

Q_1 = $Q - 0.68P/k_v$

α = $(b_0/w)(1000I/A_d^2)$

ϕ_1 = $1.125 - 1.25h_e/\ell_1$

ϕ_2 = $1 - h_e/\ell_1$

h_e = length of the bracket of the deck girder, in m (ft), as shown in 5C-3-4/Figure 12

A = total net sectional area of cross deck structure at vessel's centerline, in m^2 (ft^2), as defined in 5C-3-4/15.9.1

A_d = cross sectional area, in m^2 (ft^2), enclosed by the outside lines of upper stool

q, p, b_0, ℓ_0, ℓ_1, w, n, h, s and β are as defined in 5C-3-4/17.5.1 above.

c, Q, P, B, and D are as defined in 5C-3-4/15.9.1.

k_v is as defined in 5C-3-3/5.7.1(c) for the transverse bulkhead connected with the deck girder or supporting bracket under consideration.

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.95\,S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.3.1.

17.7.2 Depth

The depth of the deck girder inside the lines of hatch openings is not to be less than d_{w1} and d_{w2}, as defined below.

$$d_{w1} = b_o/25 \quad \text{m (ft)}$$

$$d_{w2} = \ell_o/25 \quad \text{m (ft)}$$

b_o and ℓ_o are as defined in 5C-3-4/17.5.1 above.

17.9 Minimum Thickness for Web Portion of Main Supporting Members

The net thickness of the web of the deck girder, supporting bracket or hatch-end beam is not to be less than 9.5 mm (0.374 in.).

FIGURE 11
Definition of Parameters for Corrugated Bulkhead

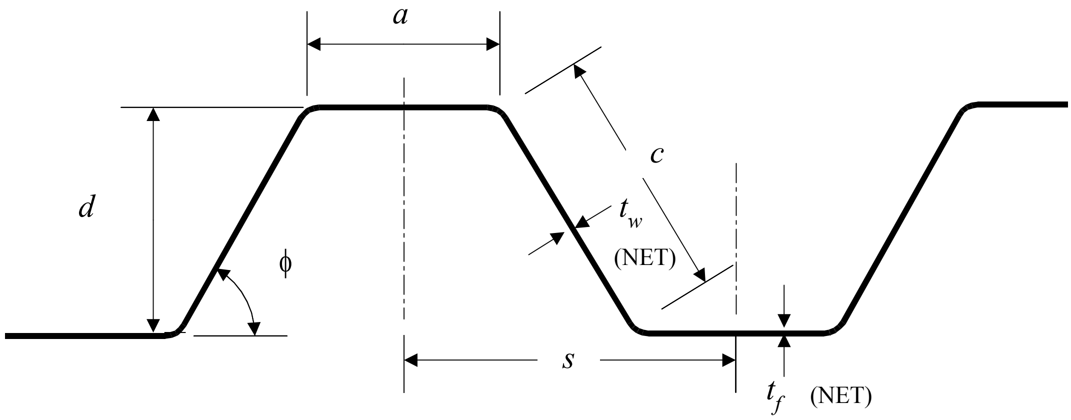
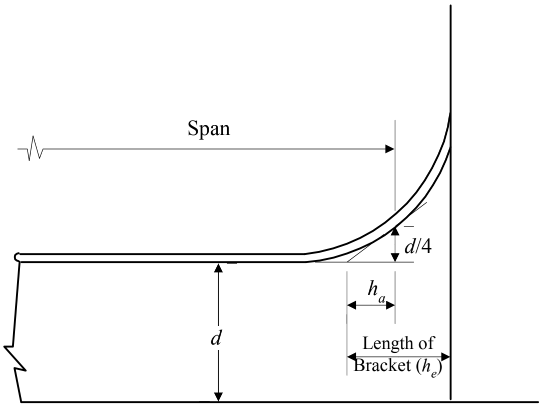
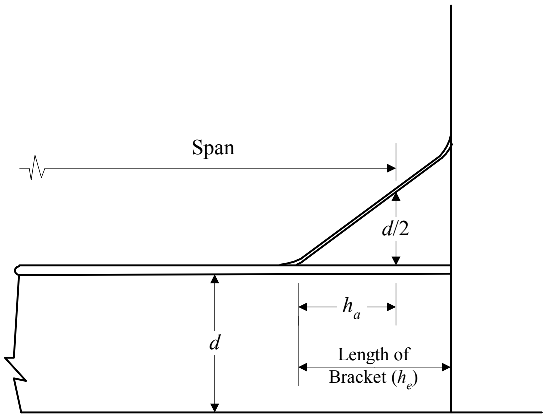


FIGURE 12
Effectiveness of Brackets

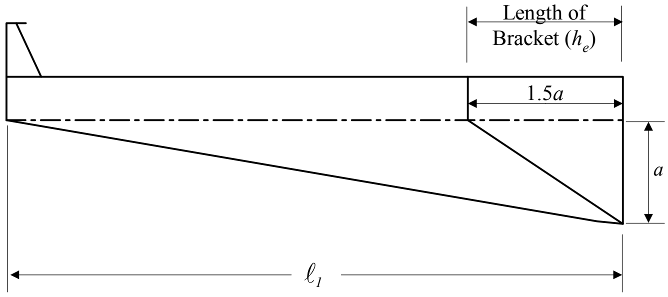


Where face plate area on the member is carried along the face of the bracket



Where face plate area on the member is not carried along the face of the bracket,and where the face plate area on the bracket is at least one-half the face plate area on the member.

Brackets are not to be considered effective beyond the point where the arm on the girder or web is 1.5 times the arm on the bulkhead or base.



Length of the "effective" bracket for supporting crossdeck bracket

19 Cargo Hold Hatch Covers, Hatch Coamings and Closing Arrangements *(2004)*

19.1 Application

The following requirements apply to bulk carriers, ore carriers and combination carriers, and are for all hatch covers, hatch coamings and closing arrangements for cargo hold hatches in position 1, as defined in 3-2-15/3.1.

These requirements for hatch covers, hatch coamings and closing arrangements are in addition to those in the applicable parts of Section 3-2-15.

19.3 Hatch Covers

These strength requirements are applicable to hatch covers of stiffened plate construction. The secondary stiffeners and primary supporting members of the hatch covers are to be continuous over the breadth and length of the hatch covers, as far as practical. When this is impractical, sniped end connections are not to be used and appropriate arrangements are to be adopted to ensure sufficient load carrying capacity.

Material for the hatch covers is to be steel, in accordance with Part 2, Chapter 1. The welding procedures including consumables are to be as required for the grade and thickness of the steel used.

19.3.1 Nominal Design Corrosion Values and Net Thickness

19.3.1(a) Nominal Design Corrosion Value. The nominal design corrosion value is to be taken as follows:

For all structures (plating and secondary stiffeners) of single skin hatch covers:

2.0 mm (0.08 in.)

For double plated hatch covers:

top and bottom plating	2.0 mm (0.08 in.)
internal structures	1.5 mm (0.06 in.)

19.3.1(b) Net Thickness In the calculation of the hatch covers, net thickness as indicated in 5C-3-2/1.1 is to be used.

19.3.2 Hatch Cover Design Pressures

19.3.2(a) On Freeboard Deck. Hatch covers are to withstand a design pressure, p, on the hatch cover panels for hatchways located at the freeboard deck:

$$p = p_0 + (p_{FP} - p_0)\,(0.25 - x/L_f)/0.25 \qquad \text{kN/m}^2\ (\text{tf/m}^2,\ \text{Ltf/ft}^2)$$

where

p_0	=	34.3 (3.5, 0.32)	kN/m^2 (tf/m^2, Ltf/ft^2)
p_{FP}	=	pressure at the forward perpendicular	
	=	$49.0 + a(L_f - 100)$	kN/m^2 for L_f in meters
	=	$5 + a(L_f - 100)$	tf/m^2 for L_f in meters
	=	$0.457 + a(L_f - 328)$	Ltf/ft^2 for L_f in feet

a = 0.0726 (0.0074, 0.000206) kN/m^2 (tf/m^2, Ltf/ft^2), for type B freeboard ships

= 0.356 (0.0363, 0.00101) kN/m^2 (tf/m^2, Ltf/ft^2), for ships with reduced freeboard

L_f = freeboard length, in m (ft), as defined in 3-1-1/3.3, to be taken not greater than 340 m (1115 ft)

x = distance, in m (ft), of the mid length of the hatch cover under examination from the forward end of L_f or $0.25L_f$, whichever is less

19.3.2(b) On Superstructure Deck. Where a position 1 hatchway is located at least one superstructure standard height higher than the freeboard deck, the pressure p may be 34.3 kN/m^2 (3.5 tf/m^2, 0.32 Ltf/ft^2).

19.3.2(c) Mechanically Connected Covers. Where two or more panels are connected by hinges, each individual panel is to be considered separately.

19.3.2(d) Other Considerations. For hatch covers in holds intended for the carriage of liquid, the structure is to be of adequate strength to resist the upward pressure of ballast water or cargo oil in the holds caused by the pitch and roll motions of the vessel specified for load cases 5 and 7 in 5C-3-3/Table 1.

Where P/V valves are fitted, the strength of the covers is to be verified for a pressure corresponding to the P/V valve setting.

19.3.3 Allowable Stress and Deflection

19.3.3(a) Allowable Stress. The normal stress σ and shear stresses τ in the hatch cover structures are not to exceed the allowable values, σ_a and τ_a, given by:

$\sigma_a = 0.8\ \sigma_F$ N/mm^2 (kgf/mm^2, psi)

$\tau_a = 0.46\ \sigma_F$ N/mm^2 (kgf/mm^2, psi)

where

σ_F = the specified yield stress, in N/mm^2 (kgf/mm^2, psi), of the material.

The normal stress in compression of the plating forming the flange of primary supporting members is not to exceed 0.8 times the critical buckling stress of the structure in 5C-3-4/19.3.7.

19.3.3(b) Allowable Deflection. The vertical deflection of primary supporting members is to be not more than 0.0056ℓ, where ℓ is the greatest span of primary supporting members.

19.3.4 Top Plate Thickness

The plate thickness, t, of the hatch cover top plating is not to be less than:

$$t = c_t F_p s \sqrt{\frac{p}{0.95\sigma_F}} \quad \text{mm (in.)}$$

but to be not less than the greater of 1% of the spacing of the stiffeners or 6 mm (0.24 in.).

where

c_t = 0.0158 (0.0158, 1.97)

F_p = factor for combined membrane and bending response

= 1.50 in general

= $1.90\sigma/\sigma_a$, for $\sigma/\sigma_a \geq 0.8$, for plates forming the flange of primary supporting members

s = stiffener spacing, in mm (in.)

p = pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), as defined in 5C-3-4/19.3.2(a) or 5C-3-4/19.3.2(b)

σ = as defined in 5C-3-4/19.3.6(a)

σ_a, σ_F = as defined in 5C-3-4/19.3.3(a)

19.3.5 Secondary Stiffeners

The required minimum section modulus, *SM*, of secondary stiffeners on the hatch cover top plate, based on stiffener net member thickness, is given by:

$$SM = c_s \frac{\ell^2 sp}{12\sigma_a} \quad \text{cm}^3 \text{ (in}^3\text{)}$$

where

c_s = 1 (1, 2240)

ℓ = secondary stiffener span, in m (ft), to be taken as the spacing, in m (ft), of primary supporting members or the distance between a primary supporting member and the edge support, as applicable. When brackets are fitted at both ends of all secondary stiffener spans, the secondary stiffener span may be reduced by an amount equal to $^2/_3$ of the minimum brackets arm length, but not greater than 10% of the gross span for each bracket.

s = secondary stiffener spacing, in mm (in.)

p = pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), as defined in 5C-3-4/19.3.2(a) or 5C-3-4/19.3.2(b)

σ_a = as defined in 5C-3-4/19.3.3(a)

The net section modulus of the secondary stiffeners is to be determined based on an attached plate width assumed equal to the stiffener spacing.

19.3.6 Primary Supporting Members

The spacing of primary supporting members parallel to the direction of secondary stiffeners is not to exceed $^1/_3$ of the span of primary supporting members.

Where it is intended that the covers may carry containers, the requirements of 3-2-15/9.9 are also to be satisfied.

19.3.6(a) Scantlings. The section modulus and web thickness of primary supporting members, based on member net thickness, are to be such that the normal stress σ in both flanges and the shear stress τ, in the web, do not exceed the allowable values σ_a and τ_a, respectively, as defined in 5C-3-4/19.3.3(a).

The stresses in hatch covers that are designed as a grillage of longitudinal and transverse primary supporting members are to be determined by a grillage or a finite element analysis.

19.3.6(b) Effective Flange Area. The effective flange area, A_f, of the plating forming the flange, to be considered for the yielding and buckling checks of primary supporting members, when calculated by means of a beam or grillage model, is obtained as the sum of the effective flange areas of each side of the girder web as indicated below:

$$A_f = \sum_{nf} \left(\frac{b_{ef}\, t}{c_a} \right) \text{ cm}^2 \text{ (in}^2\text{)}$$

where

c_a = 100 (100, 1)

nf = 2 if the plate extends on both sides of web

= 1 if the plate extends on one side of web only

t = net thickness of plate under consideration, in mm (in.)

b_{ef} = effective breadth of flange on each side of web

= b_p, but not to be taken greater than:

= 165ℓ mm, for ℓ in m

= 2ℓ in., for ℓ in ft

b_p = half distance, in m (ft), between the primary supporting member under consideration and the adjacent one

ℓ = span, in m (ft), of primary supporting member under consideration

When a beam or a grillage analysis is used, the secondary stiffeners are not to be included in the attached flange area of the primary members.

19.3.6(c) Flanges. The breadth of flange is to be not less than 40% of the depth of the primary supporting member where the distance between lateral supports is greater than 3.0 m (10 ft). Tripping brackets attached to the flange may be considered as a lateral support for the flange.

The outstanding flange is not to exceed 15 times the flange thickness.

19.3.7 Critical Buckling Stress

19.3.7(a) Hatch Cover Plating

i) *Parallel to Secondary Stiffener.* The compressive stress σ in the hatch cover plate panels, induced by the bending of primary supporting members parallel to the direction of secondary stiffeners, is not to exceed 0.8 times the critical buckling stress σ_{C1}, to be evaluated as defined below:

$$\sigma_{C1} = \sigma_{E1} \qquad \text{when } \sigma_{E1} \le \sigma_F/2$$

$$= \sigma_F[1 - \sigma_F/(4\sigma_{E1})] \qquad \text{when } \sigma_{E1} > \sigma_F/2$$

where

σ_F = as defined in 5C-3-4/19.3.3(a)

$$\sigma_{E1} = 3.6E\left(\frac{t}{s}\right)^2 \text{ N/mm}^2 \text{ (kgf/mm}^2\text{, psi)}$$

E = modulus of elasticity of steel

= 2.06×10^5 N/mm^2 (21,000 kgf/mm^2, 30×10^6 psi)

t = net thickness, in mm (in.), of plate panel

s = spacing, in mm (in.), of secondary stiffeners

ii) Perpendicular to Secondary Stiffener. The mean compressive stress σ in each of the hatch cover plate panels, induced by the bending of primary supporting members perpendicular to the direction of secondary stiffeners, is not to exceed 0.8 times the critical buckling stress σ_{C2} as defined below:

$\sigma_{C2} = \sigma_{E2}$ when $\sigma_{E2} \le \sigma_F/2$

$= \sigma_F[1 - \sigma_F/(4\sigma_{E2})]$ when $\sigma_{E2} > \sigma_F/2$

where

$$\sigma_{E2} = 0.9mE\left(\frac{t}{s_s}\right)^2 \quad \text{N/mm}^2 \text{ (kgf/mm}^2\text{, psi)}$$

$$m = c\left[1+\left(\frac{s_s}{\ell_s}\right)^2\right]^2 \frac{2.1}{\Psi+1.1}$$

s_s = length, in mm (in.), of the shorter side of the plate panel

ℓ_s = length, in mm (in.), of the longer side of the plate panel

Ψ = ratio of smallest to largest compressive stress

c = 1.3 when plating is stiffened by primary supporting members

= 1.21 when plating is stiffened by secondary stiffeners of angle or T type

= 1.1 when plating is stiffened by secondary stiffeners of bulb type

= 1.05 when plating is stiffened by flat bar

iii) Biaxial Compression. The biaxial compressive stress in the hatch cover panels, when calculated by means of FEM shell element model, is to be in accordance with the Rules as deemed equivalent to the above criteria.

19.3.7(b) Hatch Cover Secondary Stiffeners. The compressive stress σ in the top flange of secondary stiffeners, induced by the bending of primary supporting members parallel to the direction of secondary stiffeners, is not to exceed 0.8 times the critical buckling stress σ_{CS} as defined below:

$\sigma_{CS} = \sigma_{ES}$ when $\sigma_{ES} \le \sigma_F/2$

$= \sigma_{ES}[1 - \sigma_F/(4\sigma_{ES})]$ when $\sigma_{ES} > \sigma_F/2$

where

σ_F = as defined in 5C-3-4/19.3.3(a)

σ_{ES} = ideal elastic buckling stress, in N/mm^2 (kgf/mm^2, psi), of the secondary stiffener

= the lesser of σ_{E3} and σ_{E4}

σ_{E3} = $E\, I_a/(c_1 A\ell^2)$ N/mm^2 (kgf/mm^2, psi)

E = as defined in 5C-3-4/19.3.7(a)

I_a = moment of inertia, in cm^4 (in^4), of the secondary stiffener, including a top flange equal to the spacing of secondary stiffeners

c_1 = 1000 (1000, 14.4)

A = cross-sectional area, in cm^2 (in^2), of the secondary stiffener, including a top flange equal to the spacing of secondary stiffeners

ℓ = span, in m (ft), of the secondary stiffener

σ_{E4} = $\dfrac{\pi^2 EI_w}{10c_1 I_p \ell^2}\left(m^2 + \dfrac{K}{m^2}\right) + 0.385E\dfrac{I_t}{I_p}$ N/mm^2 (kgf/mm^2, psi)

K = $c_2 \dfrac{C\ell^4}{\pi^4 EI_w}$

c_2 = 10^6 (10^6, 20736)

m = number of half waves, given by the following table:

	$0 < K \le 4$	$4 < K \le 36$	$36 < K \le 144$	$(m-1)^2\, m^2 < K \le m^2\, (m+1)^2$
m	1	2	3	M

I_t = St Venant's moment of inertia, in cm^4 (in^4), of the secondary stiffener without top flange

= $c_3 \dfrac{h_w t_w^3}{3}$ for flat bar secondary stiffeners

= $c_3 \dfrac{1}{3}\left[h_w t_w^3 + b_f t_f^3\left(1 - 0.63\dfrac{t_f}{b_f}\right)\right]$ for flanged secondary stiffeners

c_3 = 10^{-4} (10^{-4}, 1)

I_p = polar moment of inertia, in cm^4 (in^4), of the secondary stiffener about its connection with the plating

= $c_3 \dfrac{h_w^3 t_w}{3}$ for flat bar secondary stiffeners

= $c_3\left(\dfrac{h_w^3 t_w}{3} + h_w^2 b_f t_f\right)$ for flanged secondary stiffeners

I_w = sectorial moment of inertia, in cm^6 (in^6), of the secondary stiffener about its connection with the plating

$$= c_4 \frac{h_w^3 t_w^3}{3} \qquad \text{for flat bar secondary stiffeners}$$

$$= c_4 \frac{t_f b_f^3 h_w^2}{12} \qquad \text{for "Tee" secondary stiffeners}$$

$$= c_4 \frac{b_f^3 h_w^2}{12(b_f + h_w)^2}\left[t_f\left(b_f^2 + 2b_f h_w + 4h_w^2\right) + 3t_w b_f h_w\right]$$

for angles and bulb secondary stiffeners

c_4 = 10^{-6} (10^{-6}, 1)

h_w, t_w = height and net thickness, in mm (in.), of the secondary stiffener web, respectively

b_f, t_f = width and net thickness, in mm (in.), of the secondary stiffener bottom flange, respectively

s = spacing, in mm (in.), of secondary stiffeners

C = spring stiffness exerted by the hatch cover top plating

$$= \frac{k_p E t_p^3}{3s\left(1 + \dfrac{1.33 k_p h_w t_p^3}{s t_w^3}\right)} \qquad \text{N (kgf, lbf)}$$

k_p = $1 - \eta_p$

= to be taken not less than zero; for flanged secondary stiffeners, k_p need not be taken less than 0.1

η_p = $\dfrac{\sigma}{\sigma_{E1}}$

σ = as defined in 5C-3-4/19.3.6(a)

σ_{E1} = as defined in 5C-3-4/19.3.7(a)

t_p = net thickness, in mm (in.), of the hatch cover plate panel.

For flat bar secondary stiffeners and buckling stiffeners, the ratio h/t_W is to be not greater than $15k^{0.5}$, where:

h, t_W = height and net thickness, in mm (in.), of the stiffener, respectively

k = Y/σ_F

Y = 235 N/mm^2 (24 kgf/mm^2, 34000 psi)

σ_F = as defined in 5C-3-4/19.3.3(a)

19.3.7(c) Web of primary supporting members. This check is to be carried out for the web panels of primary supporting members, bounded by web stiffeners or other crossing members, the face plate (or the bottom cover plate) and the top plate.

The shear stress τ in the hatch cover primary supporting member web panels is not to exceed 0.8 times the critical buckling stress τ_C, as defined below:

$$\tau_C = \tau_E \qquad \text{when } \tau_E \le \tau_F/2$$

$$= \tau_F\,[1 - \tau_F/(4\tau_E)] \qquad \text{when } \tau_E > \tau_F/2$$

where

σ_F = as defined in 5C-3-4/19.3.3(a)

τ_F = $\sigma_F/\sqrt{3}$

τ_E = $0.9k_t E\,(t_{pr,n}/d)^2$

E = as defined in 5C-3-4/19.3.7(a)

$t_{pr,n}$ = net thickness, in mm (in.), of primary supporting member

k_t = $5.35 + 4.0/(a/d)^2$

a = greater dimension, in mm (in.), of web panel of primary supporting member

d = smaller dimension, in mm (in.), of web panel of primary supporting member

For primary supporting members parallel to the direction of secondary stiffeners, the actual dimensions of the panels are to be considered.

For primary supporting members perpendicular to the direction of secondary stiffeners or for hatch covers built without secondary stiffeners, a presumed square panel of dimension d is to be taken for the determination of the stress τ_C In such a case, the average shear stress τ between the values calculated at the ends of this panel is to be considered.

19.3.8 Connections between Hatch Cover Panels

Load bearing connections are to be fitted between the hatch cover panels to restrict the relative vertical displacements.

19.5 Hatch Coamings

19.5.1 Nominal Design Corrosion Values and Net Thickness

19.5.1(a) Nominal Design Corrosion Values. The nominal design corrosion value is to be taken as follows:

In general, for compliance with 5C-3-4/19.5 and 5C-3-4/19.7, except below:	1.5 mm (0.06 in.)
For compliance with 5C-3-4/19.5.6	1.0 mm (0.04 in.)

19.5.1(b) Net Thickness. In the calculation of the hatch coaming scantlings, net thickness as indicated in 5C-3-2/1.1 is to be used.

19.5.2 Design Pressures

19.5.2(a) Green Sea Pressure

i) The pressure, p_{coam}, on the No. 1 forward transverse hatch coaming is given by:

p_{coam} = 220 (22.4, 2.05) kN/m^2 (tf/m^2, Ltf/ft^2), when a forecastle is fitted in accordance with 5C-3-1/7

= 290 (29.6, 2.70) kN/m^2 (tf/m^2, Ltf/ft^2), in the other cases

ii) The pressure, p_{coam}, on the other forward end and all side coamings is given by:

p_{coam} = 220 (22.4, 2.05) kN/m^2 (tf/m^2, Ltf/ft^2)

19.5.2(b) Other Considerations. For hatch coamings in holds intended for carriage of liquid, the structure is to be of adequate strength to resist the upward pressure of ballast water or cargo oil in the holds caused by the pitch and roll motions of the vessel specified for load cases 5 and 7 in 5C-3-3/Table 1.

19.5.3 Coaming Plate Thickness

The coaming plate thickness t is given by:

$$t = C_{coam} s \sqrt{\frac{p_{coam}}{\sigma_{a,coam}} S_{coam}} \qquad \text{mm (in.)}$$

where

c_{coam} = 0.0149 (0.0149, 1.86)

s = secondary stiffener spacing, in mm (in.)

p_{coam} = pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), as defined in 5C-3-4/19.5.2(a)

S_{coam} = safety factor to be taken equal to 1.15

$\sigma_{a,coam}$ = $0.95\sigma_F$

The coaming plate thickness is to be not less than 9.5 mm (0.37 in.).

19.5.4 Secondary Stiffeners

The secondary stiffeners of the hatch coamings are to be continuous over the breadth and length of the hatch coamings.

The required section modulus, *SM*, of the longitudinal or transverse secondary stiffeners of the hatch coamings, based on net member thickness, is given by:

$$SM = c_s \frac{S_{coam} \ell^2 s p_{coam}}{m c_p \sigma_{a,coam}} \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

where

c_s = 1 (1, 2240)

m = 16 in general

= 12 for the end spans of stiffeners

S_{coam} = safety factor, to be taken equal to 1.15

ℓ = span, in m (ft), of secondary stiffeners

s = spacing, in mm (in.), of secondary stiffeners

p_{coam} = pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), as defined in 5C-3-4/19.5.2(a)

c_p = ratio of the plastic section modulus to the elastic section modulus of the secondary stiffeners with an attached plate breadth, in mm (in.), equal to 40t, where t is the plate net thickness

= 1.16 in the absence of more precise evaluation

$\sigma_{a,coam}$ = $0.95\sigma_F$

19.5.5 Stays

19.5.5(a) Flange End Connected. The required minimum section modulus, *SM*, and web thickness, t_w, of coaming stays designed as beams with flange connected to the deck or sniped and fitted with a bracket (see 5C-3-4/Figures 13 and 14) at their connection with the deck, based on member net thickness, are given by:

$$SM = \frac{c_s H_c^2 s p_{coam}}{2\sigma_{a,coam}} \quad \text{cm}^3 \text{ (in}^3\text{)}$$

$$t_w = \frac{c_c H_c s p_{coam}}{h\tau_{a,coam}} \quad \text{mm (in.)}$$

where

c_s = 1 (1, 2240)

c_c = 1 (1, 187)

H_c = stay height, in m (ft)

s = stay spacing, in mm (in.)

h = stay depth, in mm (in.), at the connection with the deck

p_{coam} = pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), as defined in 5C-3-4/19.5.2(a)

$\sigma_{a,coam}$ = $0.95\sigma_F$

$\tau_{a,coam}$ = $0.5\sigma_F$

For calculating the section modulus of coaming stays, their face plate area is to be taken into account only when it is welded with full penetration welds to the deck plating and adequate underdeck structure is fitted to support the stresses transmitted by it.

19.5.5(b) Flange End Sniped. For other designs of coaming stays, such as, for example, those shown in 5C-3-4/Figures 15 and 16, the stress levels in 5C-3-4/19.3.3(a) will apply in lieu of $\sigma_{a,coam}$ and $\tau_{a,coam}$. The highest stressed locations are to be checked.

FIGURE 13

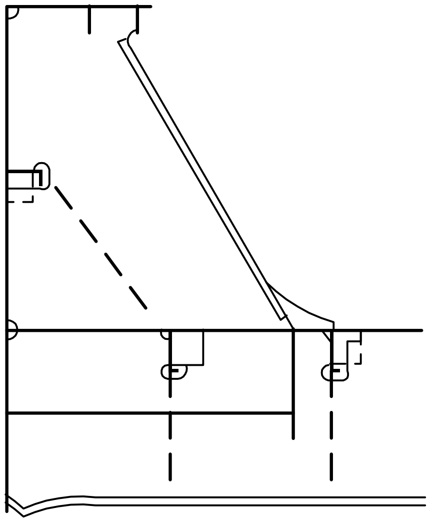


FIGURE 14

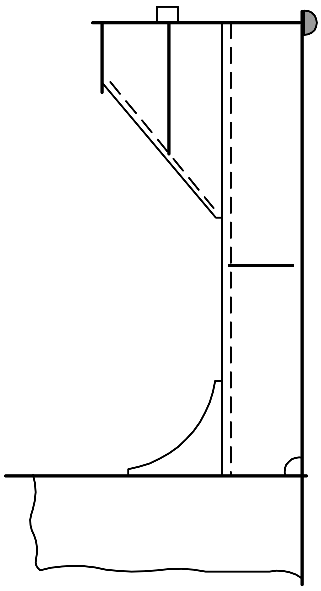


FIGURE 15

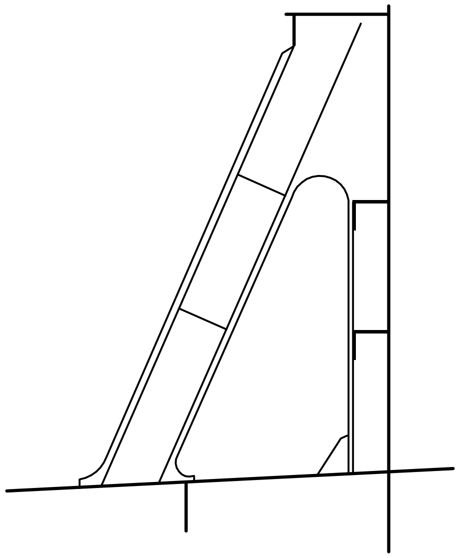
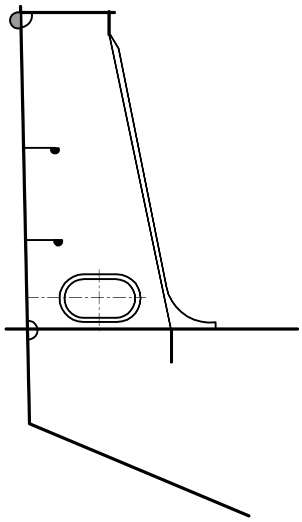


FIGURE 16



19.5.6 Long Side Coamings

The thickness of continuous longitudinal coamings having a length greater than 0.14*L* is not to be less than the value of t_3, given in 5C-3-4/15.1, with *s* taken as the spacing of the coaming stiffeners.

The stiffeners are to comply with the requirements of 5C-3-4/15.3, where ℓ is the distance between bracket, and *p* is not to be less than 1.59 N/cm^2 (0.1625 kgf/cm^2, 2.31 psi).

19.5.7 Local Details

Local details are to be designed for the purpose of transferring the pressures on the hatch covers to the hatch coamings and, through them, to the deck structures below. Hatch coamings and supporting structures are to be adequately stiffened to accommodate the loading from hatch covers, in longitudinal, transverse and vertical directions.

Underdeck structures are to be checked against the load transmitted by the stays, adopting the same allowable stresses specified in 5C-3-4/19.5.5(a).

Where rubbing bars (e.g., a half-round bar) are provided on the hatch side girders (i.e., upper portion of top side tank plates)/hatch end beams in cargo hold and/or upper portion of hatch coamings, the material of the rubbing bars is to be of Grade A steel or equivalent. Termination of these rubbing bars is to comply with 3-1-2/15.3.

Unless otherwise stated, weld connections and materials are to be in accordance with the applicable requirements in Section 3-2-19.

Double continuous welding is to be adopted for the connections of stay webs with deck plating and the weld throat is to be not less than 0.44 t_W, where t_W is the gross thickness of the stay web.

Toes of stay webs are to be connected to the deck plating with deep penetration double bevel welds extending over a distance not less than 15% of the stay width.

19.7 Closing Arrangements

19.7.1 Securing Arrangements

19.7.1(a) Securing Device. Hatch cover panels are to be secured by appropriate devices (bolts, wedges or similar) suitably spaced alongside the coamings and between panels.

Arrangement and spacing are to be determined with due attention to the weathertightness, the type and the size of the hatch cover, as well as the stiffness of the cover edges between the securing devices.

Securing devices are to be of reliable construction and securely attached to the hatchway coamings, decks or covers. Individual securing devices on each cover are to have approximately the same stiffness characteristics.

Where rod cleats are fitted, resilient washers or cushions are to be incorporated.

Where hydraulic cleating is adopted, a positive means is to be provided to ensure that it remains mechanically locked in the closed position in the event of failure of the hydraulic system.

19.7.1(b) Sectional Area. Subject to 5C-3-4/19.7.1(c), the net sectional area of each securing device is not to be less than:

$$A = c_{sd}\, a/f \qquad \text{cm}^2\ (\text{in}^2)$$

where

c_{sd} = 1.4 (1.4, 0.066)

a = spacing, in m (ft), of securing devices, not to be taken less than 2 m (6.6 ft)

f = $(\sigma_Y/Y)^e$

Y = 235 N/mm^2 (24 kgf/mm^2, 34,000 psi)

σ_Y = specified minimum upper yield stress, in N/mm^2 (kgf/mm^2, psi), of the steel, not to be taken greater than 70% of the ultimate tensile strength.

e = 0.75 for $\sigma_Y > 235$ N/mm^2 (24 kgf/mm^2, 34,000 psi)

= 1.0 for $\sigma_Y < 235$ N/mm^2 (24 kgf/mm^2, 34,000 psi)

Rods or bolts are to have a net diameter not less than 19 mm (0.75 in.) for hatchways exceeding 5 m^2 (54 ft^2) in area.

19.7.1(c) Packing Line Pressure. Between cover and coaming and at cross-joints, a packing line pressure sufficient to obtain weathertightness is to be maintained by the securing devices.

For packing line pressures exceeding 5 N/mm^2 (0.51 kgf/mm^2, 28.6 psi), the cross section area of the securing device is to be increased in direct proportion. The packing line pressure is to be specified.

19.7.1(d) Edge Stiffness. The cover edge stiffness is to be sufficient to maintain adequate sealing pressure between securing devices. The moment of inertia, *I*, of edge elements is not to be less than:

$I = c_i\, p\, a^4$ cm^4 (in^4)

where

c_i = 6 (58.8, 0.000218)

p = packing line pressure, in N/mm^2 (kgf/mm^2, psi), minimum 5 N/mm^2 (0.51 kgf/mm^2, 28.6 psi).

a = spacing, in m (ft), of securing devices.

19.7.2 Stoppers

19.7.2(a) Forces. All hatch covers are to be fitted with stoppers to limit horizontal movement of the cover against the forces caused by the following pressures:

i) *Longitudinal pressure on fore end of cover:*

No. 1 hatch cover:

where a forecastle in accordance with 5C-3-1/7 is not fitted:

230 kN/m^2 (23.5 tf/m^2, 2.14 Ltf/ft^2)

where a forecastle in accordance with 5C-3-1/7 is fitted:

175 kN/m^2 (17.8 tf/m^2, 1.63 Ltf/ft^2)

Other hatch covers: 175 kN/m^2 (17.8 tf/m^2, 1.63 Ltf/ft^2).

ii) *Transverse pressure on side of cover:*

All hatch covers: 175 kN/m^2 (17.8 tf/m^2, 1.63 Ltf/ft^2).

19.7.2(b) Allowable Stresses. The equivalent stress:

i) in stoppers and their supporting structures, and

ii) calculated in the throat of the stopper welds

is not to exceed 0.8 σ_Y under the above pressures.

19.7.3 Materials and Welding

Stoppers and securing devices are to be manufactured of materials and corresponding welding procedures and consumables, in accordance with applicable requirements of Part 2.

21 Longitudinal Bulkheads

21.1 Sloping Bulkhead Plating of Lower Wing Tank *(1999)*

The net thickness of the lower wing tank sloping bulkhead plating, in addition to complying with 5C-3-4/5.5, is to be not less than t_1, t_2 and t_3 for the amidship 0.4L, as obtained from the following equations:

$t_1 = 0.73s(k_1p/f_1)^{1/2}$ mm (in.)

$t_2 = 0.73s(k_2p/f_2)^{1/2}$ mm (in.)

$t_3 = cs(S_m f_y/E)^{1/2}$ mm (in.)

but not to be less than 9.5 mm (0.37 in.)

where

s = spacing of the longitudinal bulkhead longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.5

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as specified in 5C-3-3/Table 3

Where upper and lower wing tanks are connected by trunks or double sides, the nominal pressure, p, in load case "b" of 5C-3-3/Table 3 may be modified by the following equation:

$p = p_b - p_{uo}$

p_b is nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as defined in load case "b" of 5C-3-3/Table 3 for sloping bulkhead plating of the lower wing tank.

p_{uo} is as defined in 5C-3-4/9.1.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

f_1 = permissible bending stress, in the longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $[1 - 0.4\,(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]S_m f_y \le 0.60 S_m f_y$, for dry cargo loads

= $[1 - 0.4\,(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]S_m f_y$, for ballast/liquid loads

SM_B/SM_{RB} is not to be taken more than $1.2\alpha_1$ or 1.4, whichever is lesser.

α_1 = $S_{m1}f_{y1}/S_m f_y$

S_m = strength reduction factor of the bulkhead plating, as defined in 5C-3-4/7.3.1

f_y = minimum specified yield point of the bulkhead plating, in N/cm^2 (kgf/cm^2, lbf/in^2)

z = transverse distance, in m (ft), measured from the centerline of the section to the lower edge of the bulkhead strake under consideration

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the lower edge of the bulkhead strake under consideration.

y_n = vertical distance, in m (ft), measured from the bottom to the neutral axis of the section

f_2 = permissible bending stress, in the vertical direction

= $0.85\, S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2), for dry cargo loads

= $S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2) for ballast/liquid loads

B = vessel's breadth, in m (ft), as defined in 3-1-1/5

c = $0.7N^2 - 0.2$, not to be less than 0.33, but need not be greater than $0.45(Q/Q_b)^{1/2}$

N = $R_b\, [(Q/Q_b)(y/y_n)]^{1/2}$

Q = material conversion factor in 5C-3-4/5 for the bulkhead plating

SM_{RB}, SM_B, R_b, Q_b and E are as defined in 5C-3-4/7.3.1.

S_{m1} and f_{y1} are as defined in 5C-3-4/7.5.

The sloping bulkhead is to be longitudinally framed in the lower wing tank, except the upper part of the lower wing tank where the limited access makes longitudinal framing impractical. This part of the sloping bulkhead may be transversely framed with efficient brackets arranged in line with the side frames, provided the net thickness of sloping bulkhead plating here is not less than that of the adjacent longitudinally framed bulkhead plating and is also not less than t_4, obtained from the following equation:

$$t_4 = 0.73sk(k_2\, p/f)^{1/2} \qquad \text{mm (in.)}$$

where

s = spacing of the transverse brackets, in mm (in.)

k = $(3.075\sqrt{\alpha} - 2.072)/(\alpha + 0.272)$ $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

k_2 = 0.5

α = aspect ratio of the panel (longer edge/shorter edge)

p = nominal pressure, as defined above

f = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $[1 - 0.4\,(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]S_m f_y$,

SM_B/SM_{RB} is not to be taken more than $1.2\alpha_1$ or 1.4, whichever is lesser.

All other parameters are as defined above.

21.3 Sloping Bulkhead Plating of Upper Wing Tank *(1999)*

The net thickness of the upper wing tank sloping bulkhead plating, in addition to complying with 5C-3-4/5.5, is not to be less than t_1, t_2 and t_3, as specified below:

$$t_1 = 0.73s(k_1 p/f_1)^{1/2} \qquad \text{mm (in.)}$$

$$t_2 = 0.73s(k_2\, p/f_2)^{1/2} \qquad \text{mm (in.)}$$

$$t_3 = cs(S_m f_y/E)^{1/2} \qquad \text{mm (in.)}$$

but not to be less than 9.5 mm (0.37 in.)

where

s = spacing of longitudinal bulkhead longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.50

p = $p_n - p_{uo}$

p_n is nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as defined in 5C-3-3/Table 3 for sloping plating of the upper wing tank in dry cargo holds.

p_{uo} is as defined in 5C-3-4/9.1.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

f_1 = permissible bending stress, in the longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $1.2[1 - 0.4(z/B) - 0.52\alpha_2(SM_{RD}/SM_D)(y/y_n)]\, S_m f_y$, above the neutral axis

α_2 = $S_{m2} f_{y2} / S_m f_y$

y_n = vertical distance, in m (ft), measured from the deck to the neutral axis of the section

f_2 = permissible bending stress, in the vertical direction

= $0.8\, S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

c = $0.7N^2 - 0.2$

c for the top strake is not to be taken less than $0.4Q^{1/2}$, but need not be greater than 0.45. c for other strakes is not to be taken less than 0.33, but need not be greater than $0.45(Q/Q_d)^{1/2}$.

$N = R_d\,[(Q/Q_d)(y/y_n)]^{1/2}$

Q = material conversion factor in 5C-3-4/5 for the bulkhead plating

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the upper edge of the bulkhead strake

y_n = vertical distance, in m (ft), measured from the deck to the neutral axis of the section

B = vessel's breadth, in m (ft), as defined in 3-1-1/5

E is as defined in 5C-3-4/7.3.1.

R_d and Q_d are as defined in 5C-3-4/9.1.

SM_{RD} and SM_D are as defined in 5C-3-4/9.3.

S_{m2} and f_{y2} are as defined in 5C-3-4/15.3.

S_m, f_y, z, y and B are as defined in 5C-3-4/21.1.

The sloping bulkhead is to be longitudinally framed in the upper wing tank, except the lower part of the upper wing tank where the limited access makes longitudinal framing impractical. This part of the sloping bulkhead may be transversely framed with efficient brackets arranged in line with the side frames, provided the net thickness of the sloping bulkhead plating in this area is not less than that of the adjacent longitudinally framed bulkhead plating and is also not less than t_4, obtained from the following equation:

$t_4 = 0.73sk(k_2 p/f)^{1/2}$ mm (in.)

where

s	=	spacing of transverse brackets, in mm (in.)	
k	=	$(3.075\sqrt{\alpha} - 2.077)/(\alpha + 0.272)$	$(1 \leq \alpha \leq 2)$
	=	1.0	$(\alpha > 2)$
α	=	aspect ratio of the panel (longer edge/shorter edge)	
k_2	=	0.5	
p	=	nominal pressure as defined above	
f	=	permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)	
	=	$1.2[1 - 0.4(z/B) - 0.52\alpha_2(SM_{RD}/SM_D)(y/y_n)]S_m f_y$	

All other parameters are as defined above.

The minimum vertical extent of the top strake from the upper deck for the midship 0.4L is to be obtained from the following equation:

$b = 5L + 800$ mm for $L \leq 200$ m

$= 0.06L + 31.5$ in. for $L \leq 656$ ft

$b = 1800$ mm for $200 < L \leq 500$ m

$= 70.87$ in. for $656 < L \leq 1640$ ft

L = length of the vessel, as defined in 3-1-1/3.1, in m (ft)

b = vertical extent of the top strake, in mm (in.)

21.5 Non-tight Bulkhead in Upper Wing Tank Where Adjacent to Cargo Hold *(1999)*

The net thickness of the non-tight longitudinal bulkhead plating, where fitted in the upper wing tank, is not to be less than obtained from the following equation.

The net thickness, t, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

$t = cs(S_m f_y/E)^{1/2}$ mm (in.)

but not to be less than 13 mm (0.51 in.)

where

c = $0.7N^2 - 0.2$, not to be less than 0.33, but need not be greater than $0.45(Q/Q_d)^{1/2}$.

N is as defined in 5C-3-4/21.3.

E is as defined in 5C-3-4/7.3.1.

S_m and f_y are as defined in 5C-3-4/21.1.

21.7 Non-tight Bulkhead in Upper Wing Tank where Adjacent to Ballast or Liquid Cargo Hold *(1999)*

The net thickness of the non-tight longitudinal bulkhead plating, where fitted in the upper wing tank, is not to be less than t_1 and t_2, obtained from the following equation.

The net thickness, t_2, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

$t_1 = 0.1F/(hf_s)$ mm (in.)

$t_2 = 0.37s(S_m f_y/E)^{1/2}$ mm (in.)

but not to be less than 13 mm (0.51 in.)

$F = kpL_H b_{su}$ N (kgf, lbf)

where

k = 180 (180, 403.2)

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the intersection of longitudinal bulkhead and sloping bulkhead, as specified in 5C-3-3/Table 3

L_H = length of the ballast or liquid cargo hold, in m (ft)

b_{su} = width of the sloping bulkhead, as indicated in 5C-3-4/Figure 9, in m (ft)

h = height of the longitudinal bulkhead, in m (ft)

s = spacing of longitudinal bulkhead longitudinals, in mm (in.)

f_s = permissible shear stress, N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.5\, S_m f_y$

S_m, f_y, E are as defined in 5C-3-4/7.3.1.

21.9 Inner Hull Longitudinal Bulkhead *(1996)*

21.9.1 General

The net thickness of the inner hull longitudinal bulkhead plating, where fitted between the upper and lower wing tanks, in addition to complying with 5C-3-4/5.7, is to be not less than t, as specified below:

21.9.2 Transversely Framed Plating *(2003)*

$t = 0.73s(kp/f)^{1/2}$ mm (in.)

but not to be less than 9.5 mm (0.37 in.)

where

s = spacing of vertical stiffeners, in mm (in.)

k = 0.5

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as specified in 5C-3-3/Table 3

Where the double hull side space is a void space, the nominal pressure, p, is to be the value in 5C-3-3/Table3 for other bulkhead plating or p_v, as specified below, whichever is greater:

p_v = $k_1\rho(D-h)$ N/cm^2 (kgf/cm^2, lbf/in^2)

k_1 = conversion factor, to be taken as 0.981 (0.0981, 1/144)

ρ = density of sea water, 1.025 t/m^3 (64 lb/ft^3)

D = the molded depth of the vessel, in m (ft), defined in 3-1-1/7.1

h = vertical distance, in m (ft) from the baseline to the lower edge of the plate being considered

Where the double hull space is connected to the upper wing tank, the nominal pressure, p, in load case "b" may be modified by the following equation:

p = $p_b - p_{uo}$

p_b is nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as defined in load case "b" of 5C-3-3/Table 3 for other bulkhead plating.

p_{uo} is as defined in 5C-3-4/9.1.

f = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.75\, S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.5.

21.9.3 Longitudinally Framed Plating *(1999)*

$t_1 = 0.73s(k_1 p/f_1)^{1/2}$ mm (in.)

$t_2 = 0.73s(k_2 p/f_2)^{1/2}$ mm (in.)

$t_3 = cs(S_m f_y/E)^{1/2}$ mm (in.)

but not to be less than 9.5 mm (0.37 in.)

where

s = spacing of inner hull bulkhead longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.5

p = nominal pressure, as defined in 5C-3-4/21.9.2

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

f_1 = permissible bending stress, in the longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $[1 - 0.4(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]\, S_m f_y \le 0.60 S_m f_y$ for dry cargo loads, below neutral axis

= $[1 - 0.4(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]\, S_m f_y$ for ballast/liquid loads, below neutral axis

= $0.60\, S_m f_y$ for dry cargo loads, above neutral axis

= $1.2[1 - 0.4(z/B) - 0.52\alpha_2(SM_{RD}/SM_D)(y/y_n)]\, S_m f_y$ for ballast/liquid loads, above neutral axis

SM_B/SM_{RB} is not to be taken more than $1.2\alpha_1$ or 1.4, whichever is lesser.

y_n = vertical distance, in m (ft), measured from the deck (bottom) to the neutral axis of the section, when the strake under consideration is above (below) the neutral axis

f_2 = permissible bending stress, in the vertical direction

= $0.85\ S_m f_y$ in N/cm^2 (kgf/cm^2, lbf/in^2) for dry cargo loads

= $S_m f_y$ in N/cm^2 (kgf/cm^2, lbf/in^2) for ballast/liquid loads, below the neutral axis.

= $0.80\ S_m f_y$ in N/cm^2 (kgf/cm^2, lbf/in^2) for ballast/liquid loads, above the neutral axis

c = $0.7N^2 - 0.2$, not to be taken less than 0.33, but need not be greater than $0.45(Q/Q_d)^{1/2}$ for the strake above the neutral axis nor $0.45(Q/Q_b)^{1/2}$ for the strake below the neutral axis

N = $R_d\,[(Q/Q_d)(y/y_n)]^{1/2}$ for strake above the neutral axis

= $R_b\,[(Q/Q_b)(y/y_n)]^{1/2}$ for strake below the neutral axis

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the upper edge (lower edge) of the bulkhead strake, when the strake under consideration is above (below) the neutral axis for N

= vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the lower edge of the bulkhead strake under consideration for f_1

y_n = vertical distance, in m (ft), measured from the deck (bottom) to the neutral axis of the section, when the strake under consideration is above (below) the neutral axis

Q = material conversion factor in 5C-3-4/5 for the bulkhead plating

SM_{RB}, SM_B, R_b and Q_b are as defined in 5C-3-4/7.3.1.

R_d and Q_d are as defined in 5C-3-4/9.1.

SM_{RD} and SM_D are as defined in 5C-3-4/9.3.

α_1, S_m, f_y, y and B are as defined in 5C-3-4/21.1.

α_2 is as defined in 5C-3-4/21.3.

21.11 Longitudinal and Vertical Stiffeners *(1996)*

The net section modulus of each longitudinal or vertical stiffener on longitudinal bulkheads, in association with the effective plating to which it is attached, is not to be less than obtained from the following equation:

$SM = M/f_b$ in cm^3 (in^3)

$M = 1000 c_1 p s \ell^2/k$ in N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 83.33)

c_1 = 1.0 for longitudinals and horizontal stiffeners

= $1 + \gamma\ell/10p$ for vertical stiffeners

γ = specific weight of the liquid, ≥ 1.005 N/cm²-m (0.1025 kgf/cm²-m, 0.444 lbf/in²-ft)

s = spacing of longitudinals or vertical stiffeners, in mm (in.)

ℓ = span of longitudinals or stiffeners between effective supports, in m (ft)

p = nominal pressure, in N/cm² (kgf/cm², lbf/in²), at the longitudinal or stiffener considered as specified in 5C-3-4/21.1, 5C-3-4/21.3, 5C-3-4/21.9, and 5C-3-4/7.13. For vertical stiffeners, pressure is to be taken at the middle of span of each stiffener

f_b = permissible bending stresses, in N/cm² (kgf/cm², lbf/in²)

= $0.70\ S_m f_y$ for vertical stiffeners of dry cargo loads

= $0.80\ S_m f_y$ for vertical stiffeners of ballast/liquid loads

f_b = $1.4[1 - 0.4(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]S_m f_y \leq 0.70 S_m f_y$, for longitudinal bulkhead longitudinals of dry cargo loads, below neutral axis

= $1.4[1 - 0.4(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]S_m f_y \leq 0.90 S_m f_y$, for longitudinal bulkhead longitudinals of ballast/ liquid loads, below neutral axis

= $2.2[1 - 0.4(z/B) - 0.52\alpha_2(SM_{RD}/SM_D)(y/y_n)]S_m f_y \leq 0.90 S_m f_y$, for longitudinal bulkhead longitudinals, above neutral axis

z = transverse distance, in m (ft), measured from the centerline of the hull girder transverse section to the longitudinal under consideration at its connection to the associated plate

B = vessel's breadth, in m (ft), as defined in 3-1-1/5

S_m, f_y and α_1 are as defined in 5C-3-4/7.5.

α_2, y, y_n, SM_{RD} and SM_D are as defined in 5C-3-4/9.3.

SM_{RB} and SM_B are as defined in 5C-3-4/7.3.1.

The effective breadth of plating, b_e, is as defined in 5C-3-47.5.

The net moment of inertia of each longitudinal on the longitudinal bulkhead, with the associated effective plating ($b_{wL} \cdot t_n$), within the region of $0.1D$ from the deck at side is to be not less than i_o, as specified in 5C-3-4/9.3.

23 Plane Transverse Bulkheads *(1999)*

23.1 Plating *(1999)*

The net thickness of transverse bulkhead plating is to be not less than t, as specified below:

$$t = 0.73sk(k_2p/f)^{1/2} \qquad \text{in mm (in.)}$$

but not to be less than 9.5 mm (0.37 in.)

where

s = spacing of transverse bulkhead stiffeners, in mm (in.)

k_2 = 0.50

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha \le 2)$

= 1.0, $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as specified in 5C-3-3/Table 3

In the upper wing tank and the lower wing tank which is connected to the upper wing tank by trunks or double sides, the nominal pressure, p, in such ballast tanks may be modified by the following equation:

$$p = p_n - p_{uh}$$

In no case is p to be taken less than 2.06 N/cm^2 (0.21kgf/cm^2, 2.987 lbf/in^2).

p_n is nominal pressure in N/cm^2 (kgf/cm^2, lbf/in^2) at the lower edge of each plate, as defined in 5C-3-3/Table 3.

p_{uh} is as defined in 5C-3-4/7.3.1.

f = permissible bending stress

= $0.85\, S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

S_m and f_y are as defined in 5C-3-4/7.3.1.

23.3 Vertical and Horizontal Stiffeners

The net section modulus of each vertical or horizontal stiffener on transverse bulkheads, in association with the effective plating to which it is attached, is to be not less than obtained from the following equation:

$SM = M/f_b$ in cm^3 (in^3)

$M = 1000 c_1 p s \ell^2/k$ in N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 83.33)

c_1 = 1.0 for horizontal stiffeners

= $1 + \gamma\ell/10p$ for vertical stiffeners

γ = specific weight of the dry cargo or ballast as specified in Notes 4 and 5 in 5C-3-3/Table 3

s = spacing of vertical/horizontal stiffeners, in mm (in.)

ℓ = span of stiffeners between effective supports, in m (ft)

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the stiffener considered, as defined in 5C-3-4/23.1.

For vertical stiffeners, pressure is to be taken at the middle of span of each stiffener.

f_b = permissible bending stresses, in N/cm^2 (kgf/cm^2, lbf/ in^2)

= $0.70\, S_m f_y$ for transverse bulkhead stiffeners

S_m and f_y are as defined in 5C-3-4/7.5.

23.5 Horizontal Girder on Transverse Bulkhead

23.5.1 Section Modulus

The net section modulus of the horizontal girder with effective plating is to be not less than obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

$M = 1000kc_1 ps\,\ell_b^2$ N-cm (kgf-cm, lbf-in)

where

k = 10 (10, 26.9)

ℓ_b = span, in m (ft), of the horizontal girder, as shown in 5C-3-4/Figure 17

s = sum of the half lengths, in m (ft), of the vertical stiffeners supported on each side of the horizontal girder

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), calculated at the midspan of the horizontal girder under consideration, as specified in 5C-3-3/Table 3

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.70\,S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.3.1.

c_1 may be obtained from the following equations:

For transverse bulkheads without vertical webs

$c_1 = 0.83$

For transverse bulkheads with vertical webs

$c_1 = 0.83\alpha^2$ for $\alpha < 0.5$

$= 0.531\alpha^2 + 0.0747$ for $0.5 \le \alpha \le 1.0$

$= 0.2243\alpha + 0.3814$ for $\alpha > 1.0$

c_1 is not to be taken less than 0.10 and need not be greater than 0.83.

α = $(\ell_v \ell_b)[(I/I_v)(s_v/s)]^{1/4}$

ℓ_v = span, in m (ft), of the vertical web, as shown in 5C-3-4/Figure 17

s_v = sum of the half distance, in m (ft), between the vertical web under consideration and the main vertical supporting members on each side of the vertical web

I, I_v = moments of inertia, in cm^4 (in^4), of the horizontal girder and the vertical web clear of the end brackets

For determination of α, if more than one vertical web is fitted on the bulkhead, average values of ℓ_v, s_v and I_v are to be used when these values are not the same for each web.

23.5.2 Sectional Area

The net sectional area of the web portion of the horizontal girder is to be not less than obtained from the following equation:

$A = F/f_s$ cm^2 (in^2)

$F = 1000ksc_1 p(0.5\ell - h_e)$ N (kgf, lbf)

where

k = 1.0 (1.0, 2.24)

c_1 = 1.0 for transverse bulkheads without vertical webs

= $0.85\ \alpha^{1/2}$ for transverse bulkheads with vertical webs, but not less than 0.3 and need not be greater than 1.0

ℓ = span of the horizontal girder, in m (ft), as shown in 5C-3-4/Figure 17

h_e = length, in m (ft) of the end bracket, as shown in 5C-3-4/Figure 17

p, s and α are as defined in 5C-3-4/23.5.1.

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\ S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.3.1.

23.7 Vertical Web on Transverse Bulkhead

23.7.1 Section Modulus

The net section modulus of the vertical web in association with the effective plating is to be not less than obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

$M = 100\ kps_v \ell_v^2$ N-cm (kgf-cm, lbf-in)

where

k = 83.33 (83.33, 22.4)

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), at the midspan of the vertical web, as specified in 5C-3-3/Table 3

s_v and ℓ_v are as defined in 5C-3-4/23.5.1 above.

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.70\ S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.3.1.

23.7.2 Sectional Area

The net sectional area of the web portion of vertical members is to be not less than obtained from the following equation:

$A = F/f_s$ cm^2 (in^2)

$F = 1000ks_v p(0.5\ell - h_e)$ N (kgf, lbf)

where

k = 1.0 (1.0, 2.24)

ℓ = span of vertical web, in m (ft), as shown in 5C-3-4/Figure 17

h_e = length of the end bracket, in m (ft), as shown in 5C-3-4/Figure 17

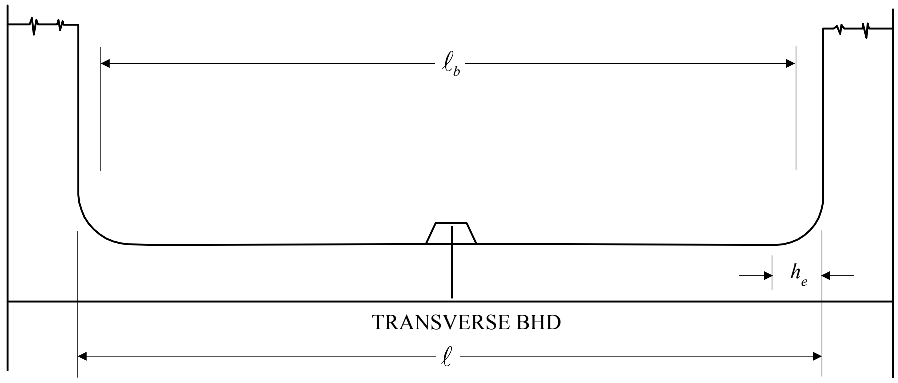
p and s_v are as defined in 5C-3-4/23.7.1.

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

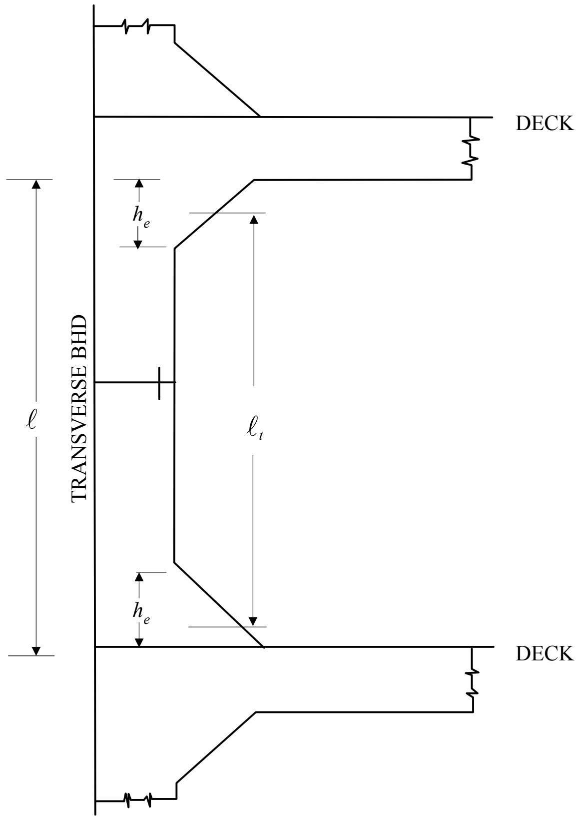
= $0.45\ S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.3.1.

FIGURE 17
Transverse Bulkheads – Definitions of Spans



a. Horizontal Girder



b. Vertical Web

25 Corrugated Transverse Bulkheads *(1995)*

25.1 General *(2001)*

All vertically corrugated transverse bulkheads in cargo holds intended for dry cargoes, ballast or liquid cargoes are to be designed in compliance with the requirements in this subsection, except that bulkheads meeting the requirements in Appendix 5C-3-A5b need not comply with the requirements in 5C-3-4/25.7. In all instances, the strength assessment criteria with respect to yielding, buckling and ultimate strength, and fatigue, as specified in Section 5C-3-5, are to be complied with.

The scantlings of water-tight vertically corrugated bulkheads in dry cargo holds of single side skin construction, intended to carry solid bulk cargoes having a density of 1.0 t/m^3 (62.4 lb/ft^3) or above, are to meet the requirements for flooded condition in Appendix 5C-3-A5b of this part.

In general, the approximation equations given below are applicable to vertical corrugations with corrugation angles ϕ (5C-3-4/Figure 11) within the range between 57 and 90 degrees. For corrugation angles less than 57 degrees and corrugation in the horizontal direction, direct calculations may be required.

25.3 Plating *(1 July 1998)*

The net thickness of the vertically corrugated plating is not to be less than t_1, t_2, t_3 and t_4, obtained from the following equations for all anticipated service loading conditions.

$t_1 = 0.516k_1a(p_\ell/f_1)^{1/2}$ in mm (in.) for flange and web plating

$t_2 = 0.42ak_2(f_y/E)^{1/2}$ in mm (in.) for flange plating

$t_3 = k(a/k_3)(f_3)^{1/2}10^{-3}$ in mm (in.) for flange plating

$t_4 = 100F/(d\,f_4)$ in mm (in.) for web plating

but not less than 9.5 mm (0.37 in.)

where

k	=	0.728(2.28, 0.605)
a	=	width of flange plating, in mm (in.) (5C-3-4/Figure 11)
c	=	width of web plating, in mm (in.) (5C-3-4/Figure 11)
d	=	depth of corrugation, in mm (in.) (5C-3-4/Figure 11)
ϕ	=	corrugation angle, (5C-3-4/Figure 11)
k_1	=	$(1 - c/a + c^2/a^2)^{1/2}$
k_2	=	$f_2/(0.73f_y)$
k_3	=	$7.65 - 0.26(c/a)^2$
F	=	shear force, in N (kgf, lbf), imposed on the web plating at the lower end of corrugation span
	=	$k_4s\ell(0.375p_\ell + 0.125p_u)$
k_4	=	10 (10, 12)
s	=	spacing of corrugation, in mm (in.)
	=	$a + c\cos\phi$, (5C-3-4/Figure 11)

ℓ = span of corrugation, in m (ft), taken as the distance between the lower and upper stools at centerline. If there is no lower stool, the span is to be taken as the distance between inner bottom and upper stool at centerline. If there is no upper stool, the span is to be taken as the distance between lower stool and upper deck at centerline, (5C-3-4/Figure 18)

p_ℓ, p_u = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower and upper ends of span, respectively, as specified in 5C-3-3/Table 3

f_1 = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.90\, S_m f_y$

f_2 = maximum vertical bending stress in the flange at the mid-depth of corrugation span to be calculated from 5C-3-4/25.5 below, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_3 = maximum vertical bending stress in the flange at the lower end of corrugation span to be calculated from 5C-3-4/25.5 below, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_4 = pemissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.40\, S_m f_y$

E, S_m and f_y are as defined in 5C-3-4/7.3.

The plate thickness, as determined above based on the maximum anticipated pressures, is to be generally maintained throughout the entire corrugated bulkhead, except that the net thickness of plating above 0.7 of span ℓ from the top of the lower stool may be reduced by 20%.

25.5 Stiffness of Corrugation

25.5.1 Depth/Length Ratio

The depth/length ratio (d/ℓ) of the corrugation is to be not less than 1/15 for cargo holds intended for ballast or liquid cargoes and 1/17.5 for all other cargo holds where d and ℓ are as defined in 5C-3-4/25.3 above.

25.5.2 Section Modulus

The net section modulus for any unit corrugation is to be not less than obtained from the following equation for all anticipated service loading conditions.

$$SM = M/f_b \quad \text{cm}^3 \text{ (in}^3\text{)}$$

$$M = 1000 C_i p s \ell_o^2 / k \quad \text{N-cm (kgf-cm, lbf-in)}$$

where

k = 12 (12, 83.33)

ℓ_o = nominal length of the corrugation, in m (ft), measured from the mid-depth of the lower stool, or the inner bottom if there is no lower stool, to the mid-depth of the upper stool or the deck at centerline if there is no upper stool

p = $(p_u + p_\ell)/2$, N/cm^2 (kgf/cm^2, lbf/in^2)

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.90\, S_m f_y$, for lower end of corrugation span ℓ

= $c_e f_y \le 0.90 S_m f_y$, for the mid $\ell/3$ region of the corrugation

c_e = $2.25/\beta - 1.25/\beta^2$ for $\beta \geq 1.25$

= 1.0 for $\beta < 1.25$

β = $(f_y/E)^{1/2}\, a/t_f$

t_f = net thickness of corrugation flange

C_i = the bending moment coefficients as given below

Values of C_i (All Bulkheads with Lower Stool)

Location	*Lower End of Span ℓ*	*Mid-depth*	*Upper End of Span ℓ*
Ballast Tank or Liquid Cargo Holds (with upper stool)	C_1	C_{m1}	$0.50C_{m1}$
Dry Cargo Holds			
(with upper stool)	C_2	C_{m2}	$0.60C_{m2}$
(without upper stool)	C_3	C_{m3}	$0.10C_{m3}$

Values of C_i (Dry Cargo Hold Bulkhead without Lower Stool for Vessels Shorter than 190 m in Length)

Location	*Lower End of Span ℓ*	*Mid-depth*	*Upper End of Span ℓ*
Dry Cargo Holds (with upper stool)	C_4	C_{m4}	$0.50C_{m4}$

$C_1 = a_1 + b_1(kA_d/L_d)^{1/2} \geq 0.6$,

where $a_1 = 0.89 - 0.152/R_b$,

$b_1 = -0.37 + 0.102/R_b$

$C_{m1} = a_{m1} + b_{m1}(kA_d/L_d)^{1/2}$,

where $a_{m1} = 0.47 + 0.08/R_b$,

$b_{m1} = -0.05 - 0.067/R_b$

$C_2 = a_2 + b_2(kA_d/L_d)^{1/2}$,

where $a_2 = 1.08 - 0.028/R_b$,

$b_2 = -0.37 + 0.026/Rb$

$C_{m2} = a_{m2} + b_{m2}(kA_d/L_d)^{1/2}$,

where $a_{m2} = 0.52 + 0.014/R_b$,

$b_{m2} = -0.07 - 0.014/R_b$

$C_3 = 1.03 - 0.035/R_b$

$C_{m3} = 0.51 + 0.014/R_b$

$C_4 = a_4 + b_4(kA_d/L_d)^{1/2}$,

where $a_4 = 1.9 - 0.209R_a - 0.504/R_a$,

$b_4 = 0.06 - 0.079R_a - 0.173/R_a$

$C_{m4} = a_{m4} + b_{m4}(kA_d/L_d)^{1/2}$,

where $a_{m4} = -0.1 + 0.208R_a + 0.484/R_a$,

$b_{m4} = -0.48 + 0.069R_a + 0.173/R_a$

$R_b = kH_s(B_c + B_s)(1 + L_h/L_b + 0.5H_b/L_h)/(2L_b)$

$R_a = k(1 + L_h/L_b + 0.5H_b/L_h)$

A_d = cross section area, in m^2 (ft^2), enclosed by the outside lines of upper stool

B_c = width of the bottom stool, in m (ft), at the top (5C-3-4/Figure 18)

B_s = width of the bottom stool, in m (ft), at the inner bottom level (5C-3-4/Figure 18)

H_b = double bottom height, in m (ft)

H_s = height of the bottom stool, in m (ft), from the inner bottom to the top (5C-3-4/Figure 18)

L_b = transverse distance, in m (ft), between hopper tanks at the inner bottom level (5C-3-4/Figure 18)

L_d = transverse distance, in m (ft), between upper wing tanks at the deck level (5C-3-4/Figure 18)

L_h = longitudinal distance, in m (ft), between bottom stools in the loaded holds at the inner bottom level (5C-3-4/Figure 18)

k = 1 (1, 3.281)

a, ℓ, s, p_u and p_ℓ are as defined in 5C-3-4/25.3 above.

E is as defined in 5C-3-4/7.3.1.

S_m and f_y are as defined in 5C-3-4/7.

The developed net section modulus SM may be obtained from the following equation, where a, c, d, t_f (net) and t_w (net), all in cm (in.), are as indicated in 5C-3-4/Figure 11.

$SM = d(3at_f + ct_w)/6$ cm^3 (in^3)

25.7 Flooded Conditions

Unless otherwise specified in 5C-3-4/25.1, the plate thickness and section modulus of the vertical corrugation of bulkheads bounding any dry cargo hold are to be in accordance with the following requirements.

25.7.1 Flooded Condition

Unless a direct calculation is carried out to determine the most probable pressures imposed on the corrugated bulkhead for a simulated flooded condition, an equivalent pressure distribution corresponding to 70% of the pressure obtained for a full ballast hold as specified in 5C-3-3/Table 3 is to be used for this purpose.

25.7.2 Plate Thickness *(1 July 1998)*

The net thickness of the flange panels and web panels below 0.7 of span ℓ from the top of the lower stool is not to be less than t_2 and t_4, respectively, as specified in 5C-3-4/25.3 above with the flooded pressure defined in 5C-3-4/25.7.1 above and bending moment coefficient defined in 5C-3-4/25.7.3(b) below. In determination of t_4, the permissible shear stress of 0.50 $S_m f_y$ is to be used.

25.7.3 Section Modulus and Ultimate Bending Moment *(1 July 1998)*

The net section modulus of the corrugation obtained from 5C-3-4/25.5 above is to be increased, as specified below.

25.7.3(a) The net section modulus for any unit corrugation below 0.7 of span ℓ from the top of the lower stool is not to be less than *SM* required in 5C-3-4/25.5 for the mid-depth region with the flooded pressure defined in 5C-3-4/25.7.1 above and bending moment coefficients given in the table in 5C-3-4/25.7.3(b) below. The permissible bending stress is as defined as follows:

$$f_b = c_e f_y \leq 0.95 S_m f_y$$

c_e, f_y and S_m are as defined in 5C-3-4/25.5 above.

25.7.3(b) The calculated maximum bending moment, M, at the lower end and mid-depth of the corrugation is not to be greater than 90% of the ultimate bending moment, M_u, defined as follows:

$$M_u = 0.25d(2at_f + ct_w)10^{-3}\ S_m f_y \qquad \text{N-cm (kgf-cm, lbf-in)}$$

For the calculation of M for 5C-3-4/25.7.3(a) and 5C-3-4/25.7.3(b) above, the following bending moment coefficients, C_i may be used.

Dry Cargo Hold Bulkhead with Lower Stool

Location	*Lower End of Span ℓ*	*Mid-depth*	*Upper End of Span ℓ*
Dry Cargo Holds			
(with upper stool)	C_1	C_{m1}	$0.50C_{m1}$
(without upper stool)	C_5	C_{m5}	$0.20C_{m5}$

Dry Cargo Hold Bulkhead without Lower Stool for Vessels Shorter than 190m in Length

Location	*Lower End of Span ℓ*	*Mid-depth*	*Upper End of Span ℓ*
Dry Cargo Holds (with upper stool)	C_6	C_{m6}	$0.50C_{m6}$

where

C_5 = $1.01 - 0.166/R_b$

C_{m5} = $0.52 + 0.085/R_b$

C_6 = $a_6 + b_6(kA_d/L_d)^{1/2}$,

where $a_6 = 1.81 - 0.118R_a - 0.266/R_a$,

$b_6 = -0.55 - 0.105R_a - 0.224/R_a$

C_{m6} = $a_{m6} + b_{m6}(kA_d / L_d)^{1/2}$,

where $a_{m6} = 0.66 + 0.041R_a + 0.085/R_a$,

$b_{m6} = -0.62 + 0.031R_a + 0.079/R_a$

All other parameters are as defined in 5C-3-4/25.5 above.

25.9 Bulkhead Lower Stool *(2004)*

The height of the lower stool is generally to be not less than three (3) times the depth of corrugation. The net thickness and material of the stool top plate is not to be less than that required for the bulkhead plating. The net thickness and material of the upper part of the vertical or sloping stool side plate, within the region of one corrugation flange width from the stool top, is not to be less than those required to meet the bulkhead stiffness requirement for the flange at the lower end of corrugation. The net thickness of the stool side plating and the net section modulus of the stool side stiffeners are to be not less than those required for plane transverse bulkhead plating and stiffeners, in 5C-3-4/23.1 and 5C-3-4/23.3 with the pressure specified in 5C-3-4/25.7.1 nor, where applicable, those required by 5C-3-A5b/13. The ends of the stool side vertical stiffeners are to be attached to brackets at the upper and lower ends of the stool.

The extension of the top plate beyond the corrugation is to be not less than the as-built flange thickness of the corrugation. See 5C-3-4/Figure 20. Proper brackets and diaphragms are to be provided in the stool to effectively support the panels of the corrugated bulkhead. The width of the stool at the inner bottom is to be not less than 2.5 times the mean depth of the corrugation. The stool bottom is to be positioned in line with double bottom floors. Scallops in the brackets and diaphragms in way of the top and bottom connections to the plate and in the double bottom floors or girders are to be avoided.

For vessels less than 190 meters in length, the lower stool may be omitted in dry cargo holds. In that case the strength of the corrugated bulkhead is to comply with the requirements in 5C-3-4/25.5 for the bulkhead without lower stool. When no lower stool is fitted, the corrugation flanges are to be in line with the supporting floors and cut-outs in the floors for inner bottom longitudinals are to be closed by collar plates. The thickness and material properties of these floors are to be at least equal to those provided for the corrugation flanges. If the stool is fitted for vessels less than 190 meters in length, the arrangements and scantlings of the stool are to comply with the requirements of this Paragraph.

25.11 Bulkhead Upper Stool *(2004)*

The upper stool, where fitted, is to have a height measured at the inboard side of the upper wing tank, generally not less than two (2) times the depth of corrugation, and is to be properly supported by girders or deep brackets between the adjacent hatch-end beams.

The width of the stool bottom plate is generally to be the same as that of the lower stool top plate. The net thickness of the stool bottom plate is generally to be not less than that required for the upper part of the bulkhead plating, and the net thickness of the lower part of the stool side plate is to be not less than 80% of that required for the stool bottom plate. The net thickness of the stool side plating and the net section modulus of the stool side stiffeners are to be not less than those required for plane transverse bulkhead plating and stiffeners, in 5C-3-4/23.1 and 5C-3-4/23.3, with the pressure specified in 5C-3-4/25.7.1 nor, where applicable, those required by 5C-3-A5b/13. The ends of the stool side stiffeners are to be attached to brackets at the upper and lower ends of the stool. Brackets or diaphragms are to be fitted to effectively support the web panels of the corrugated bulkhead. Scallops in the brackets and diaphragms in way of the connection to the stool bottom plate are to be avoided.

25.13 Bulkhead Stool Alignment

Stool side plating is to align with the corrugation flanges.

Stool side plating is not to be knuckled anywhere between the inner bottom plating and the stool top.

When no upper stool is fitted, care is to be exercised to provide proper backing structure for the corrugation flanges at the deck level. This may generally be accomplished by fitting two heavy transverse beams in line with the corrugation flanges.

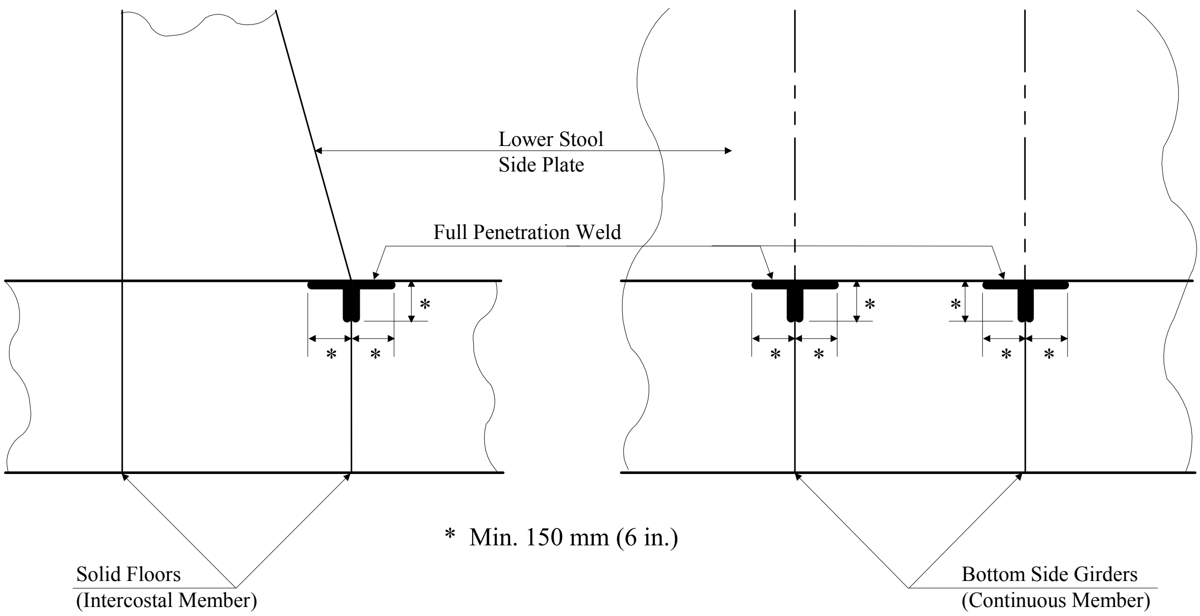
Stool side vertical stiffeners and their brackets in lower stool are to align with the inner bottom longitudinals to provide appropriate load transmission between these stiffening members.

25.15 Bulkhead End Connection *(2004)*

The structural arrangements and welding at the ends of corrugations are to be designed to develop the required strength of the corrugated bulkhead. Shedder plates (slanting plates) are to be fitted at the lower end connection of the corrugation to the lower stool. It is recommended that the upper end of the corrugation be connected to the upper stool or the upper deck with brackets or gussets arranged in line with corrugation flanges. For floor plates directly below the stool side plating or directly below the corrugation flange, if no stool is provided, cut-outs for inner bottom longitudinals are to be closed by collar plates.

Welded connections are to comply with Section 3-2-19, except as modified in the following paragraphs.

At the lower end, corrugations are to be connected to the stool top plate by full penetration welding. The stool side plating is to be connected to the stool top plate and inner bottom plating by either full penetration or deep penetration welds. The plating of the lower stool and supporting floors is to be connected to the inner bottom plating by full or “deep penetration welding” (see 5C-3-4/Figure 21). If no lower stool is fitted, corrugations are to be connected to the inner bottom plating by full penetration welding and the plating of the supporting floors is to be connected to the inner bottom plating by full or “deep penetration welding” (see 5C-3-4/Figure 21). The double bottom girders in a cargo hold intended for the carriage of ballast water at sea are to be connected to the floors and the inner bottom plating in way of the side plating of the lower stool by full penetration welding. (See Figure below.)



At the upper stool, the welds connecting the bulkhead and stool within 10% of the depth of the corrugation from the outer surface of the corrugation, d_1, are to have double continuous welds with fillet size not less than 0.7 times the thickness of the bulkhead plating or equivalent penetration welds (see 5C-3-4/Figure 19).

Shedder plates are to be welded to the corrugations and stool top plates by one-sided penetration welds or equivalent. Gusset plates are to be welded to the stool top plate with full penetration welds and to the corrugations by one-sided penetration welds or equivalent.

FIGURE 18
Definition of Parameters for Corrugated Bulkhead

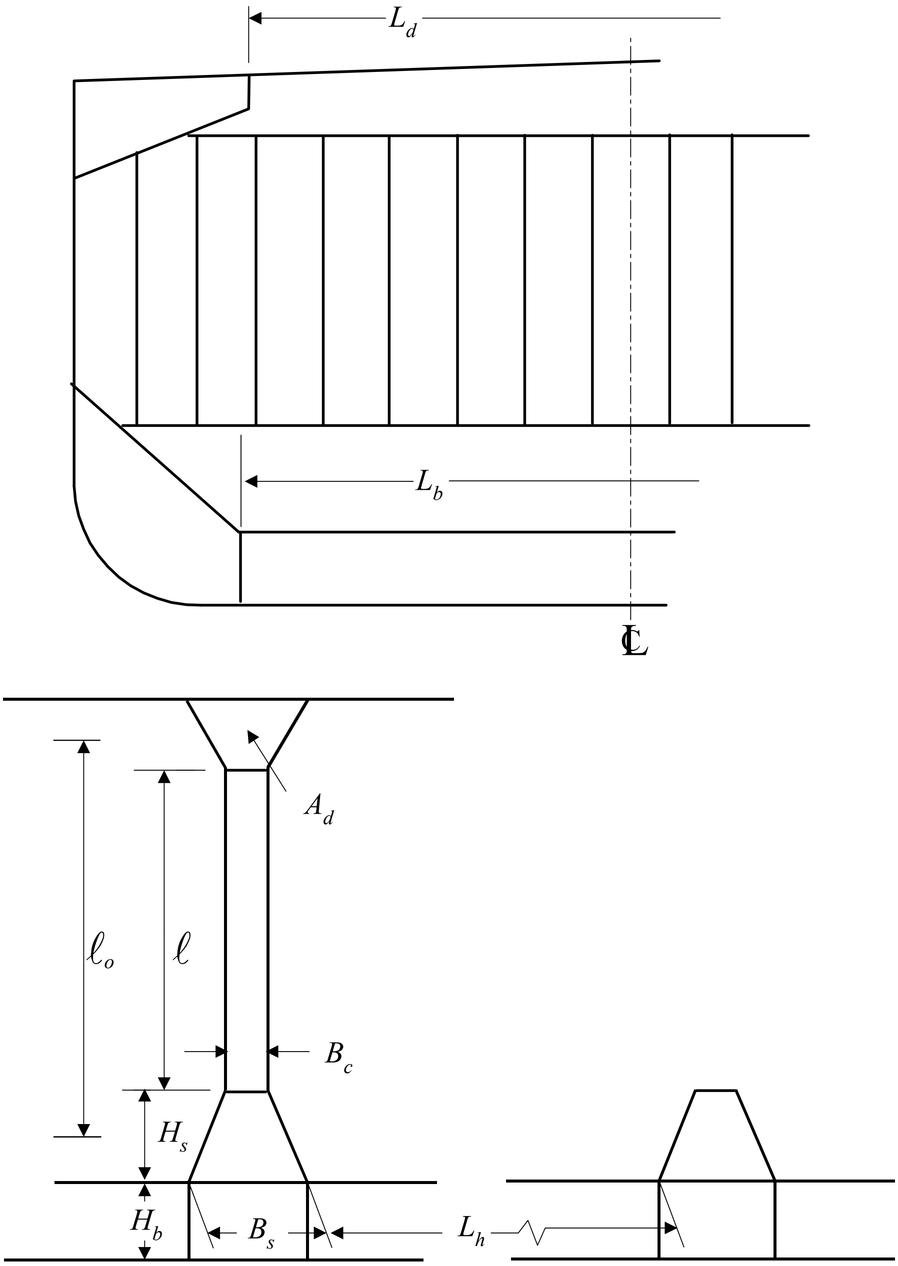


FIGURE 19
Corrugated Bulkhead End Connections

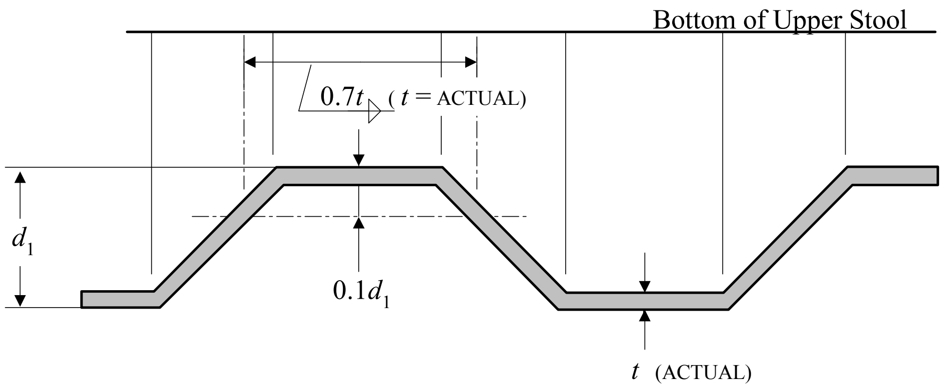


FIGURE 20
Extension of Lower Stool Top Plate *(2002)*

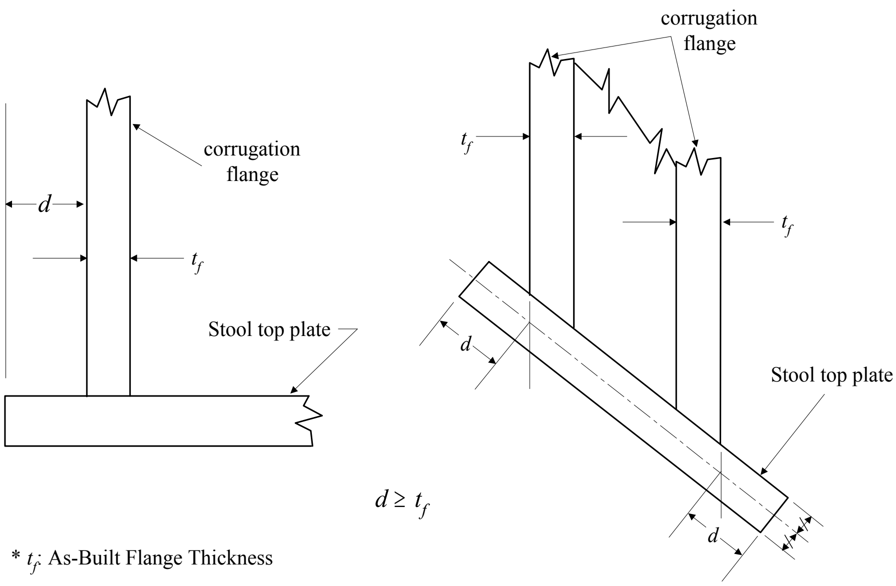
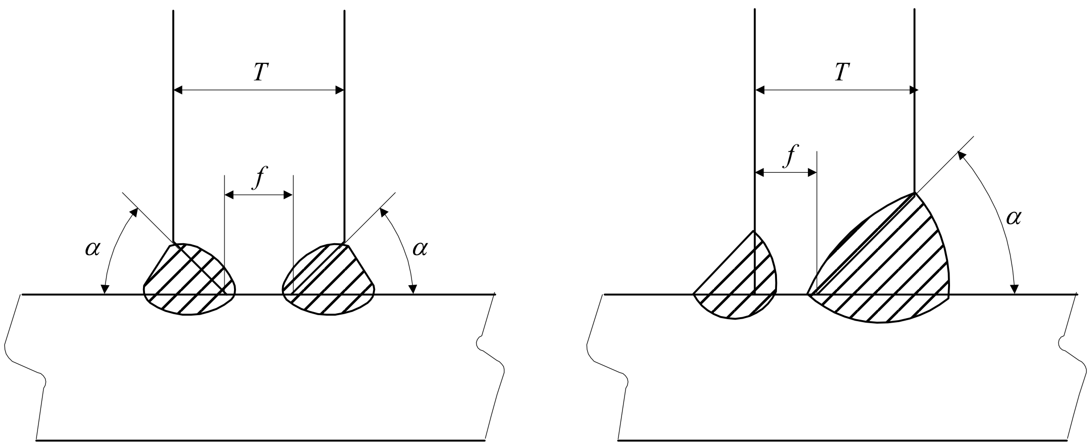


FIGURE 21
Full/Deep Penetration Welding *(2003)*



Root Face (f):	(for full penetration weld)	0 mm ≤ f ≤ 3 mm (with back gouging)
	(for deep penetration weld)	3 mm ≤ f ≤ T/3 mm
Groove Angle (α)	40º to 60º	

PART

5C

CHAPTER 3 Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)

SECTION 5 Total Strength Assessment

1 General Requirements

1.1 General *(1996)*

In assessing the adequacy of the structural configuration and the initially selected scantlings, the strength of the hull girder and the individual structural member or element is to be in compliance with the failure criteria specified in 5C-3-5/3 below. In this regard, the structural response is to be calculated by performing a structural analysis as specified in 5C-3-5/9 or by other equivalent and effective means. Due consideration is to be given to structural details as specified in 5C-3-4/1.5.

1.3 Loads and Load Cases *(1996)*

In the determination of the structural response, the combined load cases given in 5C-3-3/9.3 are to be considered together with impact loads specified in 5C-3-3/11. Vibratory hull-girder and other loads as specified in 5C-3-3/13 are also to be considered as necessary.

1.5 Stress Components *(1996)*

The total stresses in stiffened plate panels are divided into the following three categories.

1.5.1 Primary

Primary stresses are those resulting from hull-girder bending. The primary bending stresses may be determined by simple beam theory using the specified total vertical and horizontal bending moments and the effective net hull-girder section modulus at the section considered. These primary stresses, designated by f_{L1} (f_{L1V}, f_{L1H} for vertical and horizontal bending, respectively), may be regarded as uniformly distributed across the thickness of plate elements at the same level, measuring from the relevant neutral axis of the hull girder.

1.5.2 Secondary

Secondary stresses are those resulting from bending of large stiffened panels between longitudinal and transverse bulkheads due to local loads in an individual cargo or ballast hold.

The secondary bending stresses, designated by f_{L2} or f_{T2}, are to be determined by performing a 3D FEM analysis as outlined in this section.

For stiffened hull structures, there is another secondary stress due to the bending of longitudinals or stiffeners with the associated plating between deep supporting members or floors. The latter secondary stresses are designated by f^*_{L2} or f^*_{T2}, and may be approximated by simple beam theory.

The secondary stresses, f_{L2}, f_{T2}, f^*_{L2} or f^*_{T2}, may be regarded as uniformly distributed in the flange plating and face plates.

1.5.3 Tertiary

Tertiary stresses are those resulting from the local bendings of plate panels between stiffeners. The tertiary stresses, designated by f_{L3} or f_{T3}, can be calculated from classic plate theory. These stresses are referred to as point stresses at the surface of the plate.

3 Yielding Criteria

3.1 General

The calculated stresses in the hull structure are to be within the limits given below for all of the combined load cases specified in 5C-3-3/9.3.

3.3 Structural Members and Elements

For all structural members and elements, such as longitudinals/stiffeners, web plates and flanges, the combined effects of all of the calculated stress components are to satisfy the following limits:

$$f_i \le S_m f_y$$

where

f_i = stress intensity

= $(f_L^2 + f_T^2 - f_L f_T + 3 f_{LT}^2)^{1/2}$ N/cm^2 (kgf/cm^2, lbf/in^2)

f_L = calculated total in-plane stress in the longitudinal direction including primary and secondary stresses

= $f_{L1} + f_{L2} + f^*_{L2}$, N/cm^2 (kgf/cm^2, lbf/in^2)

f_{L1} = direct stress due to the primary (hull girder) bending, N/cm^2 (kgf/cm^2, lbf/in^2)

f_{L2} = direct stress due to the secondary bending between bulkheads in the longitudinal direction, N/cm^2 (kgf/cm^2, lbf/in^2)

f^*_{L2} = direct stress due to local bending of longitudinal between transverses in the longitudinal direction, N/cm^2 (kgf/cm^2, lbf/in^2)

f_T = calculated total direct stress in the transverse/vertical direction, including secondary stresses

= $f_{T1} + f_{T2} + f^*_{T2}$ N/cm^2 (kgf/cm^2, lbf/in^2)

f_{LT} = calculated total in-plane shear stress, N/cm^2 (kgf/cm^2, lbf/in^2)

f_{T1} = direct stress due to sea and cargo loads in the transverse/vertical direction, N/cm^2 (kgf/cm^2, lbf/in^2)

f_{T2} = direct stress due to the secondary bending between bulkheads in the transverse/vertical direction, N/cm^2 (kgf/cm^2, lbf/in^2)

f^*_{T2} = direct stress due to local bending of stiffeners in the transverse/vertical direction, N/cm^2 (kgf/cm^2, lbf/in^2)

f_y = specified minimum yield point, N/cm^2 (kgf/cm^2, lbf/in^2)

S_m = strength reduction factor, as defined in 5C-3-4/7.3.1

For this purpose, f^*_{L2} and f^*_{T2} in the flanges of longitudinals and stiffeners, at the ends of span may be obtained from the following equation.

$$f^*_{L2}\ (f^*_{T2}) = 0.071sp\ell^2/SM_L\ (SM_T) \qquad N/cm^2\ (kgf/cm^2,\ lbf/in^2)$$

where

s = spacing of longitudinals (stiffeners), in cm (in.)

ℓ = unsupported span of the longitudinal (stiffener), in cm (in.)

p = net pressure load, in N/cm^2 (kgf/cm^2, lbf/in^2), for the longitudinal (stiffener)

SM_L (SM_T) = net section modulus, in cm^3 (in^3), of the longitudinal (stiffener)

3.5 Plating

For plating subject to both in-plane and lateral loads, the combined effects of all the calculated stress components are to satisfy the limits specified in 5C-3-5/3.3 with f_L and f_T modified as follows:

$$f_L = f_{L1} + f_{L2} + f^*_{L2} + f_{L3} \qquad N/cm^2\ (kgf/cm^2,\ lbf/in^2)$$

$$f_T = f_{T1} + f_{T2} + f^*_{T2} + f_{T3} \qquad N/cm^2\ (kgf/cm^2,\ lbf/in^2)$$

where

f_{L3}, f_{T3} = plate bending stresses between stiffeners in the longitudinal and transverse directions, respectively, and may be approximated as follows.

f_{L3} = $k_L\, p(s/t_n)^2$ N/cm^2 (kgf/cm^2, lbf/in^2)

f_{T3} = $k_T\, p(s/t_n)^2$ N/cm^2 (kgf/cm^2, lbf/in^2)

k_L = 0.182 or 0.266 for stiffeners in the longitudinal or transverse direction, respectively

k_T = 0.266 or 0.182 for stiffeners in the longitudinal or transverse direction, respectively

p = lateral pressures for the combined load case considered (see 5C-3-3/9), in N/cm^2 (kgf/cm^2, lbf/ in^2)

s = spacing of longitudinals or stiffeners, in mm (in.)

t_n = net plate thickness, in mm (in.)

$f_{L1}, f_{L2}, f^*_{L2}, f_{T1}, f_{T2}$ and f^*_{T2} are as defined in 5C-3-5/3.3.

5 Buckling and Ultimate Strength Criteria *(1996)*

5.1 General

5.1.1 Approach

The strength criteria given here correspond to either serviceability (buckling) state limits or ultimate state limits for structural members and panels, according to the intended functions and buckling resistance capability of the structure. For plate panels between stiffeners, buckling in the elastic range is acceptable, provided the ultimate strength of the structure satisfies the specified design limits. The critical buckling stresses and ultimate strength of structures may be determined based on either well-documented experimental data or a calibrated analytical approach. When a detailed analysis is not available, the equations given in Appendix 5C-3-A2 may be used to assess the buckling strength.

For vertically corrugated transverse bulkheads, the buckling and ultimate strength is to be in compliance with the criteria given in 5C-3-5/5.11 below. In this case, the buckling of the flange and web panels is not acceptable for the load cases specified in 5C-3-3/9.

5.1.2 Buckling Control Concepts

The strength criteria in 5C-3-5/5.3 through 5C-3-5/5.13 are based on the following assumptions and limitations with respect to buckling control in design.

5.1.2(a) The buckling strength of longitudinals and stiffeners is generally greater than that of the plate panels they support.

5.1.2(b) All longitudinals with the associated effective plating are to have moments of inertia not less than i_o given in 5C-3-A2/11.1.

5.1.2(c) The main supporting members, including transverses, girders and floors, with the effective associated plating are to have moments of inertia not less than I_s given in 5C-3-A2/11.5.

In addition, tripping (e.g., torsional instability) is to be prevented as specified in 5C-3-A2/9.5.

5.1.2(d) Face plates and flanges of girders, longitudinals and stiffeners are proportioned such that local instability is prevented. (See 5C-3-A2/11.7)

5.1.2(e) Webs of longitudinals and stiffeners are proportioned such that local instability is prevented. (See 5C-3-A2/11.9).

5.1.2(f) Webs of girders, floors and transverses are designed with proper proportions and stiffening systems to prevent local instability. Critical buckling stresses of the webs may be calculated from equations given in 5C-3-A2/3.

For structures which do not satisfy these assumptions, a detailed analysis of the buckling strength using an acceptable method is to be submitted for review.

5.3 Plate Panels

5.3.1 Buckling State Limit

The buckling state limit for plate panels between stiffeners is defined by the following equation.

$$(f_{Lb}/R_\ell f_{cL})^2 + (f_{Tb}/R_t f_{cT})^2 + (f_{LT}/f_{cLT})^2 \leq 1.0$$

where

f_{Lb} = $f_{L1} + f_{L2}$ = calculated total compressive stress in the longitudinal direction for the plate, in N/cm^2 (kgf/cm^2, lbf/in^2), induced by bending of the hull girder and large stiffened panels between bulkheads

f_{Tb} = $f_{T1} + f_{T2}$ = calculated total compressive stress in the transverse/vertical direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{LT} = calculated total in-plane shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{cL}, f_{cT} and f_{cLT} are the critical buckling stresses corresponding to uniaxial compression in the longitudinal, transverse/vertical directions and edge shear, respectively, in N/cm^2 (kgf/cm^2, lbf/in^2), and may be determined from the equations given in 5C-3-A2/3.

R_ℓ, R_t = reduction factors accounting for lateral load effects, and may be approximated by:

$R_\ell = 1.0$, $R_t = 1.0 - 0.45\,(q - 0.5)$, $q \geq 0.5$ for plating longitudinally stiffened

$R_t = 1.0$, $R_\ell = 1.0 - 0.45\,(q - 0.5)$, $q \geq 0.5$ for plating transversely stiffened

q = lateral load parameter = $p_n(s/t_n)^4/\pi^2E$

p_n = lateral pressure for the combined load case considered (see 5C-3-3/9), in N/cm^2 (kgf/cm^2, lbf/in^2)

s = longitudinal spacing, in mm (in.)

t_n = net thickness of the plate, in mm (in.)

E = Young's modulus, in N/cm^2 (kgf/cm^2, lbf/in^2), for steel 2.06×10^7 (2.10×10^6, 30×10^6)

R_ℓ, R_t are not to be taken less than 0.50.

f_L, f_T and f_{LT} are to be determined for the panel in question under the load cases specified in 5C-3-3/9, including the primary and secondary stresses as defined in 5C-3-5/3.1.

5.3.2 Effective Width

When the buckling state limit specified in 5C-3-5/5.3.1 above is not satisfied, the effective width b_{wL} or b_{wT} of the plating given below is to be used instead of the full width between longitudinals, s, for determining the effective hull-girder section modulus SM_e, specified in 5C-3-5/5.13 and also for verifying the ultimate strength as specified in 5C-3-5/5.3.3 below. When the buckling state limit in 5C-3-5/5.3.1 is satisfied, the full width between longitudinals, s, may be used as the effective width b_{wL} for verifying the ultimate strength of longitudinals and stiffeners specified in 5C-3-5/5.5 and for determining the effective hull-girder section modulus SM_e specified in 5C-3-5/5.13 below.

5.3.2(a) For long plate (compression on the short edges)

$$b_{wL}/s = C$$

$$C = 2.25/\beta - 1.25/\beta^2 \quad \text{for } \beta \geq 1.25$$

$$= 1.0 \quad \text{for } \beta < 1.25$$

$$\beta = (f_y/E)^{1/2}\, s/t_n$$

s, t_n and E are as defined in 5C-3-5/5.3.1 above.

f_y = specified minimum yield point of the material, in N/cm^2 (kgf/cm^2, lbf/in^2)

5.3.2(b) For wide plate (compression on the long edges)

$$b_{wt}/\ell = Cs/\ell + 0.115(1 - s/\ell)(1 + 1/\beta^2)^2 \le 1.0$$

where

ℓ = spacing of transverses/girders, in cm (in.)

s = longitudinal spacing, in cm (in.)

C, β are as defined in 5C-3-5/5.3.2(a) above

5.3.3 Ultimate Strength

The ultimate strength of a plate panel between stiffeners is to satisfy all of the following equations:

$$(f_{Lb}/R_\ell f_{uL})^2 + (f_{LT}/f_{uLT})^2 \le S_m$$

$$(f_{Tb}/R_t f_{uT})^2 + (f_{LT}/f_{uLT})^2 \le S_m$$

$$(f_{Lb}/R_\ell f_{uL})^2 + (f_{Tb}/R_t f_{uT})^2 - \eta(f_{Lb}/R_\ell f_{uL})(f_{Tb}/R_t f_{uT}) + (f_{LT}/f_{uLT}) \le S_m$$

where

f_{Lb}, f_{Tb}, f_{LT}, R_ℓ and R_t are as defined in 5C-3-5/5.3.1 above.

S_m is as defined in 5C-3-4/7.3.1.

$$\eta = 1.5 - \beta/2 \ge 0$$

β is as defined in 5C-3-5/5.3.2 above.

f_{uL}, f_{uT} and f_{uLT} are the ultimate strengths with respect to uniaxial compression and edge shear, respectively, and may be obtained from the following equations, except that they need not be taken less than the corresponding critical buckling stresses specified in 5C-3-5/5.3.1 above.

$f_{uL} = f_y\, b_{wL}/s \ge f_{cL}$, $f_{uT} = f_y\, b_{wT}/\ell \ge f_{cT}$ for plating longitudinally stiffened

$f_{uT} = f_y\, b_{wT}/\ell \ge f_{cL}$, $f_{uT} = f_y\, b_{wL}/s \ge f_{cT}$ for plating transversely stiffened

$$f_{uLT} = f_{cLT} + 0.5(f_y - \sqrt{3} f_{cLT})/(1 + \alpha + \alpha^2)^{1/2} \ge f_{cLT}$$

where

$$\alpha = \ell/s$$

f_y, b_{wL}, b_{wT}, s, ℓ, f_{cL}, f_{cT} and f_{cLT} are as defined in 5C-3-5/5.3.1 and 5C-3-5/5.3.2 above.

For assessing the ultimate strength of plate panels between stiffeners, special attention is to be paid to the longitudinal bulkhead plating in the regions of high hull girder shear forces and the bottom and inner bottom plating in the mid region of cargo holds subject to bi-axial compression.

5.5 Longitudinals and Stiffeners

5.5.1 Beam-Column Buckling State Limits and Ultimate Strength *(2002)*

The buckling state limits for longitudinals and stiffeners are considered as the ultimate state limits for these members and are to be determined as follows:

$$f_a/(f_{ca}A_e/A) + mf_b/f_y \le S_m$$

where

f_a	=	nominal calculated compressive stress
	=	P/A, N/cm^2 (kgf/cm^2, lbf/in^2)
P	=	total compressive load, N (kgf, lbf)
f_{ca}	=	critical buckling stress, as given in 5C-3-A2/5.1, N/cm^2 (kgf/cm^2, lbf/in^2)
A	=	total net sectional area, cm^2 (in^2)
	=	$A_s + st_n$
A_s	=	net sectional area of the longitudinal, excluding the associated plating, cm^2 (in^2)
A_e	=	effective net sectional area, cm^2 (in^2)
	=	$A_s + b_{wL}t_n$
b_{wL}	=	effective width, as specified in 5C-3-5/5.3.2(a) above
E	=	Young's modulus, 2.06×10^7 N/cm^2 (2.1×10^6 kgf/cm^2, 30×10^6 lbf/in^2) for steel
f_y	=	minimum specified yield point of the longitudinal or stiffener under consideration, N/cm^2 (kgf/cm^2, lbf/in^2)
f_b	=	bending stress, N/cm^2 (kgf/cm^2, lbf/in^2)
	=	M/SM_e
M	=	maximum bending moment induced by lateral loads
	=	$c_m ps\ell^2/12$ N-cm (kgf-cm, lbf-in)
c_m	=	moment adjustment coefficient, and may be taken as 0.75
p	=	lateral pressure for the region considered, N/cm^2 (kgf/cm^2, lbf/in^2)
s	=	spacing of the longitudinals, cm (in.)
SM_e	=	effective section modulus of the longitudinal at flange, accounting for the effective breadth, b_e, cm^3 (in^3)
b_e	=	effective breadth, as specified in 5C-3-4/Figure 4, line b
m	=	amplification factor
	=	$1/[1 - f_a/\pi^2E(r/\ell)^2] \ge 1.0$

S_m is as defined in 5C-3-4/7.3.1.

r and ℓ are as defined in 5C-3-A2/5.1.

5.5.2 Torsional-Flexural Buckling State Limit *(2002)*

In general, the torsional-flexural buckling state limit of longitudinals and stiffeners is to satisfy the ultimate state limits given below:

$$f_a/(f_{ct}A_e/A) \le S_m$$

where

f_a = nominal calculated compressive stress in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in 5C-3-5/5.5.1 above

f_{ct} = critical torsional-flexural buckling stress in N/cm^2 (kgf/cm^2, lbf/in^2), and may be determined by equations given in 5C-3-A2/5.3

A_e and A are as defined in 5C-3-5/5.5.1 above and S_m is as defined in 5C-3-4/7.3.1.

5.7 Stiffened Panels

5.7.1 Large Stiffened Panels Between Bulkheads

For a vessel under the assumptions made in 5C-3-5/5.1.2 above with respect to the buckling control concepts, the large stiffened panels of the double bottom and wing tank structures between transverse bulkheads should automatically satisfy the design limits, provided each individual plate panel and longitudinally and uniaxially stiffened panel satisfy the specified ultimate state limits. Assessments of the buckling state limits are to be performed for large stiffened panels of the deck structure, side shell and plane transverse bulkheads. In this regard, the buckling strength is to satisfy the following condition for uniaxially or orthogonally stiffened panels.

$$(f_{L1}/f_{cL})^2 + (f_{T1}/f_{cT})^2 \le S_m$$

where

f_{L1}, f_{T1} = the calculated average compressive stresses in the longitudinal and transverse/vertical directions respectively, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{cL}, f_{cT} = the critical buckling stresses for uniaxial compression in the longitudinal and transverse direction, respectively, and may be determined in accordance with 5C-3-A2/7, in N/cm^2 (kgf/cm^2, lbf/in^2)

S_m = strength reduction factor, as defined in 5C-3-4/7.3.1

5.7.2 Uniaxially Stiffened Panels between Transverses and Girders

The buckling strength of uniaxially stiffened panels between deep transverses and girders is also to be examined in accordance with the specifications given in 5C-3-5/5.7.1 by replacing f_{L1} and f_{T1} with f_{Lb} and f_{Tb}, respectively. f_{Lb} and f_{Tb} are as defined in 5C-3-5/5.3.1.

5.9 Deck Girders and Webs

5.9.1 Buckling Criteria

In general, the stiffness of the web stiffeners along the depth of the web plating is to be in compliance with the requirements in 5C-3-A2/11.3. Web stiffeners which are oriented parallel to and near the face plate, thus subject to axial compression, are also to satisfy the limits specified in 5C-3-5/5.5, considering the combined effect of the compressive and bending stresses in the web. In this case, the unsupported span of these parallel stiffeners may be taken between tripping brackets, as applicable.

The buckling strength of the web plate between stiffeners and flange/face plate is to satisfy the limits specified below.

5.9.1(a) For Web Plate

$$(f_{Lb}/f_{cL})^2 + (f_b/f_{cb})^2 + (f_{LT}/f_{cLT})^2 \leq S_m$$

where

f_{Lb} = calculated uniform compressive stress along the length of the girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_b = calculated ideal bending stresses, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{LT} = calculated total in-plane shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{Lb}, f_b and f_{LT} are to be calculated for the panel in question under the combined load cases specified in 5C-3-3/9.3.

f_{cL}, f_{cb} and f_{cLT} are critical buckling stresses with respect to uniform compression, ideal bending and shear, respectively, and may be determined in accordance with Appendix 5C-3-A2. S_m is as defined in 5C-3-4/7.3.1.

In the determination of f_{cL} and f_{cLT}, the effects of openings are to be considered.

5.9.1(b) For Face Plate and Flange. The breadth to thickness ratio of face plate and flange is to satisfy the limits given in 5C-3-A2/11.

5.9.1(c) For Large Brackets and Sloping Webs. The buckling strength is to satisfy the limits specified above for web plate.

5.9.2 Tripping

Tripping brackets are to be provided in accordance with 5C-3-A2/9.5.

5.11 Corrugated Bulkheads

5.11.1 Local Plate Panels

5.11.1(a) Buckling Criteria. The buckling strength of the flange and web plate panels are to satisfy the conditions specified below:

$$(f_{Lb}/R_\ell f_{cL})^2 + (f_{Tb}/R_t f_{cT})^2 + (f_{LT}/f_{cLT})^2 \leq S_m \qquad \text{for flange panels}$$

$$(f_{Lb}/R_\ell f_{cL})^2 + (f_b/f_{cb})^2 + (f_{LT}/f_{cLT})^2 \leq S_m \qquad \text{for web panels}$$

All the parameter definitions and calculations are as specified in 5C-3-5/5.3.1 and 5C-3-5/5.9.1(a) above, except that f_{Lb} is the average compressive stress at the upper and lower ends of the corrugation and an average value of f_{LT} and f_b calculated along the entire length of the panel is to be used in the above equation. When a direct calculation is not available, the f_{LT} in the flange panels may be taken as one half of that in the web panels and f_{Tb} for the flange panels may be approximated by

$$f_{Tb} = p(c + a\cos\phi)/(2t\sin\phi)$$

where

p = nominal pressure specified in Section 5C-3-3 for the corrugated bulkhead, in N/cm^2 (kgf/cm^2, lbf/in^2)

a = width of flange panel, in cm (in.)

c = width of web panel, in cm (in.)

ϕ = corrugation angle, in degrees

t = net thickness of the flange panel, in cm (in.)

5.11.1(b) Ultimate Strength. The ultimate strength of flange panels in the middle third region of the depth is to satisfy the following criteria for all service load cases and the specified flooded conditions. In this case, a part of the flange panel with a length of three times the panel width, a, covering the worst bending moments in the mid-depth region is to be considered.

$$(f_{Lb}/f_{uL})^2 + (f_{Tb}/f_{uT})^2 \leq S_m$$

where

f_{Lb} = the calculated average compressive bending stress in the region within $3a$ in length, N/cm^2 (kgf/cm^2, lbf/in^2)

f_{Tb} = horizontal compressive stresses, as specified in 5C-3-5/5.11.1(a) above

f_{uL} and f_{uT} may be calculated in accordance with 5C-3-5/5.3.3.

5.11.2 Unit Corrugation

Any unit corrugation of the bulkhead may be treated as a beam column and is to satisfy the buckling criteria (same as the ultimate strength) specified in 5C-3-5/5.5.1. The ultimate bending stress is to be determined in accordance with 5C-3-A2/5.5.

5.11.3 Entire Corrugation

The buckling strength of the entire corrugation is to satisfy the equation given in 5C-3-5/5.7.1 with respect to bi-axial compressions by replacing the subscripts "L" and "T" with "V" and "H" for the vertical and horizontal directions, respectively.

5.13 Hull Girder Ultimate Strength

In addition to the strength requirements specified in 5C-3-4/3.1, the ultimate strength of the hull-girder is to be assessed for the combined load cases given in 5C-3-3/9.3 and the specifications given in 5C-3-5/5.13.1 and 5C-3-5/5.13.2 below.

5.13.1 Maximum Longitudinal Bending Stresses

The maximum longitudinal bending stresses in the deck and bottom plating are not to be greater than that given in 5C-3-5/5.13.1(a) below.

5.13.1(a) $f_L \leq S_m f_y$

where

f_L = total direct stress in the longitudinal direction, N/cm^2 (kgf/cm^2, lbf/in^2)

= $f_{b1} + f_{b2}$

f_{b1} = effective longitudinal bending stress, N/cm^2 (kgf/cm^2, lbf/in^2)

= M_t/SM_e

M_t = $M_s + k_u k_c M_w$, $k_u = 1.15$, $k_c = 1.0$, N-cm (kgf-cm, lbf-in)

For vessels having significant bowflare, k_u is to be increased based on 5C-3-3/11.3.3.

SM_e = the effective section modulus, as obtained from 5C-3-5/5.13.1(b) below, cm^3 (in^3)

S_m = the strength reduction factor, as defined in 5C-3-4/7.3.1

f_y = minimum specified yield point of the material, N/cm^2 (kgf/cm^2, lbf/in^2)

f_{b2} = secondary bending stress of large stiffened panel between longitudinal bulkheads and transverse bulkheads, N/cm^2 (kgf/cm^2, lbf/in^2)

5.13.1(b) Calculation of SM_e. For assessing the hull girder ultimate strength, the effective section modulus is to be calculated, accounting for the buckling of the plate panels and shear lag effects, as applicable.

i) *Effective Width.* The effective widths of the side, bottom shell, inner bottom plating and longitudinal bulkhead plating are to be used instead of the full width between longitudinals. The effective width, b_{wL}, is given in 5C-3-5/5.3.2(a) above.

ii) *Shear Lag.* For vessels with alternate hold loading patterns, the effective breadths (B_e) of the deck, and inner and outer bottom plating are to be determined based on the cL/b_i ratio as defined below.

cL/b =	12	10	9	8	7	6	5	4
$2B_e/B$ =	0.98	0.96	0.95	0.93	0.91	0.88	0.84	0.78

where

cL is the length between two points of zero bending moment, away from the midship, may be taken as 60% of the vessel length.

b_i is the width of the upper wing tank (b_d) or the half width of the double bottom (b_b), as shown in 5C-3-5/Figure 1.

For $cL/b_i > 12$, no shear lag effects need to be considered.

The effective sectional areas of deck, inner bottom and bottom longitudinals are to be reduced by the same ratio, $2B_e/B$, for calculating SM_e.

5.13.2 Buckling and Ultimate Strength of Large Stiffened Panels

Under the combined effects of the normal stresses, f_L and f_T, the buckling and ultimate strength of the stiffened panel is to satisfy the requirements specified in 5C-3-5/5.7.

5.13.3 Hull Girder Shearing Strength

The hull girder shearing stress in the side shell and longitudinal bulkhead is not to be greater than that given below.

$$f_s \le S_m f_{uLT}$$

where

f_s = hull girder shearing stress, N/cm^2 (kgf/cm^2, lbf/in^2), and may be calculated for F_t from the equations in 5C-3-4/5.3, 5C-3-4/5.5 and 5C-3-4/5.7 using net thickness of side shell and longitudinal bulkhead

F_t = $F_s + k_c k_u F_w$, $k_u = 1.15$, $k_c = 1.0$, N-cm (kgf-cm, lbf-in).

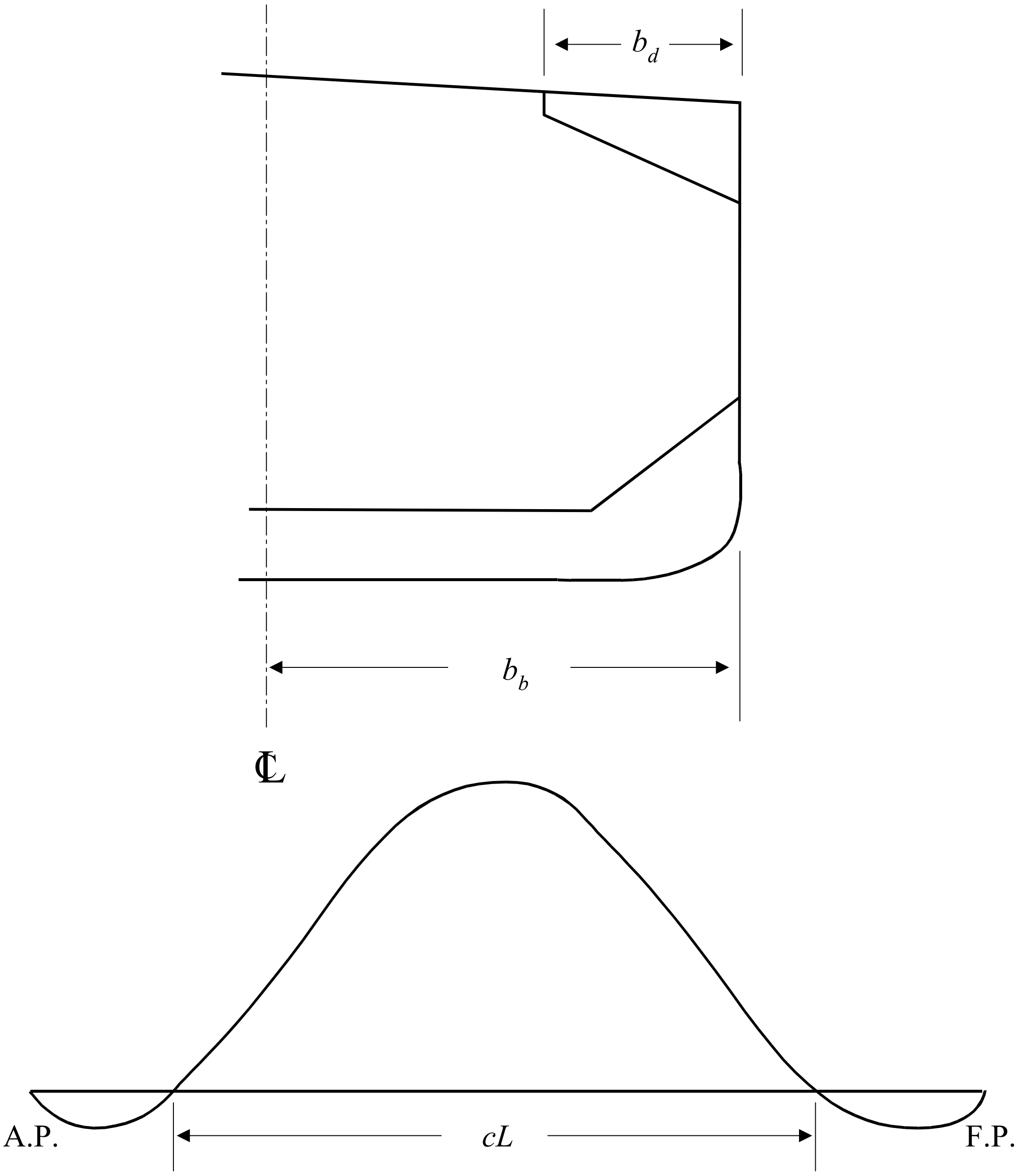
For vessels having flare parameter A_r exceeding 21 m (68.9 ft), k_u is to be increased as required by 5C-3-3/11.3.3.

S_m = strength reduction factor, as defined in 5C-3-4/7.3.1

f_{uLT} = ultimate shearing strength of panel, as defined in 5C-3-5/5.3.3

A_r is as defined in 5C-3-3/11.3.

FIGURE 1



7 Fatigue Life *(1996)*

7.1 General

The fatigue strength of welded joints and details in highly stressed areas is to be analyzed, especially where higher strength steel is used. Special attention is to be given to structural notches, cut-outs and bracket toes and also to abrupt changes of structural sections. A simplified assessment of the fatigue strength of structural details may be accepted when carried out in accordance with Appendix 5C-3-A1.

The following subparagraphs are intended to emphasize the main points and to outline procedures where refined spectral analysis techniques are used to establish fatigue strength.

7.1.1 Workmanship

Most fatigue data available were experimentally developed under controlled laboratory conditions. Therefore, consideration is to be given to the workmanship expected during construction.

7.1.2 Fatigue Data

In the selection of S-N curves and the associated stress concentration factors, attention is to be paid to the background of all design data and its validity for the details being considered. In this regard, recognized design data, such as those by AWS (American Welding Society), API (American Petroleum Institute), and DEn (Department of Energy), should be considered. Sample fatigue data and their applications are shown in Appendix 5C-3-A1 "Guide for Fatigue Strength Assessment of Bulk Carriers."

If other fatigue data are to be used, the background and supporting data are to be submitted for review.

In this regard, clarification is required whether or not the stress concentration due to the weld profile, certain structural configurations and also the heat effects are accounted for in the proposed S-N curve. Consideration is also to be given to the additional stress concentrations.

7.1.3 Total Stress Range

For determining total stress ranges, the fluctuating stress components resulting from the load combinations specified in 5C-3-A1/7.5 are to be considered.

7.1.4 Design Consideration

In design, consideration is to be given to the minimization of structural notches and stress concentrations. Areas subject to highly concentrated forces are to be properly configured and stiffened to dissipate the concentrated loads. See also 5C-3-4/1.5.

7.3 Procedures

The analysis of fatigue strength for a welded structural joint/detail may be performed in accordance with the following procedures.

7.3.1 Step 1 – Classification of Various Critical Locations

The class designations and associated load patterns are given in 5C-3-A1/Table 1.

7.3.2 Step 2 – Permissible Stress Range Approach

Where deemed appropriate, the total applied stress range of the structural details classified in Step 1 may be checked against the permissible stress ranges, as shown in Appendix 5C-3-A1.

7.3.3 Step 3 – Refined Analysis

Refined analyses are to be performed, as outlined in 5C-3-5/7.3.3(a) or 5C-3-5/7.3.3(b) below, for the structural details for which the total applied stress ranges obtained from Step 2 are greater than the permissible stress ranges, or for which the fatigue characteristics are not covered by the classified details and the associated S-N curves.

The fatigue life of the structure is generally not to be less than 20 years unless otherwise specified.

7.3.3(a) Spectral Analysis. Alternatively, a spectral analysis may be performed, as outlined in 5C-3-5/7.5 below, to directly calculate fatigue lives for the structural details in question.

7.3.3(b) Refined Fatigue Data. For structural details which are not covered by the detail classifications, proposed S-N curves and the associated SCFs, when applicable, may be submitted for consideration. In this regard, sufficient supporting data and background are also to be submitted for review. The refined SCFs may be determined by finite element analyses.

7.5 Spectral Analysis

Where the option in 5C-3-5/7.3.3(a) is exercised, a spectral analysis is to be performed in accordance with the following guidelines.

7.5.1 Representative Loading Patterns

Several representative loading patterns are to be considered to cover the worst scenarios anticipated for the design service life of the vessel with respect to the hull girder local loads.

7.5.2 Environmental Representation

Instead of the design wave loads specified in Section 5C-3-3, a wave scatter diagram (such as Walden's Data) is to be employed to simulate a representative distribution of all of the wave conditions expected for the design service life of the vessel. In general, the wave data is to cover a time period of not less than 20 years. The probability of occurrence for each combination of significant wave height and mean period of the representative wave scatter diagram is to be weighted based on the transit time of the vessel at each wave environment within the anticipated shipping routes. The representative environment (the wave scatter diagram) is not to be taken less severe than the North Atlantic Ocean in terms of the fatigue damage.

7.5.3 Calculation of Wave Load RAOs

The wave load RAOs with respect to the wave induced bending moments, shear forces, motions, accelerations and hydrodynamic pressures can then be predicted by ship motion calculation for a selected representative loading condition.

7.5.4 Generation of Stress Spectrum

The stress spectrum for each critical structural detail (spot) may be generated by performing a structural analysis, accounting for all of the wave loads separately for each individual wave group. For this purpose, the 3D structural model and 2D models specified in 5C-3-5/9 may be used for determining structural responses. The additional secondary and tertiary stresses are also to be considered.

7.5.5 Cumulative Fatigue Damage and Fatigue Life

Based on the stress spectrum and the wave scatter diagram established above, the cumulative fatigue damage and the corresponding fatigue life can be estimated by the Palmgren-Miner linear damage rule.

9 Calculation of Structural Responses *(1996)*

9.1 Methods of Approach and Analysis Procedures *(1996)*

Maximum stresses in the structure are to be determined by performing structural analyses as outlined below. Guidelines on structural idealization, load application and structural analysis are given in ABS *Guidance for Finite Element Analysis of Bulk Carrier Structures*.

9.3 3D Finite Element Models *(1996)*

A simplified three-dimensional (3D) finite element model, usually representing three cargo holds within 0.4*L* amidships, is required to determine the load distribution in the structure.

The same 3D finite element model may be used for hull structures beyond 0.4*L* amidships, with modifications to the structural properties and the applied loads, provided that the structural configurations are considered as representative of the location under consideration.

A separate 3D finite element model is recommended to represent the forebody structures for the analysis when bottom slamming and bowflare slamming are to be considered, as specified in 5C-3-3/11.1 and 5C-3-3/11.3.

9.5 2D Finite Element Models *(1996)*

Two-dimensional fine mesh finite element models are required to determine the stress distribution in major supporting structures, particularly at intersections of two or more structural members.

9.7 Local Structural Models *(1996)*

A 3D fine mesh finite element model is to be used to examine stress concentrations such as at intersections of the transverse bulkheads with sloping longitudinal bulkheads.

9.9 Load Cases *(1996)*

When performing structural analysis, the ten combined load cases specified in 5C-3-3/9.1 are to be considered. 5C-3-5/Table 1 indicates the load cases to be investigated in assessing the adequacy of structures in each designated hold. In general, the structural responses for the still water conditions are to be calculated separately to establish reference points for assessing the wave-induced responses. Additional load cases may be required for special loading patterns and unusual design functions, such as impact loads as specified in 5C-3-3/11. Additional load cases may also be required for hull structures beyond the region of 0.4*L* amidships.

TABLE 1
Combined Load Cases to be Investigated for Each Structural Member (4)

Structural Members/Components	*Holds Designed for Alternate Hold Loading (1)* Loaded Holds	Empty Holds	Holds Designed for Ballast Loading (1, 3)
Bottom, Inner Bottom, Side, Deck, Wing Tank Structures (Plate, Stiffeners, Frames (2), Floors, Webs (2), Stringers (2), and Girders	LC 1, 3, 5, 7 & 10	LC 2, 4, 6, 7, 8 & 10	LC 9 & 10
Transverse Bulkhead (including stools) in Holds and Tanks	LC 1, 2, 3, 4, 5, 6, 7 & 8	LC 1, 2, 3, 4, 5, 6, 7 & 8	LC 9 & 10

Notes:

1 In general, the strength assessment is to be focused on the results obtained from structures in the mid cargo hold of a three hold length model.

2 Notwithstanding the above, hold frames, web frames and stringers of side structures in loaded holds under alternate loading condition are also to be assessed for load case 6, using the end holds of a three hold length model. Similarly, transverse webs in lower and upper wing tanks in all holds are also to be assessed for load case 9, using the end holds.

3 A ballast hold is also to be assessed as a hold designed for alternate hold loading, either loaded or empty depending upon its designation.

4 A vessel designed for homogeneous loading only may be subject to special consideration.

PART

5C

CHAPTER 3 Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)

SECTION 6 Hull Structure Beyond 0.4L Amidships

1 General Requirements

1.1 General

The structural configurations, stiffening systems and design scantlings of the hull structures located beyond 0.4*L* amidships, including the forebody, aft end and machinery spaces, are to be in compliance with this Chapter and other relevant sections of the Rules.

Forebody Structures – In addition to the requirements specified in other relevant sections of the Rules, the scantlings of structures forward of 0.4*L* amidships are also to satisfy the requirements in 5C-3-6/3, 5C-3-6/5, 5C-3-6/7, 5C-3-6/9 and 5C-3-6/11 below.

The nominal design corrosion values in the forepeak tank may be taken as 1.5 mm in determining design scantlings.

1.3 Structures within Cargo Spaces

The scantlings of longitudinal structural members and elements in way of cargo spaces beyond 0.4*L* amidships may be gradually reduced toward 0.125*L* from the ends, provided the hull girder section modulus is in compliance with 5C-3-4/3.1.1 and the strength of the structure satisfies the requirements specified in 5C-3-6/1.1 and the material yielding, buckling and ultimate strength criteria specified in 5C-3-5/3 and 5C-3-5/5.

In addition, consideration is to be given to the effects of bottom and bowflare slamming as specified in 5C-3-3/11.1 and 5C-3-3/11.3 with respect to the strength of both the hull girder and local structures as outlined in 5C-3-6/13.1.

The scantlings of main supporting members (transverse webs in lower and upper wing tanks) in way of cargo spaces beyond 0.4*L* amidships are to be checked for compliance with the specifications given in 5C-3-4/13. In this case, the nominal pressure is to be calculated with the hold or tank at the location under consideration.

3 Bottom Shell Plating and Stiffeners in Forebody

3.1 Bottom Shell Plating *(2002)*

The net thickness of the bottom shell plating forward of 0.3L from the FP is not to be less than t_1 and t_2, obtained from the following equations:

$t_1 = 0.73s(k_1p/f_1)^{1/2}$ in mm (in.)

$t_2 = 0.73s(k_2p/f_2)^{1/2}$ in mm (in.)

where

s = spacing of longitudinal, in mm (in.)

k_1 = 0.342

k_2 = 0.50

p = nominal pressure $|p_i - p_e|$, in N/cm² (kgf/cm², lbf/in²), as specified in 5C-3-3/Table 3, with the following modifications.

i) A_{ti} is to be calculated at the forward end of the tank. Between 0.3L and 0.25L aft of the FP, the internal pressure need not be greater than that obtained amidships.

ii) A_e is to be calculated at the center of the panel in accordance with 5C-3-3/5.5.3, using L.C.1 and wave trough located amidships.

iii) B_e is to be calculated at the center of the panel in accordance with 5C-3-3/5.5. ($p_s + k_u p_d$, full draft, heading angle = 0, k_u = 1.1)

iv) *(1999)* Where upper and lower wing tanks are connected by trunks or double sides, the internal pressure, p_i, in the lower wing tank may be calculated by the following equation:

v) $p_i = p_{ia} - p_{uh}$

vi) p_{ia} is internal pressure in the lower wing tank, in N/cm² (kgf/cm², lbf/in²), as defined in 5C-3-3/Table 3 for bottom plating.

vii) p_{uh} is as defined in 5C-3-4/7.3.1.

f_1/f_2 = permissible bending stress in the longitudinal/transverse direction, in N/cm² (kgf/cm², lbf/in²)

f_1 = $0.45\, S_m f_y$, forward of 0.2L from the FP

f_2 = $0.8\, S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.3.1. The permissible stress, f_1, between 0.3L and 0.2L from the FP is to be obtained by linear interpolation between midship region (5C-3-4/7.3.1) and the permissible stress at 0.2L from the FP, as specified above.

Bottom shell plating may be transversely framed in limited areas such as pipe tunnels, provided the net thickness of the bottom shell plating is not less than t_3, obtained from the following equation:

$t_3 = 0.73sk(k_2\, p/f_3)^{1/2}$ mm (in.)

where

s = spacing of bottom transverse frame, in mm (in.)

k_2 = 0.5

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.273)$, $(1 \leq \alpha \leq 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

f_3 = $0.45S_mf_y$ at $0.2L$ from the FP

= $0.6S_mf_y$ forward of $0.1L$ from the FP

The permissible stress, f_3, between $0.2L$ and $0.1L$ from the FP is to be obtained by linear interpolation. The permissible stress, f_3, between $0.3L$ and $0.2L$ from the FP is to be obtained by linear interpolation between midship region (5C-3-4/7.3.1) and the permissible stress at $0.2L$ from the FP, as specified above. All other parameters are as defined above.

3.3 Bottom Longitudinals/Stiffeners

The section modulus of the longitudinal/stiffener, including the associated effective plating on the bottom plating forward of $0.3L$ from the FP, is not to be less than that obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

$M = 1000ps\ell^2/k$ N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 83.33)

p = nominal pressure $|p_i - p_e|$, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-3-3/Table 3 with the following modifications.

i) A_{ti} is to be calculated at the forward end of the tank. Between $0.3L$ and $0.25L$ aft of the FP, the internal pressure need not be greater than that obtained amidships.

ii) A_e is to be calculated at the middle of the unsupported span in accordance with 5C-3-3/5.5.3 using L.C.1 and wave trough located amidships.

iii) B_e is to be calculated at the middle of the unsupported span in accordance with 5C-3-3/5.5 ($p_s + k_uP_d$, full draft, heading angle = 0, k_u = 1.1)

iv) *(1999)* Where upper and lower wing tanks are connected by trunks or double sides, the internal pressure, p_i, in the lower wing tank may be calculated as defined in 5C-3-6/3.1iv).

s = spacing of longitudinal or transverse stiffeners, in mm (in.)

ℓ = the unsupported span of the longitudinal or stiffener, in m (ft)

f_b = $0.65\ S_mf_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

The effective breadth of plating, b_e, is as defined in 5C-3-4/7.5. The permissible stress, f_b, between $0.3L$ and $0.2L$ from the FP is to be obtained by linear interpolation between midship region (5C-3-4/7.5) and the permissible stress at $0.2L$ from the FP, as specified above.

3.5 Bottom Girders and Floors

The net thickness of bottom girders and floors may be determined by the equations given in 5C-3-4/7.7, 5C-3-4/7.9, and 5C-3-4/7.11, with the following modifications.

$$b_s = b_{sa} - (b_{sa} - b_{sf})\, x/\ell_s$$

where

x = longitudinal distance from the aft end of double bottom length (ℓ_s) to the location under consideration, in m (ft)

b_{sa} = breadth at the aft end of the double bottom structure under consideration, in m (ft), as shown in 5C-3-6/Figure 1

b_{sf} = breadth at the forward end of the double bottom structure, in m (ft), as shown in 5C-3-6/Figure 1

β_1 = $1 - (1.2z_1/b_{sa}) \geq 0.6$ for loaded holds under alternate loading conditions

= $1.25 - (2z_1/b_{sa}) \geq 0.6$ for all holds or tanks under all other loading conditions and for slamming loads

β_3 = $1 - 0.4z_2/b_{sa}$ for loaded holds under alternate loading conditions

= 1 for all holds or tanks under all other loading conditions and for slamming loads

γ_1 = $(C_{cg} - x)/(\ell_s - C_{cg} - s_f/2) \leq 1.0$ for $x \leq C_{cg}$ for centerline girder

= $(x - C_{cg})/(\ell_s - C_{cg} - s_f/2) \leq 1.0$ for $x > C_{cg}$ for centerline girder

= $(C_{sg} - x)/(\ell_{sg} - C_{sg} - s_f/2) \leq 1.0$ for $x \leq C_{sg}$ for side girder

= $(x - C_{sg})/(\ell_{sg} - C_{sg} - s_f/2) \leq 1.0$ for $x > C_{sg}$ for side girder

γ_2 = $1 - (C_f - x)(1.245\lambda + 0.044)/2C_f \geq 0.4$ for $x \leq C_f$ for floor

= $1 - (x - C_f)(1.245\lambda + 0.044)/2C_f \geq 0.4$ for $x > C_f$ for floor

C_{cg} = $[\ell_s(2b_{sf} + b_{sa})]/[3(b_{sa} + b_{sf})]$

C_{sg} = C_{cg} for $z_1 \leq b_{sf}/2$

= $[\ell_s\,(b_{sa} - 2z_1)(4z_1 + b_{sa})]/[3(b_{sa} - b_{sf})\,(b_{sa} + 2z_1)]$ for $z_1 > b_{sf}/2$

C_f = $(1.08 - 0.58(b_{sf}/b_{sa})^{1/2})\ell_s$

ℓ_{sg} = ℓ_s for $z_1 \leq b_{sf}/2$

= $[\ell_s\,(b_{sa} - 2z_1)/(b_{sa} - b_{sf})]$ for $z_1 > b_{sf}/2$

For calculation of shear force in the side girders, ℓ_{sg} is to be used in lieu of ℓ_s.

P = nominal pressure $|p_i - p_e|$, in kN/m^2 (tf/m^2, Ltf/ ft^2), as specified in 5C-3-3/Table 3, with modification that A_{bi}, A_e and B_e are to be calculated in accordance with 5C-3-3/5.5 and 5C-3-3/5.7 at the center of the double bottom under consideration. A_e is to be calculated at the center of the double bottom with wave trough located amidships. B_e is to be calculated with wave crest at the center of the double bottom under consideration. The pressure is not to be taken less than required by 5C-3-4/7.7, 5C-3-4/7.9 and 5C-3-4/7.11 for the double bottom amidships.

The net thickness of floors and girders (including centerline girder) are also not to be less than the following:

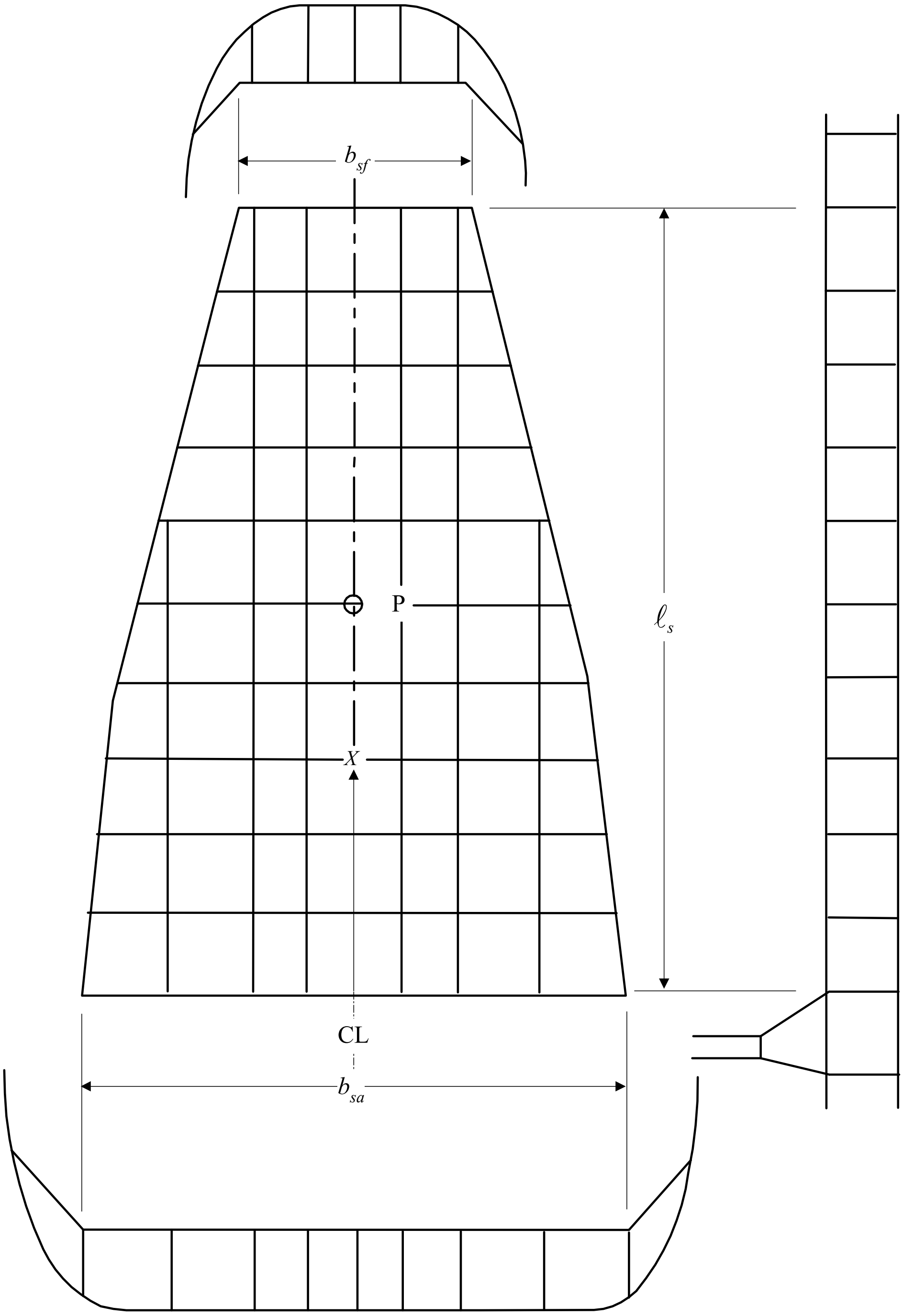
$$t = (0.026L + 4.5)R \qquad \text{mm (in.)}$$

where

L is as defined in 3-1-1/3.

R is as defined in 5C-3-4/7.7.

FIGURE 1
Double Bottom Structure in Forebody Region



5 Side Shell Plating and Stiffeners in Forebody

5.1 General

The thickness as determined below is to be extended from the bilge to the freeboard deck, provided there is no significant bowflare (see 5C-3-3/11.3).

Otherwise, the thickness of side shell plating above the *LWL* is to be determined based on 5C-3-6/13.1 of this section

5.3 Plating Forward of Forepeak Bulkhead

The net thickness of the side shell plating forward of the forepeak bulkhead is to be not less than t_1, t_2 and t_3, specified below.

$t_1 = 0.73s(k_1 p/f_1)^{1/2}$ in mm (in.)

$t_2 = 0.73s(k_2 p/f_2)^{1/2}$ in mm (in.)

$t_3 = 0.73sk(k_3 p_b/f_3)^{1/2}$ in mm (in.) for side shell and bow plating above the *LWL* in the region from the forward end to the forepeak bulkhead

where

s = spacing of stiffeners, in mm (in.)

k_1 = 0.342 for longitudinally and 0.50 for transversely stiffened plating

k_2 = 0.50 for longitudinally and 0.342 for transversely stiffened plating

k_3 = 0.50

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

f_1 = 0.45 $S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2), in the longitudinal direction for longitudinally stiffened plating *(1998)*

f_1 = 0.60 $S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2), in the longitudinal direction for transversely stiffened plating *(1998)*

f_2 = 0.80 $S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2), in the transverse (vertical) direction

f_3 = 0.85 $S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

p = nominal pressure $|p_i - p_e|$, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-3-3/Table 3 at the upper turn of bilge level amidships, with the following modifications:

i) A_{ti} is to be calculated at the forward or aft end of the tank, whichever is greater

ii) A_e is to be calculated at the center of the panel in accordance with 5C-3-3/5.5.3, using L.C.7 with k_{fo} = 1.0 and x_o located amidships

iii) B_e is to be calculated at 0.05*L* from the FP in accordance with 5C-3-3/5.5 ($p_s + k_u p_d$, full draft, heading angle = 0, k_u = 1.1)

p_b = design bow pressure = $k_u p_{bij}$

k_u = 1.1

p_{bij} = nominal bow pressure, as specified in 5C-3-3/5.5.4 at the center of the supported panel under consideration, in N/cm^2 (kgf/cm^2, lbf/in^2)

S_m and f_y are as defined in 5C-3-4/7.3.1.

5.5 Plating between Forepeak Bulkhead and 0.125L from the FP

Aft of the forepeak bulkhead and forward of 0.125L from the FP, the side shell plating is to be not less than as given in 5C-3-6/5.3 with B_e calculated at 0.125L. Side shell plating in upper and lower wing tanks, see 5C-3-6/5.9.

5.7 Plating between 0.3L and 0.125L from the FP *(1998)*

The net thickness of the side shell plating between 0.3L and 0.125L from the FP is to be determined from the equations in 5C-3-6/5.3 and 5C-3-6/5.5 above, with B_e calculated at the longitudinal location under consideration. Between 0.3L and 0.25L from the FP, the internal pressure need not be greater than that obtained amidships. The permissible stress f_1 between 0.3L and 0.2L from the FP is to be obtained by linear interpolation between midship region (5C-3-4/9.1) and the permissible stress f_1, as specified in 5C-3-6/5.3. Side shell plating in upper and lower wing tanks, see 5C-3-6/5.9.

5.9 Plating in Upper and Lower Wing Tanks

The side shell is to be longitudinally framed in the lower and upper wing tanks, except the upper part of the lower wing tank and the lower part of the upper wing tank where the limited access makes this impractical. These portions of the side shell may be transversely framed with efficient brackets arranged in line with the side frames, provided the net thickness of the side shell plating in this area is not less than that of the adjacent longitudinally framed shell and is also not less than t_4, obtained from the following equation:

$$t_4 = 0.73sk(k_2\,p/f)^{1/2} \quad \text{mm (in.)}$$

where

s = spacing of side transverse brackets, in mm (in.)

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$ $(1 \leq \alpha \leq 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

k_2 = 0.5

p = nominal pressure $|p_i - p_e|$ at the lower end of the panel, as specified in 5C-3-3/Table 3 with the following modifications:

i) A_{ti} is to be calculated at the forward or aft end of the tank, whichever is greater. Between 0.3L and 0.25L aft of the FP, the internal pressure need not be greater than that obtained amidships

ii) A_e is to be calculated in accordance with 5C-3-3/5.5.3 using L.C.7 with k_{fo} = 1.0 and x_o located amidships

iii) B_e is to be calculated in accordance with 5C-3-3/5.5 ($p_s + k_u p_d$, full draft, heading angle = 0, k_u = 1.1) *iv)* *(1999)* In the upper wing tank and the lower wing tank which is connected to the upper wing tank by trunks or double sides, the internal pressure, p_i, in the wing tanks may be calculated by the following equation:

$p_i = p_{ia} - p_{uo}$

p_{ia} is internal pressure in the wing tanks, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in 5C-3-3/Table 3 for side shell plating.

p_{uo} is as defined in 5C-3-4/9.1.

f = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.60\ S_m f_y$ within $0.2L$ from the FP

The permissible stress, f, between $0.3L$ and $0.2L$ from the FP is to be obtained by linear interpolation between midship region (5C-3-4/9.1) and the permissible stress at $0.2L$ from the FP, as specified above.

The net thickness of the side shell plating, where transversely framed between upper and lower wing tanks, is not to be less than t_4, as specified above, with the nominal pressure calculated at the top of lower wing tank. The thickness is also not to be less than that of the adjacent shell.

5.11 Side Frames and Longitudinals Forward of 0.3L from the FP

The net section modulus of side longitudinals and frames in association with the effective plating to which they are attached, is to be not less than that obtained from the following equation:

$SM = M/f_{bi}$ in cm^3 (in^3)

$M = 1000ps\ell^2/k$ in N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 83.33)

p = nominal pressure $|p_i - p_e|$, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-3-3/Table 3 with the following modifications:

i) A_{ti} is to be calculated at the forward or aft end of the tank, whichever is greater. Between $0.3L$ and $0.25L$ aft of the FP the internal pressure need not be greater than that obtained amidships.

ii) A_e is to be calculated at the center of the panel, in accordance with 5C-3-3/5.5.3 using L.C.7 with k_{fo} = 1.0 and x_o located amidships.

iii) B_e is to be calculated at the center of the panel, in accordance with 5C-3-3/5.5 ($p_s + k_u p_d$, full draft, heading angle = 0, k_u = 1.1), with the distribution of p_d, as shown in 5C-3-6/Figure 2, at the side longitudinal and frame under consideration.

iv) *(1999)* In the upper wing tank and the lower wing tank which is connected to the upper wing tank by trunks or double sides, the internal pressure, p_i, in the wing tanks may be calculated as defined in 5C-3-6/5.9iv).

Longitudinal distribution of p_d may be taken as constant from the FP to the forepeak bulkhead, as per 5C-3-6/5.3, and from 0.125L to the forepeak bulkhead, as per 5C-3-6/5.5. p_d is to be calculated in accordance with 5C-3-3/5.5 between 0.3L and 0.125L from the FP, as per 5C-3-6/5.7.

f_{bi} = $0.80\ S_m f_y$, in N/cm² (kgf/cm², lbf/in²) for longitudinals between 0.125L and 0.2L from the FP

= $0.85\ S_m f_y$, in N/cm² (kgf/cm², lbf/in²) for longitudinals forward 0.125L from the FP

= $0.85\ S_m f_y$, in N/cm² (kgf/cm², lbf/in²) for vertical frames (other than hold frames)

Between 0.3L and 0.2L from the FP, the permissible stress is to be obtained by linear interpolation between midship region and $0.80 S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.3.1.

s and ℓ are as defined in 5C-3-4/7.5.

For side longitudinals/stiffeners in the region forward of 0.0125L from the FP and above the LWL, the section modulus is not to be less than obtained from the above equation, based on $p = p_b$, $f_b = 0.95 S_m f_y$ and k = 16 (16, 111.1), where p_b is as defined in 5C-3-6/5.3 above.

5.13 Hold Frames

The net section modulus of the hold frames forward 0.3L measured from the FP, in association with effective shell plating to which they are attached, is not to be less than obtained from the following equation:

$$SM_F = M/f_b \quad \text{in cm}^3\ (\text{in}^3)$$

$$M = 1000 c_1 p s \ell^2 / k \quad \text{in N-cm (kgf-cm, lbf-in)}$$

where

k = 12 (12, 83.33)

ℓ = unsupported span of hold frames, in m (ft), (see 5C-3-4/Figure 6) measured along the chord of the member

p = nominal external pressure, in N/cm² (kgf/cm², lbf/ in²), at the middle of the unsupported span of each hold frame, calculated in accordance with 5C-3-3/5.5.

= $p_s + k_u p_d$, (Full draft, wave heading angle = 0, k_u = 1.1)

f_b = $0.80\ S_m f_y$, in N/cm² (kgf/cm², lbf/in²)

c_1 and s are as defined in 5C-3-4/11.3.

S_m and f_y are as defined in 5C-3-4/7.3.1.

The effective breadth of plating, b_e, is as defined in 5C-3-4/7.5.

Where a cargo hold is intended to be used for the carriage of water ballast or liquid cargoes, the net section modulus of the hold frame is also not to be less than obtained from the above equation with p as nominal internal pressure, in N/cm² (kgf/cm², lbf/in²), at the middle of unsupported span of hold frames calculated in accordance with 5C-3-3/5.7 for the forward end of the particular hold [5C-3-3/Table 3 hold frame (ballast or liquid cargo holds)].

The net section modulus of the lower and upper brackets at the top of the lower wing tank and the bottom of the upper wing tank is not to be less than obtained from 5C-3-4/11.7.1 with h_3 as the chord distance, in m (ft), measured between the top of the lower wing tank and the bottom of the upper wing tank.

The net thickness of the upper and lower brackets and the web part of the frames is not to be less than as specified in 5C-3-4/11.7.3, respectively.

5.15 Hold Frames in the Foremost Cargo Hold *(1 July 1998)*

In addition to the requirements of 5C-3-6/5.13, hold frames in the foremost cargo hold are to meet the following requirements.

i) The gross thickness of the web portion of the frames is to be increased by a factor of 1.15 over that required by 5C-3-4/11.7.3, except that t_n need not exceed 13.5 mm (0.53 in.)

ii) The gross thickness of lower brackets is to be at least the gross thickness of the web of the frames being supported or the gross thickness required by 5C-3-6/5.15i) above, increased by 2 mm (0.08 in.), whichever is greater.

iii) The gross thickness of upper brackets is to be at least the gross thickness of the web of the frames being supported or the gross thickness required by 5C-3-6/5.15i) above, whichever is greater.

iv) When hold frames are asymmetric sections, tripping brackets are to be fitted at approximately mid-span and at every two frames, as shown in 5C-3-6/Figure 3.

FIGURE 2
Transverse Distribution of p_d

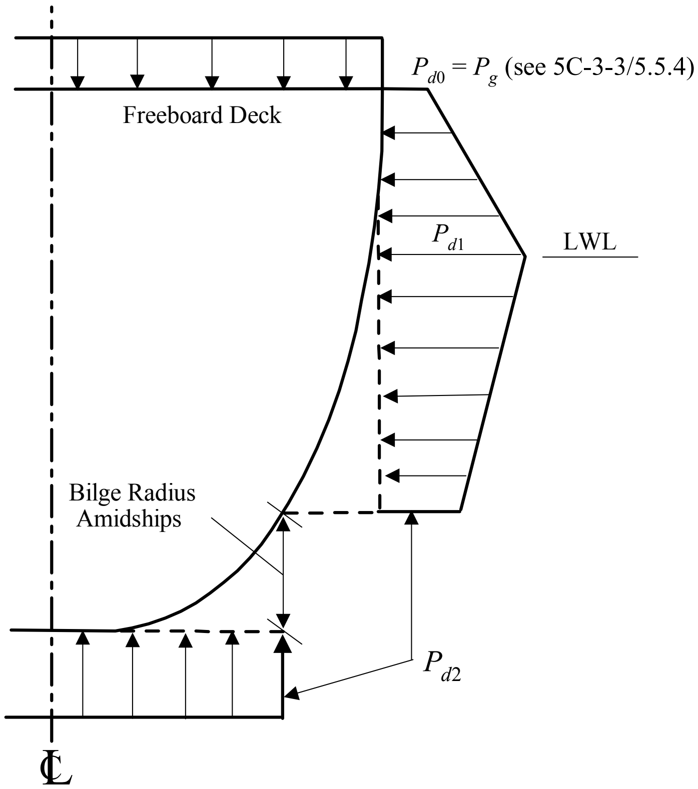
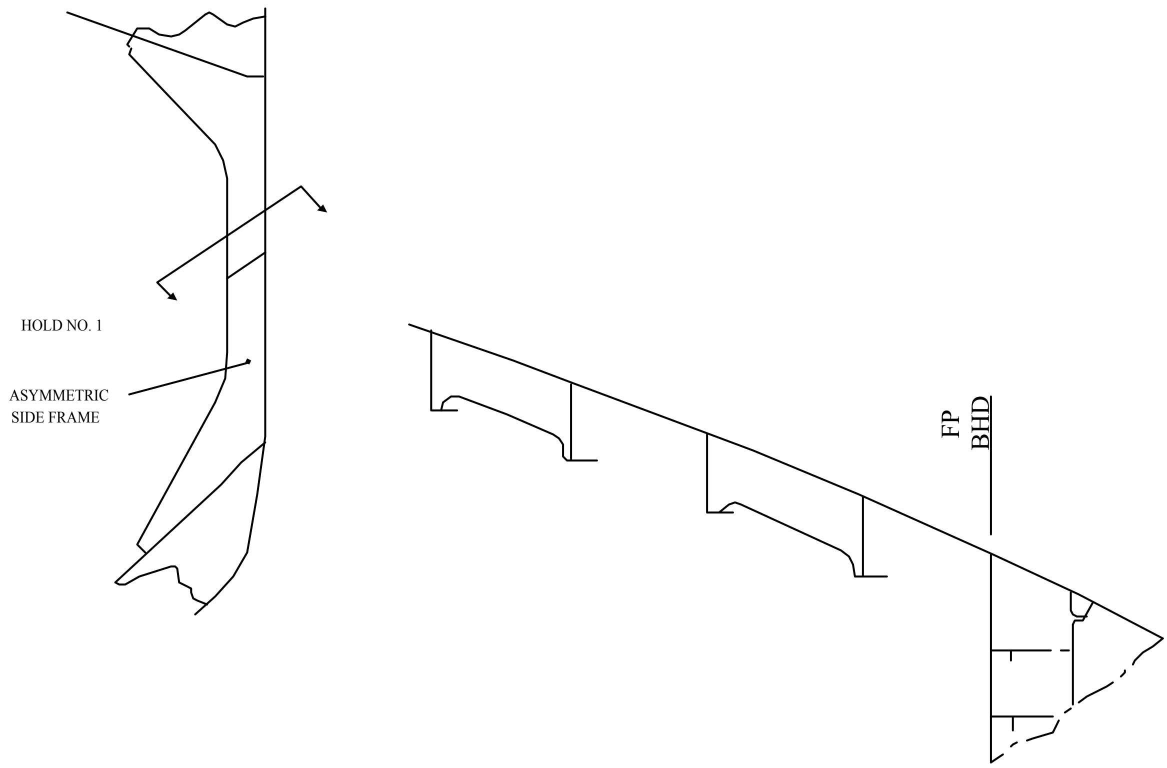


FIGURE 3
Arrangement of Tripping Brackets for Hold Frames with Asymmetric Sections *(1 July 1998)*



7 Side Transverses and Stringers in Forebody

7.1 Section Modulus

The net section modulus of side transverses and stringers in association with the effective side shell plating is not to be less than that obtained from the following equation:

$SM = M/f_b$ in cm^3 (in^3)

7.1.1 Longitudinally Framed Side Shell

For side stringer

$M = 1000c_1c_2ps\ell_t\ell_s/k$ in N-cm (kgf-cm, lbf-in)

For side transverse, M is not to be less than M_1 or M_2, whichever is greater.

$M_1 = 1000c_3 ps\ell_t^2 (1.0 - c_4\phi)/k$ in N-cm (kgf-cm, lbf-in)

$M_2 = 850p_1s\ell_{t1}^2/k$ in N-cm (kgf-cm, lbf-in)

where

k = 0.12 (0.12, 0.446)

c_1 = 0125 + 0.875ϕ, but not less than 0.3

Coefficients c_2, c_3 and c_4 are given in the tables below.

Coefficient c_2

Number of Side Stringers Between Platforms (flats)	No Stringer	One Stringer	More than one Stringer
Top Stringer			0.70
Stringers Between Top and Lowest Stringers	0.0	0.90	0.75
Lowest Stringer			0.80

Coefficient c_3

Number of Side Stringers Between Platforms (flats)	No Stringer	One Stringer	More than one Stringer
Transverse above Top Stringer		0.55	0.55
Transverse Between Top and Lowest Stringers	0.85	—	0.64
Transverse Below Lowest Stringer		0.68	0.68

Coefficient c_4

Number of Side Stringers Between Platforms (flats)	No Stringer	One Stringer	More than one Stringer
Transverses	0.0	0.75	0.80

p = nominal pressure, $|p_i - p_e|$, in kN/m² (tf/m², Ltf/ft²), over the side transverses using the same load cases as specified in 5C-3-3/Table 3 for side transverses in lower wing tank. A_{ti}, A_e and B_e may be taken at the center of the side shell panel under consideration with the following modifications:

i) A_e is to be calculated in accordance with 5C-3-3/5.5.3, using L.C.7 with k_{fo} = 1.0 and x_o located amidships

ii) B_e is to be calculated in accordance with 5C-3-3/5.5 ($p_s + k_u p_d$, full draft, heading angle = 0, k_u = 1) with the distribution of p_d as shown in 5C-3-6/Figure 2.

p_1 = nominal pressure, $|p_i - p_e|$, in kN/m² (tf/m², Ltf/ft²), using the same load cases as specified in 5C-3-3/Table 3 for side transverses in lower wing tank, with A_{ti}, A_e and B_e calculated at the midspan ℓ_{s1} (between side stringers or between side stringer and platform, flat as shown in 5C-3-6/Figure 4) of the side transverse under consideration, with the following modifications:

i) A_e is to be calculated in accordance with 5C-3-3/5.5.3, using L.C.7 with k_{fo} = 1.0 and x_o located amidships

ii) B_e is to be calculated in accordance with 5C-3-3/5.5 ($p_s + k_u p_d$, full draft, heading angle = 0, k_u = 1) with the distribution of p_d as shown in 5C-3-6/Figure 2.

For side transverses

s = sum of half distances, in m (ft), between side transverse under consideration and adjacent side transverses or transverse bulkhead

For side stringers

s = $0.45\ell_s$

ϕ = $1/(1 + \alpha)$

α = $1.33(I_t/I_s)(\ell_s/\ell_t)^3$

I_t = moment of inertia, in cm⁴ (in⁴), (with effective side plating) of side transverse. I_t is to be taken as average of those at the middle of each span ℓ_{t1} between side stringers or side stringer and platform (flat), clear of the bracket

I_s = moment of inertia, in cm⁴ (in⁴), (with effective side plating) of side stringer at the middle of the span ℓ_s, clear of the bracket

ℓ_t, ℓ_s = spans, in m (ft), of the side transverse (ℓ_t) and side girder (ℓ_s) under consideration as shown in 5C-3-6/Figure 4

ℓ_{t1} = span, in m (ft), of side transverse under consideration between stringers, or stringer and platform (flat) as shown in 5C-3-6/Figure 4b

When calculating α, if more than one side transverse or stringer is fitted and they are not identical, average values of I_t and I_s within side shell panel (panel between transverse bulkheads and platforms, flats) are to be used.

f_b = permissible bending stress, in N/cm² (kgf/cm², lbf/in²)

= $0.75\, S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.3.1.

The bending moment for a side transverse below stringer (or below the platform if no stringer is fitted) is not to be less than 80% of that for a side transverse above stringer (or above platform if no stringer is fitted).

7.1.2 Transversely Framed Side Shell

For side transverses:

$M = 1000 c_1 p s \ell_t \ell_s / k$ in N-cm (kgf-cm, lbf-in)

For side stringers, M is not to be less than M_1 or M_2, whichever is greater:

$M_1 = 1000 c_2 p s \ell_s^2 (1.0 - c_3 \phi_1)/k$ in N-cm (kgf-cm, lbf-in)

$M_2 = 1100 p_1 s \ell_{s1}^2 / k$ in N-cm (kgf-cm, lbf-in)

where

k = 0.12 (0.12, 0.446)

c_1 = $0.10 + 0.7\phi_1$, but not to be taken less than 0.085

If no side transverses are fitted between transverse bulkheads

c_2 = 1.1

c_3 = 0

If side transverses are fitted between transverse bulkheads

c_2 = 0.8

c_3 = 0.8

p = nominal pressure, $|p_i - p_e|$, in kN/m^2 (tf/m^2, Ltf/ft^2), over the side stringers using the same load cases as specified in 5C-3-3/Table 3 for side transverses in lower wing tank. A_{ti}, A_e and B_e may be taken at the center of the side shell panel under consideration with the following modifications

i) A_e is to be calculated in accordance with 5C-3-3/5.5.3, using L.C.7 with k_{fo} = 1.0 and x_o located amidships

ii) B_e is to be calculated in accordance with 5C-3-3/5.5 ($p_s + k_u p_d$, full draft, heading angle = 0, k_u = 1) with the distribution of p_d as shown in 5C-3-6/Figure 2.

p_1 = nominal pressure, $|p_i - p_e|$, in kN/m^2 (tf/m^2, Ltf/ft^2), using the same load cases as specified in 5C-3-3/Table 3 for side transverses in lower wing tank, with A_{ti}, A_e and B_e calculated at the midspan ℓ_{s1} (between side transverses or between side transverse and transverse bulkhead as shown in 5C-3-6/Figure 4a) of the side stringer under consideration, with the following modifications.

i) A_e is to be calculated in accordance with 5C-3-3/5.5.3, using L.C.7 with k_{fo} = 1.0 and x_o located amidships

ii) B_e is to be calculated in accordance with 5C-3-3/5.5 ($p_s + k_u p_d$, full draft, heading angle = 0, k_u = 1) with the distribution of p_d as shown in 5C-3-6/Figure 2.

For side stringers

s = sum of half distances, in m (ft), between side stringer under consideration and adjacent side stringers or platforms (flats)

For side transverses

s = $0.45\ell_t$

ϕ_1 = $\alpha/(1 + \alpha)$

ℓ_{s1} = span, in m (ft), of the side stringer under consideration between side transverses or side transverse and transverse bulkhead, as shown in 5C-3-6/Figure 4a

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.75\ S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.3.1.

ℓ_t, ℓ_s and α are as defined in 5C-3-6/7.1.1.

7.3 Sectional Area of Web

The net sectional area of the web portion of the side transverse and side stringer is not to be less than obtained from the following equation.

$$A = F/f_s$$

7.3.1 Longitudinally Framed Side Shell

For side stringers:

$$F = 1000kc_1p\ell s \qquad \text{N (kgf, lbf)}$$

For side transverses, F is not to be less than F_1 or F_2, whichever is greater:

$$F_1 = 850kc_2p\ell s(1.0 - c_3\phi - 2h_e/\ell) \qquad \text{N (kgf, lbf)}$$

$$F_2 = 1700kc_2p_1s(0.5\ell_1 - h_e) \qquad \text{N (kgf, lbf)}$$

where

k = 0.5 (0.5, 1.12)

Coefficients c_1, c_2 and c_3 are given in the tables below.

Coefficient c_1

Number of Side Stringers Between Platforms (flats)	No Stringer	One Stringer	More than one Stringer
Stringers	0.0	0.52	0.40

Coefficient c_2

Number of Side Stringers Between Platforms (flats)	No Stringer	One Stringer	More than one Stringer
Transverses Above Top Stringer	1.0	0.9	0.9
Transverse Between Top and Lowest Stringers		—	0.95
Transverse Below Lowest Stringer		1.0	1.0

Coefficient c_3

Number of Side Stringers Between Platforms (flats)	No Stringer	One Stringer	More than one Stringer
Transverses	0.0	0.5	0.6

ℓ = span, in m (ft), of the side transverse under consideration between platforms (flats), as shown in 5C-3-6/Figure 4b

ℓ_1 = span, in m (ft), of the side transverse under consideration between side stringers or side stringer and platform (flat), as shown in 5C-3-6/Figure 4b

h_e = length, in m (ft), of the end bracket of the side transverse, as shown in 5C-3-6/Figure 4b

To obtain F_1, h_e is equal to the length of the end bracket at the end of span ℓ of side transverse, as shown in 5C-3-6/Figure 4b.

To obtain F_2, h_e is equal to the length of the end bracket at the end of span ℓ_1 of side transverse, as shown in 5C-3-6/Figure 4b.

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\, S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.3.1.

p, p_1, ϕ and s are as defined in 5C-3-6/7.1.1.

The shear force for the side transverse below the lowest stringer (or below the platform if no stringer is fitted), is not to be less than 110% of that for the side transverse above the top stringer (or above the platform is no stringer is fitted).

7.3.2 Transversely Framed Side Shell

For side transverses:

$$F = 850kc_1p\ell s \qquad \text{in N (kgf, lbf)}$$

For side stringers, F is not to be less than F_1 or F_2, whichever is greater:

$$F_1 = 1000kp\ell s(1.0 - 0.6\phi_1 - 2h_e/\ell) \qquad \text{in N (kgf, lbf)}$$

$$F_2 = 2000kp_1s(0.5\ell_1 - h_e) \qquad \text{in N (kgf, lbf)}$$

where

k = 0.5 (0.5, 1.12)

c_1 = $0.1 + 0.7\phi_1$, but not to be taken less than 0.2

ℓ = span, in m (ft), of the side stringer under consideration between transverse bulkheads, as shown in 5C-3-6/Figure 4a

ℓ_1 = span, in m (ft), of the side stringer under consideration between side transverses or side transverse and bulkhead, as shown in 5C-3-6/Figure 4a

h_e = length, in m (ft), of the end bracket of the side stringer under consideration, as shown in 5C-3-6/Figure 4a

To obtain F_1, h_e is equal to the length of the end bracket at the end of span ℓ of the side stringer, as shown in 5C-3-6/Figure 4a.

To obtain F_2, h_e is equal to the length of the end bracket at the end of span ℓ_1 of the side stringer, as shown in 5C-3-6/Figure 4a.

f_s = permissible shear stress, in N/cm² (kgf/cm², lbf/in²)

= $0.45\ S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.3.1.

p, p_1, ϕ_1 and s are as defined in 5C-3-6/7.1.2 above.

7.5 Depth of Transverse/Stringer

The depths of side transverses and stringers, d_w, are neither to be less than obtained from the following equations, nor to be less than 2.5 times the depth of the slots, respectively.

7.5.1 Longitudinally Framed Shell

For side transverses:

If side stringer is fitted between platforms (flats):

$$d_w = (0.08 + 0.80\alpha)\ell_t \qquad \text{for } \alpha \le 0.05$$

$$= (0.116 + 0.084\alpha)\ell_t \qquad \text{for } \alpha > 0.05$$

and need not be greater than $0.2\ell_t$

If no side stringer is fitted between platforms (flats), d_w is not to be less than $0.2\ell_t$ or $0.06D$, whichever is greater.

For side stringers:

$$d_w = (0.42 - 0.9\alpha)\ell_s \qquad \text{for } \alpha \le 0.2$$

$$= (0.244 - 0.0207\alpha)\ell_s \qquad \text{for } \alpha > 0.2$$

α is not to be taken greater than 8.0 to determine the depth of the side stringer.

ℓ_t, ℓ_s and α are as defined in 5C-3-6/7.1.1.

D is as defined in 3-1-1/7.

7.5.2 Transversely Framed Side Shell

For side stringers:

If side transverse is fitted between transverse bulkheads

$$d_w = (0.08 + 0.80\alpha_1)\ell_s \qquad \text{for } \alpha_1 \le 0.05$$

$$= (0.116 + 0.084\alpha_1)\ell_s \qquad \text{for } \alpha_1 > 0.05$$

and need not be greater than $0.2\ell_s$.

If no side transverse is fitted between transverse bulkheads

$$d_w = 0.2\ell_s$$

For side transverses:

$$d_w = (0.277 - 0.385\alpha_1)\ell_t \qquad \text{for } \alpha_1 \le 0.2$$

$$= (0.204 - 0.205\alpha_1)\ell_t \qquad \text{for } \alpha_1 > 0.2$$

α_1 is not to be taken greater than 7.5 to determine the depth of the side transverse.

where

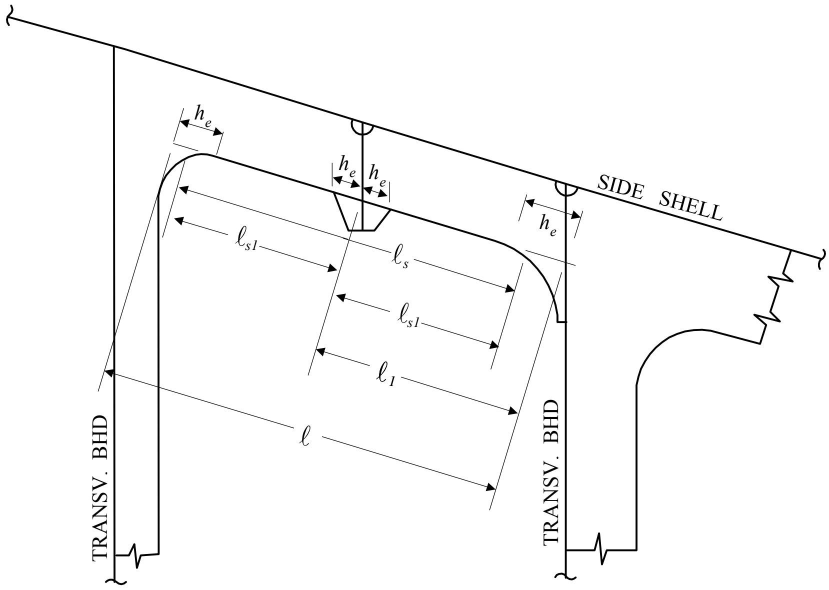
$$\alpha_1 = 1/\alpha$$

ℓ_t, ℓ_s and α are as defined in 5C-3-6/7.1.1 above.

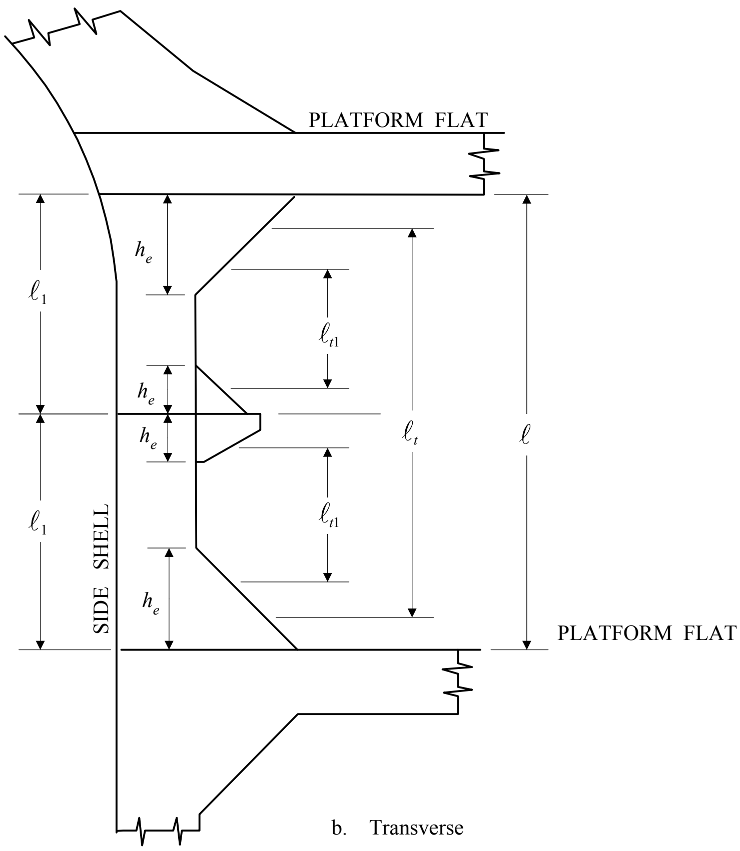
7.7 Thickness

The net thickness of side transverse and stringer is not to be less than 9.5 mm (0.374 in.).

FIGURE 4
Definition of Spans



a. Stringer



b. Transverse

9 Deck Structures in Forebody *(1999)*

9.1 General

The deck plating, longitudinals, beams, girders and transverses forward of 0.25L from the FP are to meet the requirements specified in 5C-3-4/15 with the deck pressure, $p = p_g$, where p_g is the nominal green water loading given in 5C-3-3/5.5.4(b) or the normal internal pressure as specified in 5C-3-3/Table 3 at the forward end of the particular tank, whichever is greater, and the permissible stresses as specified below. The nominal internal pressure for deck plating and longitudinals in the upper wing tank may be calculated by the following equation:

$$p = p_i - p_{uh}$$

In no case is p to be taken less than 2.06 N/cm^2 (0.21 kgf/cm^2, 2.987 lbf/in^2).

p_i is nominal pressure in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in 5C-3-3/Table 3 for deck members within the upper wing tank.

p_{uh} is as defined in 5C-3-4/7.3.1.

9.3 Deck Plating *(1999)*

The net thickness of deck plating is to be not less than t_1 and t_2, as specified in 5C-3-4/15.1, with the following modifications:

$f_1 = 0.50\ S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2), for main deck within 0.1L from the FP.

$f_1 = 0.60\ S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2), for forecastle deck

$f_2 = 0.80\ S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

The permissible stress, f_1, for main deck between 0.25L and 0.1L from the FP is to be obtained by linear interpolation between midship region (5C-3-4/15.1) and the permissible stress at 0.1L from the FP, as specified above.

In addition, the net thickness of main deck plating is also not to be less than t_3, as specified below.

$t_3 = 0.30s(S_m f_y/E)^{1/2}$ mm (in.) for main deck within 0.1L from the FP

The required thickness, t_3, between 0.30L and 0.1L from the FP is to be obtained by linear interpolation between midship region and the t_3 above.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

9.5 Deck Longitudinals/Beams

The net section modulus is not to be less than obtained from 5C-3-4/15.3 with the following modifications.

$f_b = 0.70\ S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2), for main deck longitudinals within 0.1L from the FP and forecastle deck longitudinals

$f_b = 0.80\ S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2), for main deck beams forward of the foremost hatch opening (No. 1 hatch) and forecastle deck beams

The permissible bending stress, f_b, for main deck longitudinals between 0.25L and 0.1L from the FP is to be obtained by linear interpolation between midship region (5C-3-4/15.3) and the permissible stress at 0.1L from the FP, as specified above.

9.7 Cross Deck Beams

The net section modulus of the deck beams inside the lines of hatch openings Nos. 1 and 2 is not to be less than obtained from 5C-3-4/15.7 with the green water loading and the following modification, or directly obtained from 5C-3-4/15.7, whichever is greater.

$f_b = 0.6\ S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

9.9 Hatch End Beams

The scantlings of hatch end beams are to satisfy 5C-3-4/17.5 with the green water loading and the following modification, or directly obtained from 5C-3-4/17.5, whichever is greater.

$f_b = 0.9\ S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

$q = (p_g - kd)$, in kN/m^2 (tf/m^2, Ltf/ft^2)

where

d = depth of hatch coaming, in m (ft)

p_g = nominal green water pressure, in kN/m^2 (tf/m^2, Ltf/ft^2)

k = 10.05 (1.025, 0.0286)

9.11 Deck Girders Inside the Lines of Hatch Opening

The scantlings of deck girders inside the lines of hatch openings are to satisfy 5C-3-4/17.7 with the green water loading and the following modification, or directly obtained from 5C-3-4/17.7, whichever is greater.

$f_b = 0.9\ S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

$q = (p_g - kd)$, in kN/m^2 (tf/m^2, Ltf/ft^2)

where

d = depth of hatch coaming, in m (ft)

k = 10.05 (1.025, 0.0286)

9.13 Deck Transverse in Upper Wing Tank

The scantlings of deck transverses are to satisfy 5C-3-4/13.5 with the green water loading and the following modification, or directly obtained from 5C-3-4/13.5, whichever is greater.

$M_1 = 0$, for 5C-3-4/13.5.1

$F = 1000 k p_g s (0.5\ell - h_e)$ N (kgf, lbf) for 5C-3-4/13.5.2

where

k = 0.9 (0.9, 2.016)

ℓ = span, in m (ft.), of deck transverse, as shown in 5C-3-4/Figure 9

h_e = length, in m (ft.), of the end brackets of deck transverse, as shown in 5C-3-4/Figure 9

s is as defined in 5C-3-4/13.5.1.

11 Transition Zone

11.1 General *(2002)*

In the transition zone between the forepeak and the No. 1 cargo hold, due consideration is to be given to the proper tapering of major longitudinal members within the forepeak such as flats, decks, horizontal ring frames or side stringers aft into the cargo hold. Where such structure is in line with longitudinal members aft of the forward cargo hold bulkhead, such as in the upper and lower wing tanks, this may be effected by the fitting of large tapering brackets inside the wing tanks. These brackets are to have a taper of 4:1 based on the size of the wing tank longitudinal. When forepeak structure does not align with longitudinal structure in the cargo hold area and terminates at the forward cargo hold bulkhead, in way of the hold frames, either of the following arrangements is to be adopted.

11.1.1

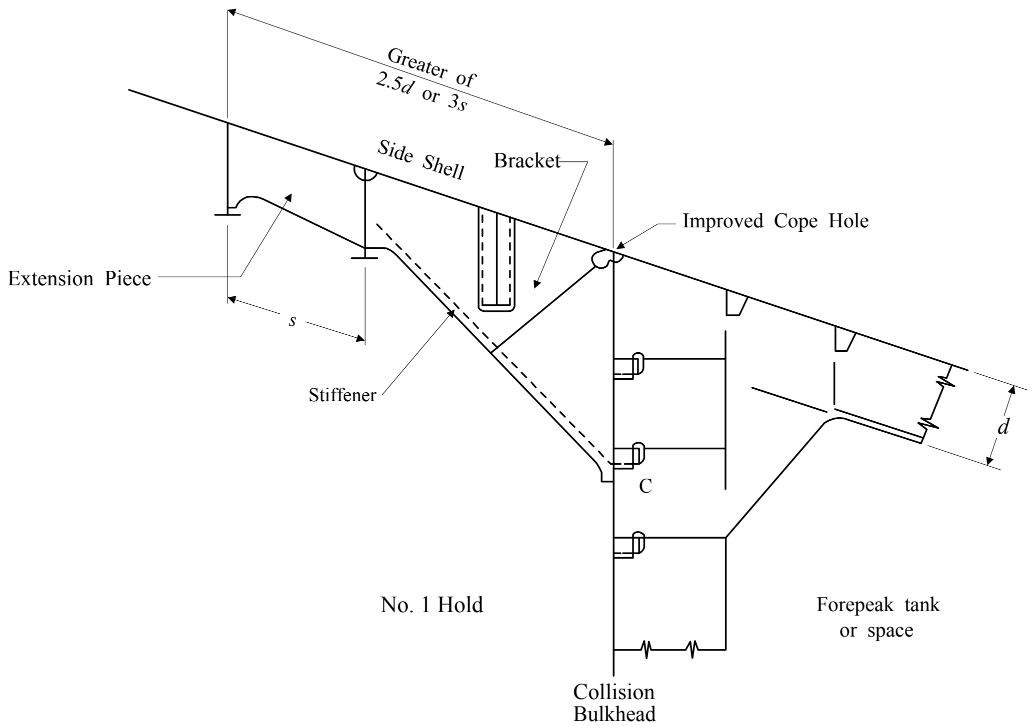
For a stringer, a bracket of length $2^1/_2$ times the depth of the stringer or 3 frame spaces, whichever is greater, is to be fitted at the end of the stringer. The bracket is to be gradually tapered, suitably stiffened and have collars fitted at the slots for the vertical frames. (See 5C-3-6/Figure 5.)

11.1.2

The first two hold frames aft of the forepeak bulkhead are to have a section modulus at least $2^1/_2$ times the SM_F required by 5C-3-6/5.13.

Where major longitudinal structures within the forepeak do not terminate in way of the hold framing, no special arrangements are required.

FIGURE 5
Transition Zone



13 Forebody Strengthening for Slamming

13.1 General

Where the hull structure is subject to slamming as specified in 5C-3-3/11, proper strengthening may be required as outlined below.

13.3 Bottom Slamming

13.3.1 Bottom Plating *(2001)*

When bottom slamming as specified in 5C-3-3/11.1 is considered, the bottom structure in the region of the flat of bottom forward of 0.25L measured from the FP is to be in compliance with the following requirements.

The net thickness of the flat of bottom plating forward of 0.25L measured from the FP is not to be less than that obtained from the following equation:

$$t = 0.73s(k_2 k_3 p_s/f)^{1/2} \quad \text{in mm (in.)}$$

where

s = spacing of longitudinal or transverse stiffeners, in mm (in.)

k_2 = $0.5\,k^2$ for either transversely or longitudinally stiffened plating

k_3 = 0.74

k = $(3.075\,(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

p_s = the design slamming pressure = $k_u p_{si}$

For determination of t, the pressure p_s is to be taken at the center of the supported panel.

p_{si} = nominal bottom slamming pressure, as specified in 5C-3-3/11.1.1, in N/cm^2 (kgf/cm^2, lbf/in^2)

The maximum nominal bottom slamming pressure occurring along the vessel is to be applied to the bottom plating between the foremost extent of the flat of bottom and 0.125L from the FP. The pressure beyond this region may be gradually tapered to the longitudinal location where the nominal slamming pressure is calculated as zero.

k_u = slamming load factor = 1.1

f = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.85\,S_m f_y$

S_m and f_y are as defined in 5C-3-4/7.3.1.

13.3.2 Bottom Longitudinals and Stiffeners

The section modulus of the stiffener including the associated effective plating on the flat of bottom forward of 0.25L measured from the FP is not to be less than that obtained from the following equation:

$SM = M/f_b$ in cm^3 (in^3)

$M = 1000 p_s s \ell^2/k$ in N-cm (kgf-cm, lbf-in)

where

k = 16 (16, 111.1)

p_s = the design slamming pressure = $k_u p_{si}$

For determination of M, the pressure p_s is to be taken at the midpoint of the span ℓ.

p_{si} = nominal bottom slamming pressure, as specified in 5C-3-3/11.1.1, in N/cm^2 (kgf/cm^2, lbf/in^2)

The maximum nominal bottom slamming pressure occurring along the vessel is to be applied to the bottom plating between the foremost extent of the flat of bottom and 0.125L from the FP. The pressure beyond this region may be gradually tapered to the longitudinal location where the nominal slamming pressure is calculated as zero.

k_u = slamming load factor = 1.1

s = spacing of longitudinal or transverse stiffeners, in mm (in.)

ℓ = the unsupported span of the stiffener, in m (ft)

f_b = 0.9 $S_m f_y$ for transverse and longitudinal stiffeners in the region forward of 0.125L, measured from the FP

= 0.8 $S_m f_y$ for longitudinal stiffeners in the region between 0.125L and 0.25L, measured from the FP

The effective breadth of plating b_e is as defined in 5C-3-4/7.5.

Struts connecting the bottom and inner bottom longitudinals are not to be fitted.

13.3.3 Supporting Members

The thickness of floors, girders and partial girders/floors, if any, are to be checked against the expected shear forces in the region of the flat of bottom forward of 0.25L measured from the FP in accordance with the formula in 5C-3-6/3.5. In this case nominal pressure, p, may be taken as:

$$p = c\frac{\sum b_i^* s_{3i}}{\sum 0.5 b_{si} s_{3i}} p_s, \qquad i = 1 \ldots N, \text{ but not less than } 0.5 p_s$$

where

c = $1.185 \times 10^{-3} L + 0.485$ for SI and MKS units ($3.612 \times 10^{-4} L + 0.485$ for US units)

p_s = the maximum bottom slamming pressure within the particular double bottom panel

= $k_u p_{si}$

p_{si} = nominal bottom slamming pressure, as specified in 5C-3-3/11.1.1, in kN/m^2 (tf/m^2, Ltf/ft^2)

k_u = slamming loading factor = 1.0

b_i^* = half width of flat of bottom at the *i*-th floor in the double bottom panel, in m (ft), but should not be greater than $0.5b_{si}$

b_{si} = unsupported width of the *i*-th floor in the double bottom panel, in m (ft)

s_{3i} = sum of one-half of floor spacings on both sides of the *i*-th floor, in m (ft)

N = number of floors in the double bottom panel

L is as defined in 3-1-1/3.1.

The permissible shear stress may be taken as $0.5\ S_m f_y$.

13.5 Bowflare Slamming

When bowflare slamming as specified in 5C-3-3/11.3 is considered, the side shell structure above the waterline in the region between $0.0125L$ and $0.25L$ from the FP is to be in compliance with the following requirements.

13.5.1 Side Shell Plating *(1999)*

The net thickness of the side shell plating between $0.0125L$ and $0.25L$ from the FP is not to be less than t_1 or t_2, whichever is greater, obtained from the following equations:

$$t_1 = 0.73s(k_1\, p_s / f_1)^{1/2} \quad \text{in mm (in.)}$$

$$t_2 = 0.73s(k_2\, p_s / f_2)^{1/2} \quad \text{in mm (in.)}$$

where

p_s = the design slamming pressure = $k_u\, p_{ij}$

p_{ij} = nominal bowflare slamming pressure, as specified in 5C-3-3/11.3.1, at the center of the supported panel under consideration, in N/cm^2 (kgf/cm^2, lbf/in^2)

k_u = slamming load factor = 1.1

f_1 = $0.85\ S_m f_y$ for side shell plating forward of $0.125L$ from the FP, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.75\ S_m f_y$ for side shell plating in the region between $0.125L$ and $0.25L$ from the FP, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_2 = $0.85\ S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

s, k_1, k_2, S_m and f_y are as defined in 5C-3-6/13.3 above.

13.5.2 Side Longitudinals and Stiffeners

The section modulus of the stiffener, including the associated effective plating, is not to be less than obtained from the following equation:

$SM = M/f_b$ in cm^3 (in^3)

$M = 1000 p_s s \ell^2/k$ in N-cm (kgf-cm, lbf-in)

where

k = 16 (16, 111.1)

ℓ = unsupported span of the stiffener, in m (ft)

p_s = the maximum slamming pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in 5C-3-6/13.5.1, at the midpoint of the span ℓ

s and f_b are as defined in 5C-3-6/13.3.2 above.

The effective breadth of plating, b_e, is as defined in 5C-3-4/7.5.

13.5.3 Side Transverses and Side Stringers *(1 July 2008)*

For the region between 0.0125L and 0.25L from the FP, the net section modulus and sectional area requirements for side transverses and side stringers in 5C-3-6/7 are to be met with the bow flare slamming pressure as specified in 5C-3-3/11.3.1 and with the permissible bending stress of $f_b = 0.64 S_m f_y$ and the permissible shear stress of $f_s = 0.38 S_m f_y$.

PART

5C

CHAPTER 3 **Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)**

SECTION 7 **Cargo Safety and Vessel Systems**

1 Application

Provisions of Part 5C, Chapter 3, Section 7 (referred to as Section 5C-3-7) apply to vessels intended to carry ore or solid bulk cargoes in respect of the hazards of the cargo carried. They form a part of the necessary condition for assigning the class notation **Bulk Carrier** or **Ore Carrier**. The provisions of Part 4, specifying conditions for assigning the machinery class notation **AMS** (see 4-1-1/1.5), are applicable to these vessels in addition to the provisions of this section.

Attention is directed to the requirements of the IMO BC Code which may be prescribed by the vessel's Flag Administration. If requested by the vessel's owner and authorized by the Flag Administration, the Bureau will review plans and carry out surveys for purposes of verifying compliance with the Code on behalf of the Administration.

3 Bulk Cargo Spaces

3.1 Fire Protection

Except for cargoes in 5C-3-7/3.3, cargo spaces of vessels of 2,000 gross tonnage and upwards are to be protected by a fixed gas fire-extinguishing system complying with the provisions of 4-7-3/3 or by a fire extinguishing system which gives equivalent protection.

3.3 Vessels Carrying Low Fire Risk Cargoes *(2007)*

Cargo spaces of any vessel if constructed and solely intended for carrying ore, coal, grain, unseasoned timber, non-combustible cargoes or cargoes which constitute a low fire risk may be exempt from the requirements of 5C-3-7/3.1. Such exemptions may be granted only if the vessel is fitted with steel hatch covers and effective means of closing all ventilators and other openings leading to the cargo spaces. Vessels with an exemption are to be distinguished in the *Record* as suitable for carriage of low fire risk cargoes only. See also 4-7-2/7.

In accordance with IMO MSC/Circ.671 List of solid bulk cargoes which are non-combustible or constitute a low fire risk or for which a fixed gas fire extinguishing system is ineffective, the following solid bulk cargoes may be regarded as non-combustible or constitute a low fire risk:

- Cargoes listed in IMO BC Code Appendix A *List of bulk materials which may liquefy*: all.
- Cargoes listed in IMO BC Code Appendix B *List of bulk materials possessing chemical hazards*: only the following:
  - Aluminum processing by-products
  - Aluminum ferrosilicon powder (including briquettes)
  - Aluminum silicon powder, uncoated
  - Calcined pyrides (Pyritic ash, Fly ash)
  - Direct reduced iron briquettes, hot moulded
  - Ferrophospherous (including briquettes)
  - Ferrosilicon containing 25% to 30% silicon, or 90% or more silicon (including briquettes)
  - Ferrosilicon, containing more than 30% but less than 90% silicon (including briquettes)
  - Fluorspar (calcium fluoride)
  - Lime (unslaked)
  - Magnesia (Unslaked)
  - Pencil pitch
  - Petroleum coke (when loaded and transported under the provisions of the BC Code)
  - Radioactive material, low specific activity material (LSA-1)
  - Radioactive material, surface contaminated objects (SCO-1)
  - Silicomanganese
  - Sulfur (lump or coarse grained powder)
  - Vanadium ore
  - Woodchips with moisture content of 15% or more
  - Wood pulp pellets with moisture content of 15% or more
  - Zinc ashes
  - Zinc dross
  - Zinc residues
  - Zinc skimmings
- Cargoes listed in IMO BC Code Appendix C List of bulk materials which are neither liable to liquefy nor to possess chemical hazards: all.

3.5 Vessels Intended to Carry Solid Dangerous Goods in Bulk

3.5.1 General

Bulk cargo holds intended for the carriage of dangerous goods are to comply with the following tabulated requirements, except when carrying dangerous goods in limited quantities (as defined in section 18 of the General Introduction of *IMDG Code*):

- 5C-3-7/Table 1 provides a description of the list of dangerous goods as defined in IMDG Code.
- 5C-3-7/Table 2 provides the application of the requirements described in 4-7-2/7.3 to the different classes of solid dangerous goods in bulk.

TABLE 1
Dangerous Goods Classes

CLASS	*SUBSTANCE*
1 (1.1 through 1.6)	Explosives
2.1	Flammable gases (compressed, liquefied or dissolved under pressure)
2.2	Non flammable gases (compressed, liquefied or dissolved under pressure)
2.3	Toxic gases
3 (3.1 through 3.3)	Flammable liquids
4.1	Flammable solids
4.2	Substances liable to spontaneous combustion
4.3	Substances which, in contact with water, emit flammable gases
5.1	Oxidizing substances
5.2	Organic peroxides
6.1	Toxic substances
6.2	Infectious substances
7	Radioactive materials
8	Corrosives
9	Miscellaneous dangerous substances and articles, that is, any substance which experience has shown, or may show, to be of such a dangerous character that the provisions for dangerous substance transportation are to be applied.

TABLE 2
Application of the Requirements to Different Classes of Solid Dangerous Goods in Bulk

4-7-2/...	*Requirements*	*Dangerous goods classes*						
		4.1	*4.2*	*4.3(1)*	*5.1*	*6.1*	*8*	*9*
7.3.1(a)	Availability of water	x	x	-	x	-	-	x
7.3.1(b)	Quantity of water	x	x	-	x	-	-	x
7.3.2	Sources of ignition	x	x (2)	x	x (3)	-	-	x (3)
7.3.4(a)	Number of air changes	-	x (2)	x	-	-	-	-
7.3.4(b)	Ventilation fan	x (4)	x (2)	x	x (2),(4)	-	-	x (2),(4)
7.3.4(c)	Natural ventilation	x	x	x	x	x	x	x
7.3.6	Personnel protection	x	x	x	x	x	x	x
7.3.8	Insulation of machinery space boundary	x	x	x	x (2)	-	-	x (5)

Notes

1. The hazards of substances in this class which may be carried in bulk are such that special consideration must be given to the construction and equipment of the vessels involved in addition to meeting the requirements enumerated in this table. Complete design and installation details are to be submitted for review in each case.
2. Only applicable to Seedcake containing solvent extractions, to Ammonia nitrate, and to Ammonia nitrate fertilizers.
3. Only applicable to Ammonia nitrate and to Ammonia nitrate fertilizers. However, a degree of protection in accordance with standards contained in IEC 79 *Electrical Apparatus for Explosive Gas Atmosphere* is sufficient.
4. Only suitable wire mesh guards are required.
5. The requirements of the *Code of Safe Practice for Solid Bulk Cargoes* (IMO Resolution A.434(XI), as amended), are sufficient.

3.5.2 Cargoes for which Fixed Gas Fire-extinguishing System is Ineffective

A fixed gas fire-extinguishing system is considered ineffective for the following solid bulk cargoes, for which a fire-extinguishing system giving equivalent protection is to be available:

Aluminum nitrate	Magnesium nitrate
Ammonium nitrate	Potassium nitrate
Ammonium nitrate fertilizers	Sodium nitrate
Barium nitrate	Chilean natural nitrate
Calcium nitrate	Sodium nitrate and potassium nitrate, mixture
Lead nitrate	Chilean natural potassic nitrate

3.7 Vessels Intended to Carry Coal in Bulk

3.7.1 Flag Administration *(1998)*

Attention is directed to the requirements for the carriage of coal in bulk in the IMO BC Code and their application as may be prescribed by the vessel's flag administration. If requested by the vessel's owner and authorized by the Administration, the Bureau will review the plans and carry out surveys in accordance with the above Code on behalf of the Administration.

3.7.2 Hazardous Areas

Areas where flammable or explosive gases, vapors or dust are normally present or likely to be present are known as hazardous areas. For vessels intended to carry coal in bulk, the following areas are to be regarded as hazardous areas:

- Cargo hold spaces,
- Enclosed and semi-enclosed spaces having a direct opening to cargo hold space, and
- Open deck areas within 3 m (10 ft) of cargo hold mechanical ventilation outlets.

3.7.3 Installation of Electrical Equipment in Hazardous Areas

Electrical equipment installed in hazardous areas, identified in 5C-3-7/3.7.2, is to be:

i) Intrinsically safe type (Ex ia or ib);

ii) Flame-proof (explosion-proof) type (Ex d Group IIA T4);

iii) Pressurized or purged type (Ex p); or

iv) Increased safety type (Ex e) in open deck hazardous areas only.

See also 4-8-3/13 and 4-8-4/27.

3.7.4 Installation of Internal Combustion Engines in Hazardous Areas

Where essential for the operation of the vessel, the installation of internal combustion engines in hazardous areas, identified in 5C-3-7/3.7.2, may be permitted. This is subject to the elimination of all sources of ignition from the installation; the engine exhaust being led outside the hazardous areas, and the engine air intake being not less than 3 m (10 ft) from the hazardous areas. Complete details are to be submitted for review in each case.

3.7.5 Cargo Hold Atmosphere Measuring Instruments *(1998)*

3.7.5(a) Required measurements. Instruments are to be provided to measure the following in the cargo holds:

- Concentration of methane in the atmosphere;
- Concentration of oxygen in the atmosphere;
- Concentration of carbon monoxide in the atmosphere; and
- pH value of cargo hold bilge samples.

In addition, where self-heating coals are to be carried, it is recommended that consideration be given by the Owner/designer to provide the means for measuring the temperature of the cargo in the range of 0°C (32°F) to 100°C (212°F) during loading operations and during the voyage.

Means for calibration of the above instruments are to be provided onboard.

3.7.5(b) Arrangements of measurement. The required measurements and their readings are to be obtainable without entry into the cargo hold, and without introducing a source of ignition or otherwise endangering the cargo and cargo hold atmosphere. Instruments for measuring methane, oxygen and carbon monoxide concentrations are to be provided, together with an aspirator, flexible connection, a length of tubing and means for sealing the sampling hole, in order to enable a representative sample to be obtained from within the hatch cover surroundings. Alternative means for obtaining a representative sample will be considered.

3.7.5(c) Sampling points. Sampling points are to be provided for each hold, one on the port side and the other on the starboard side of the hatch cover, as near to the top of the hatch cover as possible. Each sampling point is to be fitted with a screw cap or equivalent and a threaded stub of approximately 12 mm (0.5 in.) bore welded to the side of the hatch cover to prevent ingress of water and air. Alternative sampling point arrangements/details will be considered.

3.7.6 Warning Plate *(1998)*

A permanent warning plate is to be installed in conspicuous places in cargo areas to state that smoking, naked flames, burning, cutting, chipping, welding or other sources of ignition are prohibited.

3.7.7 Hot Areas

Coal is not to be stowed adjacent to hot surfaces having a temperature of 45°C or above. Spaces adjacent to cargo holds that are likely to be hot, such as heated fuel oil tanks, are to be provided with suitable measures to prevent the common boundaries from being raised to a temperature beyond that considered safe for the carriage of the coal.

3.9 Vessels Intended to Carry Materials Hazardous Only in Bulk

Vessels intended to carry materials hazardous only in bulk (MHB), other than coal as addressed in 5C-3-7/3.7, are to comply with the recommendations of the *Code of Safe Practice for Solid Bulk Cargoes* (IMO Resolution A.434(XI), as amended) and the intent of 5C-3-7/3.7.

3.11 Cable Support *(2005)*

Cable inside of the vertical cable conduit pipe is to be suitably supported, e.g., by sand-filling or by strapping to a support wire. Alternatively, the cable inside of the vertical conduit pipe may be accepted without provided support if the mechanical strength of the cable is sufficient to prevent cable damage due to the cable weight within the conduit pipe under continuous mechanical load. Supporting documentation is to be submitted to verify the mechanical strength of the cable with respect to the cable weight inside of the conduit.

5 Hold Piping

Where the cargo hold is used alternately for dry cargo or ballast water, the following arrangements are to be made:

i) When the hold is used for ballast, the bilge suction is to be blanked off. Suitable means of venting and overflow, in accordance with the intent of 4-6-4/9, is to be provided.

ii) When the cargo hold is used for dry cargo, the ballast line is to be blanked off and the bilge suction is to be effective.

7 Self-unloading Cargo Gear

Dry bulk cargo vessels are to meet the following additional requirements when fitted with self-unloading cargo handling equipment.

7.1 Fail-safe Arrangements and Safety Devices

Fail-safe arrangements and safety devices are to be provided on the self-unloading equipment. A system is considered fail-safe if a component failure or loss of power will result in a controlled securing of the equipment or control of movement so as not to endanger personnel.

7.3 Hydraulic Piping Installations

The passage of self-unloading system hydraulic pipes through cargo holds is to be limited to only that which is necessary for operational purposes. Pipes installed within cargo holds are to be protected from mechanical damage.

System connection to other hydraulic systems is subject to special consideration. Failure in any one part of the self-unloading hydraulic system is not to cause the failure of other parts of the self-unloading system or of other ship's systems.

7.5 Equipment in Hazardous Areas

For requirements regarding the installation of equipment associated with the self-unloading cargo gear in hazardous areas, see 5C-3-7/3.7, as applicable.

7.7 Self-unloading Gear Controls and Alarms

7.7.1 General

Where vessels are equipped with self-unloading systems, controls are to be provided for the safe operation of the self-unloading system. These controls are to be clearly marked to show their functions. Energizing the power unit at a location other than the cargo control station is not to set the gear in motion.

7.7.2 Monitors

As appropriate, monitoring is to indicate system operational status (operating or not operating), availability of power, overload alarm, air pressure, hydraulic pressure, electrical power or current, motor running and motor overload, and brake mechanism engagement.

7.7.3 Emergency Shutdowns

Remote emergency shutdowns of power units for self-unloading equipment are to be provided outside of the power unit space so that they may be stopped in the event of fire or other emergency. Where remote controls are provided for cargo gear operation, means for the local emergency shutdowns are to be provided.

9 Draining and Pumping Forward Spaces in Bulk Carriers *(2005)*

9.1 Application

This requirement applies to bulk carriers constructed generally with single deck, top-side tanks and hopper side tanks in cargo spaces intended primarily to carry dry cargo in bulk, and includes such types as ore carriers and combination carriers.

9.3 Availability of Pumping Systems for Forward Spaces *(2006)*

On bulk carriers, the means for draining and pumping ballast tanks forward of the collision bulkhead and bilges of dry spaces, any part of which extends forward of the forward most cargo hold, are to be capable of being brought into operation from a readily accessible enclosed space, the location of which is accessible from the navigation bridge or propulsion machinery control position without traversing exposed freeboard or superstructure decks. Where pipes serving such tanks or bilges pierce the collision bulkhead, valve operation by means of remotely operated actuators may be accepted, as an alternative to the valve control specified in 4-6-2/9.7.3, provided that the location of such valve controls complies with the above arrangement.

9.5 Dewatering Capacity

The dewatering system for ballast tanks located forward of the collision bulkhead and for bilges of dry spaces any part of which extends forward of the foremost cargo hold is to be designed to remove water from the forward spaces at a rate not less than that determined from the following equation:

$$Q = 320A \quad \text{m}^3/\text{hr}$$

$$Q = 0.908A \quad \text{gpm}$$

where

A = cross-sectional area, in m^2 (in^2), of the largest air pipe or ventilator pipe connected from the exposed deck to a closed forward space that is required to be dewatered by these arrangements

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PART

5C

CHAPTER **3** **Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)**

APPENDIX **1** **Guide for Fatigue Strength Assessment of Bulk Carriers**

1 General

1.1 Note

This Guide provides a designer-oriented approach to fatigue strength assessment which may be used, for certain structural details, in lieu of more elaborate methods such as spectral fatigue analysis. The term assessment is used here to distinguish this approach from the more elaborate analysis.

The criteria in this Guide are developed from various sources including the Palmgren-Miner linear damage model, S-N curve methodologies, a long-term environment data of the North-Atlantic Ocean (Walden's Data), etc., and assume workmanship of commercial marine quality acceptable to the Surveyor. The capacity of structures to resist fatigue is given in terms of permissible stress range to allow designers the maximum flexibility possible.

While this is a simplified approach, a good amount of effort is still required in applying these criteria to the actual design. For this reason, a PC-based software has been developed and is available to the clients. Interested parties are kindly requested to contact the nearest ABS plan approval office for more information.

1.3 Applicability *(1996)*

The criteria in this Guide are specifically written for bulk carriers to which Part 5C, Chapter 3 is applicable. For vessels intended to carry oil/bulk cargoes/ores, Appendix 5C-1-A1 is also applicable.

1.5 Loadings *(1996)*

The criteria have been written for ordinary wave-induced motions and loads. Other cyclic loadings which may result in significant levels of stress ranges over the expected lifetime of the vessel are also to be considered by the designer.

Where it is known that a vessel will be engaged in long-term service on a route with a more severe environment, the fatigue strength assessment criteria in this Guide are to be modified accordingly.

1.7 Effects of Corrosion *(1996)*

To account for the mean wastage throughout the service life, the total stress range calculated using the net scantlings (i.e., deducting nominal design corrosion values, see 5C-3-2/Table 1) is modified by a factor c_f. See 5C-3-A1/9.1.1.

1.9 Format of the Criteria *(1996)*

The criteria in this Guide are presented as a comparison of fatigue strength of the structure (capacity) and fatigue inducing loads (demands) as represented by the respective stress ranges. In other words, the permissible stress range is to be not less than the total stress range acting on the structure.

5C-3-A1/5 provides the basis to establish the permissible stress range for the combination of the fatigue classification and typical structural joints of bulk carriers. 5C-3-A1/7 presents the procedures to be used to establish the applied total stress range. 5C-3-A1/11 provides typical stress concentration factors (SCFs) and guidelines for direct calculation of the required SCFs. 5C-3-A1/13 provides the guidance for assessment of stress concentration factors and the selection of compatible S-N data where a fine mesh finite element approach is used.

3 Connections to be Considered for the Fatigue Strength Assessment

3.1 General *(1996)*

These criteria have been developed to allow consideration of a broad variation of structural details and arrangements so that most of the important structural details anywhere in the vessel can be subjected to an explicit (numerical) fatigue assessment using these criteria. However, where justified by comparison with details proven satisfactory under equal or more severe conditions, an explicit assessment can be exempted.

3.3 Guidance on Locations *(1996)*

As a general guidance for assessing fatigue strength for a bulk carrier, the following connections and locations are to be considered:

3.3.1 Connections of Hold Frame

All typical end connections of hold frames to the upper and lower wing tanks in the ballast, heavy cargo and general cargo holds, as illustrated for Class F_2 item 2 in 5C-3-A1/Table 1.

3.3.2 Connections of Longitudinal Stiffeners to Transverse Web/Floor and to Transverse Bulkhead

3.3.2(a) Two (2) to three (3) selected side longitudinals in the upper and lower wing tanks for the midship region and also in the region between 0.15*L* and 0.25*L* from the FP

3.3.2(b) One (1) to two (2) selected longitudinals from each of the following groups:

- Deck longitudinals, bottom longitudinals, inner bottom longitudinals and longitudinals on the slope/longitudinal bulkheads.
- One longitudinal on the inner skin longitudinal bulkhead within 0.10*D* from the deck is to be included.

For these structural details, the fatigue assessment is to be first focused on the flange of the longitudinal at the rounded toe welds of attached flat bar stiffeners and brackets, as illustrated for Class F item 2) and Class F_2 item 1) in 5C-3-A1/Table 1.

Then, the critical spots on the web plate cut-out, on the lower end of the stiffener as well as the weld throat are also to be checked for the selected structural detail. For illustration see 5C-3-A1/11.3.1 and 5C-3-A1/11.3.2(a), 5C-3-A1/11.3.2(b) and 5C-3-A1/11.3.2(c).

Where the longitudinal stiffener end bracket arrangements are different on opposing sides of a transverse web or transverse bulkhead, both configurations are to be checked.

3.3.3 End Connections of Transverse Bulkhead

Connections of transverse bulkhead plating (corrugated) to the stools or the sloping longitudinal plates.

3.3.4 Shell, Bottom or Bulkhead Plating at Connections to the Sloping Longitudinal Bulkhead Plating, Transverse Webs or Floors

3.3.4(a) One (1) to two (2) selected locations of side shell plating at connections of the sloping bulkhead plating and hold frames, and near the summer *LWL* amidships, and also between 0.15*L* and 0.25*L* from the FP

3.3.4(b) One (1) to two (2) selected locations in way of bottom, inner bottom and lower strakes of the sloping longitudinal bulkhead of the lower wing tanks amidships, respectively.

For this structural detail, the value of f_R, the total stress range as specified in 5C-3-A1/9.1, is to be determined from fine mesh F.E.M. analyses for the combined load cases, as specified for Zone B in 5C-3-A1/7.5.2.

3.3.5 End Bracket Connections for Transverses and Girders

One (1) to two (2) selected locations in the midship region for each type of bracket configuration

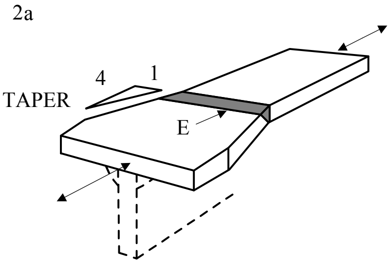
3.3.6 Other Regions and Locations

Other regions and locations, highly stressed by fluctuating loads, as identified from structural analysis

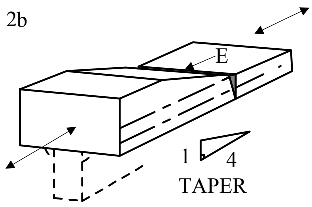
TABLE 1
Fatigue Classification for Structural Details *(1996)*

Class Designation		*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* *kgf/mm²*
B		Parent materials, plates or shapes as-rolled or drawn, with no flame-cut edges	0.7	92.2*
			0.8	75.9
			0.9	64.2
			1.0	55.6
C	1)	Parent material with automatic flame-cut edges	0.7	79.2
			0.8	63.9
	2)	Full penetration seam welds or longitudinal fillet welds made by an automatic submerged or open arc process, and with no stop-start positions within the length	0.9	53.3
			1.0	45.7
D	1)	Full penetration butt welds made either manually or by an automatic process other than submerged arc, from both sides, in downhand position	0.7	59.9
			0.8	47.3
			0.9	38.9
			1.0	32.9
	2)	Welds in C-2) with stop-start positions within the length		
E	1)	Full penetration butt welds made by other processes than those specified under D-1)	0.7	52.8
			0.8	41.7
			0.9	34.2
	2)	Full penetration butt welds made from both sides between plates of unequal widths or thicknesses	1.0	29.0

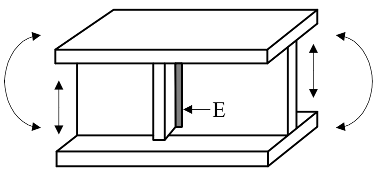
2a



2b



3) welds of brackets and stiffeners to web plate of girders

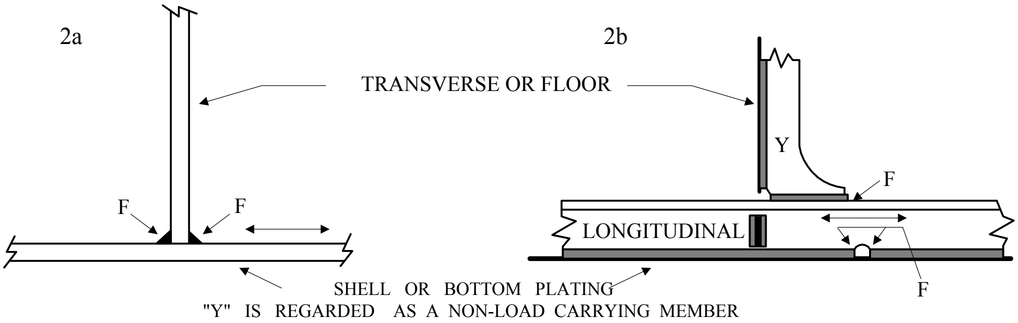


*1) The permissible stress range cannot be taken greater than two times the specified minimum tensile strength of the material.

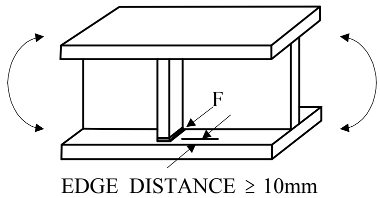
2) To obtain the permissible stress range in SI and U.S. Units, the conversion factors of 9.807 (N/mm²) and 1422 (lbf/in²) can be used, respectively.

TABLE 1 (continued)
Fatigue Classification for Structural Details *(1996)*

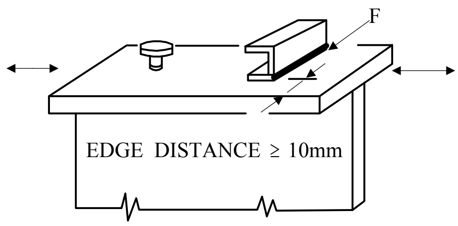
Class Designation		*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* kgf/mm^2
F	1)	Full penetration butt welds made on a permanent backing strip	0.7 0.8 0.9 1.0	44.7 35.3 29.0 24.5
	2)	Rounded fillet welds as shown below		



3) Weld of brackets and stiffeners to flanges



4) Attachments on plate or face plate

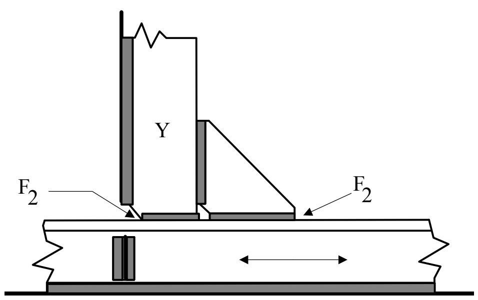


(Class G for edge distance < 10 mm)

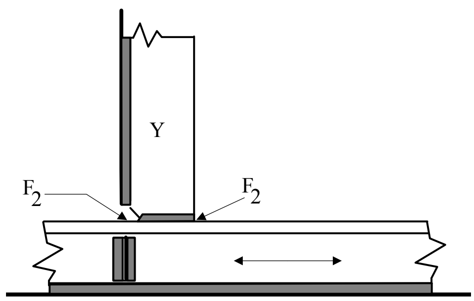
TABLE 1 (continued)
Fatigue Classification for Structural Details *(1996)*

Class Designation	*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* *kgf/mm²*
F_2	1) Fillet welds as shown below with rounded welds and no undercutting	0.7	39.3
		0.8	31.1
		0.9	25.5
		1.0	21.6

1a



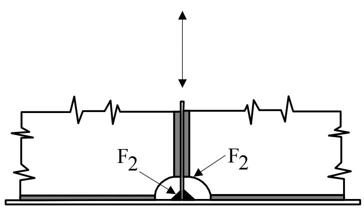
1b



"Y" is a non-load carrying member

2) Fillet welds with any undercutting at the corners dressed out by local grinding

2a



2b

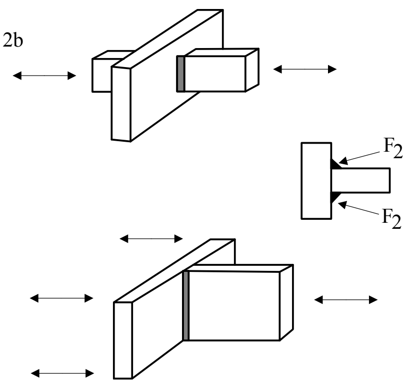
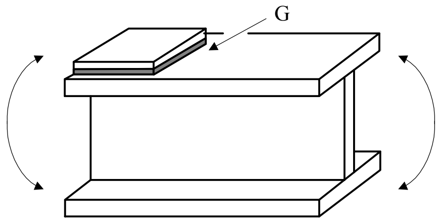
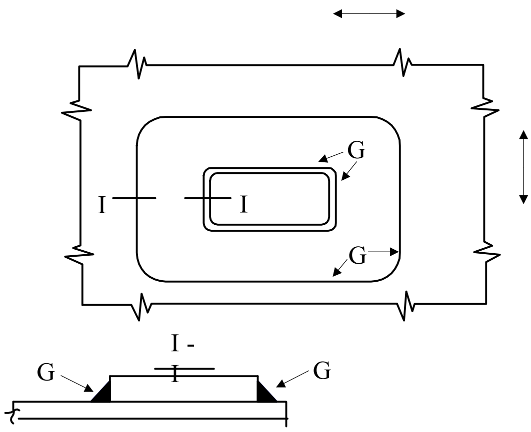


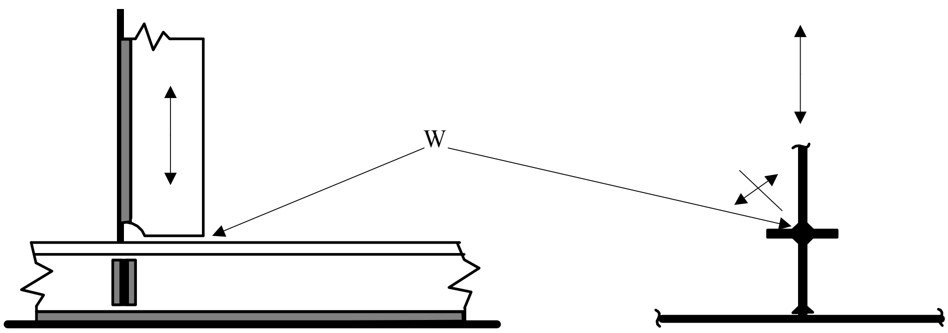
TABLE 1 (continued)
Fatigue Classification for Structural Details *(1996)*

Class Designation		*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* kgf/mm^2
G	1)	Fillet welds in F_2-1) without rounded toe welds or with limited minor undercutting at corners or bracket toes	0.7	32.8
			0.8	25.9
			0.9	21.3
			1.0	18.0
	2)	Fillet welds in F_2-2) with minor undercutting		
	3)	Doubler on face plate or flange		





W	1)	Fillet welds in G-3) with any undercutting at the toes	0.7	28.3
			0.8	22.3
			0.9	18.4
	2)	Fillet welds—weld throat	1.0	15.5



5 Permissible Stress Range

5.1 Assumptions *(1996)*

The fatigue strength of a structural detail under the loads specified here in terms of a long term, permissible stress range, is to be evaluated using the criteria contained in this section. The key assumptions employed are listed below for guidance.

- A linear cumulative damage model (i.e., Palmgren-Miner's Rule) has been used in connection with the S-N data in 5C-3-A1/Figure 1 (extracted from Ref. 1*).
- Cyclic stresses due to the loads in 5C-3-A1/7 have been used and the effects of mean stress have been ignored.
- The target design life of the vessel is taken to be 20 years.
- The long-term stress ranges on a detail can be characterized using a modified Weibull probability distribution parameter (γ).
- Structural details are classified and described in 5C-3-A1/Table 1, "Fatigue Classification of Structural Details".
- Simple nominal stress (e.g., determined by P/A and M/SM) is the basis of fatigue assessment rather than more localized peak stress in way of weld.

The structural detail classification in 5C-3-A1/Table 1 is based on joint geometry and direction of the dominant load. Where the loading or geometry is too complex for a simple classification, a finite element analysis of the details is to be carried out to determine stress concentration factors. 5C-3-A1/13 contains guidance on finite element analysis modeling to determine stress concentration factors for weld toe locations that are typically found at longitudinal stiffener end connections.

* Ref 1: "Offshore Installations: Guidance on Design, Construction and Certification", Department of Energy, U.K., Fourth Edition—1990, London: HMSO

5.3 Criteria *(1996)*

The permissible stress range obtained using the criteria in 5C-3-A1/5 is to be not less than the fatigue inducing stress range obtained from 5C-3-A1/7.

5.5 Long Term Stress Distribution Parameter, γ *(1996)*

In 5C-3-A1/Table 1, the permissible stress range is given as a function of the long term distribution parameter, γ, as defined below.

$$\gamma = m_s \gamma_o$$

m_s = 1.05 for deck and bottom structures of vessels with a bowflare parameter $A_\gamma = 27$ as defined in 5C-3-3/11.3, and vessels with bottom slamming (draft at FP = $0.03L$) as defined in 5C-3-3/11.1.

= 1.02 for deck and bottom structures of vessels with a bowflare parameter $A_\gamma = 24$ and vessels subject to bottom slamming (draft at FP = $0.035L$)

= 1.0 for structures elsewhere, and all structures of vessels without bottom and bowflare slamming ($A_\gamma \leq 21$, draft at FP $\geq 0.04L$)

For intermediate values of A_γ and draft at FP, m_s may be obtained by linear interpolation. For $A_\gamma > 27$ and draft at FP < $0.03L$, m_s is to be determined by direct calculations

γ_o	=	$1.40 - 0.2\alpha L^{0.2}$	for $150 < L \leq 305$ m
	=	$1.54 - 0.245\alpha^{0.8}L^{0.2}$	for $L > 305$ m
γ_o	=	$1.40 - 0.16\alpha L^{0.2}$	for $492 < L \leq 1001$ ft
	=	$1.54 - 0.19\alpha^{0.8}L^{0.2}$	for $L > 1001$ ft

where

α = 1.0 for deck structures, including side shell and longitudinal bulkhead structures within 0.1D from the deck

= 0.93 for bottom structures, including inner bottom, and side shell and longitudinal bulkhead structures within 0.1D from the bottom

= 0.86 for side shell and longitudinal bulkhead structures within the region of 0.25D upward and 0.3D downward from the mid-depth

= 0.80 for hold frames and transverse bulkhead structures

α may be linearly interpolated for side shell and longitudinal bulkhead structures between 0.1D and 0.25D (0.2D) from the deck (bottom).

L and D are the vessel's length and depth and as defined in 3-1-1/3.1 and 3-1-1/7.3, respectively.

5.7 Permissible Stress Range *(1996)*

5C-3-A1/Table 1 contains a listing of the permissible stress ranges, PS, for various categories of structural details with 20-year minimum design fatigue life. The permissible stress range is determined for the combination of the types of connections/details, the direction of dominant loading and the parameter, γ, as defined in 5C-3-A1/5.5. Linear interpolation may be used to determine the values of permissible stress range for a value of γ between those given.

(2003) For vessels designed for a fatigue life in excess of the minimum design fatigue life of 20 years (see 5C-3-1/1.2), the permissible stress ranges (PS) calculated above are to be modified by the following equation:

$$PS[Y_r] = C(20/Y_r)^{1/m}\,PS$$

where

$PS[Y_r]$ = permissible stress ranges for the design fatigue life for the Y_r

Y_r = target value of "design fatigue life" set by the applicant in five (5) year increments

m = 3 for Class D through W of S-N curve, 3.5 for Class C or 4 for Class B curves

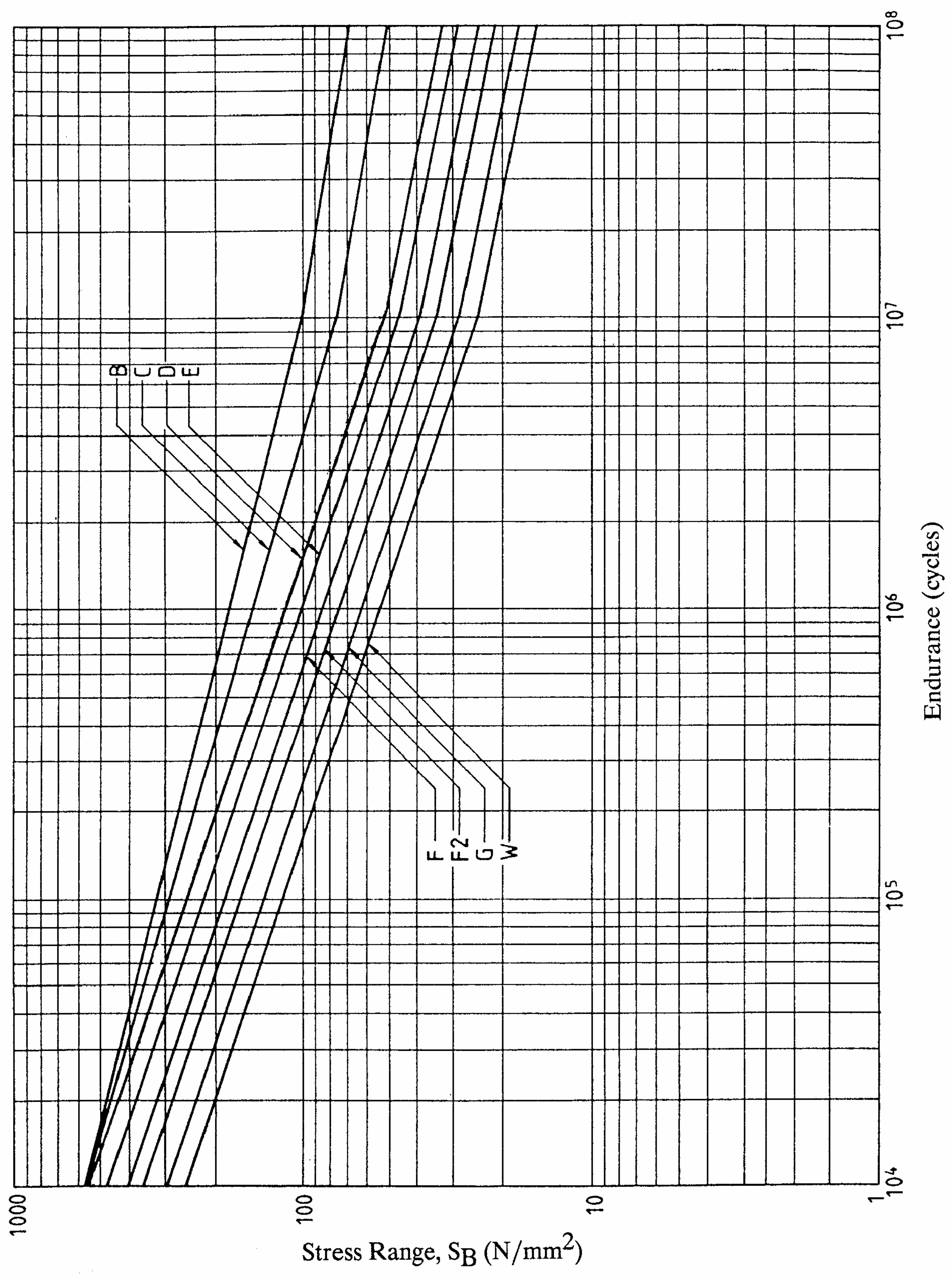
C = correction factor related to target design fatigue life considering the two-segment S-N curves (see 5C-3-A1/Table 1A).

TABLE 1A
Coefficient, C

Long-term stress distribution parameter γ	*Target Design Fatigue Life, years* Y_r	*S-N Curve Classes*		
		B	*C*	*D through W*
0.7	20	1.000	1.000	1.000
	30	1.004	1.006	1.011
	40	1.007	1.012	1.020
	50	1.010	1.016	1.028
0.8	20	1.000	1.000	1.000
	30	1.005	1.008	1.014
	40	1.009	1.015	1.025
	50	1.013	1.021	1.035
0.9	20	1.000	1.000	1.000
	30	1.006	1.010	1.016
	40	1.012	1.019	1.030
	50	1.017	1.026	1.042
1.0	20	1.000	1.000	1.000
	30	1.008	1.012	1.019
	40	1.015	1.022	1.035
	50	1.020	1.031	1.049

Note: Linear interpolations may be used to determine the values of C where Y_r = 25, 35 and 45

FIGURE 1
Basic Design S-N Curves *(1995)*



Notes (For 5C-3-A1/Figure 1)

a) Basic design S-N curves

The basic design curves consist of linear relationships between $\log(S_B)$ and $\log(N)$. They are based upon a statistical analysis of appropriate experimental data and may be taken to represent two standard deviations below the mean line.

Thus, the basic S-N curves are of the form:

$$\log(N) = \log(K_2) - m \log(S_B)$$

where

$$\log(K_2) = \log(K_1) - 2\sigma$$

N is the predicted number of cycles to failure under stress range S_B;

K_1 is a constant relating to the mean S-N curve;

σ is the standard deviation of log N;

m is the inverse slope of the S-N curve.

The relevant values of these terms are shown in the table below.

The S-N curves have a change of inverse slope from m to $m + 2$ at $N = 10^7$ cycles.

Details of basic S-N curves

Class	K_1	K_1 $\log_{10}$	K_1 $\log_e$	m	*Standard deviation* $\log_{10}$	*Standard deviation* $\log_e$	K_2
B	2.343×10^{15}	15.3697	35.3900	4.0	0.1821	0.4194	1.01×10^{15}
C	1.082×10^{14}	14.0342	32.3153	3.5	0.2041	0.4700	4.23×10^{13}
D	3.988×10^{12}	12.6007	29.0144	3.0	0.2095	0.4824	1.52×10^{12}
E	3.289×10^{12}	12.5169	28.8216	3.0	0.2509	0.5777	1.04×10^{12}
F	1.726×10^{12}	12.2370	28.1770	3.0	0.2183	0.5027	0.63×10^{12}
F_2	1.231×10^{12}	12.0900	27.8387	3.0	0.2279	0.5248	0.43×10^{12}
G	0.566×10^{12}	11.7525	27.0614	3.0	0.1793	0.4129	0.25×10^{12}
W	0.368×10^{12}	11.5662	26.6324	3.0	0.1846	0.4251	0.16×10^{12}

7 Fatigue Inducing Loads

7.1 General *(1996)*

This section provides: 1) the criteria to define the individual load components considered to cause fatigue damage (see 5C-3-A1/7.3); 2) the load combination cases to be considered for different regions of the hull containing the structural detail being evaluated (see 5C-3-A1/7.5) and 3) procedures to idealize the structural components to obtain the total stress range acting on the structure.

7.3 Wave-induced Loads

The fatigue-inducing load components to be considered are those induced by the seaway. They are divided into the following three groups:

- Hull girder wave-induced moments (vertical, horizontal and torsional), see 3-2-1/3.5 and 5C-3-3/5.
- External hydrodynamic pressures, and
- Internal cargo/liquid loads (including inertial loads and added static head due to ship's motion), see 5C-3-3/5.5 and 5C-3-3/5.7.

7.5 Fatigue Assessment Zones and Controlling Load Combination *(1996)*

Depending on the location of the structural details undergoing the fatigue assessment, different combinations of load cases are to be used to find the appropriate stress range as indicated below for indicated respective zones.

7.5.1 Zone A

Zone A consists of deck and bottom structures; side shell and longitudinal bulkhead structures, including the upper and lower wing tanks, within 0.1*D* (*D* is vessel's molded depth) from deck and bottom, respectively. For Zone A, stresses are to be calculated based on the wave induced loads specified in 5C-3-3/Table 1, as follows.

7.5.1(a) Calculate dynamic component of stresses for load cases LC1 through LC4, respectively.

7.5.1(b) Calculate two sets of stress ranges, one each for the following two pairs of combined loading cases.

LC1 and LC2, and

LC3 and LC4

7.5.1(c) Use the greater of the stress ranges obtained by 5C-3-A1/7.5.1(b).

7.5.2 Zone B

Zone B consists of side shell and all longitudinal bulkhead structures within the region between 0.25*D* upward and 0.30*D* downward from the mid-depth, hold frames and transverse bulkhead structures. The total stress ranges for Zone B may be calculated based on the wave-induced loads specified in 5C-3-3/Table 1 as follows:

7.5.2(a) Calculate dynamic component of stresses for load cases LC5 through LC10, respectively.

7.5.2(b) Calculate three sets of stress ranges, one each for the following three pairs of combined loading cases.

LC5 and LC6,

LC7 and LC8, and

LC9 and LC10

However, for inner bottom, sloping bulkhead, inner skin and side shell of holds other than the ballast hold, the stress range of LC9 and LC10 may be neglected.

7.5.2(c) Use the greater of the stress ranges obtained by 5C-3-A1/7.5.2(b).

7.5.3 Transitional Zone

The transitional zone between Zone A and Zone B consists of side shell and all longitudinal bulkhead structures between 0.1*D* and 0.25*D* (0.2*D*) from deck (bottom).

$$f_R = f_{R(B)} - [f_{R(B)} - f_{R(A)}]\, y_u/0.15D \qquad \text{for upper transitional zone}$$

$$f_R = f_{R(B)} - [f_{R(B)} - f_{R(A)}]\, y_\ell/0.1D \qquad \text{for lower transitional zone}$$

where

$f_{R(A)}, f_{R(B)}$ = the total stress ranges based on the combined load cases defined for Zone A or Zone B, respectively

y_u, y_ℓ = vertical distances from 0.25*D* (0.3*D*) upward (downward) from the mid-depth to the location considered

7.5.4 Vessels with Either Special Loading Patterns or Special Structural Configuration

For vessels with either special loading patterns or special structural configurations/features, additional load cases may be required for determining the stress range.

7.7 Primary Stress f_{d1} *(1996)*

f_{d1v} and f_{d1h} may be calculated by a simple beam approach. For assessing fatigue strength of side shell and longitudinal bulkhead plating at welded connections, the value of wave-induced primary stress is to be taken as that of maximum principal stresses at the location considered to account for the combined load effects of the direct stresses and shear stresses. For calculating the value of f_{d1v} for longitudinal deck members, normal camber may be disregarded.

For Panamax class and other bulk carriers of length not greater than 230 meters, the primary stress range f_{R1} may be calculated based on 85% of the wave-induced moments induced in 5C-3-3/5.3.

7.9 Secondary Stress f_{d2} *(1996)*

When a 3D structural analysis is not available, the secondary bending stress ranges may be obtained from an analytic calculation or experimental data with appropriate boundary conditions. Otherwise, the secondary bending stresses may be calculated using the approximate equations given below.

7.9.1 Double Bottom

The secondary longitudinal bending stress ranges in double bottom panels may be obtained from the following equation:

$$f_{d2i} = k_{1b}k_{2b}k_{3b}p_e b^2 r_i/(i_L i_T)^{1/2} \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

f_{d2i} = secondary longitudinal bending stress range in the structural member "i" at the intersection with the transverse bulkhead, N/cm^2 (kgf/cm^2, lbf/in^2)

k_{1b} = 0.075 for bottom or inner bottom plating

= 0.068 for face plates, flanges and web plates

k_{2b} = coefficients depending on apparent aspect ratio "ρ_b"

= as given in 5C-3-A1/Table 2 for $\rho_b \geq 1$

= $\rho_b^2\, k_b'$ where k_b' is as given in 5C-3-A1/Table 3 for $\rho_b < 1$

ρ_b = $(\ell/b)(i_T/i_L)^{1/4}$

k_{3b} = coefficients given in 5C-3-A1/Table 4 depending on the number of longitudinal girders in the double bottom and location of the longitudinal member considered

p_e = effective average lateral pressure range on the double bottom panel for the load case considered, as specified in 5C-3-A1/7.3, in N/cm^2 (kgf/cm^2, lbf/in^2)

b = width of the double bottom panel (see also 5C-3-A1/Figure 2), in cm (in.)

ℓ = length of the cargo hold being considered (see 5C-3-A1/Figure 2), in cm (in.)

i_L, i_T = unit moments of inertia of the double bottom panel in the longitudinal and transverse directions, respectively, in cm^3 (in^3)

i_L = I_L/S_L

i_T = I_T/S_T

I_L, I_T = moments of inertia of equally spaced girders and floors, respectively, including the effective width of plating and stiffeners attached to the effective plating, in cm^4 (in^4)

S_L, S_T = spacing of bottom girders and floors, respectively, in cm (in.)

r_i = distance between the horizontal neutral axis of the double bottom cross section and the location of the structural element being considered (bending lever arm – see 5C-3-A1/Figure 2), in cm (in.)

7.9.2 Double Sides

For double side's structural members, the secondary longitudinal bending stress range at the intersection with the transverse bulkhead may be obtained from the following equation.

$$f_{d2i} = k_{1s} k_{2s} k_{3s} p_e h^2 r_i / (i_L i_V)^{1/2} \quad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

f_{d2i} = secondary longitudinal bending stress in the structural element "i"

k_{1s} = 0.075 for shell or inner skin plating

= 0.068 for face plates, flanges, and web plates

k_{2s} = coefficients depending on apparent aspect ratio "ρ"

= as given in 5C-3-A1/Table 5 for $\rho_s \geq 1$

= $\rho_s^2 k_s'$ where k_s' is as given in 5C-3-A1/Table 6 for $\rho_s < 1$

ρ_s = $(\ell_1/h)(i_V/i_L)^{1/4}$

k_{3s} = coefficients given in 5C-3-A1/Table 7 depending on the number of side stringers in the double side

p_e = effective lateral pressure range, which is the maximum pressure (pressure range) on the double side for the load case being considered, as specified in 5C-3-A1/7.3, in N/cm^2 (kgf/cm^2, lbf/in^2)

h = height of the double side panel between upper and lower wing tanks (see also 5C-3-A1/Figure 2), in cm (in.)

ℓ_1 = length of the cargo hold being considered (see 5C-3-A1/Figure 2), in cm (in.)

i_L, i_V = unit moments of inertia of the double side panel in the longitudinal and vertical directions, respectively, in cm^3 (in^3)

i_L = I_L/S_L

i_V = I_V/S_V

I_L, I_V = moments of inertia of equally spaced longitudinal stringers and web frames, respectively, including the effective width of plating and stiffeners attached to the effective plating, in cm^4 (in^4)

S_L, S_V = spacing of longitudinal stringers and web frames, respectively, in cm (in.)

r_i = distance between the vertical neutral axis of the double side cross section and the structural member in question (bending lever arm – see 5C-3-A1/Figure 2, in cm (in.)

7.9.3

For those connections specified in 5C-3-A1/3.3.2, the wave-induced secondary bending stress f_{d2} may be ignored.

7.11 Additional Secondary Stresses f^*_{d2} and Tertiary Stresses f_{d3}

7.11.1 Calculation of f^*_{d2} *(1997)*

Where required, the additional secondary stresses acting at the flange of a longitudinal stiffener, f^*_{d2}, may be approximated by

$$f^*_{d2} = C_t C_y M/SM \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

M = $C_d ps\ell^2/12$ N-cm (kgf-cm, lbf-in), at the supported ends of longitudinal

Where flat bar stiffeners or brackets are fitted, the bending moment, M, given above, may be adjusted to the location of the brackets toe, i.e., M_x in 5C-3-4/Figure 4.

Where a longitudinal has remarkably different support stiffness at its two ends (e.g., a longitudinal connected to a transverse bulkhead on one end), considerations are to be given to the increase of bending moment at the joint.

C_d = 1.15 for longitudinal stiffener connections at the transverse bulkhead for side longitudinals, deck longitudinals, and longitudinals on longitudinal bulkheads.

= 1.0 elsewhere

p = wave induced local net pressure range, in N/cm² (kgf/cm², lbf/in²), for the specified location and load cases at the mid-span of the longitudinal considered

s = spacing of longitudinals/stiffeners, in cm (in.)

ℓ = unsupported span of longitudinal/stiffener, in cm (in.), as shown in 5C-3-4/Figure 3

SM = net section modulus of longitudinal with the associated effective plating, in cm³ (in³), at flange or point considered. The effective breadth, b_e, in cm (in.), may be determined as shown in 5C-3-4/Figure 4.

C_y = $0.656(d/z)^4$ for side shell longitudinals only where $z/d \geq 0.9$, but $C_y \geq 0.30$

= 1.0 elsewhere

z = distance above keel of side shell longitudinal under consideration

d = scantling draft, m (ft)

C_t = correction factor for the combined bending and torsional stress induced by lateral loads at the welded connection of the flat bar stiffener or bracket to the flange of longitudinal as shown in 5C-3-4/Figure 3.

= $1.0 + a_r$ for unsymmetrical sections, fabricated or rolled

= 1.0 for tee and flat bars

a_r = $C_n C_p SM/K$

C_p = $31.2d_w(e/\ell)^2$

e = horizontal distance between web centerline and the shear center of the cross section, including longitudinal and the effective plating

$\doteq$ $d_w b_f^{\,2} t_f u/(2\,SM)$ cm (in.)

K = St. Venant torsion constant for the longitudinal's cross section, excluding the associated plating.

= $[b_f t_f^3 + d_w t_w^3]/3$ cm^4 (in^4)

C_n = coefficient given in 5C-3-A1/Figure 3, as a function of ψ, for point (1) shown in 5C-3-A2/Figure 1.

u = $1 - 2b_1/b_f$

ψ = $0.31\ell(K/\Gamma)^{1/2}$

Γ = warping constant

= $mI_{yf}\, d_w^2 + d_w^3\, t_w^3/36$ cm^6 (in^6)

I_{yf} = $t_f\, b_f^3\,(1.0 + 3.0u^2A_w/A_s)/12$ cm^4 (in^4)

A_w = $d_w t_w$ cm^2 (in^2)

A_s = net sectional area of the longitudinals, excluding the associated plating, in cm^2 (in^2)

m = $1.0 - u(0.7 - 0.1d_w/b_f)$

d_w, t_w, b_1, b_f, t_f, all in cm (in.), are as defined in 5C-3-A2/Figure 1. For general applications, a_r needs not to be taken greater than 0.65 for a fabricated angle bar and 0.50 for a rolled section.

For connection as specified in 5C-3-A1/3.3.4, the wave-induced additional secondary stress f_{d2}^* may be ignored.

7.11.2 Calculation of f_{d3}

For welded joints of a stiffened plate panel, f_{d3} may be determined based on the wave-induced local loads as specified in 5C-3-A1/7.11.1 above, using the approximate equations given below. For direct calculation, non-linear effect and membrane stresses in the plate may be considered.

For plating subjected to lateral load, f_{d3} in the longitudinal direction is determined as:

$$f_{d3} = 0.182p(s/t_n)^2 \quad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

p = wave-induced local net pressure range, in N/cm^2 (kgf/cm^2, lbf/in^2)

s = spacing of longitudinal stiffeners, in mm (in.)

t_n = net thickness of plate, in mm (in.)

7.13 Calculation of Stress Range for Hold Frame

For the fatigue strength assessment, the stress range acting at the flange of a hold frame may be obtained from the following equation:

$$f_R = c_f c_w K_s | f^*_{R2} | \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

the value of f^*_{R2} may be approximated by

$$f^*_{R2} = C_t M/SM + F/A \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

M = $ps\ell^2/12$ N-cm (kgf-cm, lbf-in.), at the supported ends of the hold frame

F = $10(0.5 + 2\ell_H/b_e)Bsp_b$, N (kgf, lbf)

At the locations [1] in 5C-3-A1/Figure 4, the bending moment, M, given above, may be adjusted to the location of the bracket toe, i.e., M_x in 5C-3-4/Figure 4, but not less than 65% of M. At locations [2] and [3] in 5C-3-A1/Figure 4, the bending moment, M, given above, may be used without modification.

K_s = stress concentration factor

= 1.0 for location [1]

= 2.0 for locations [2] and [3] unless otherwise determined from FEM analysis based on 5C-3-A1/13

p = total range of the net fluctuating local loads of hold frame, N/cm^2 (kgf/cm^2, lbf/in^2), for the specified load cases, (LC5 and LC6) and (LC7 and LC8). For hold frames in ballast holds, the local loads are also to be investigated for the load cases (LC9 and LC10). The local loads are to be taken as an average value of those calculated at the lower and upper end of the span.

p_b = total range of the net fluctuating loads of double bottom, N/cm^2 (kgf/cm^2, lbf/in^2), for the corresponding load cases as mentioned above. The local loads are to be taken at B/4 off the centerline of the hull girder transverse section

s = spacing of hold frames, in cm (in.)

ℓ = unsupported span of the hold frame, as shown in 5C-3-A1/Figure 4, in cm (in.)

ℓ_H = length of the cargo hold, in m (ft)

b_e = breadth of the double bottom structure, in m (ft).

For vessels having lower wing tanks with sloping tops, making an angle of about 45 degrees with horizontal, the breadth may be measured between the midpoints of the sloping plating

B = breadth of the vessel, in m (ft), as defined in 3-1-1/5

SM = section modulus of the hold frame with the associated effective plating, at the flange or point considered, cm^3 (in^3). The effective breadth, b_e, may be determined as shown in 5C-3-4/Figure 4, in cm (in.). For the fatigue assessment at locations [2] and [3] in 5C-3-A1/Figure 4, SM is to be taken at the lower and upper supported ends of the hold frame, respectively. Where the bracket is fitted with the face plate or flange sniped at both ends, such face plate or flange is not to be included in the calculation of the section modulus.

A = net sectional area of the frame and the associated plating (st_n), in cm^2 (in^2)

c_f, c_w and C_t are as defined in 5C-3-A1/9.1.1 and 5C-3-A1/7.11.1 above.

TABLE 2
Coefficient k_{2b} for Double Bottom Panels when $\rho_b \geq 1.0$

ρ_b	*Bulk Carriers with Double Sides or Two Long. Bulkheads*	*Bulk Carriers with Single Sides and no long. Bulkheads*
1.0	0.57	0.69
1.2	0.61	0.82
1.4	0.62	0.91
1.6	0.63	0.96
1.8	0.63	0.99
2.0	0.63	1.01
2.2	0.63	1.03
2.5 & up	0.63	1.04

TABLE 3
Coefficient k_b' for Double Bottom Panels when $\rho_b \leq 1.0$

$1/\rho_b$	*Bulk Carriers with Double Sides or Two Long. Bulkheads*	*Bulk Carriers with Single Sides and no long. Bulkheads*
1.0	0.57	0.69
1.2	0.70	0.79
1.4	0.80	0.86
1.6	0.86	0.90
1.8	0.89	0.92
2.0	0.91	0.93
2.2 & up	0.92	0.92

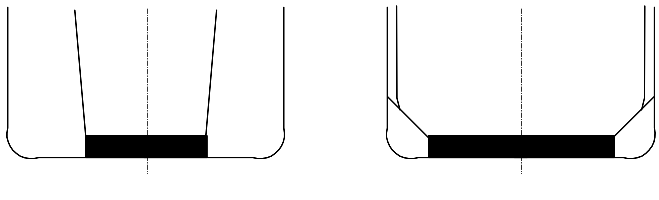


TABLE 4
Coefficient k_{3b} for Double Bottom Panels

Distance of the longitudinal member in question from the middle of panel's width	*Number of equally spaced* long. girders in the panel*					
	None	1	2	3	4	5 & up
0	1.0	1.15	0.9	1.05	0.98	1.0
0.1*b*	0.95	1.0		0.9	0.9	0.95
b/6			0.9			
0.25*b*	0.75	0.75	0.75	0.75	0.75	0.75
0.45*b*	0.30	0.25	0.35	0.30	0.33	0.30
0.50*b*	0	0	0	0	0	0

* *Notes:*

1 Girders are considered to be equally spaced if adjacent spacings differ by less than 15%.

2 For locations other than those given in Column 1, k_{3b} is to be obtained by linear interpolation.

FIGURE 2
Dimensions of Double Bottom, Double Side

Type I when one or more longitudinal girders are fitted in double-skin structures

Type II when no longitudinal girders are fitted in double-skin structure

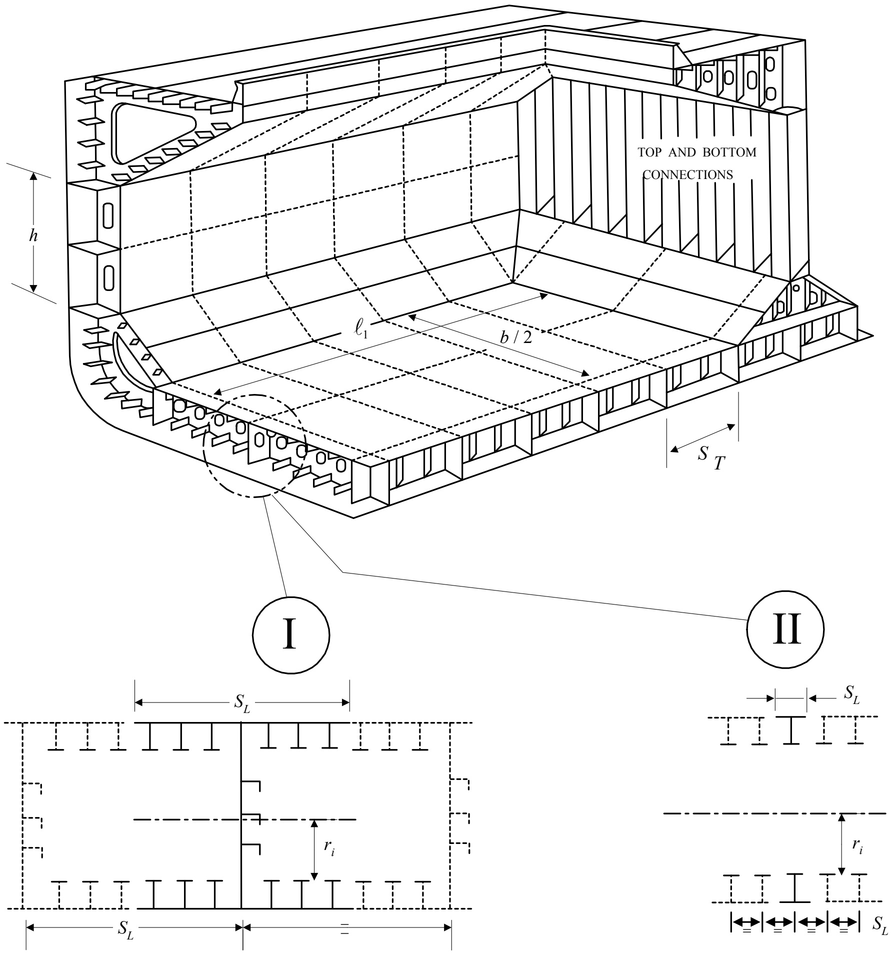


TABLE 5
Coefficient k_{2s} for Double Side Panels when $\rho_s \geq 1.0$

ρ_s	k_{2s}
1.0	0.31
1.2	0.39
1.4	0.41
1.6	0.43
1.8	0.44
2.0	0.45
2.2 & up	0.45

TABLE 6
Coefficient k_s' for Double Side Panels when $\gamma_s \leq 1.0$

$1/\rho_s$	k_s'
1.0	0.31
1.2	0.34
1.4	0.35
1.6	0.39
1.8	0.40
2.0	0.40
2.2 & up	0.40

TABLE 7
Coefficient k_{3s} for Double Side Panels

Distance of the longitudinal member under consideration from the middle of panel's width	*Number of side stringers*			
	None	1	2	3 & up
0	1.0	1.15	0.9	1.0
$0.1h$	0.95	1.0	—	0.95
$h/6$	—	—	0.9	—
$0.25h$	0.75	0.75	0.75	0.75
$0.45h$	0.30	0.25	0.35	0.30
$0.50h$	0	0	0	0

* *Note:* For locations other than those given is column 1, k_{3s} is to be obtained by linear interpolation.

FIGURE 3
$C_n = C_n(\psi)$

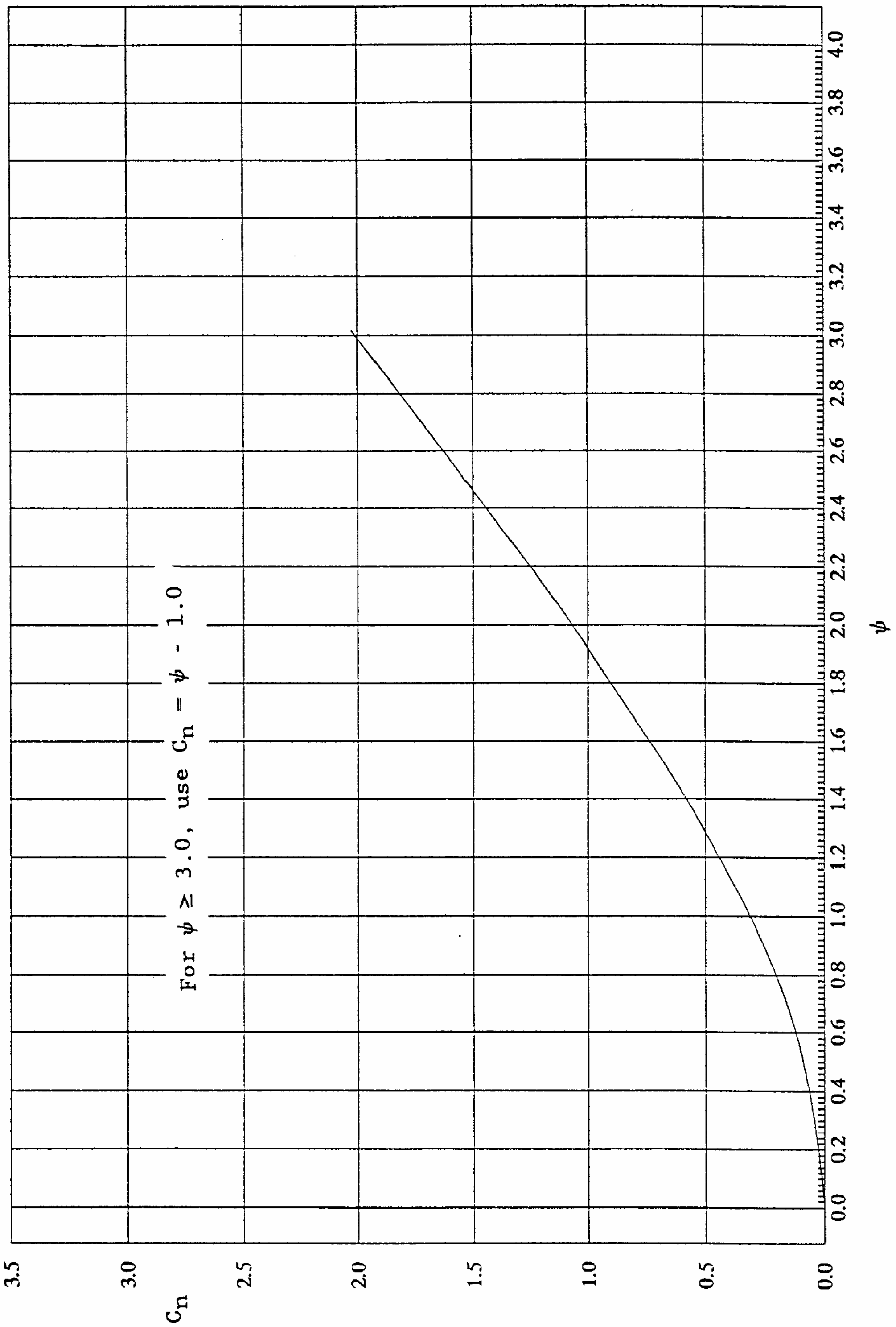
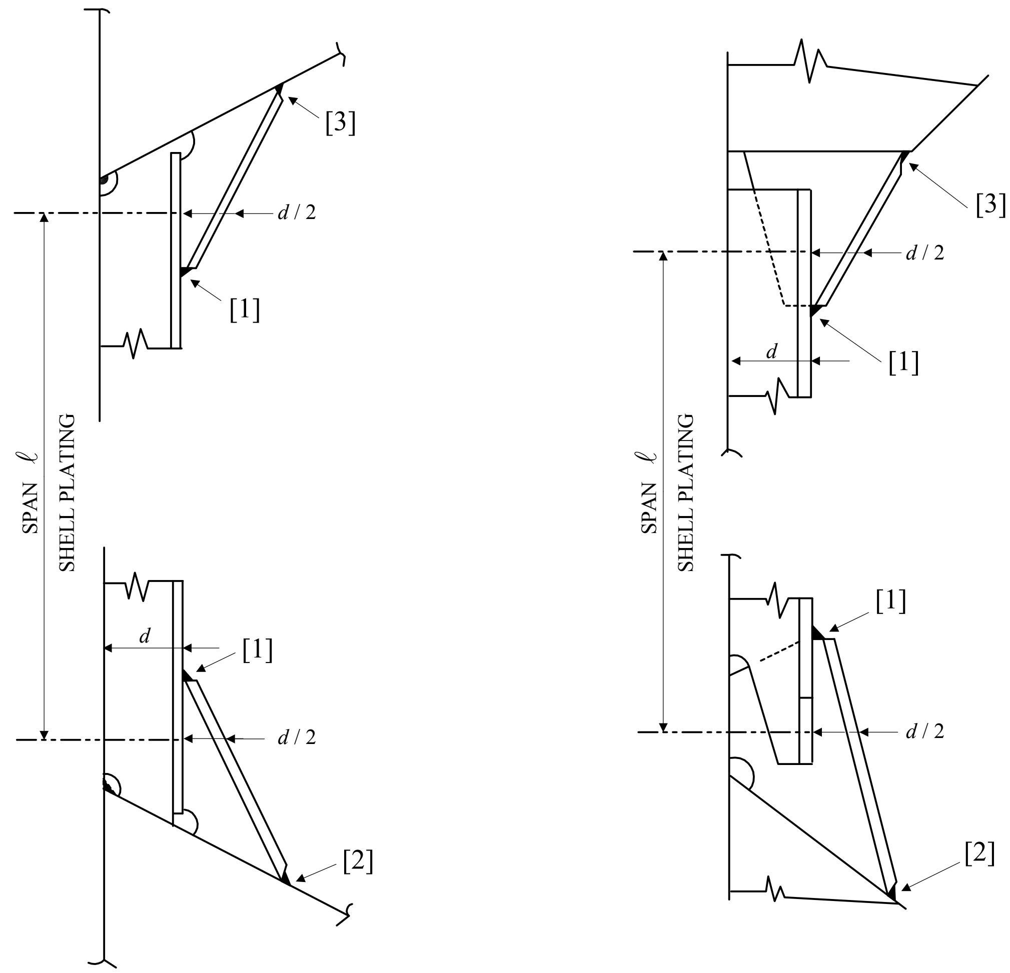


FIGURE 4
Hold Frame



9 Resulting Total Stress Ranges

9.1 Definitions *(1996)*

9.1.1

The total stress range, f_R, is computed as the sum of the two stress ranges as follows:

$$f_R = c_f(f_{RG} + f_{RL}) \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

f_{RG} = global dynamic stress range in N/cm^2 (kgf/cm^2, lbf/in^2)

= $|(f_{d1vi} - f_{d1vj}) + (f_{d1hi} - f_{d1hj})|$

f_{RL} = local dynamic stress range in N/cm^2 (kgf/cm^2, lbf/in^2)

= $c_w\,|(f_{d2i} + f^*_{d2i} + f_{d3i}) - (f_{d2j} + f^*_{d2j} + f_{d3j})|$

c_f = adjustment factor to reflect a mean wasted condition

= 0.95

c_w = coefficient for the weighted effects of the two paired loading patterns

= 0.75

f_{d1vi}, f_{d1vj} = wave-induced component of the primary stresses produced by hull girder vertical bending in, N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively

f_{d1hi}, f_{d1hj} = wave-induced component of the primary stresses produced by hull girder horizontal bending in, N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively

f_{d2i}, f_{d2j} = wave-induced component of the secondary bending stresses produced by the bending of cross-stiffened panels between transverse bulkheads, in N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively

f^*_{d2i}, f^*_{d2i} = wave-induced component of the additional secondary stresses produced by the local bending of the longitudinal stiffener between supporting structures (e.g., transverse bulkheads and web frames), in N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively

f_{d3i}, f_{d3j} = wave-induced component of the tertiary stresses produced by the local bending of plate elements between the longitudinal stiffeners, in N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively

For calculating the wave induced stresses, the sign convention is to be observed for the respective directions of wave-induced loads as specified in 5C-3-3/Table 1. The wave-induced local loads are to be calculated with the sign convention for the external and internal loads; however, the total of the external and internal pressures, including both static and dynamic components, need not be taken less than zero.

These wave-induced stresses are to be determined based on the net ship scantlings (see 5C-3-A1/1.7) and in accordance with 5C-3-A1/7.5 through 5C-3-A1/7.11. The results of direct calculation where carried out may also be considered.

11 Determination of Stress Concentration Factors (SCFs)

11.1 General *(1995)*

This section contains information on stress concentration factors (SCFs) to be considered in the fatigue assessment.

Where, for a particular example shown, no specific value of SCF is given when one is called for, it indicates that a finite element analysis is needed. When the fine mesh finite element approach is used, additional information on calculations of stress concentration factors and the selection of compatible S-N data is given in 5C-3-A1/13.

11.3 Sample Stress Concentration Factors (SCFs) *(1 July 2001)*

11.3.1 Cut-outs (Slots) for Longitudinals *(1995)*

SCFs, fatigue classifications and peak stress ranges may be determined in accordance with 5C-3-A1/Table 8 and 5C-3-A1/Figure 5.

TABLE 8
K_s (SCF) Values

	K_s *(SCF)*					
Configuration	*Unsymmetrical Flange*			*Symmetrical Flange*		
Location	[1]	[2]	[3]	[1]	[2]	[3]
Single-sided Support	2.0	2.1	—	1.8	1.9	—
Single-sided Support with F.B. Stiffener	1.9	2.0	—	1.7	1.8	—
Double-sided Support	2.4	2.6	1.9	2.4	2.4	1.8
Double-sided Support with F.B. Stiffener	2.3	2.5	1.8	2.3	2.3	1.7

Notes:

a The value of K_S is given based on nominal shear stresses near the locations under consideration.

b Fatigue classification

Locations [1] and [2]: Class C or B as indicated in 5C-3-A1/Table 1

Location [3]: Class F

c The peak stress range is to be obtained from the following equations:

1 **For locations [1] and [2]** *(1999)*

$$f_{Ri} = c_f\,[K_{si} f_{si} + f_{ni}]$$

where

c_f = 0.95

f_{si} = $f_{sc} + \alpha_i f_{swi}$, $f_{si} \geq f_{sc}$

α_i = 1.8 for single-sided support

= 1.0 for double-sided support

f_{ni} = normal stress range in the web plate

f_{swi} = shear stress range in the web plate

= F_i/A_w

F_i is the calculated web shear force range at the location considered. A_w is the area of web.

f_{sc} = shear stress range in the support (lug or collar plate)

= $C_y P/(A_c + A_s)$

C_y is as defined in 5C-3-A1/7.11.1.

P = $s\ell p_o$

p_o = fluctuating lateral pressure

A_c = sectional area of the support or of both supports for double-sided support

A_s = sectional area of the flat bar stiffener, if any

K_{si} = SCFs given above

s = spacing of longitudinal/stiffener

ℓ = spacing of transverses

2 For location [3]

$$f_{R3} = c_f [f_{n3}^2 + (K_s f_{s2})^2]^{1/2}$$

where

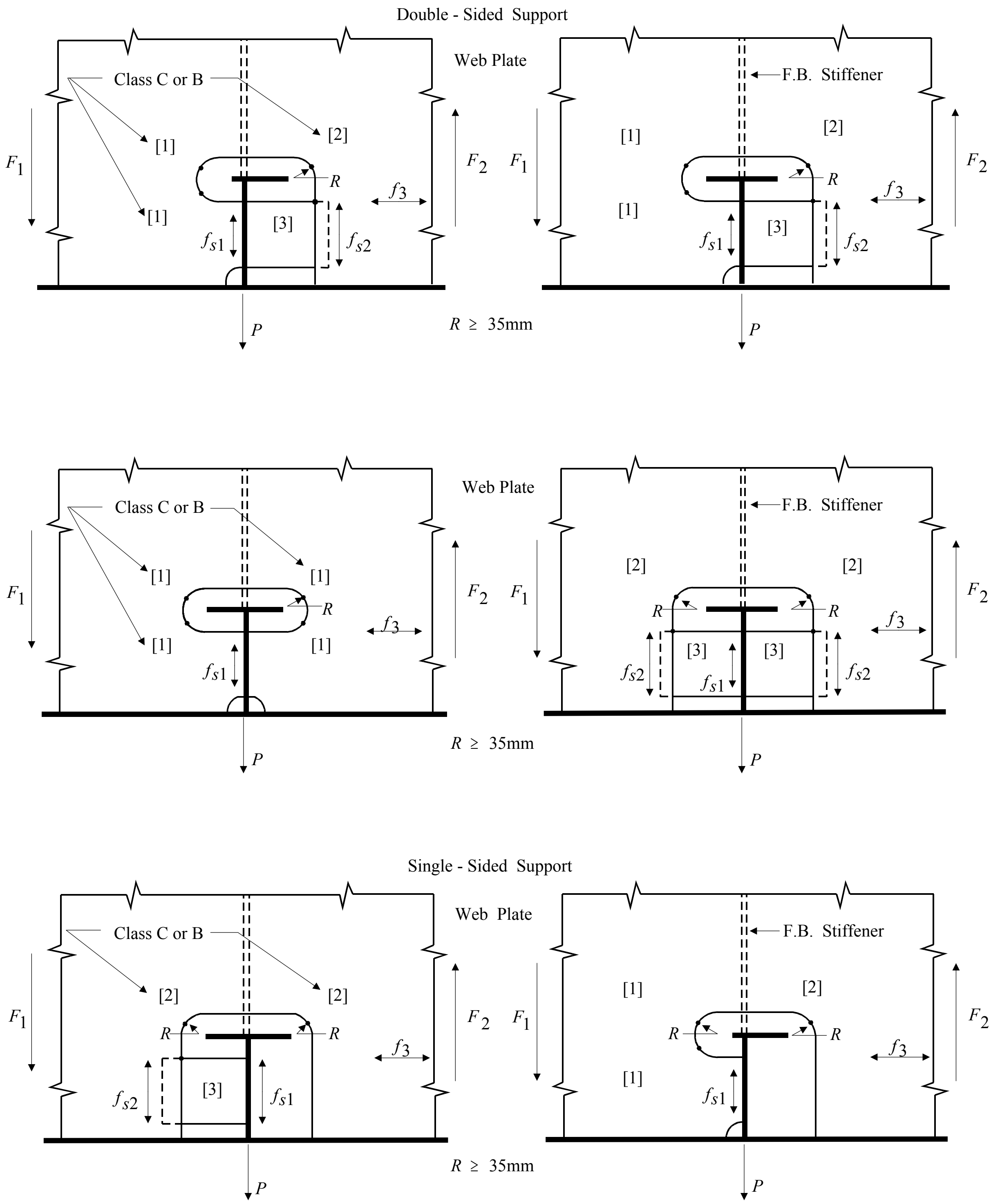
c_f = 0.95

f_{n3} = normal stress range at location [3]

f_{s2} = shear stress range as defined in 1 above near location [3].

K_s = SCFs given above

FIGURE 5
Cut-outs (Slots) For Longitudinal *(1995)*



11.3.2 Flat Bar Stiffeners for Longitudinals *(1999)*

11.3.2(a) For assessing fatigue life of a flat bar stiffener at location [1] or [2] as shown in 5C-3-A1/Figure 6, the peak stress range is to be obtained from the following equations:

$$f_{Ri} = [(\alpha_i f_s)^2 + f_L{}^2]^{1/2} \qquad (i = 1 \text{ or } 2)$$

where

f_s = nominal stress range in the flat bar stiffener.

= $c_f C_y P/(A_s + A_c)$

P, A_s, A_c, c_f are as defined in 5C-3-A1/11.3.1 and C_y in 5C-3-A1/7.11.1. For flat bar stiffener with soft-toed brackets, the brackets may be included in the calculation of A_s.

f_{Li} = stress range in the longitudinal at Location i (i = 1or 2), as specified in 5C-3-A1/9

α_i = stress concentration factor at Location i (i = 1or 2) accounting for misalignment and local distortion.

At location [1]

For flat bar stiffener without brackets

α_1 = 1.50 for double-sided support connection

= 2.00 for single-sided support connection

For flat bar stiffener with brackets

α_1 = 1.00 for double-sided support connection

= 1.25 for single-sided support connection

At location [2]

For flat bar stiffener without brackets

α_2 = 1.25 for single or double-sided support connection

For flat bar stiffener with brackets

α_2 = 1.00 for single or double-sided support connection

11.3.2(b) For assessing the fatigue life of the weld throat as shown in 5C-3-A1/Table 1, Class W, the peak stress range f_R at the weld may be obtained from the following equation:

$$f_R = 1.25 f_s A_s / A_{sw}$$

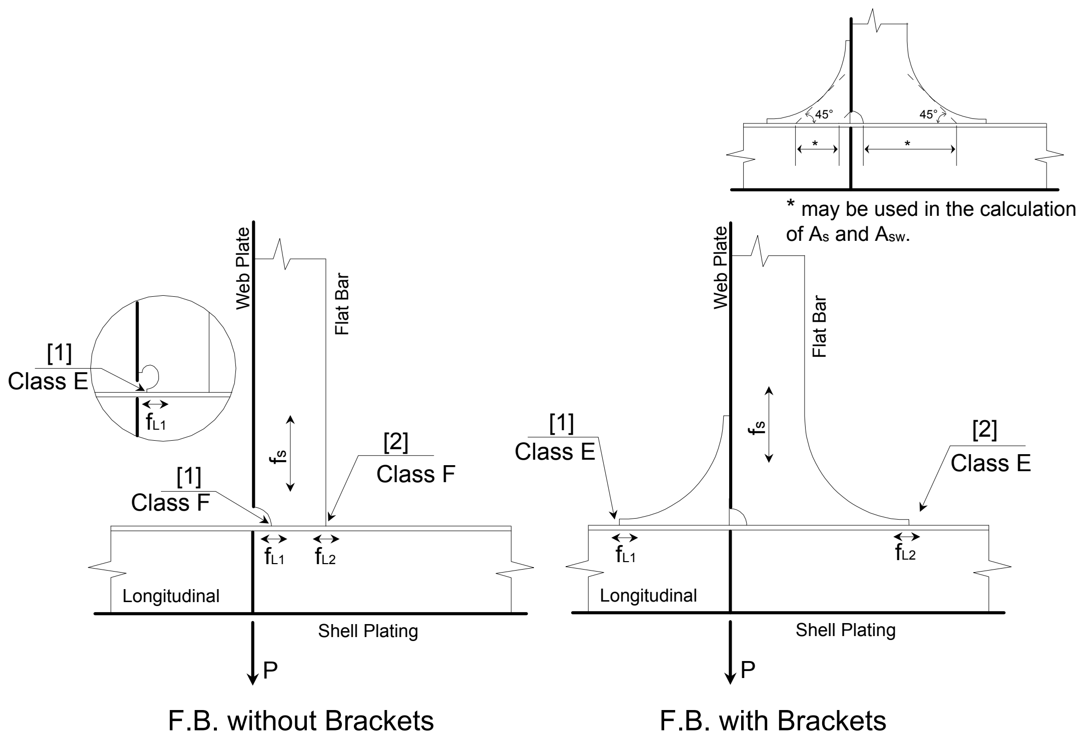
where

A_{sw} = sectional area of the weld throat. Brackets may be included in the calculation of A_{sw}.

f_s and A_s are as defined in 5C-3-A1/11.3.2(a).

11.3.2(c) For assessing fatigue life of the longitudinal, the fatigue classification given in 5C-3-A1/Table 1 for a longitudinal as the only load carrying member is to be considered. Alternatively, the fatigue classification shown in the 5C-3-A1/Figure 6 in conjunction with the combined stress effects, f_R, may be used. In calculation of f_R, the α_i may be taken as 1.25 for both locations [1] and [2].

FIGURE 6
Fatigue Classification for Longitudinals in way of Flat Bar Stiffener



11.3.3 Welded Connection with Two or More Load Carrying Members

For brackets connecting two or more load carrying members, an appropriate stress concentration factor (SCF) determined from fine mesh 3D or 2D finite element analysis is to be used. In this connection, the fatigue class at bracket toes may be upgraded to class E. Sample connections are illustrated below with SCF.

11.3.3(a) Connection of Longitudinal and Stiffener. Fatigue class designation and SCFs may be determined as shown in 5C-3-A1/Figure 7.

11.3.3(b) Connection Between Corrugated Transverse Bulkhead and Deck. Fatigue class designation and SCFs may be determined as shown in 5C-3-A1/Figure 8.

11.3.3(c) Connection Between Corrugated Transverse Bulkhead and Inner Bottom with Respect to Lateral Load on the Bulkhead. Fatigue class designation and SCFs may be determined as shown in 5C-3-A1/Figure 9.

11.3.3(d) Connection Between Inner Bottom and Hopper Tank Slope. Fatigue class designation and SCFs may be determined as shown in 5C-3-A1/Figure 10.

11.3.3(e) Hatch Corner. Fatigue class designation and SCFs may be determined as shown in 5C-3-A1/Figure 11.

11.3.3(f) Hold Frames. Fatigue class designation and SCFs may be determined as shown in 5C-3-A1/Figure 12.

11.3.3(g) Doublers and Non-Load Carrying Members on Deck or Shell Plating. Fatigue class designation and SCFs may be determined as shown in 5C-3-A1/Figure 13.

FIGURE 7
Connection of Longitudinal and Stiffener

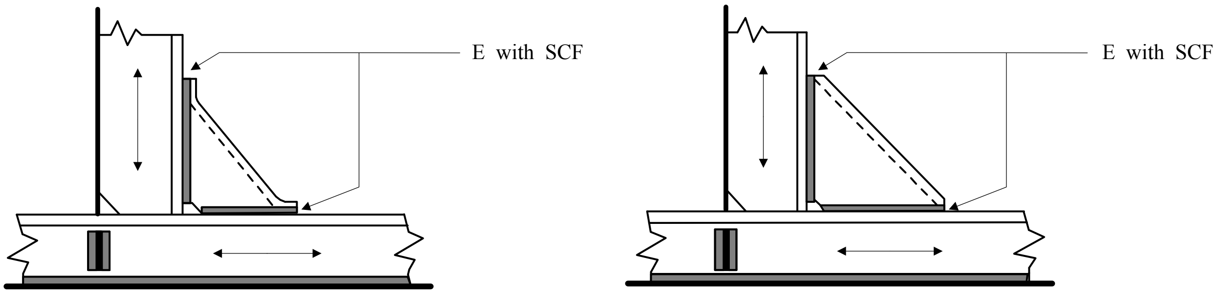


FIGURE 8
Connection Between Corrugated Transverse Bulkhead and Deck

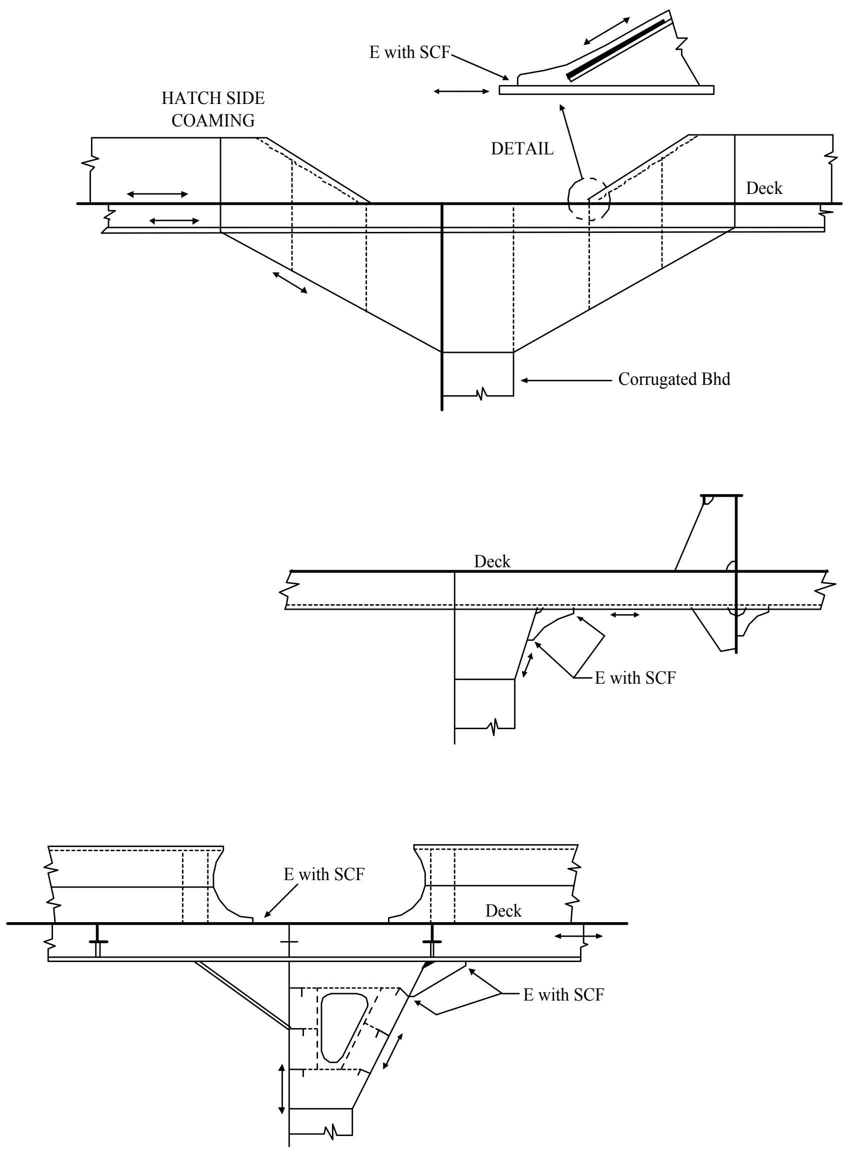


FIGURE 9
Connection between Corrugated Transverse Bulkhead and Inner Bottom with Respect to Lateral Load on the Bulkhead

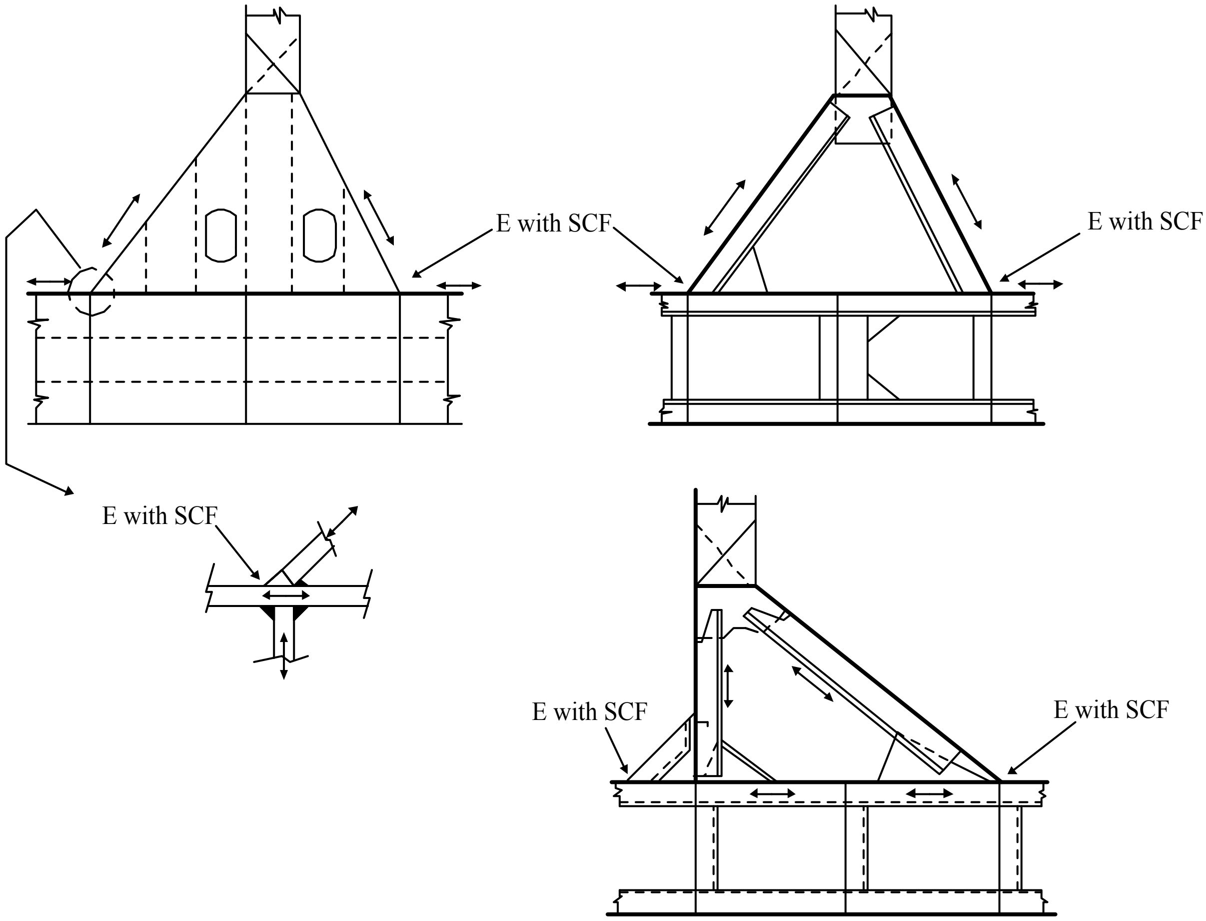


FIGURE 10
Connection between Inner Bottom and Hopper Tank Slope

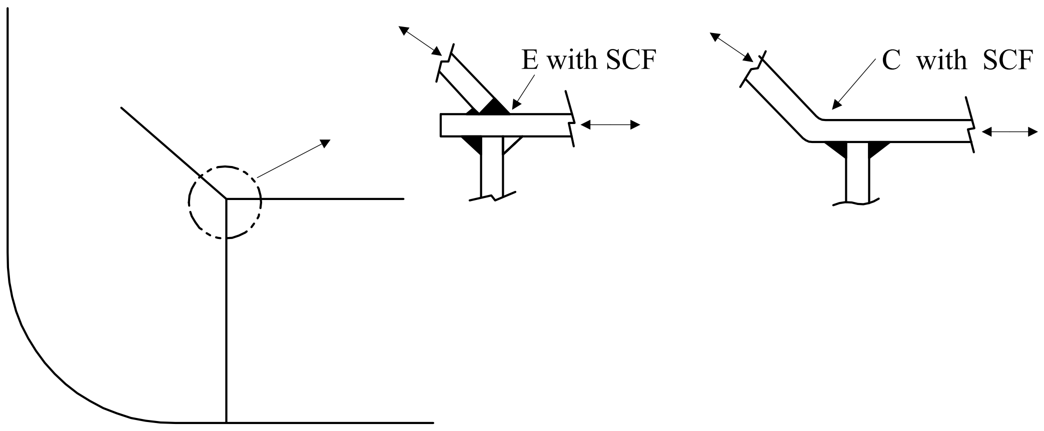


FIGURE 11
Hatch Corner

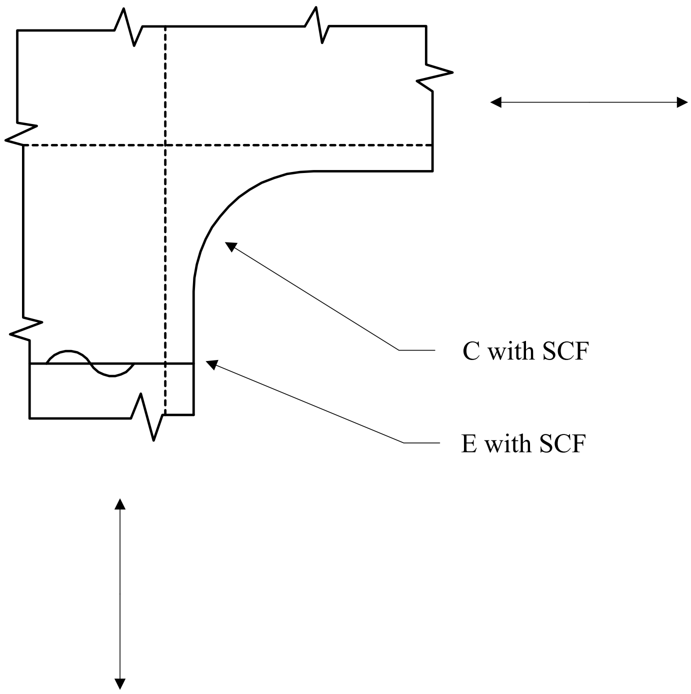


FIGURE 12
Hold Frames

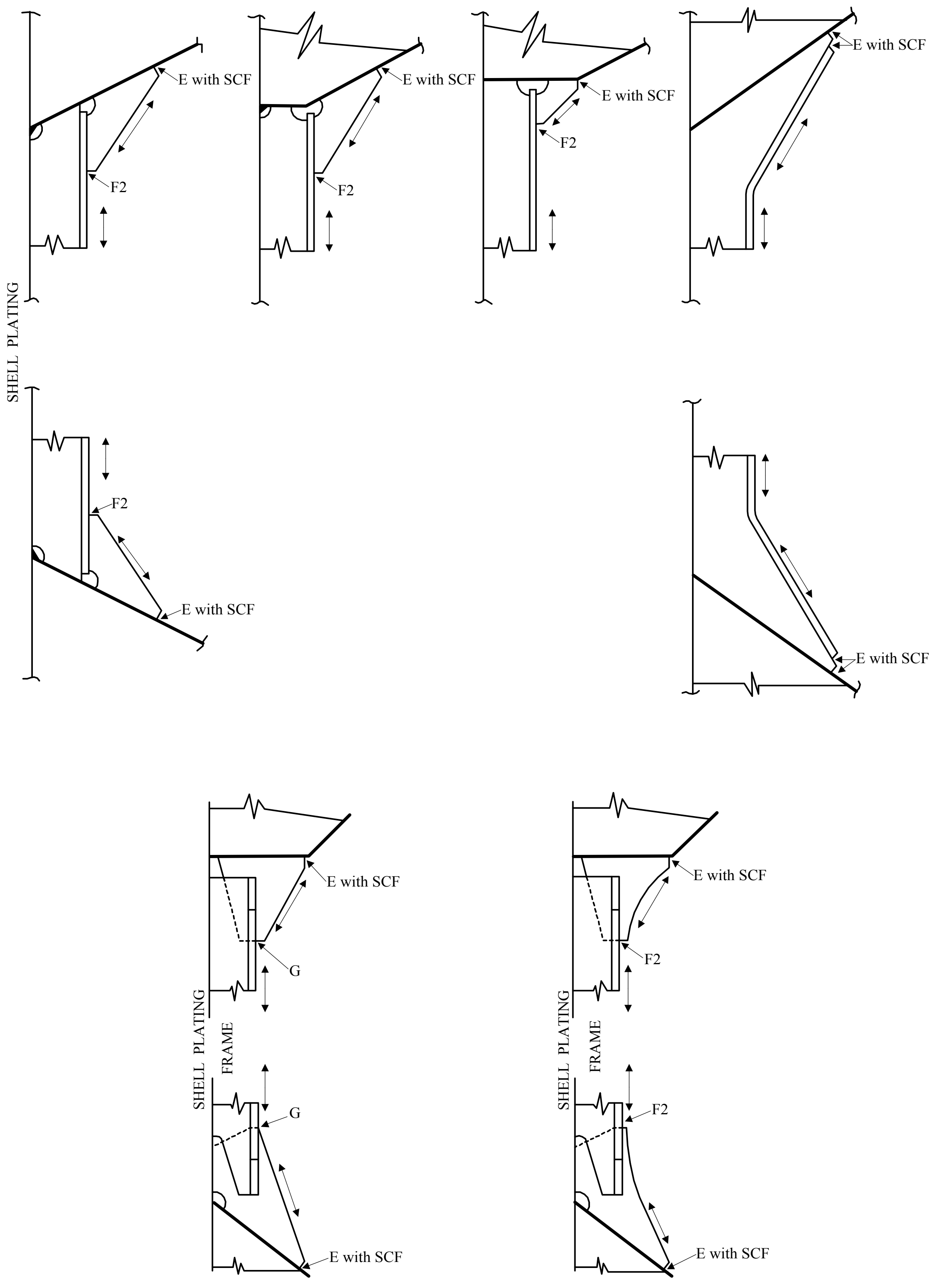
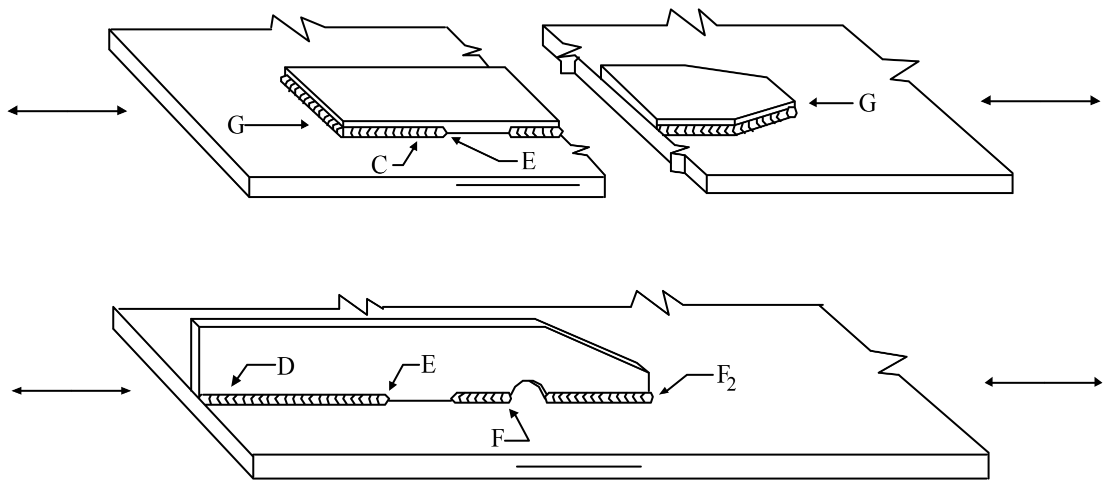


FIGURE 13
Doublers and Non-load Carrying Members on Deck or Shell Plating



13 Stress Concentration Factors Determined From Finite Element Analysis

13.1 Introduction *(1995)*

S-N data and stress concentration factors (SCFs) are related to each other and therefore should be considered together so that there is a consistent basis for the fatigue assessment.

The following guidance is intended to help make correct decisions.

13.3 S-N Data *(1995)*

S-N data are presented as a series of straight-lines plotted on log-log scale. The data reflect the results of numerous tests which often display considerable scatter. The recommended design curves for different types of structural details and welded connections recognize the scatter in test results in that the design curves have been based on the selection of the lower bound, 95% confidence limit. In other words, about 2.5% of the test failure results fall below this curve. Treating the design curve in this manner introduces a high, yet reasonable degree of conservatism in the design and fatigue evaluation processes.

Individual S-N curves are presented to reflect certain generic structural geometries or arrangements. 5C-3-A1/Table 1 and 5C-3-A1/11.3 contain sketches of typically found weld connections and other details in ship structure, giving a list of the S-N classification. This information is needed to assess the fatigue strength of a detail. Also needed is a consistent way to establish the demands or load effects placed on the detail so that a compatible assessment can be made of the available strength versus the demand. Here is where interpretation and judgment enter the fatigue assessment.

S-N curves are obtained from laboratory sample testing. The applied reference stress on the sample which is used to establish the S-N data is referred to as the nominal stress. The nominal stress is established in a simple manner, such as force divided by area and bending moment divided by section modulus (P/A & M/SM). The structural properties used to establish the nominal stress are taken from locations away from any discontinuities to exclude local stress concentration effects arising from the presence of a weld or other local discontinuity. In an actual structure, it is rare that a match will be found between the tested sample geometry and loadings. One is then faced with the problem of making the appropriate interpretation.

13.5 S-N Data and SCFs *(2003)*

Selection of appropriate S-N data are straightforward with respect to “standard details” offered in 5C-3-A1/Table 1 or other similar reference. However, in the case of welded connections in complex structures, it is required that SCFs be used to modify the nominal stress range. An example of the need to modify nominal stress for fatigue assessment purposes is shown in 5C-3-A1/Figure 14 below, relating to a hole drilled in the middle of a flat plate traversed by a butt weld.

In this example, the nominal stress S_N is P/Area, but the stress to be used to assess the fatigue strength at point A is S_A or S_N·SCF. This example is deceptively simple because it does not tell the entire story. The deficiency of the example is that one needs to have a definitive and consistent basis to obtain the SCF. There are reference books which indicate that based on the theory of elasticity, the SCF to be applied in this case is 3.0. However, when the SCF is computed using the finite element analysis techniques, the SCF obtained can be quite variable depending on the mesh size. The example does not indicate which S-N curve should be applied, nor does the example show how the selection of the design S-N data could be affected by the mentioned finite element analysis issues. Therefore, if such interpretation questions exist for a simple example, the higher difficulty of appropriately treating more complex structures should be evident.

Referring to the S-N curves to be applied to welded connections (for example S-N curves D-W in 5C-3-A1/Figure 1), the SCFs resulting from the presence of the weld itself are already accounted for in these curves. If one were to have the correct stress distribution in the region – from the weld to a location sufficiently away from the weld toe (where the stress is suitably established by the nominal stress obtained from *P*/*A* and *M*/*SM* – the stress distribution may be generically separated into three distinct segments as shown in the 5C-3-A1/Figure 15 below.

- Region III is a segment where the stress gradient is controlled by the nominal stress gradient.
- Region II is a segment where the nominal stress gradient is being modified due to the presence of other structure such as the bracket end shown in the figure. This must be accounted for to obtain an appropriate stress to be used in the fatigue analysis at the weld toe.
- Region I is a segment where the stress gradient is being modified due to the presence of the weld metal itself. The stress concentration due to the weld is already accounted for in the S-N design curve and need not be discussed further. Since the typical way to determine the stress distribution is via planar/linear elements which ignore the weld, this is consistent with the method of analysis.

This general description of the stress distribution is again inconclusive because one does not know in advance and with certainty the distances from the weld toe where the indicated changes of slope for the stress gradient occur. For this reason, definite rules need to be established to determine the slopes, then criteria can be established and used to find the stress at the weld toe which is to be used in the fatigue assessment.

In this regard two approaches can be used to find the stress at the weld toe, which reflect two methods of structural idealization. One of these arises from the use of a conventional beam element idealization of the structure including the end bracket connection, and the other arises from the use of a fine mesh finite element idealization.

Using a beam element idealization, the nominal stress at any location (i.e., *P*/*A* and *M*/*SM*) can be obtained. (See 5C-3-4/Figure 4 for a sample beam element model).

In the beam element idealization, there will be questions as to whether or not the geometric stress concentration due to the presence of other structure is adequately accounted for; this is the "Segment II" stress gradient previously described. In the beam modeling approach shown in the figure, the influence on stresses arising from the "carry over" of forces and bending moments from adjacent structural elements has been approximately accounted for. At the same time, the strengthening effect of the brackets has been ignored. Hence, for engineering purposes, this approach is considered to be sufficient in conjunction with the nominal stress obtained at the location of interest and the nominal S-N curve, i.e., the F or F_2 Class S-N data, as appropriate.

In the fine mesh finite element analysis, approach one needs to define the element size to be used. This is an area of uncertainty because the calculated stress distribution can be unduly affected by both the employed mesh size and the uniformity of the mesh adjacent to the weld toe. Therefore, it is necessary to establish "rules" as given below to be followed in the producing of the fine mesh model adjacent to the weld toe. Further, since the area adjacent to the weld toe (or other discontinuity of interest) may be experiencing a large and rapid change of stress (i.e., a high stress gradient), it is also necessary to provide a rule which can be used to establish the stress at the location where the fatigue assessment is to be made.

5C-3-A1/Figure 16 shows an acceptable method which can be used to extract and interpret the "near weld toe" element stresses and to obtain a (linearly) extrapolated stress at the weld toe. When plate or shell elements are used in the modeling, it is recommended that each element size is to be equal to the plate thickness. When stresses are obtained in this manner the use of the E Class S-N data is considered to be acceptable.

Weld hot spot stress can be determined from linear extrapolation of surface component stresses at $t/2$ and $3t/2$ from weld toe. The principal stresses at hot spot are then calculated based on the extrapolated stresses and used for fatigue evaluation. Description of the numerical procedure is given in 5C-3-A1/13.7 below.

FIGURE 14
(1995)

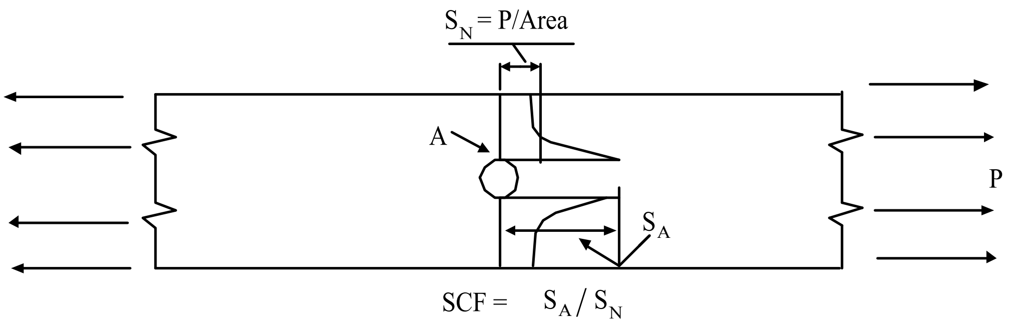


FIGURE 15
(1995)

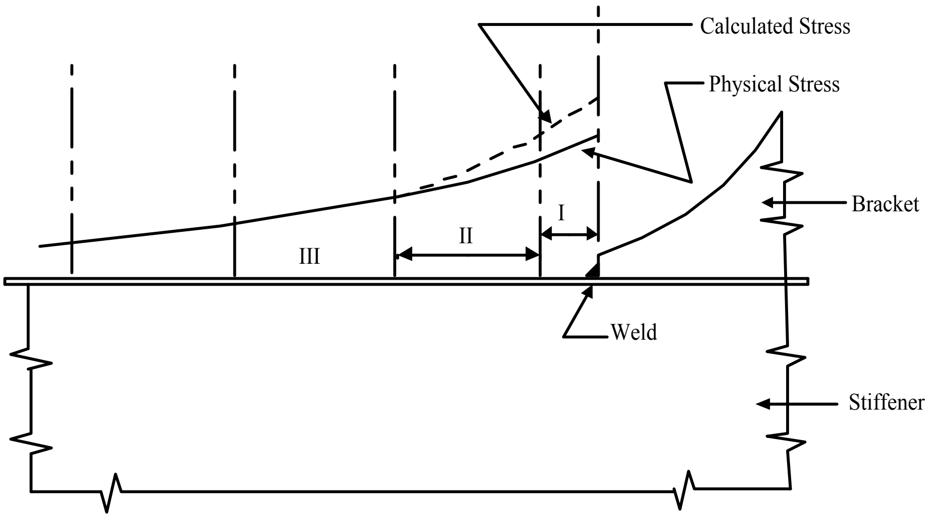
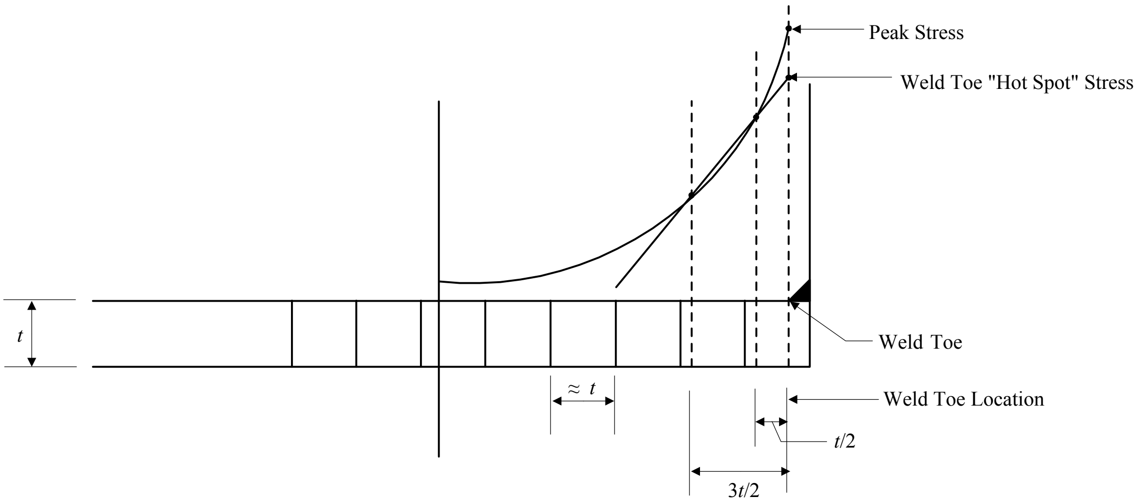


FIGURE 16
(2003)



13.7 Calculation of Hot Spot Stress for Fatigue Analysis of Ship Structures *(2003)*

The algorithm described in the following is applicable in order to obtain the hot spot stress for the point at the toe of a weld. The weld typically connects either a flat bar member or a bracket to the flange of a longitudinal stiffener as shown in 5C-3-A1/Figure 17.

Consider the four points, P_1 to P_4, measured by the distances X_1 to X_4 from the weld toe, designated as the origin of the coordinate system. These points are the centroids of four neighboring finite elements, the first of which is adjacent to the weld toe. Assuming that the applicable surface component stresses, S_i, at P_i have been determined from FEM analysis, the corresponding stresses at "hot spot", i.e., the stress at the weld toe, can be determined by the following procedure:

13.7.1

Select two points, L and R, such that points L and R are situated at distances $t/2$ and $3t/2$ from the weld toe; i.e.,

$$X_L = t/2, \qquad X_R = 3t/2$$

where t denotes the thickness of the member to which elements 1 to 4 belong (e.g., the flange of a longitudinal stiffener).

13.7.2

Let $X = X_L$ and compute the values of four coefficients as follows:

$$C_1 = [(X - X_2)(X - X_3)(X - X_4)] / [(X_1 - X_2)(X_1 - X_3)(X_1 - X_4)]$$

$$C_2 = [(X - X_1)(X - X_3)(X - X_4)] / [(X_2 - X_1)(X_2 - X_3)(X_2 - X_4)]$$

$$C_3 = [(X - X_1)(X - X_2)(X - X_4)] / [(X_3 - X_1)(X_3 - X_2)(X_3 - X_4)]$$

$$C_4 = [(X - X_1)(X - X_2)(X - X_3)] / [(X_4 - X_1)(X_4 - X_2)(X_4 - X_3)]$$

The corresponding stress at Point L can be obtained by interpolation as:

$$S_L = C_1S_1 + C_2S_2 + C_3S_3 + C_4S_4$$

13.7.3

Let $X = X_R$ and repeat Step in 5C-3-A1/13.7.2 to determine four new coefficients, the stress at Point R can be interpolated likewise, i.e.,

$$S_R = C_1S_1 + C_2S_2 + C_3S_3 + C_4S_4$$

13.7.4 *(2003)*

The corresponding stress at hot spot, S_0, is given by

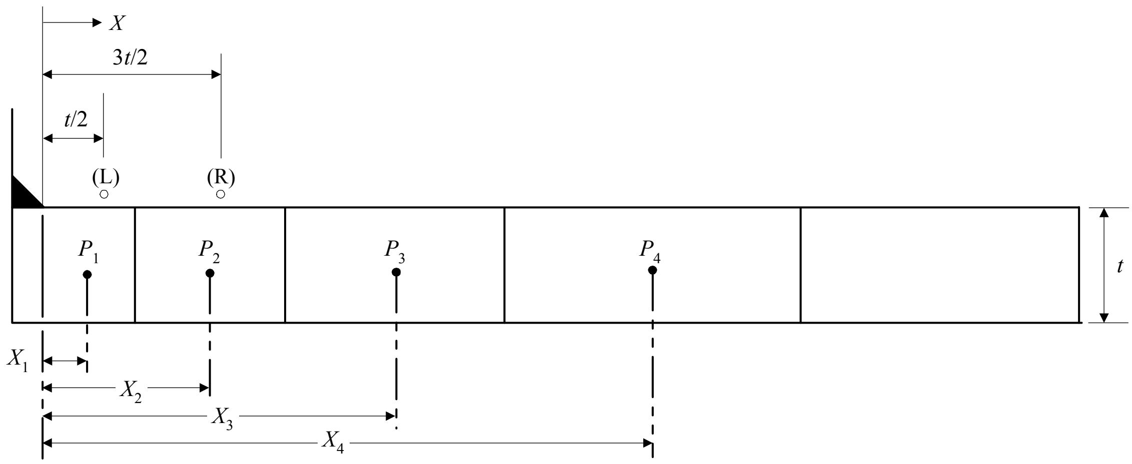
$$S_0 = (3S_L - S_R)/2$$

Footnotes:

The algorithm presented in the foregoing involves two types of operations. The first is to utilize the stress values at the centroid of the four elements considered to obtain estimates of stress at Points L and R by way of an interpolation algorithm known as Lagrange interpolation. The second operation is to make use of the stress estimates S_L and S_R to obtain the hot spot stress via linear extrapolation.

While the Lagrange interpolation is applicable to any order of polynomial, it is not advisable to go beyond the 3rd order (cubic). Also, the even order polynomials are biased; so that leaves the choice between a linear scheme and a cubic scheme. Therefore, the cubic interpolation as described in 5C-3-A1/13.7.2 should be used. It can be observed that the coefficients, C_1 to C_4 are all cubic polynomials. It is also evident that, when $X = X_j$ which is not equal to X_i all the C's vanish except C_i; and if $X = X_i$, $C_i = 1$.

FIGURE 17
(1995)



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PART

5C

CHAPTER 3 **Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)**

APPENDIX 2 **Calculation of Critical Buckling Stresses**

1 General

The critical buckling stresses for various structural elements and members may be determined in accordance with this Appendix or other recognized design practices. Critical buckling stresses derived from experimental data or analytical studies may be considered, provided well documented supporting data are submitted for review.

3 Rectangular Plates *(1995)*

The critical buckling stresses for rectangular plate elements, such as plate panels between stiffeners; web plates of longitudinals, girders, floors and transverses; flanges and face plates, may be obtained from the following equations with respect to uniaxial compression, bending and edge shear, respectively.

$$f_{ci} = f_{Ei} \qquad \text{for } f_{Ei} \leq P_r f_{yi}$$

$$f_{ci} = f_{yi}[1 - P_r(1 - P_r) f_{yi}/f_{Ei}] \qquad \text{for } f_{Ei} > P_r f_{yi}$$

where

f_{ci} = critical buckling stress with respect to uniaxial compression, bending or edge shear, separately, N/cm^2 (kgf/cm^2, lbf/in^2)

f_{Ei} = $K_i[\pi^2 E/12(1 - \nu^2)](t_n/s)^2$, N/cm^2 (kgf/cm^2, lbf/in^2)

K_i = buckling coefficient as given in 5C-3-A2/Table 1

E = modulus of elasticity of the material, may be taken as 2.06×10^7 N/cm^2 (2.1×10^6 kgf/cm^2, 30×10^6 lbf/in^2) for steel

ν = Poisson's ratio, may be taken as 0.3 for steel

t_n = net thickness of the plate, in cm (in.)

s = spacing of longitudinals/stiffeners, in cm (in.)

P_r = proportional linear elastic limit of the structure, may be taken as 0.6 for steel

f_{yi} = f_y, for uniaxial compression and bending

= $f_y/\sqrt{3}$, for edge shear

f_y = specified minimum yield point of the material, in N/cm^2 (kgf/cm^2, lbf/in^2)

TABLE 1
Buckling Coefficient, K_i *(1995)*

For Critical Buckling Stress Corresponding to f_L, f_T, f_b or f_{LT}

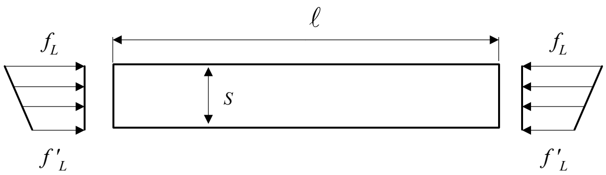
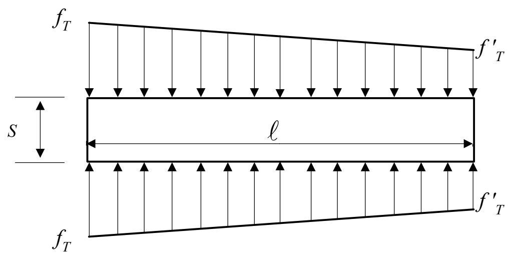
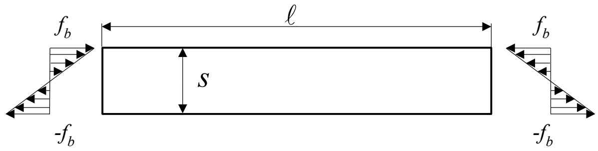
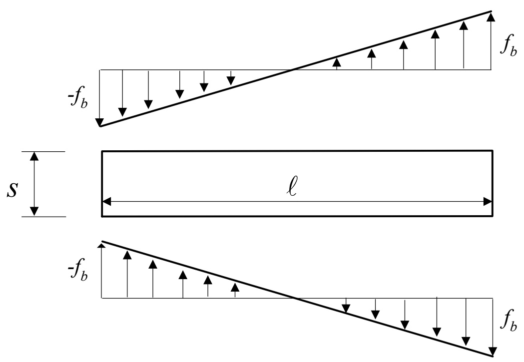
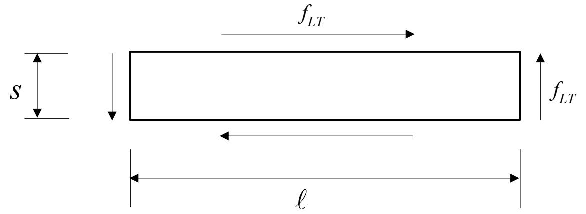
I. Plate panel between stiffeners			K_i
A Uniaxial compression 1. Long plate $\ell \geq s$		a. For f'_L, $= f_L$: b. For f'_L, $= f_L/3$: (see note)	$4C_1$, $5.8C_1$,
2. Wide plate $\ell \geq s$		a. For f'_T, $= f_T$: b. For f'_T, $= f_T/3$: (see note)	$[1 + (s/\ell)^2]^2C_2$ $1.45[1 + (s/\ell)^2]^2C_2$
B Ideal Bending 1. Long plate $\ell \geq s$			$24C_1$
2. Wide plate $\ell \geq s$		a. For $1.0 \leq \ell/s \leq 2.0$: b. For $2.0 < \ell/s$:	$24\ (s/\ell)^2C_2$ $12\ (s/\ell)C_2$

TABLE 1 (continued)
Buckling Coefficient, K_i *(1995)*

C Edge Shear — K_i



K_i = $[5.34 + 4\,(s/\ell)^2]C_1$

D Values of C_1 and C_2

1. For plate panels between angles or tee stiffeners

C_1 = 1.1

C_2 = 1.3 within the double bottom or double side*

C_2 = 1.2 elsewhere

2. For plate panels between flat bars or bulb plates

C_1 = 1.0

C_2 = 1.2 within the double bottom or double side*

C_2 = 1.1 elsewhere

* applicable where shorter edges of a panel are supported by rigid structural members, such as bottom, inner bottom, side shell, inner skin bulkhead, double bottom floor/girder and double side web stringer.

II. Web of Longitudinal or Stiffener — K_i

A Axial compression

Same as I.A.1 by replacing s with depth of the web and ℓ with unsupported span

a. For $f'_L = f_L$: — $4C$

b. For $f'_L = f_L/2$: — $5.2C$

(see note)

where

C = 1.0 for angle or tee stiffeners

C = 0.33 for bulb plates

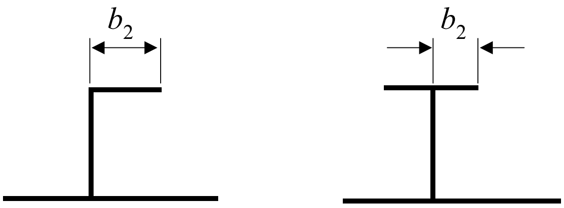
C = 0.11 for flat bars

B Ideal Bending

Same as I.B.1 by replacing s with depth of the web and ℓ with unsupported span — $24C$

TABLE 1 (continued)
Buckling Coefficient, K_i *(1995)*

III. Flange and Face Plate	K_i
Axial Compression	0.44



$s = b_2$

ℓ = unsupported span

Note:

In I.A. (II.A), K_i for intermediate values of f'_L/f_L (f'_T/f_T) may be obtained by interpolation between a and b.

5 Longitudinals, Stiffeners, Hold Frames and Unit Corrugation for Transverse Bulkhead

5.1 Axial Compression *(2002)*

The critical buckling stress, f_{ca}, of a beam-column, i.e., the longitudinal and the associated effective plating, with respect to axial compression may be obtained from the following equations:

$$F_{ca} = f_E \qquad \text{for } f_E \le P_r f_y$$

$$f_{ca} = f_y[1 - P_r(1 - P_r)f_y/f_E], \qquad \text{for } f_E > P_r f_y$$

where

f_E = $\pi^2 E/(\ell/r)^2$, N/cm^2 (kgf/cm^2, lbf/in^2)

ℓ = unsupported span of the longitudinal or stiffener, in cm (in.), as defined in 5C-3-4/Figure 3

r = radius of gyration of area A_e, in cm (in.)

A_e = $A_s + b_{wL}t_n$

A_s = net sectional area of the longitudinals or stiffeners excluding the associated plating, cm^2 (in^2)

b_{wL} = effective width of the plating, as given in 5C-3-5/5.3.2, in cm (in.)

t_n = net thickness of the plating, in cm (in.)

f_y = minimum specified yield point of the longitudinal or stiffener under consideration, N/cm^2 (kgf/cm^2, lbf/in^2)

P_r and E are as defined in 5C-3-A2/3.

5.3 Torsional/Flexural Buckling *(2002)*

The critical torsional/flexural buckling stress with respect to axial compression of a longitudinal, including its associated plating (effective width, b_{wL}) may be obtained from the following equations:

$f_{ct} = f_{ET}$ for $f_{ET} \leq P_r f_y$

$f_{ct} = f_y[1 - P_r(1 - P_r)f_y/f_{ET}]$ for $f_{ET} \geq P_r f_y$

where

f_{ct} = critical torsional/flexural buckling stress with respect to axial compression, N/cm^2 (kgf/cm^2, lbf/in^2)

f_{ET} = $E[K/2.6 + (n\pi/\ell)^2\Gamma + C_o(\ell/n\pi)^2/E]/I_o[1 + C_o(\ell/n\pi)^2/I_o f_{cL}]$, N/cm^2 (kgf/cm^2, lbf/in^2)

K = St. Venant torsion constant for the longitudinal's cross section, excluding the associated plating.

= $1/3[b_f t_f^3 + d_w t_w^3]$

I_o = polar moment of inertia of the longitudinal, excluding the associated plating, about the toe (intersection of web and plating), in cm^4 (in^4)

= $I_x + mI_y + A_s(x_o^2 + y_o^2)$

I_x, I_y = moment of inertia of the longitudinal about the x-and y-axis, respectively, through the centroid of the longitudinal, excluding the plating (x-axis perpendicular to the web), in cm^4 (in^4)

m = $1.0 - u(0.7 - 0.1\, d_w/b_f)$

u = unsymmetry factor

= $1 - 2b_1/b_f$

x_o = horizontal distance between centroid of stiffener A_s and centerline of the web plate, cm (in.)

y_o = vertical distance between the centroid of the longitudinal's cross section and its toe, cm (in.)

d_w = depth of the web, cm (in.)

t_w = net thickness of the web, cm (in.)

b_f = total width of the flange/face plate, cm (in.)

b_1 = smaller outstanding dimension of flange with respect to centerline of web (see 5C-3-A2/Figure 1), cm (in.)

t_f = net thickness of the flange/face plate, cm (in.)

C_o = $E t_n^3/3s$

Γ = warping constant

$\cong$ $mI_{yf} d_w^2 + d_w^3 t_w^3/36$

I_{yf} = $t_f b_f^3 (1.0 + 3.0u^2 d_w t_w/b_f t_f)/12$, cm^4 (in^4)

f_{cL} = critical buckling stress for the associated plating corresponding to n half-waves, N/cm^2 (kgf/cm^2, lbf/in^2)

= $\pi^2 E(n/\alpha + \alpha/n)^2(t_n/s)^2/12(1 - \nu^2)$

α = ℓ/s

n = number of half-wave which yield a smallest f_{ET}

= 1 for fixed end beam

f_y = minimum specified yield point of the longitudinal or stiffener under consideration, N/cm^2 (kgf/cm^2, lbf/in^2)

P_r, E, s and ν are as defined in 5C-3-A2/3.

A_s, t_n and ℓ are as defined in 5C-3-A2/5.1.

5.5 Buckling Criteria for Unit Corrugation of Transverse Bulkhead

The critical buckling stress, which is also the ultimate bending stress, f_{cb}, for a unit corrugation may be determined from the following equation (See 5C-3-5/5.11.2):

$f_{cb} = f_{Ec}$ for $f_{Ec} \leq P_r f_y$

$f_{cb} = [1 - P_r(1 - P_r)f_y/f_{Ec}]f_y$ for $f_{Ec} > P_r f_y$

where

f_{Ec} = $k_c E(t/a)^2$

k_c = $0.091\ [7.65 - 0.26(c/a)^2]^2$

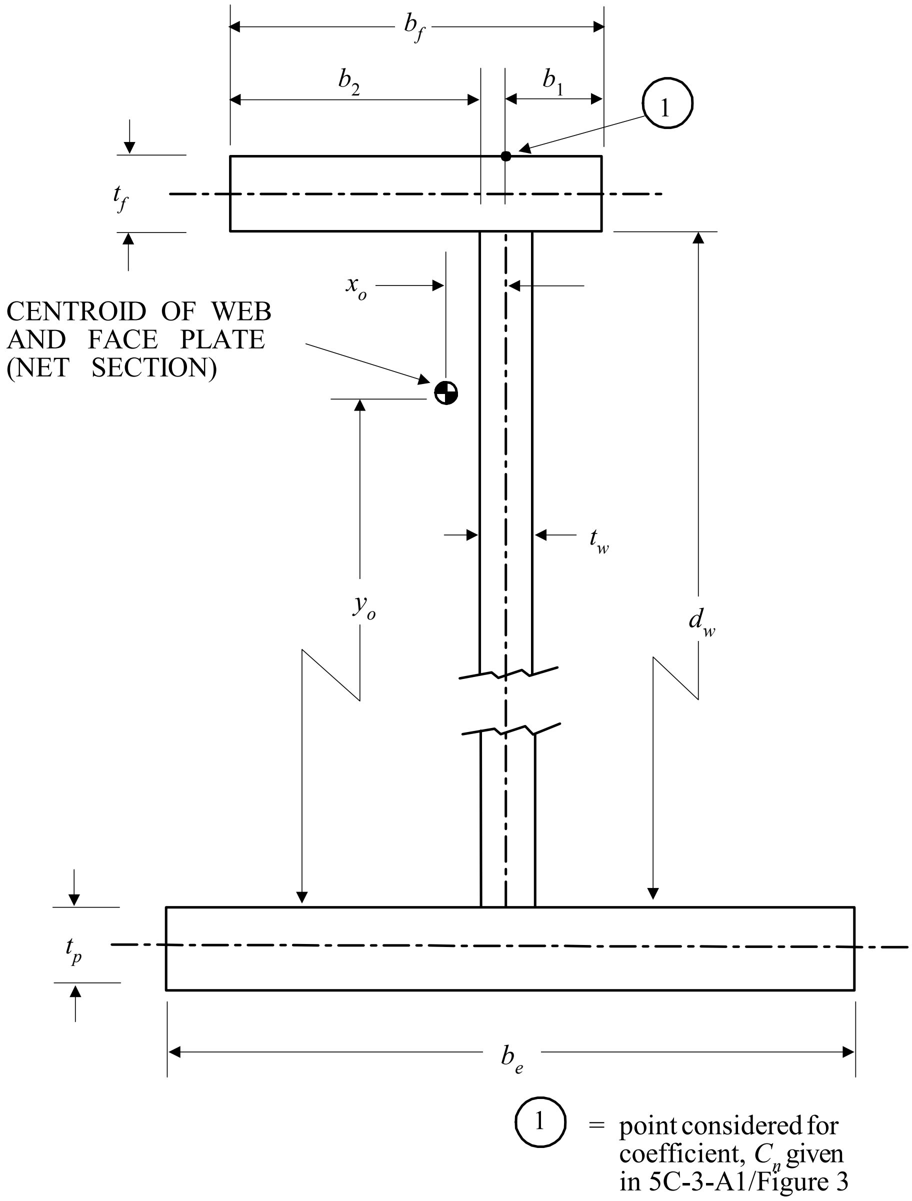
c and a are widths of the web and flange panels, respectively, in cm^2 (in^2)

t = net thickness of the flange panel, in cm (in.)

P_r, f_y and E are as defined in 5C-3-A2/3.

The maximum vertical bending moment, M, may be determined in accordance with 5C-3-4/25 at the lower end of the corrugation.

FIGURE 1
Net Dimensions and Properties of Stiffeners *(1995)*



7 Stiffened Panels *(1996)*

7.1 Large Stiffened Panels

For large stiffened panels between bulkheads or panels stiffened in one direction between transverses and girders, the critical buckling stresses with respect to uniaxial compression may be determined from the following equations:

$$f_{ci} = f_{Ei} \qquad \text{for } f_{Ei} \le P_r f_y$$

$$f_{ci} = f_y[1 - P_r(1 - P_r) f_y / f_{Ei}] \qquad \text{for } f_{Ei} > P_r f_y$$

where

f_{Ei} = $k_L \pi^2 (D_L D_T)^{1/2}/t_L b^2$ in the longitudinal direction, N/cm^2 (kgf/cm^2, lbf/in^2)

f_{Ei} = $k_T \pi^2 (D_L D_T)^{1/2}/t_T \ell^2$ in the transverse direction, N/ cm^2 (kgf/cm^2, lbf/in^2)

k_L = 4 for $\ell/b \geq 1$

= $[1/\phi_L^2 + 2\eta + \phi_L^2]$ for $\ell/b < 1$

k_T = 4 for $b/\ell > 1$

= $[1/\phi_T^2 + 2\eta + \phi_T^2]$ for $b/\ell < 1$

D_L = $EI_L/s_L(1 - \nu^2)$

D_L = $E t_n^3/12(1 - \nu^2)$ if no stiffener in the longitudinal direction

D_T = $EI_T/s_T(1 - \nu^2)$

D_T = $E t_n^3/12(1 - \nu^2)$ if no stiffener in the transverse direction

ℓ, b = length and width between transverse and longitudinal bulkheads, respectively, cm (in.) (See 5C-3-A2/Figure 2.)

t_L, t_T = net equivalent thickness of the plating and stiffener in the longitudinal and transverse direction, respectively, cm (in.)

= $(s_L t_n + A_{sL})/s_L$ or $(s_T t_n + A_{sT})/s_T$

s_L, s_T = spacing of longitudinals and transverses, respectively, cm (in.) (See 5C-3-A2/Figure 2.)

ϕ_L = $(\ell/b)(D_T/D_L)^{1/4}$

ϕ_T = $(b/\ell)(D_L/D_T)^{1/4}$

η = $[(I_{pL} I_{pT})/(I_L I_T)]^{1/2}$

A_{sL}, A_{sT} = net sectional area of the longitudinal and transverse, excluding the associated plating, respectively, cm^2 (in^2)

I_{pL}, I_{pT} = net moment of inertia of the effective plating (effective breadth due to shear lag) alone about the neutral axis of the combined cross section, including stiffener and plating, cm^4 (in^4)

I_L, I_T = net moment of inertia of the stiffener (one) with effective plating in the longitudinal or transverse direction, respectively, cm^4 (in^4). If no stiffener, the moment of inertia is calculated for the plating only.

f_y, P_r, E and ν are as defined in 5C-3-A2/3. t_n is as defined in 5C-3-A2/5.1.

Except for deck panels, when the lateral load parameter, q_o, defined below is greater than 5, reduction of the critical buckling stresses given above is to be considered.

$$q_o = p_n b^4/(\pi^4 t_T D_T)$$

$$q_o = p_n \ell^4/(\pi^4 t_L D_L)$$

where

p_n = average net lateral pressure N/cm^2 (kgf/cm^2, lbf/in^2)

D_T, b, ℓ, t_T and s_T are as defined above.

In this regard, the critical buckling stress may be approximated by:

$f'_{ci} = R_o f_{ci}$ N/cm^2 (kgf/cm^2, lbf/in^2)

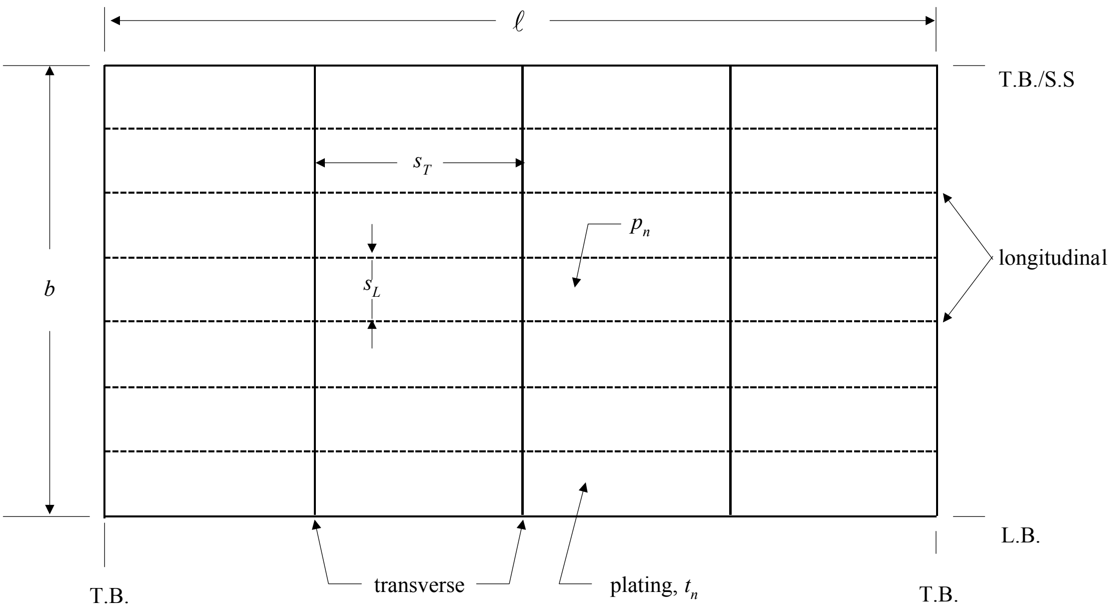
where

R_o = $1 - 0.045(q_o - 5)$ for $q_o \geq 5$

R_o is not to be taken less than 0.5.

For deck panels, $R_o = 1.0$ and $f'_{ci} = f_{ci}$

FIGURE 2



7.3 Corrugated Transverse Bulkheads

For corrugated transverse bulkheads, the critical buckling stresses with respect to uniaxial compression may be calculated from the equations given in 5C-3-A2/7.1 above by replacing the subscripts "*L*" and "*T*" with "*V*" and "*H*" for the vertical and horizontal directions, respectively, and with the following modifications. The rigidities D_V and D_H are defined as follows:

$D_V = EI_v/s$

$D_H = [s/(a+c)][Et^3/12(1 - \nu^2)]$

where

I_v = moment of inertia of a unit corrugation with spacing s, $s = a + c \cos \phi$

= $t/4[c \sin \phi]^2 (a + c/4 + c \sin \phi/12)$, in cm^4 (in^4)

a, c = widths of the flange and web panels, respectively, in cm (in.)

t = net thickness of the corrugations, in cm (in.)

E and ν are as defined in 5C-3-A2/3.

ℓ = length of the corrugation, in cm (in.)

s_v, s_H = s

η, I_{pH}, A_{sH} = 0

A_{sV} = $t\, c \sin \phi$

ϕ is as defined in 5C-3-4/Figure 11.

9 Deep Girders, Webs and Stiffened Brackets

9.1 Critical Buckling Stresses of Web Plates and Large Brackets *(1995)*

The critical buckling stresses of web plates and large brackets between stiffeners may be obtained from the equations given in 5C-3-A2/3 for uniaxial compression, bending and edge shear.

9.3 Effects of Cut-outs *(1995)*

The depth of cut-out, in general, is to be not greater than $d_w/3$ and the stresses in the area calculated are to account for the local increase due to the cut-out.

When cut-outs are present in the web plate, the effects of the cut-outs on reduction of the critical buckling stresses is to be considered, as outlined below:

9.3.1 Reinforced by Stiffeners Around Boundaries of Cut-outs

When reinforcement is made by installing straight stiffeners along boundaries of the cut-outs, the critical buckling stresses of web plate between stiffeners with respect to compression and shear may be obtained from equations given in 5C-3-A2/3

9.3.2 Reinforced by Face Plates Around Contour of Cut-outs

When reinforcement is made by adding face plates along contour of the cut-out, the critical buckling stresses with respect to compression, bending and shear may be obtained from equations given in 5C-3-A2/3, without reduction, provided that the net sectional area of the face plate is not less than $8\,t_w^2$, where t_w is the net thickness of the web plate and that depth of cut-out is not greater than $d_w/3$, where d_w is the depth of the web.

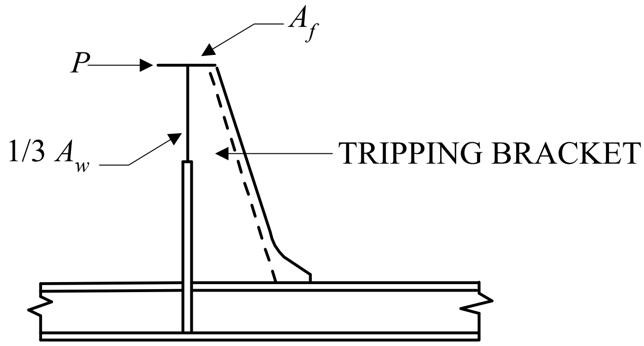
9.9.3 No Reinforcement Provided

When reinforcement is not provided, the buckling strength of the web plate surrounding the cut-out may be treated as a strip of plate with one edge free and the other edge simply supported.

9.5 Tripping *(1995)*

To prevent tripping of deep girders and webs with wide flanges, tripping brackets are to be installed with a spacing generally not greater than 3 meters (9.84 ft). Design of tripping brackets may be based on the force P acting on the flange, as given by the following equation:

$$P = 0.02 f_{c\ell}\left(A_f + \frac{1}{3}A_w\right)$$



where

$f_{c\ell}$	=	critical lateral buckling stress with respect to axial compression between tripping brackets, N/cm² (kgf/cm², lbf/in²)	
$f_{c\ell}$	=	f_{ce},	for $f_{ce} \le P_r f_y$
	=	$f_y[1 - P_r(1 - P_r) f_y/f_{ce}]$,	for $f_{ce} > P_r f_y$
f_{ce}	=	$0.6E[(b_f/t_f)(t_w/d_w)^3]$,	N/cm² (kgf/cm², lbf/in²)
A_f	=	net cross sectional area of the flange/face plate, in cm² (in²)	
A_w	=	net cross sectional area of the web, in cm² (in²)	

b_f, t_f, d_w, t_w are as defined in 5C-3-A2/5.3.

E, P_r and f_y are as defined in 5C-3-A2/3.

11 Stiffness and Proportions

To fully develop the intended buckling strength of the assemblies of structural members and panels, supporting elements of plate panels and longitudinals are to satisfy the following requirements for stiffness and proportion in highly stressed regions.

11.1 Stiffness of Longitudinals *(1995)*

The net moment of inertia of the longitudinals, i_o, with effective breadth of net plating is to be not less than that given by the following equation:

$$i_o = \frac{st_n^3}{12(1-\nu^2)}\ \gamma_o \qquad \text{cm}^4\ (\text{in}^4)$$

where

γ_o	=	$(2.6 + 4.0\delta)\alpha^2 + 12.4\alpha - 13.2\alpha^{1/2}$
δ	=	A/st_n
α	=	ℓ/s
s	=	spacing of longitudinals, cm (in.)
t_n	=	net thickness of plating supported by the longitudinal, cm (in.)

ν = Poisson's ratio

= 0.3 for steel

A = net sectional area of the longitudinal (excluding plating), cm^2 (in^2)

ℓ = unsupported span of the longitudinal, cm (in.)

11.3 Stiffness of Web Stiffeners *(1995)*

The net moment of inertia i of the web stiffener, with the effective breadth of net plating, not exceeding s or 0.33ℓ, whichever is less, is not to be less than obtained from the following equations:

$i = 0.17\ell t^3(\ell/s)^3$ cm^4 (in^4), for $\ell/s \le 2.0$

$i = 0.34\ell t^3(\ell/s)^2$ cm^4 (in^4), for $\ell/s > 2.0$

where

ℓ = length of stiffener between effective supports, in cm (in.)

t = required net thickness of web plating, in cm (in.)

s = spacing of stiffeners, in cm (in.)

11.5 Stiffness of Supporting Members *(1995)*

The net moment of inertia of the supporting members such as transverses and webs is not to be less than that obtained from the following equation:

$$I_s/i_o \ge 0.2(B_s/\ell)^3(B_s/s)$$

where

I_s = moment of inertia of the supporting member, including the effective plating, cm^4 (in^4)

i_o = moment of inertia of the longitudinals, including the effective plating, cm^4 (in^4)

B_s = unsupported span of the supporting member, cm (in.)

ℓ and s are as defined in 5C-3-A2/11.1.

11.7 Proportions of Flanges and Face Plates *(1995)*

The breadth-thickness ratio of flanges and face plates of longitudinals and girders is to satisfy the limits given below.

$$b_2/t_f = 0.4(E/f_y)^{1/2}$$

where

b_2 = larger outstanding dimension of flange, as given in 5C-3-A2/Figure 1, cm (in.)

t_f = net thickness of flange/face plate, cm (in.)

E and f_y are as defined in 5C-3-A2/3.

11.9 Webs of Longitudinals and Stiffeners

Depth-thickness ratio of webs of longitudinals and stiffeners is to satisfy the limits given below:

$d_w/t_w \leq 1.5(E/f_y)^{1/2}$ for angles and tee bars

$d_w/t_w \leq 0.85(E/f_y)^{1/2}$ for bulb plates

$d_w/t_w \leq 0.5(E/f_y)^{1/2}$ for flat bars

where d_w and t_w are as defined in 5C-3-A2/5.3 and E and f_y are as defined in 5C-3-A2/3

When these limits are complied with, the assumption on buckling control stated in 5C-3-5/5.1.2(e) is considered satisfied. If not, the buckling strength of the web is to be further investigated as per 5C-3-A2/3 of this Appendix.

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PART

5C

CHAPTER 3 **Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)**

APPENDIX 3 **The Design and Evaluation of Ore and Ore/Oil Carriers**

1 General

This Appendix is intended to provide guidance for the design and evaluation of ore and ore/oil carriers, ranging in length from 150 to 350 meters, fitted with two complete longitudinal bulkheads which divide the cross section into three holds of approximately equal breadth. The vessels may have a complete or partial double bottom with a single bottom in the wing spaces and the double bottom space may be designated for ballast, fuel oil or as voids. The ore cargo is to be carried only in the center holds with the wing spaces used for ballast or cargo oil. The center holds may also be used for cargo or ballast. The vessels are assumed to have large openings in the decks for hatchways.

The design criteria specified in Part 5C, Chapter 3 are generally applicable to this type of vessel with modifications and additions as given in this appendix. The strength criteria as specified in Part 5C, Chapter 1, and Part 5C, Chapter 2 may be applied to the same type of vessel for carriage of oil cargoes.

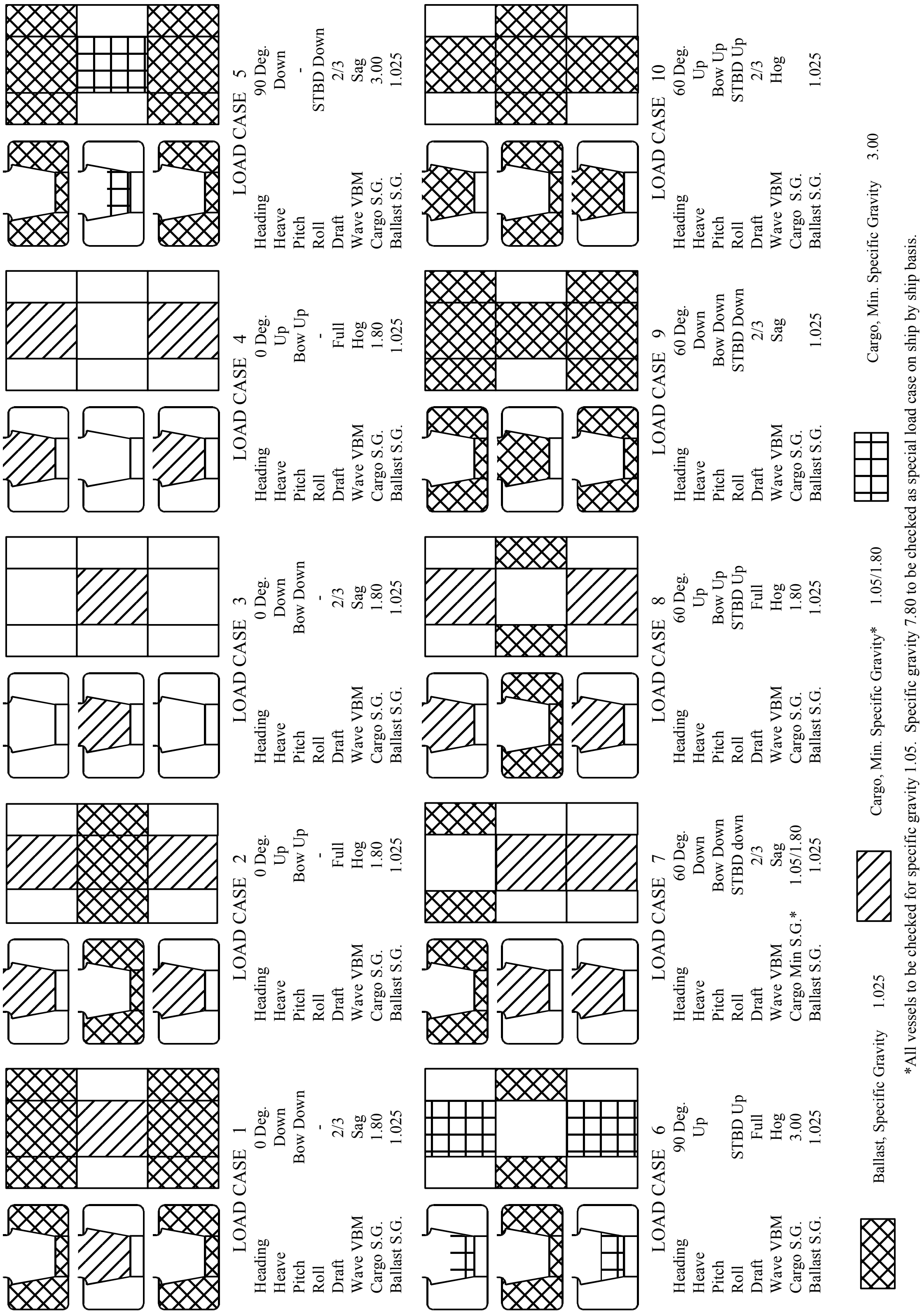
3 Nominal Design Corrosion Values

The nominal design corrosion values for an ore carrier may be taken the same as for a single hull tanker in the wing tanks and as for a bulk carrier in the center hold. In ore/oil carriers where the wing spaces alternate between ballast and cargo usage, the corrosion values for longitudinal scantlings are to be those specified for ballast spaces while the nominal design corrosion values for transverse members may correspond to the actual usage of the tank. Where two corrosion values are specified for one structural item, as is the case for the longitudinal bulkheads, the larger value is to be adopted. The nominal design corrosion value for double bottom voids may be 1.00 mm for transverse members.

5 Loading Patterns

Ten loading patterns given in 5C-3-A3/Figure 1 are to be used for determining local loads and calculating structural responses for design and evaluation. These are applicable in conjunction with the ten combined load cases specified in 5C-3-3/Table 1.

FIGURE 1
Loading Pattern of Ore/Oil Carrier



7 Strength Criteria

In general, initial scantlings for wing tank plating, stiffeners and main supporting structures may be determined based on the requirements specified in Part 5C, Chapter 1 and Part 5C, Chapter 2. In way of the center ore holds, the applicable portions of Section 5C-3-4 may be used. Certain structural members, which may be alternately subject to dry and liquid cargo loading, such as the inner bottom and longitudinal and transverse bulkheads, are to be checked against both the Tanker and Bulk Carrier Rules to determine the proper initial scantling.

Alternatively, the distribution of bending and shear in the main supporting structure for the determination of initial scantlings may be obtained from a structural analysis with the loads specified in 5C-3-A3/5 above.

The required thickness of the longitudinal bulkheads for hull girder shear is to be determined in accordance with 5C-1-4/5 with the distribution factors D_s and D_i determined by direct calculation or by Appendix 5C-2-A1.

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PART

5C

CHAPTER 3 **Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)**

APPENDIX 4 **Load Cases for Structural Analysis with Respect to Slamming**

1 Bowflare Slamming

1.1 Load Case – A

First cargo hold filled; second cargo hold empty; ballast tanks in both holds and fore peak ballast tank empty (see 5C-3-A4/Figure 1).

1.3 Load Case – B

First cargo hold and ballast tanks in both holds empty; second cargo hold filled; fore peak ballast tank filled (see 5C-3-A4/Figure 1).

1.5 Hull Girder Loads

Additional inertial load may be applied in conjunction with other local loads to yield the specified total hull girder vertical shear force (VSF) at the aft transverse bulkhead of the first cargo hold of the fore-end structural model.

Static VSF* $k_c = \pm 0.5$

Dynamic VSF $k_c = \pm 1.0$

* Maximum allowable still water VSF at aft transverse bulkhead section.

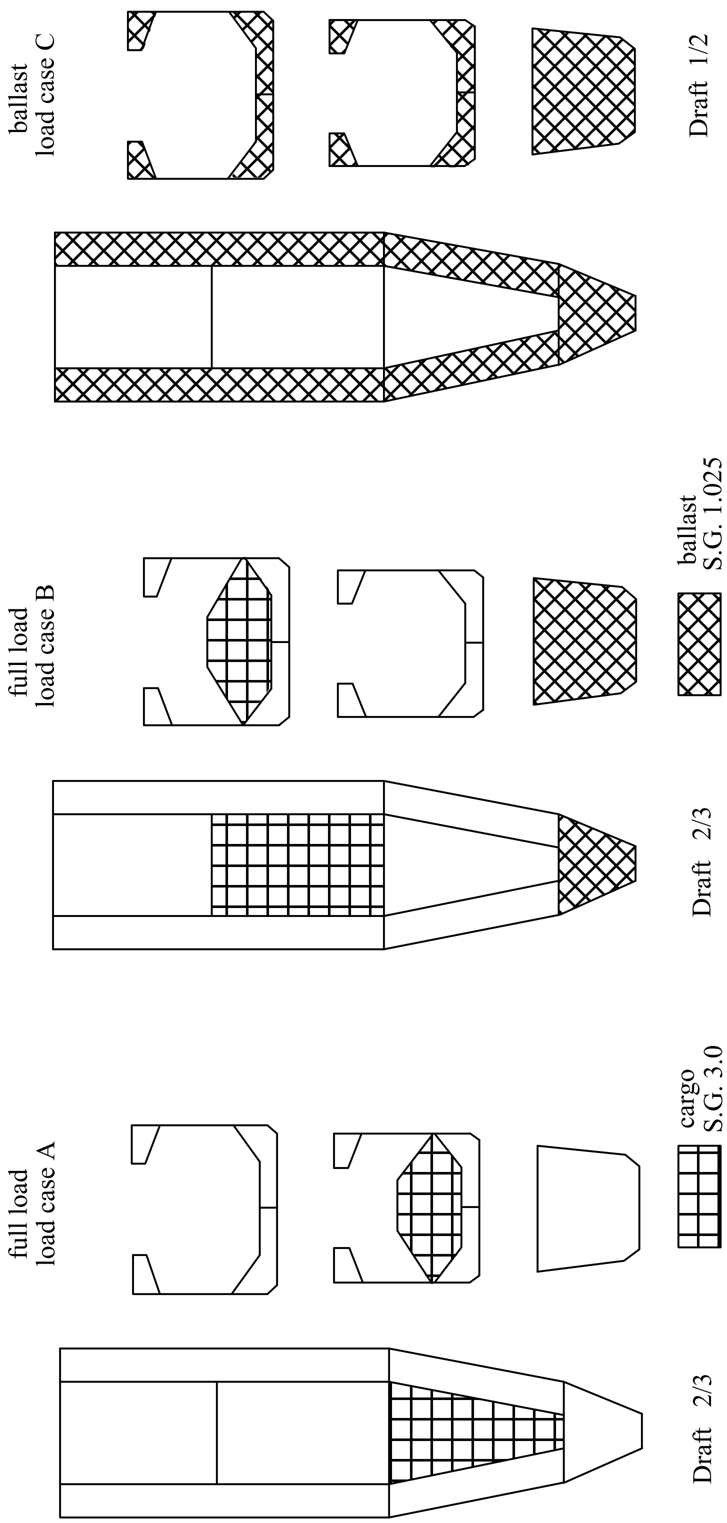
1.7 External Pressures

(including P_{ij} as specified in 5C-3-3/11.3.1 and 5C-3-3/11.3.2, and 5C-3-3/5.5.4(a) for load case A, and 5C-3-3/11.3.1 and 5C-3-3/11.3.2, for load case B).

K_c = +1.0

K_{fo} = –1.0 sagging wave

FIGURE 1
Loading Patterns for Slamming Study



1.9 Internal Bulk and Ballast Pressures

K_c = + 0.5 for bulk and ballast

W_v = + 0.6

W_ℓ = Forward bulkhead + 0.6, Aft bulkhead –0.6

Pitch = –0.5

Roll = 0.0

1.11 Reference Wave Heading and Position

Heading Angle = 0 (head wave)

Heave = Down

Pitch = Bow down

Roll = 0

3 Bottom Slamming

3.1 Load Case – C

First cargo hold empty; second cargo hold empty; ballast tanks in both holds filled; fore peak ballast tank filled (see 5C-3-A4/Figure 1).

3.3 Hull Girder Loads

Additional inertial load may be applied in conjunction with other local loads to yield the specified total hull girder vertical bending moment (VBM) at the aft transverse bulkhead of the first cargo hold of the fore-end structural model.

Static VBM* k_c = +0.5

Dynamic VBM k_c = +0.3

* Maximum allowable still water VBM at aft transverse bulkhead section.

3.5 External Pressures

(including P_{si} as specified in 5C-3-3/11.1.1 and 5C-3-3/11.1.3).

K_c = +1.0

k_{fo} = +1.0 hogging wave

3.7 Internal Ballast Pressures (no bulk pressure)

K_c = +1.0 for ballast

W_v = –0.4

W_ℓ = Forward bulkhead –0.2, Aft bulkhead +0.2

Pitch = +0.5

Roll = 0.0

3.9 Reference Wave Heading and Position

Heading angle	=	0 (head wave)
Heave	=	Up
Pitch	=	Bow up
Roll	=	0

PART

5C

CHAPTER 3 **Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)**

APPENDIX 5a **Longitudinal Strength of Bulk Carriers in Flooded Condition**
(1 July 2003)

1 General

1.1 Application *(1 July 2006)*

This Appendix is to be complied with in respect to the flooding of any floodable cargo hold (see 5C-3-A5a/3.1) of bulk carriers with the notation **BC-A** or **BC-B**, as defined in Appendix 5C-3-A6, that are constructed on or after 1 July 2006.

1.3 Loading Conditions

Such vessels are to have their hull girder strength checked for specified flooded conditions, in each of the cargo and ballast loading conditions defined in 3-2-1/3.3 and in every other condition considered in the intact longitudinal strength calculations, including those in 3-2-A3/Table 1 and 3-2-A3/Table 2, except that harbor conditions, docking condition afloat, loading and unloading transitory conditions in port and loading conditions encountered during ballast water exchange need not be considered.

3 Flooding Conditions

3.1 Floodable Holds *(1 July 2006)*

Each cargo hold is to be considered individually flooded up to the equilibrium waterline.

3.3 Loads

The still water loads in the flooded condition are to be calculated for the above cargo and ballast loading conditions.

The wave loads in the flooded condition are assumed to be equal to 80% of those given in 3-2-1/3.5.

3.5 Flooding Criteria

To calculate the weight of flooded water, the following assumptions are to be made:

i) The permeability of empty cargo spaces and volume left in loaded cargo spaces above any cargo is to be taken as 0.95.

ii) For the space below the top surface of bulk cargo in the loaded hold, appropriate permeabilities and bulk cargo densities are to be used for any cargo carried. For iron ore, a permeability of 0.3 with a corresponding bulk density of 3.0 t/m^3 (187 lb/ft^3) is to be used. For cement, a permeability of 0.3 with a corresponding bulk density of 1.3 t/m^3 (81 lb/ft^3) is to be used. In this respect, "permeability" for bulk cargo means the ratio of the floodable volume between the particles, granules or any larger piece of the bulk cargo, to the gross volume occupied by the bulk cargo.

For packed cargoes (such as steel mill products), permeability is to be based on the actual floodable volume.

5 Strength Assessment

5.1 Stress Calculation *(1 July 2006)*

For strength evaluation, the hull structure is to be assumed to remain fully effective in resisting the applied loading. The actual hull girder bending stress, σ_{bf}, in kN/cm^2 (tf/cm^2, Ltf/in^2) at any location is given by:

$$\sigma_{bf} = (M_{swf} + 0.8M_w)/SM$$

where

M_{swf} = still water bending moment, in kN-m (tf-m, Ltf-ft), in the flooded conditions for the section under consideration

M_W = wave bending moment, in kN-m (tf-m, Ltf-ft), as given in 3-2-1/3.5.2 for the section under consideration

SM = gross hull girder section modulus, in cm^2-m (in^2-ft) for the section under consideration.

The shear strength of the side shell and the inner hull (i.e., longitudinal bulkhead for double side skin bulk carriers) at any location of the vessel, is to be checked according to the requirements specified in 3-2-1/3.9 in which F_{SW} and F_W are to be replaced respectively by F_{SWF} and F_{WF}, where:

F_{SWF} = still water shear force, in kN (tf, Ltf), in the flooded conditions for the section under consideration, corrected as per 3-2-1/3.9.3

F_W = wave shear force, in kN (tf, Ltf), as given in 3-2-1/3.5.3 for the section under consideration

F_{WF} = $0.8F_W$

5.3 Strength Criteria

The calculated hull girder bending and shear stresses are not to exceed the values given below:

in bending: $f_{bf} = 17.5/Q$ kN/cm^2 ($1.784/Q$ tf/cm^2, $11.33/Q$ Ltf/in^2)

in shear: $f_{sf} = 11.0/Q$ kN/cm^2 ($1.122/Q$ tf/cm^2, $7.122/Q$ Ltf/in^2)

where Q is as defined in 3-2-1/5.5.

5.5 Buckling Strength

The buckling strength of the effective members of the longitudinal hull girder at the deck (from the deck to the bottom of the upper wing tank) and bottom (from the bottom to the top of the lower wing tank) are to be verified using the procedures given in 3-2-A4/1, 3-2-A4/3, 3-2-A4/5, and 3-2-A4/9.

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PART

5C

CHAPTER **3 Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)**

APPENDIX **5b Bulk Carriers in Flooded Conditions – Corrugated Transverse Watertight Bulkheads** *(1 July 1998)*

1 Corrugated Transverse Watertight Bulkheads *(1998)*

1.1 Application *(1 July 2006)*

This Appendix will apply to vertically corrugated transverse watertight bulkheads between two cargo holds of Single or Double Skin construction, in bulk carriers of 150 m (492 ft) or more in length, constructed on or after 1 July 2006, and intended to carry solid bulk cargoes having a density of 1.0 t/m^3, (62.4 lb/ft^3) or above.

1.3 Definitions

1.3.1 Homogeneous Loading

In Appendix 5C-3-A5b, a homogeneous loading is a loading condition wherein cargo is loaded in two adjacent holds and wherein the ratio between the higher and lower filling levels, after correction for different cargo densities, does not exceed 1.20.

1.3.2 Non-homogeneous Loading

Any loading condition not fitting the description in 5C-3-A5b/1.3.1 is considered non-homogeneous for the application of Appendix 5C-3-A5b, except that non-homogeneous partial loading conditions associated with multi-port loading and unloading operations for initially homogeneous loading conditions are excluded.

1.5 Net Thickness and Nominal Design Corrosion Value

In calculating the scantlings for bulkhead and stool structures, the net thickness is to be used. The design nominal corrosion value for these structures is to be taken as 3.5 mm (0.14 in.).

3 Load Model

3.1 General

The loads to be considered as acting on the bulkheads are those given by the combination of the cargo loads with those induced by the flooding of one hold of single side skin construction and adjacent to the bulkhead under examination. The scantlings of each bulkhead are to be checked using the design loading conditions included in the longitudinal strength calculations and in the loading manual (see 3-2-1/7) and the most severe combinations of cargoes and flooded water are to be used. Holds carrying packaged cargoes are to be considered as empty holds for the application of Appendix 5C-3-A5b.

Vessels which are not designed to operate exclusively in non-homogenous conditions carrying heavy ore cargoes [density greater than 1.78 t/m^3 (111 lb/ft^3)] are to have their bulkheads evaluated assuming the hold is filled to the level of the deck at centerline with cargo at the nominal design density. The nominal design density is defined as the maximum cargo mass in the hold divided by the hold volume.

3.3 Minimum Bulkhead Loading

For any bulkhead, the pressure due to the flooding water alone is to be considered as the minimum loading.

3.5 Flooding Head

The flooding head h_f (see 5C-3-A5b/Figure 1) is the distance, in m (ft), measured vertically with the vessel in the upright position, from the point under consideration to a level located at a distance d_f, in m (ft), from the baseline as given in the following table:

		d_f			
		After Bulkhead of Foremost Hold [(1)]		*All Other Bulkheads*	
DWT (tonnes)	*Type of Freeboard*	$\rho_c \geq 1.78$ *or homo. cargo*	$\rho_c < 1.78$ *& non-homo.*	$\rho_c \geq 1.78$ *or homo. cargo*	$\rho_c < 1.78$ *& non-homo.*
≥ 50,000 or B60, B100		D	$0.95D$	$0.9D$	$0.85D$
< 50,000 and B0		$0.95D$	$0.9D$	$0.85D$	$0.8D$

Note: 1 Applicable for either case of flooding No.1 cargo hold or No.2 cargo hold

where D is the molded depth of the vessel, in m (ft), defined in 3-1-1/7.1 (see 5C-3-A5b/Figure 1).

3.7 Cargo Pressure in the Intact Holds

At each point of the bulkhead, the pressure p_c, in N/cm^2 (kgf/cm^2, lbf/in^2), is given by:

$$p_c = k_1 \cdot \rho_c \, h_1 \cdot \frac{(1 - \sin \alpha)}{(1 + \sin \alpha)}$$

The force F_c, in N (kgf, lbf), acting on a corrugation is given by:

$$F_c = k_2 \cdot \rho_c \, s_1 \cdot \frac{(d_1 - h_{DB} - h_{LS})^2}{2} \cdot \frac{(1 - \sin \alpha)}{(1 + \sin \alpha)}$$

where

k_1 = conversion factor, to be taken as 0.981 (0.01, 1/144)

ρ_c = bulk cargo density, in t/m^3 (lb/ft^3)

d_1 = vertical distance, in m (ft), from the baseline to a horizontal plane corresponding to the average height of the cargo (see 5C-3-A5b/Figure 1)

h_1 = vertical distance, in m (ft), from the calculation point to horizontal plane corresponding to the average height of the cargo (see 5C-3-A5b/Figure 1)

α = angle of repose of the cargo, in degrees, that may generally be taken as 35° for iron ore and 25° for cement

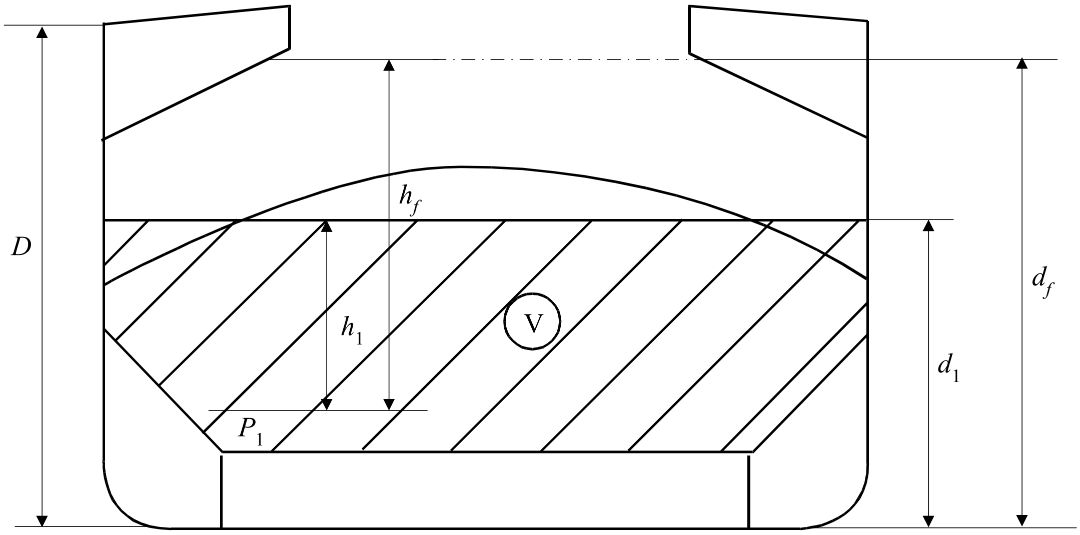
k_2 = conversion factor, to be taken as 98.1 (10, 1/12)

s_1 = spacing of corrugations, in cm (in.) (see 5C-3-A5b/Figure 2)

h_{LS} = mean height of the lower stool, in m (ft), from the inner bottom

h_{DB} = height of the double bottom, in m (ft)

FIGURE 1



3.9 Combined Cargo/Flooding Pressure in the Flooded Holds

3.9.1 Bulk Cargo Holds

Two cases are to be considered, depending on the values of d_1 and d_f.

3.9.1(a) $d_f \geq d_1$

i) At each point of the bulkhead located at a distance between d_1 and d_f from the baseline, the pressure $p_{c,f}$, in N/cm² (kgf/cm², lbf/in²), is given by:

$$p_{c,f} = k_1 \cdot \rho \cdot h_f$$

ii) At each point of the bulkhead located at a distance less than d_1 from the baseline, the pressure $p_{c,f}$, in N/cm², (kgf/cm², lbf/in²), is given by:

$$p_{c,f} = k_1 \cdot \rho \cdot h_f + k_1 \cdot [\rho_c - \rho \cdot (1 - perm)] \cdot h_1 \cdot \frac{1 - \sin\alpha}{1 + \sin\alpha}$$

iii) The force $F_{c,f}$, in N (kgf, lbf), acting on a corrugation is given by:

$$F_{c,f} = k_2 \cdot s_1 \cdot \left[\rho \cdot \frac{(d_f - d_1)^2}{2} + \frac{p \cdot (d_f - d_1) + (p_{c,f})_{\ell e}}{2} \cdot (d_1 - h_{DB} - h_{LS}) \right]$$

where

ρ = density of sea water, in t/m^3 (lb/ft^3)

k_1 = as defined in 5C-3-A5b/3.7

h_f = flooding head as defined in 5C-3-A5b/3.5

d_f = as given in 5C-3-A5b/3.5

perm = permeability of cargo, to be taken as 0.3 for ore (corresponding bulk cargo density for iron ore may be 3.0 t/m^3), coal cargoes and for cement (corresponding bulk cargo density for cement may be 1.3 t/m^3)

$(p_{c,f})_{\ell e}$ = pressure, in N/cm^2, (kgf/cm^2, lbf/in^2), at the lower end of the corrugation

k_1, k_2, s_1, d_1, h_1, h_{DB}, h_{LS}, ρ_c, α are as given in 5C-3-A5b/3.7

3.9.1(b) $d_f < d_1$

i) At each point of the bulkhead located at a distance between d_f and d_1 from the baseline, the pressure $p_{c,f}$, in N/cm^2, (kgf/cm^2, lbf/in^2), is given by:

$$p_{c,f} = k_1 \cdot \rho_c \; h_1 \cdot \frac{(1 - \sin \alpha)}{(1 + \sin \alpha)}$$

ii) At each point of the bulkhead located at a distance lower than d_f from the baseline, the pressure $p_{c,f}$, in N/cm^2 (kgf/cm^2, lbf/in^2), is given by:

$$p_{c,f} = k_1 \cdot \rho \cdot h_f + k_1 \cdot [\rho_c \cdot h_1 - \rho \cdot (1 - perm) \cdot h_f] \cdot \left[\frac{1 - \sin \alpha}{1 + \sin \alpha} \right]$$

iii) The force $F_{c,f}$, in N (kgf, lbf) acting on a unit corrugation is given by:

$$F_{c,f} = k_2 \cdot s_1 \cdot [\rho_c \cdot \frac{(d_1 - d_f)^2}{2} \cdot \frac{(1 - \sin\alpha)}{(1 + \sin\alpha)} + \frac{\rho_c \cdot (d_1 - d_f)\left[\frac{1 - \sin\alpha}{1 + \sin\alpha}\right] + (p_{c,f})_{\ell e}}{2} \cdot (d_f - h_{DB} - h_{LS})]$$

where

ρ = density of sea water, in t/m^3 (lb/ft^3)

perm = permeability of cargo, to be taken as 0.3 for ore (corresponding bulk cargo density for iron ore may be 3.0 t/m^3), coal cargoes and for cement (corresponding bulk cargo density for cement may be 1.3 t/m^3)

d_f = as given in 5C-3-A5b/3.5

$(p_{c,f})_{\ell e}$ = pressure, in N/cm^2, (kgf/cm^2, lbf/in^2), at the lower end of the corrugation

k_1, k_2, ρ_c, s_1, d_1, h_1, h_f, h_{DB}, h_{LS}, α are as given in 5C-3-A5b/3.7.

3.9.2 Empty Holds Pressure due to Flooding Water Alone

At each point of the bulkhead, the hydrostatic pressure p_f, in N/cm^2 (kgf/cm^2, lbf/in^2), induced by the flooding water alone is given by:

$$p_f = k_1 \cdot \rho \cdot h_f$$

The force F_f, in N (kgf, lbf), acting on a unit corrugation is given by:

$$F_f = k_2 \cdot s_1 \cdot \rho \cdot \frac{(d_f - h_{DB} - h_{LS})^2}{2}$$

where

ρ = as given in 5C-3-A5b/3.9.1(a)

d_f = as given in 5C-3-A5b/3.5

k_1, k_2, s, h_{DB} , h_{LS} are as given in 5C-3-A5b/3.7.

3.11 Resultant Pressure and Force

3.11.1 Homogeneous Loading Conditions

At each point of the bulkhead structures, the resultant pressure p, in N/cm^2 (kgf/cm^2, lbf/in^2), acting on the bulkhead is given by:

$$p = p_{c,f} - 0.8P_c \quad \text{or} \quad p = p_f \quad \text{whichever is greater}$$

The resultant force F, in N (kgf, lbf), acting on a unit corrugation is given by:

$$F = F_{c,f} - 0.8F_c \quad \text{or} \quad F = F_f \quad \text{whichever is greater}$$

3.11.2 Non-homogeneous Loading Conditions

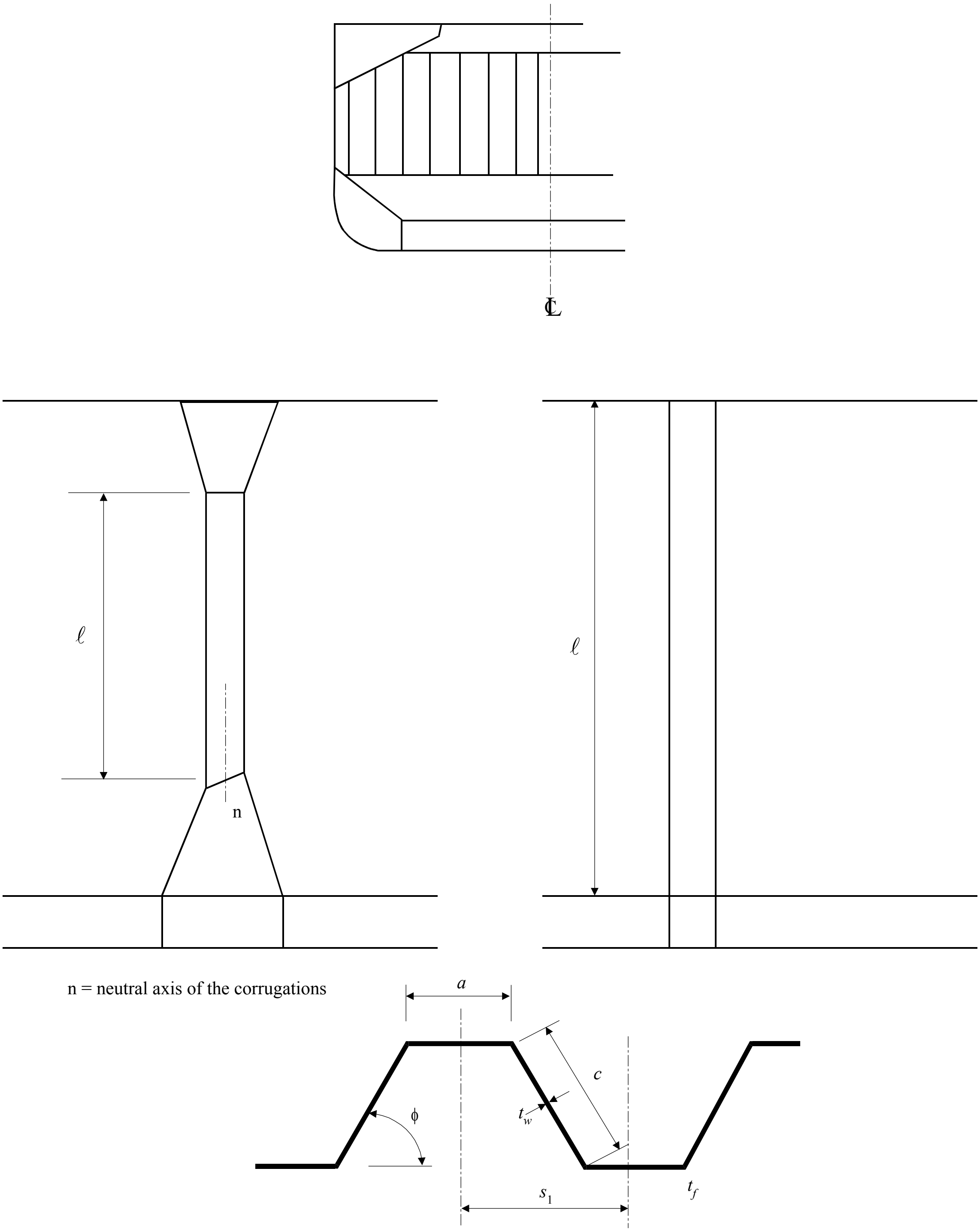
At each point, the resultant pressure p, in N/cm^2 (kgf/cm^2, lbf/in^2), acting on the bulkhead is given by:

$$p = p_{c,f} \quad \text{or} \quad p = p_f \quad \text{whichever is greater}$$

The resultant force F, in N (kgf, lbf), acting on a unit corrugation is given by:

$$F = F_{c,f} \quad \text{or} \quad F = F_f \quad \text{whichever is greater}$$

FIGURE 2



5 Bending Moment and Shear Force

The bending moment, M, and the shear force, Q, in the bulkhead corrugations are obtained using the formulae given in 5C-3-A5b/5.1 and 5C-3-A5b/5.3. The M and Q values are to be used for the checks in 5C-3-A5b/7.3 and 5C-3-A5b/11.

5.1 Bending Moment

The design bending moment M, in N-cm (kgf-cm, lbf-in.), for the bulkhead corrugations is given by:

$M = 12.5F\ell$ (SI/MKS units) $M = 1.5F\ell$ (US units)

where

F = resultant force, in N (kgf, lbf), as given in 5C-3-A5b/3.11

ℓ = span of the corrugation, in m (ft), to be taken according to 5C-3-A5b/Figure 2 and 5C-3-A5b/Figure 3

5.3 Shear Force

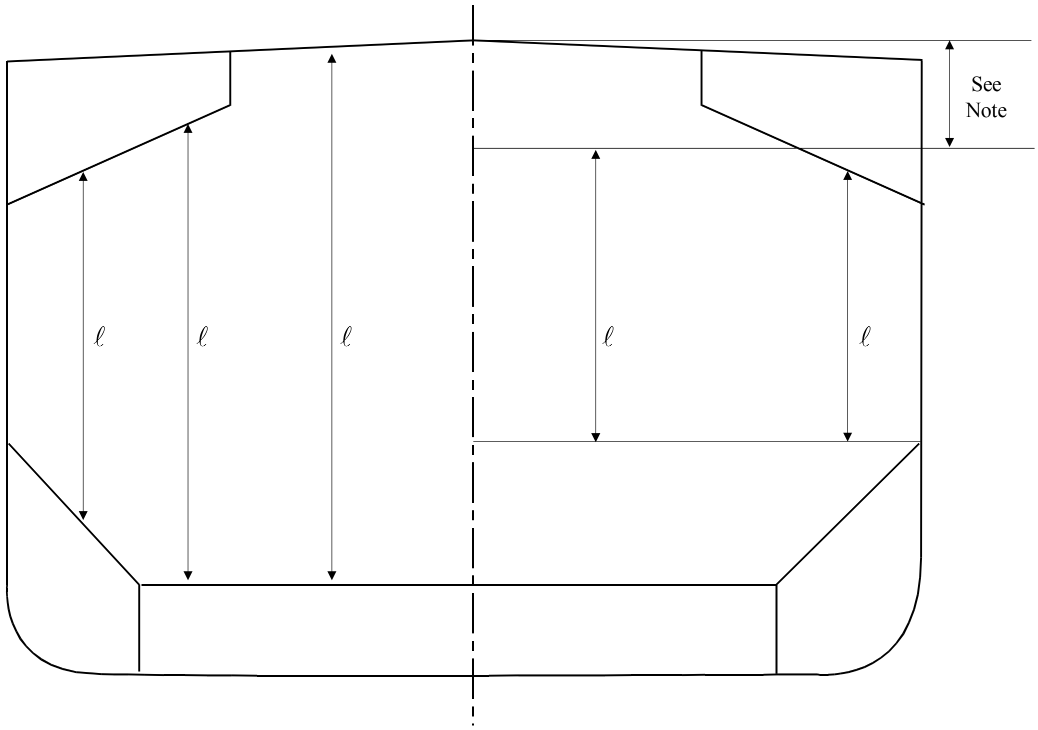
The shear force Q, in N (kgf, lbf), at the lower end of the bulkhead corrugations is given by:

$Q = 0.8F$

where

F = as given in 5C-3-A5b/3.11

FIGURE 3 *(2004)*



Note: For the definition of ℓ, its upper end is not to be taken more than a distance from the deck at the centerline equal to:

- Three (3) times the depth of corrugations, in general

- Two (2) times the depth of corrugations, for rectangular stool

7 Strength Criteria

7.1 General

The following criteria are applicable to transverse bulkheads with vertical corrugations (see 5C-3-A5b/Figure 2). For vessels of 190 m or more in length, these bulkheads are to be fitted with a bottom stool, and generally with an upper stool below deck. For smaller vessels, corrugations may extend from inner bottom to deck.

The corrugation angle ϕ shown in 5C-3-A5b/Figure 2 is not to be less than 55°.

Requirements for local net plate thickness are given in 5C-3-A5b/13.

In addition, the criteria as given in 5C-3-A5b/7.7 and 5C-3-A5b/9 are to be complied with.

The thickness and material of the lower part of corrugations considered in the application of 5C-3-A5b/7.3 and 5C-3-A5b/9.1 are to be maintained for a distance from the inner bottom (if no lower stool is fitted) or the top of the lower stool not less than 0.15ℓ, where ℓ is defined in 5C-3-A5b/5.1

The thickness and material of the middle part of corrugations, as considered in the application of 5C-3-A5b/7.3 and 5C-3-A5b/9.3, are to be maintained up to the level within 0.3ℓ from the deck (if no upper stool is fitted) or the bottom of the upper stool.

The section modulus of the corrugation in the remaining upper part of the bulkhead is not to be less than 75% of that required for the middle part, corrected for any difference in yield stress.

7.3 Bending Capacity

The bending capacity of the corrugation is to comply with the following relationship:

$$\frac{M}{0.5 \cdot SM_{\ell e} \cdot f_{y,\ell e} + SM_m \cdot f_{y,m}} \le 0.95$$

where

M = bending moment, in N-cm (kgf-cm, lbf-in), as given in 5C-3-A5b/5.1

$SM_{\ell e}$ = section modulus, in cm^3 (in^3), at the lower end of corrugations, to be calculated according to 5C-3-A5b/9.1. $SM_{\ell e}$ is to be taken not greater than $SM'_{\ell e}$

$$SM'_{\ell e} = SM_g + k \cdot \frac{Q \cdot h_g - 0.5 \cdot k \cdot h_g^2 \cdot s_1 \cdot p_g}{f_{y,\ell e}}$$

k = 100 (100, 12)

SM_g = section modulus, in cm^3 (in^3), of the corrugations calculated, according to 5C-3-A5b/9.3, in way of the upper end of shedder or gusset plates, as applicable

Q = shear force, in N (kgf, lbf), as given in 5C-3-A5b/5.3

h_g = height, in m (ft), of shedders or gusset plates, as applicable (see 5C-3-A5b/Figure 4, 5C-3-A5b/Figure 5, and 5C-3-A5b/Figure 6)

s_1 = as given in 5C-3-A5b/3.7

p_g = resultant pressure, in N/cm^2(kgf/cm^2, lbf/in^2), as defined in 5C-3-A5b/3.11, calculated at the middle of the shedders or gusset plates, as applicable

SM_m = section modulus, in cm^3 (in^3), at the mid-span of corrugations, to be calculated according to 5C-3-A5b/9.3. SM_m is to be taken not greater than 1.15 $SM_{\ell e}$

$f_{y,\,\ell e}$ = minimum specified yield stress, in N/cm^2 (kgf/cm^2, lbf/in^2), of the material for the lower end of corrugations

$f_{y,\,m}$ = minimum specified yield stress, in N/cm^2 (kgf/cm^2, lbf/in^2), of the material for the mid-span of corrugations

7.5 Effective Shedder Plates

In order for shedder plates to be considered effective for the application of 5C-3-A5b/9.1.1, the following requirements are to be complied with:

7.5.1

The shedder plate lies in one plane, i.e., is not knuckled.

7.5.2

The shedder plate is welded to the corrugations and the top of the lower stool by one side penetration welds or equivalent.

7.5.3

The shedder plate angle with respect to the base line is at least 45° and the lower edge is in line with the stool side plating.

7.5.4

The shedder plate is to have a thickness not less than 75% of that of the corrugation flange.

7.5.5

Shedders are to have material properties at least equal to those for the flanges.

7.7 Effective Gusset Plates

In order for gusset plates to be considered effective for the application of 5C-3-A5b/9.1.2, in combination with shedder plates having thickness, material properties and welded connections in accordance with the above, the following requirements are to be complied with:

7.7.1

The height of the gusset plates is not to be less than half the corrugation flange width.

7.7.2

The gusset plates are to be fitted in line with the stool side plating.

7.7.3

Gusset plates are to be generally welded to the top of the lower stool by full penetration welds, and to the corrugations and shedder plates by one side penetration welds or equivalent.

7.7.4

Gusset plates are to have thickness and material properties at least equal to those provided for the flanges.

FIGURE 4 Symmetric Shedder Plates

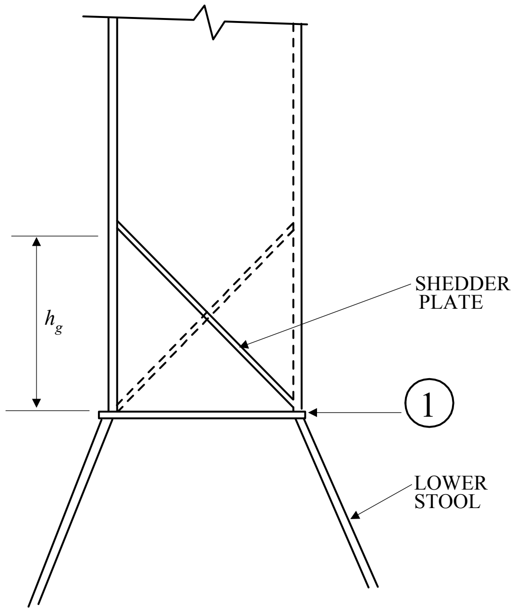


FIGURE 5 Asymmetric Shedder Plates

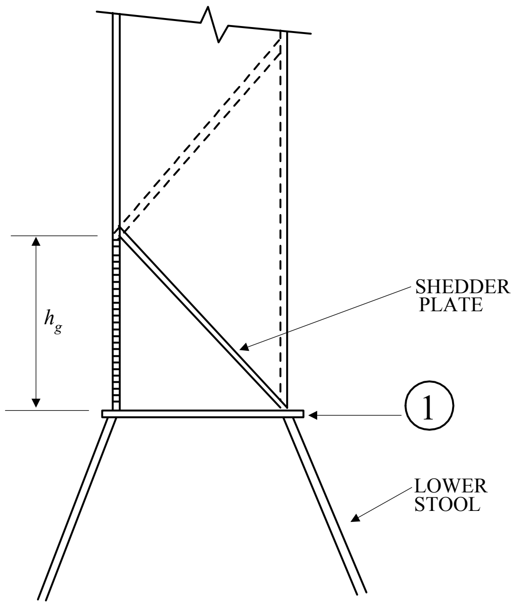
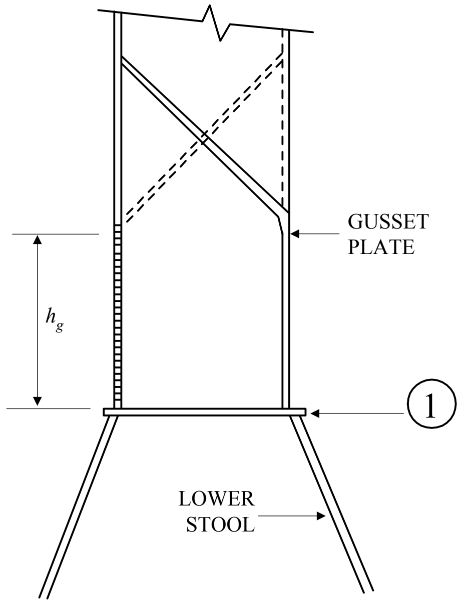


FIGURE 6
Symmetric Gusset/Shedder Plates



9 Section Properties

All section properties are to be calculated using the net plate thickness.

The section modulus of corrugations are to be calculated on the basis of the procedure given below in 5C-3-A5b/9.1 and 5C-3-A5b/9.3

9.1 Section Modulus at the Lower End of Corrugations

The section modulus is to be calculated with the compression flange having an effective flange width not greater than one half of b_{ef} as given in 5C-3-A5b/9.5.

If the corrugation webs are not supported by local brackets below the stool top (or below the inner bottom) in the lower part, the section modulus of the corrugations is to be calculated considering the corrugation webs 30% effective.

9.1.1

Provided effective shedder plates, as defined in 5C-3-A5b/7.5, are fitted above a horizontal stool top plate, (see 5C-3-A5b/Figure 4 and 5C-3-A5b/Figure 5), when calculating the section modulus of corrugations at the lower end (cross-section a-a), the area of each applicable flange may be increased by ($k\ a\ \sqrt{t_f \cdot t_{sh}}$) cm^2 (in^2)

where

k	=	1.25 (1.25, 1.5)
a	=	width, in m (ft), of the corrugation flange (see 5C-3-A5b/Figure 2)
t_{sh}	=	net shedder plate thickness, in mm (in.); not to be taken greater than t_f
t_f	=	net flange thickness, in mm (in.)

9.1.2

Provided effective gusset plates, as defined in 5C-3-A5b/7.7, are fitted (see 5C-3-A5b/Figure 6), when calculating the section modulus of corrugations at the lower end (cross-section 1), the area of each applicable flange may be increased by ($k \cdot h_g \cdot t_f$) cm^2 (in^2) where:

k = 3.5 (3.5, 4.2)

h_g = height of gusset plate, in m (ft), see 5C-3-A5b/Figure 6, not to be taken greater than

$$\left(\frac{10}{7} \cdot s_{gu}\right)$$

s_{gu} = width of the gusset plates, in m (ft)

t_f = net flange thickness, in mm (in.)

9.1.3

If the sloping stool top plate is at least 45 degrees to the horizontal, the section modulus of the corrugations may be calculated considering the corrugation webs fully effective. In case effective gusset plates are fitted, when calculating the section modulus of corrugations, the area of the flange may be increased as specified in 5C-3-A5b/9.1.2 above. No credit can be given to shedder plates only. If the angle to the horizontal is less than 45 degrees, the effectiveness of the web may be obtained by linear interpolation between 30% at 0 degrees and 100% at 45 degrees.

9.3 Section Modulus of Corrugations at Cross-Sections other than the Lower End

The section modulus is to be calculated with the corrugation webs considered effective and the compression flange having an effective flange width, not greater than one half of b_{ef}, as given in 5C-3-A5b/9.5.

9.5 Effective Width of the Compression Flange

The effective width b_{ef}, in cm (in.), of the compression flange is given by:

$$b_{ef} = C_e \cdot a$$

where

$$C_e = \frac{2.25}{\beta} - \frac{1.25}{\beta^2} \qquad \text{for } \beta > 1.25$$

$$C_e = 1.0 \qquad \text{for } \beta \le 1.25$$

$$\beta = \frac{a}{t_f} \cdot \sqrt{\frac{f_y}{E}}$$

t_f = net flange thickness, in cm (in.)

a = width, in cm (in.), of the corrugation flange (see 5C-3-A5b/Figure 2)

f_y = minimum specified yield stress of the material, in N/cm^2 (kgf/cm^2, lbf/in^2)

E = modulus of elasticity of the material, in N/cm^2 (kgf/cm^2, lbf/in^2)

11 Shear Strength

11.1 Shear Stress

The shearing stress f_s in the corrugation web plate is calculated as follows:

$$f_s = \frac{Q}{c \cdot \sin \cdot \phi \cdot t_w}$$

and is not to exceed the allowable value f_a given by:

f_a = $0.5f_y$

Q = shear force in web, in N (kgf, lbf), calculated in accordance with 5C-3-A5b/5.3

f_y = minimum specified yield stress, in N/cm^2 (kgf/cm^2, lbf/in^2), of the web material

ϕ = corrugation angle (see 5C-3-A5b/Figure 2)

c = corrugation web length (see 5C-3-A5b/Figure 2), in cm (in.)

t_w = net thickness of the corrugation web plating, in cm (in.)

11.3 Shear Buckling

The buckling check is to be performed for the web plates at the corrugation ends.

The shear stress f_s is not to exceed the critical value τ_c, in N/mm^2, (kgf/cm^2, psi), as given in Appendix 3-2-A4, with k_t = 6.34 and t_b = net thickness of the corrugation web plating.

13 Local Net Plate Thickness

The bulkhead local net plate thickness t_n or t_{w1}, in mm (in.), is given by:

$$t_n = 0.483 s_n \sqrt{\frac{p}{f_y}}$$

$$t_{w1} = 0.483 s_w \sqrt{\frac{p}{f_y}}$$

where

s_n, (s_w) = width, in mm (in.), of the narrower (wider) plate of the corrugation (a or c as shown in 5C-3-A5b/Figure 2)

p = resultant pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in 5C-3-A5b/3.11, at the bottom of each strake of plating. The net thickness of the lowest strake is to be determined using the resultant pressure at the top of the lower stool, or at the inner bottom, if no lower stool is fitted or at the top of shedders, if shedder or gusset/shedder plates are fitted.

f_y, = minimum specified yield stress, in N/cm^2 (kgf/cm^2, lbf/in^2), of the material

In addition, where the proposed net thickness t_{np} of narrower plating is less than t_{w1} given above, the net thickness of the wider plating is to be not less than t_{w2}, in mm (in.), obtained by the following:

$$t_{w2} = \sqrt{2 \cdot t_{w1}^2 - t_{npn}^2}$$

t_{np} = proposed net thickness of the narrower plate, in mm (in.)

15 Stool Construction

The scantlings, details and arrangements of the upper and lower stool structures are to comply with the requirements of 5C-3-4/25.9 to 5C-3-4/25.13.

17 Local Scantlings and Details

17.1 Shedder Plates

In addition to the requirements of 5C-3-A5b/7.5, shedder plates are to have a net thickness not less than t in 5C-3-4/23.1 with the pressure, p, determined as per 5C-3-A5b/3.11 at the middle of the shedder.

17.3 Gusset Plates

In addition to the requirements of 5C-3-A5b/7.7, gusset plates are to comply with the following:

The gusset plating is to be sized in accordance with 5C-3-A5b/13 with s taken as the distance between gusset stiffeners or the dimension – $(a + 2c \cos \alpha)$ or h_g, whichever is less if no stiffening is provided. The pressure, p is to be taken at the lower edge of the gusset.

Gusset plate stiffeners, where fitted, are to comply with the net SM in 5C-3-4/23.3 with the pressure p determined as per 5C-3-A5b/3.9, $c_1 = 1.0$, $k = 8$ (8, 125) and $f_b = 0.90\ S_m f_y$.

PART

5C

CHAPTER 3 **Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)**

APPENDIX 5c **Bulk Carriers in Flooded Conditions – Permissible Cargo Loads in Holds** *(1 July 1998)*

1 Permissible Cargo Loads in Holds

1.1 Application *(1 July 2006)*

This Appendix will apply to cargo loading in each hold of Single or Double Side Skin construction in bulk carriers of 150 m (492 ft) or more in length, constructed on or after 1 July 2006, intended to carry solid bulk cargoes having a density of 1.0 t/m^3 (62.4 lb/ft^3) or more, and having conventional double bottom structures formed by a grillage consisting of regularly spaced floors and girders with a complete inner bottom supported by hopper tanks at the side and transverse bulkheads at the ends.

1.3 Net Thickness and Nominal Design Corrosion Value

In calculating the shear strength, the net thickness of floors and girders is to be used. The nominal design corrosion value for the floors and girders is to be taken as 2.5 mm (0.10 in.).

1.5 Check of Proposed Loading Conditions

All proposed cargo loading conditions including the following:

- homogeneous loading conditions;
- non-homogeneous loading conditions;
- packaged cargo conditions (such as steel mill products),

are to be checked against the allowable load in the flooded condition calculated in accordance with 5C-3-A5c/7.

In general, the maximum bulk cargo density to be carried is to be considered in calculating the allowable load in the hold. In no case is the allowable hold loading in flooded condition to be taken greater than the design hold loading in intact conditions.

3 Load Model

3.1 General

The loads considered in the assessment of allowable load in cargo holds of single side skin construction are those by the external sea pressure, the combination of the cargo and flooded water in the hold and the weight of the contents of the double bottom space in way of the hold.

3.3 Flooding Head

The flooding head h_f (see 5C-3-A5c/Figure 1) is the distance, in m (ft), measured vertically with the vessel in the upright position, from the point under consideration to a level located at a distance d_f, in m (ft), from the baseline given in the following table:

DWT (tonnes) and/or Type of Freeboard	d_f	
	Foremost Hold	*All Other Holds*
≥ 50,000 or B60, B100	D	$0.9D$
<50,000 and B0	$0.95D$	$0.85D$

where D is the distance, in m (ft), from the baseline to the freeboard deck at side amidships, as defined in 3-1-1/7.1.

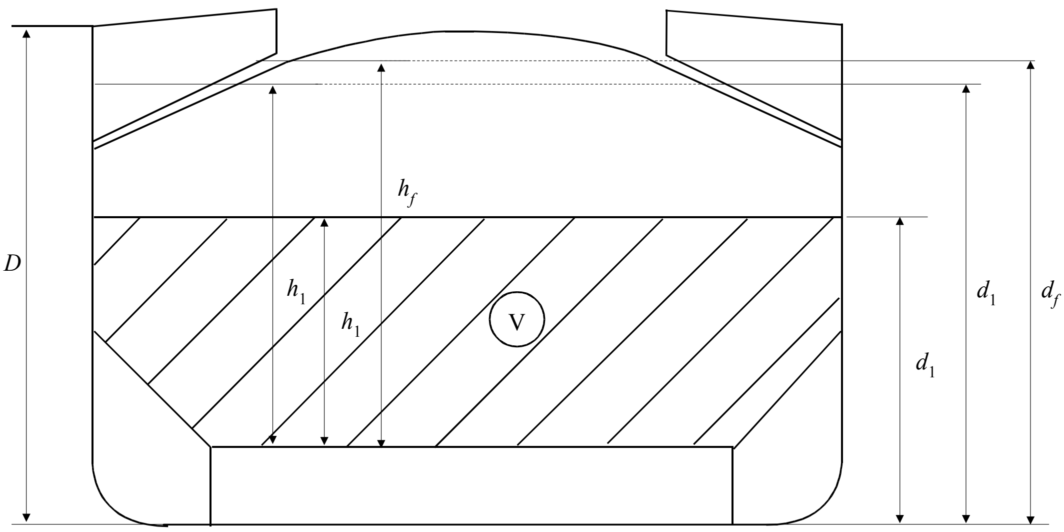
3.5 External Sea Water Head

The external sea water head (E), in m (ft), is measured vertically from the baseline of the vessel with the vessel in the upright position, and is given by the following:

$$E = d_f - 0.1D$$

where d_f, D are as defined above.

FIGURE 1



V= Volume of cargo

5 Shear Strength and Shear Capacity

5.1 Floor Shear Strength

The shear strength of the floor panel adjacent to hoppers, S_{f1}, and in way of any openings in the same panel, S_{f2}, are given by the following:

$$S_{f1} = 10^{-3} m A_f \frac{f_s}{\eta_1} \quad \text{in kN (tf, Ltf)}$$

$$S_{f2} = 10^{-3} m A_{f,h} \frac{f_s}{\eta_2} \quad \text{in kN (tf, Ltf)}$$

where

A_f = sectional area of the floor panel adjacent to hoppers, in cm^2 (in^2)

$A_{f,h}$ = sectional area in way of the openings in the same panel, in cm^2 (in^2)

f_s = allowable shear stress, in kN/cm^2 (tf/cm^2, Ltf/in^2), to be taken equal to the lesser of: $\dfrac{k \cdot f_y^{0.6}}{(s/t_{net})^{0.8}}$ or $\dfrac{f_y}{k_1\sqrt{3}}$

k = 1.022 (0.41, 0.529)

k_1 = 1000 (1000, 2240)

For floors next to stools or transverse bulkheads, as identified in 5C-3-A5c/Figure 2, f_s may be taken equal to:

$$\frac{f_y}{k_1\sqrt{3}}$$

f_y = minimum specified yield stress of the material, in N/cm^2 (kgf/cm^2, lbf/in^2)

m = 0.50 for the floor next to the stool or transverse bulkhead, see 5C-3-A5c/Figure 2

= 1.0 for all other floors

η_1 = 1.10

η_2 = 1.20, in general. If the opening in the floor is reinforced by a ring stiffener or "boxed" by additional panel stiffeners, η_2 may be taken as 1.10

5.3 Girder Shear Strength

The shear strength of the girder panel adjacent to stools (or transverse bulkheads, if no stool is fitted), S_{g1}, and in way of the largest of any openings in the same panel, S_{g2}, are given by the following:

$$S_{g1} = 10^{-3} A_g \frac{f_s}{\eta_1} \quad \text{in kN (tf, Ltf)}$$

$$S_{g2} = 10^{-3} A_{g,h} \frac{f_s}{\eta_2} \quad \text{in kN (tf, Ltf)}$$

where

A_g = sectional area of the girder panel adjacent to stools (or transverse bulkheads, if no stool is fitted), in cm^2 (in^2)

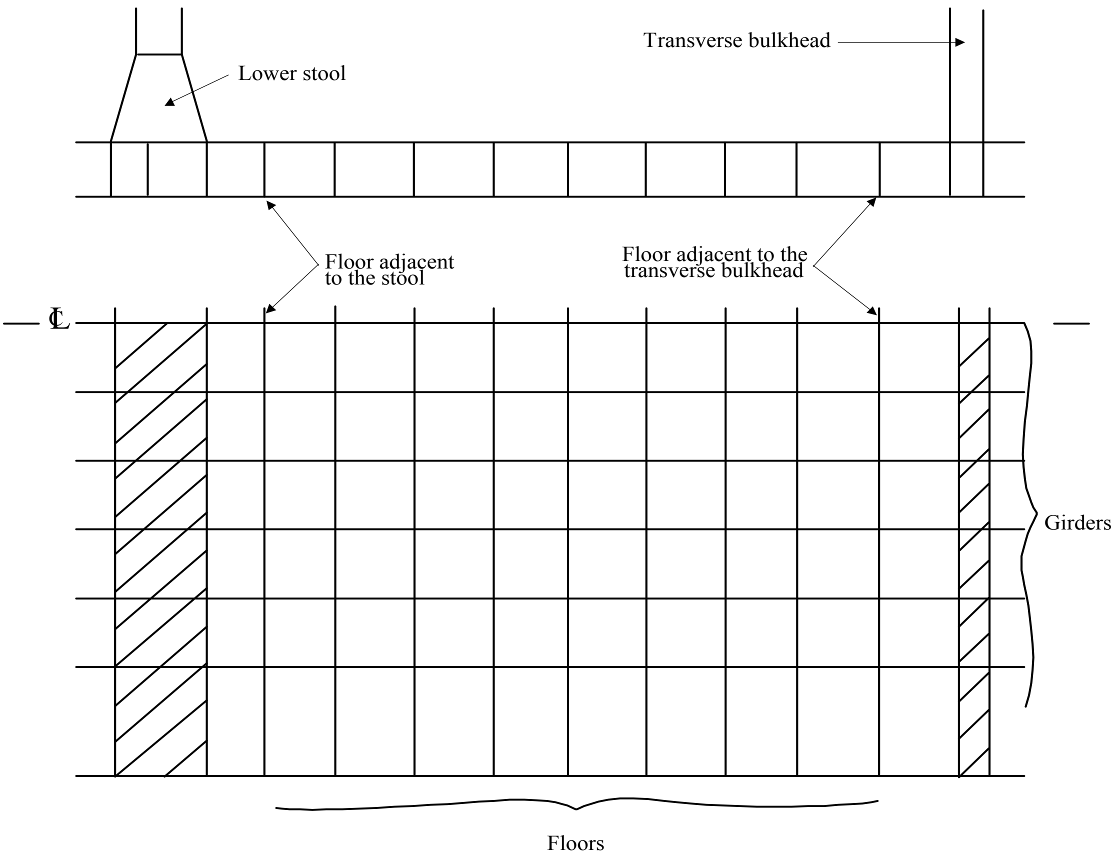
$A_{g,h}$ = sectional area in way of the largest opening in the same panel, in cm^2 (in^2)

f_s = allowable shear stress, in kN/cm^2 (tf/cm^2, Ltf/in^2), as given in 5C-3-A5c/5.1

η_1 = 1.10

η_2 = 1.15 in general. If the opening in the girder is reinforced by a ring stiffener or 'boxed' by additional panel stiffeners, η_2 may be taken as 1.10.

FIGURE 2



5.5 Shear Capacity of Double Bottom

The shear capacity, C, of the double bottom, is defined as the sum of the shear strength at each end of complete floors and girders attached directly to the boundary hopper or stool/bulkhead.

Where in the end holds, girders run out and are not directly attached to the boundary stool/bulkhead, their strength is to be evaluated for the attached end only.

Only the floors and girders inside the hold boundaries formed by the hoppers and stools (or transverse bulkheads if no stool is fitted) may be considered. The hopper side girders and the floors directly below the connection of the bulkhead stools (or transverse bulkheads if no stool is fitted) to the inner bottom are not to be included.

The shear capacity C_e and C_h for use with Z_1 and Z_2 in 5C-3-A5c/7 are to be in accordance with the above definition, with consideration for the type of shear strength, as follows:

C_h = shear capacity of the double bottom, in kN (tf, Ltf), considering for each floor, the lesser of the shear strengths S_{f1} and S_{f2} (see 5C-3-A5c/5.1) and, for each girder, the lesser of the shear strengths S_{g1} and S_{g2} (see 5C-3-A5c/5.3)

C_e = shear capacity of the double bottom, in kN (tf, Ltf), considering for each floor, the shear strength S_{f1} (see 5C-3-A5c/5.1) and, for each girder, the lesser of the shear strengths S_{g1} and S_{g2} (see 5C-3-A5c/5.3)

Where the geometry and/or the structural arrangement of the double bottom differs from the above, the shear capacity C of double bottom may be determined by an approved method.

7 Allowable Cargo Load in Holds

The allowable cargo load in hold W, is given by:

$$W = k_1 \cdot \frac{\rho_c \cdot V}{F} \qquad \text{in kN(tf, Ltf)}$$

where

k_1 = conversion factor, to be taken as 9.81 (1.0, 1/2240)

F = 1.10 for bulk cargoes

= 1.05 for steel mill products

ρ_c = cargo density, in t/m^3 (lb/ft^3). Generally, for bulk cargoes the maximum density to be carried is to be considered.

V = volume, in m^3 (ft^3), occupied by cargo at a level h_1

h_1 = average height of the cargo, in m (ft) – See 5C-3-A5c/Figure 1

$= \dfrac{X}{k_1 \cdot \rho_c}$

X = for bulk cargoes, the lesser of X_1 or X_2

$$X_1 = \frac{Z + k_1 \cdot \rho \cdot (E - h_f)}{1 - \dfrac{\rho}{\rho_c}(1 - perm)}$$

$X_2 = Z + k_1\,\rho \cdot (E - h_f \cdot perm)$

= for steel mill products, X may be taken as X_1, using $perm = 0$.

ρ = sea water density, 1.025 t/m^3 (64 lb/ft^3)

E = external sea water head, in m (ft), as defined in 5C-3-A5c/3.5

h_f = flooding head, in m (ft), as defined in 5C-3-A5c/3.3

$perm$ = cargo permeability, (for bulk cargoes, the ratio of floodable volume between the particles, granules or any larger piece of the cargo, to the gross volume occupied by the bulk cargo; but need not be taken greater than 0.3)

Z = the lesser of Z_1 and Z_2 given by:

Z_1 = $\dfrac{C_h - M_{DB,h}}{A_{DB;h}}$

Z_2 = $\dfrac{C_e - M_{DB,e}}{A_{DB,e}}$

C_h, C_e = as defined in 5C-3-A5c/5.5

$M_{DB,\,h}$ = load in kN (tf, Ltf) of the contents of the double bottom space within $A_{DB,\,h}$ in way of the holdunder consideration

$M_{DB,\,e}$ = load in kN (tf, Ltf) of the contents of the double bottom space within $A_{DB,\,e}$ in way of the hold under consideration

$A_{DB,\,e}$ = $\sum_{i=1}^{i=n} S_i \cdot B_{DB,\,i}$

$A_{DB,\,e}$ = $\sum_{i=1}^{i=n} S_i \cdot (B_{DB} - s)$

n = number of floors between stools (or transverse bulkheads, if no stool is fitted)

S_i = space of i-th -floor, in m (ft)

$B_{DB,\,i}$ = $B_{DB} - s$ for the floor for which S_{f1} is used in determining C_h or C_e (see 5C-3-A5c/5.5)

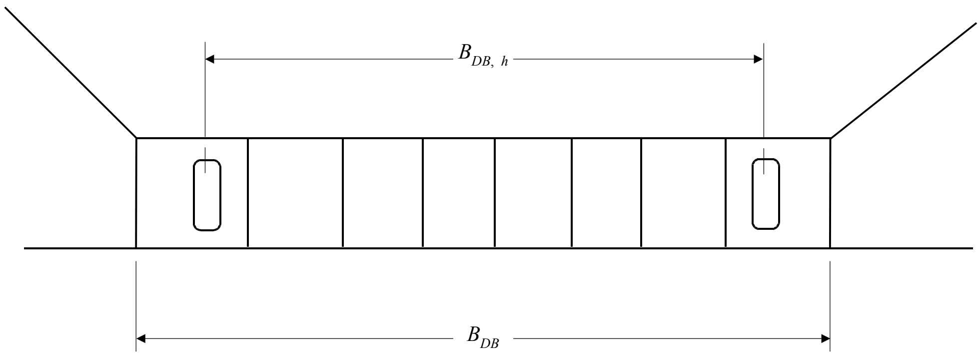
$B_{DB,\,i}$ = $B_{DB,\,h}$ for the floor for which S_{f2} is used in determining C_h (see 5C-3-A5c/5.5)

B_{DB} = breadth, in m (ft), of double bottom between hoppers (see 5C-3-A5c/Figure 3)

$B_{DB,\,h}$ = distance, in m (ft), between the two considered openings (see 5C-3-A5c/Figure 3)

s = spacing, in m (ft), of double bottom longitudinals next to hoppers

FIGURE 3



PART

5C

CHAPTER **3** **Vessels Intended to Carry Ore or Bulk Cargoes (150 meters (492 feet) or more in Length)**

APPENDIX **6** **Harmonized System of Notations and Corresponding Design Loading Conditions for Bulk Carriers**

(1 July 2003)

1 General

1.1

This Appendix is intended to improve the transparency of the Rules regarding cargo carrying capabilities of bulk carriers by applying a harmonized system of notations for corresponding design loading conditions with respect to strength and stability. This Appendix is an integral part of the ABS Rules.

1.3

This Appendix is not intended to prevent any other loading conditions from being included in the loading manual for which calculations are to be submitted as required by the Rules, nor is it intended to replace in any way the required loading manual/instrument.

1.5

The assigned notations and corresponding design loading conditions are to be included in the loading manual for each vessel and are to be identified as such. It is to be noted that these design loading conditions are developed to allow maximum operational flexibility and are not intended as specific sample operating conditions.

A bulk carrier in actual operation may be loaded differently from the design loading conditions, provided the limitations for longitudinal and local strength and stability as defined in the loading manual and loading instrument onboard are not exceeded.

1.7

The heavy ballast condition, as required by 5C-3-A6/7.1.4, is to be used while the vessel is operated in heavy weather.

3 Application

3.1

This Appendix is applicable to bulk carriers as defined in 5C-3-1/1.5.1 with length as defined in 3-1-1/3.1 of 150 meters (492 feet) or more and are contracted for new construction on or after 1 July 2003.

3.3

The loading conditions listed under 5C-3-A6/7.1 are to be used, as may be indicated in the respective paragraph, for the longitudinal strength, local strength and stability criteria in the Rules. The loading conditions listed under 5C-3-A6/7.3 are to be used for local strength. See 5C-3-A6/Table 1.

5 Harmonized Notations

5.1 Mandatory Notations and Notes

5.1.1 Mandatory Notations

One of the following notations will be assigned to any given ship in association with the design loading conditions in 5C-3-A6/7.1.

BC-A: for bulk carriers designed to carry dry bulk cargoes of cargo density 1.0 tonne/m^3 and above with specified holds empty at the summer load line, in addition to in all holds

BC-B: for bulk carriers designed to carry dry bulk cargoes of cargo density of 1.0 tonne/m^3 and above in all cargo holds, without any hold being specified empty

BC-C: for bulk carriers designed to carry dry bulk cargoes of cargo density less than 1.0 tonne/m^3

5.1.2 Supplementary Notes

For all **BC-A** ships, a supplementary note describing all approved combinations of specified empty holds are to be entered in the *Record*:

(all approved combinations of specified empty holds)

This supplementary note will be placed immediately after the mandatory notation in 5C-3-A6/5.1.1.

5.3 Additional Notations

Additional notations will be entered in the *Record* to identify the particular loading condition, wherever it is chosen for the design

This supplementary note will be placed immediately after the mandatory notation in 5C-3-A6/5.1.1 or, where applicable, the supplementary notation in 5C-3-A6/5.1.2.

(maximum cargo density (in tonnes/m^3)) – for **BC-A** and **BC-B** if the maximum cargo density is less than 3.0 tonne/m^3 ;

(no MP) – for all notations when the vessel has not been designed for loading and unloading in multiple ports. See 5C-3-A6/7.3.3.

7 Design Loading Conditions for Harmonized Notations

7.1 General Loading Conditions

The following loading conditions are to be applied in association with the harmonized system of bulk carrier notations in 5C-3-A6/5.1.

7.1.1 BC-C

Fully homogeneous cargo condition with all cargo holds, including hatchways, 100% full at the summer load line with all ballast tanks empty.

7.1.2 BC-B

The design loading conditions are:

7.1.2(a) As required for **BC-C** in 5C-3-A6/7.1.1, plus:

7.1.2(b) Heavy cargo condition wherein cargoes having a density of 3.0 tonnes/m^3 (187 lb/ft^3) are loaded in all cargo holds at the same filling rate (cargo volume/hold cubic capacity) at the summer load line with all ballast tanks empty.

7.1.2(c) Where the vessel is not intended to carry 3.0 tonnes/m^3 (187 lb/ft^3) or higher density cargoes, the design may be based on the maximum density of the cargo the vessel is intended to carry. In such cases, the maximum density of the cargo that the vessel is allowed to carry will be distinguished by an additional notation **(maximum cargo density (in tonnes/m^3))** following a bulk carrier notation. See 5C-3-A6/5.3 and 5C-3-1/1.1.

7.1.3 BC-A

The design loading conditions are:

7.1.3(a) As required for **BC-B** in 5C-3-A6/7.1.2, plus:

7.1.3(b) At least one cargo loaded condition with specified holds empty, with cargo density 3.0 tonnes/m^3 (187 lb/ft^3), and at the same filling rate (cargo volume/hold cubic capacity) in all loaded cargo holds at the summer load line with all ballast tanks empty.

7.1.3(c) Approved combination of specified empty holds is to be indicated by a supplementary note "**(holds 1, 2… may be empty)**". Where more than one combination is approved, each approved combination is to be indicated, e.g., "**(holds 1, 3, 5 and 7 or holds 2, 4 and 6 may be empty)**" See 5C-3-A6/5.1.2.

7.1.3(d) Where the vessel is not intended to carry 3.0 tonnes/m^3 (187 lb/ft^3) or higher density cargoes with specified hold(s) empty, the design may be based on the maximum density of the cargo the vessel is intended to carry. In such cases, the maximum density of the cargo that the vessel is allowed to carry in that loading condition is to be included in the additional notation in the *Record* which will read "**(holds 1, 2… may be empty, with maximum cargo density ρ tonnes/m^3)**". See 5C-3-A6/5.3.

7.1.4 Ballast Conditions (applicable to all notations)

7.1.4(a) Ballast Tank Capacity. All bulk carriers are to have ballast tanks of sufficient capacity so disposed to fulfil at least the following requirements:

i) *Normal Ballast Condition. Normal ballast condition* for the purpose of this Appendix is a ballast (no cargo) condition where:

1. The ballast tanks may be full, partially full or empty. Where partially full option is exercised, the conditions in the second paragraph of 3-2-1/3.3 are to be complied with,
2. Any cargo hold or holds adapted for the carriage of water ballast at sea are to be empty,
3. The propeller is fully immersed, and
4. The trim is by the stern and is not to exceed $0.015L$, where L is the length between perpendiculars of the vessel.

In the assessment of the propeller immersion and trim, the drafts at the forward and after perpendiculars may be used.

ii) *Heavy Ballast Condition. Heavy ballast condition* for the purpose of this Appendix is a ballast (no cargo) condition utilizing all ballast tanks including one or more cargo holds adapted and designated for the carriage of water ballast at sea. In this condition,

1. The ballast tanks may be full, partially full or empty. Where partially full option is exercised, the conditions in the second paragraph of 3-2-1/3.3 are to be complied with,
2. At least one cargo hold adapted for the carriage of water ballast at sea where required or provided, is to be full,
3. The propeller immersion I/D is to be at least 60% where

   I = the distance from propeller centerline to the waterline

   D = propeller diameter,
4. The trim is to be by the stern and is not to exceed $0.015L$, where L is the length between perpendiculars of the ship, and
5. The molded forward draft in the heavy ballast condition is not to be less than the smaller of $0.03L$ or 8 m (26.25 ft)

7.1.4(b) Strength Requirements

i) *Normal Ballast Condition*

1. The structures of bottom forward are to be strengthened in accordance with the requirements of 5C-3-6/13 against slamming for the condition of 5C-3-A6/7.1.4(a)i) at the lightest forward draft,
2. The longitudinal strength requirements are to be complied with for the condition of 5C-3-A6/7.1.4(a)i), and
3. In addition, the longitudinal strength requirements are to be met with all ballast tanks 100% full.

ii) *Heavy Ballast Condition*

1. The longitudinal strength requirements are to be met for the condition of 5C-3-A6/7.1.4(a)ii),
2. In addition to the conditions in 5C-3-A6/7.1.4(b)ii)1, the longitudinal strength requirements are to be met under a condition with all ballast tanks 100% full and one cargo hold adapted and designated for the carriage of water ballast at sea, where provided, 100% full, and

3. Where more than one hold is adapted and designated for the carriage of water ballast at sea, it will not be required that two or more holds be assumed 100% full simultaneously in the longitudinal strength assessment, unless such conditions are expected in the heavy ballast condition. Unless each hold is individually investigated, the designated heavy ballast hold and any/all restrictions for the use of other ballast hold(s) are to be indicated in the loading manual

7.1.5 Departure and Arrival Conditions

Unless otherwise specified, each of the design loading conditions in 5C-3-A6/7.1 through 5C-3-A6/7.4 is to be investigated for the arrival and departure conditions, as defined below:

- Departure condition: with bunker tanks not less than 95% full and other consumables 100%.
- Arrival condition: with all consumables 10%

7.1.6 Summary of Applicable Requirements

For the application of Rule requirements in the respective loading conditions in 5C-3-A6/7.1, see 5C-3-A6/Table 1 below.

TABLE 1
Application of 5C-3-A6/7.1

z	*Notation*	*Density*	*Emp. Hold*	*Dep or Arr*	*Long'l Strength*		*Stability*		*Prop. Imm.*	*Trim*	*Fwd Draft*	*Bridge Visibility*
					Intact	*Dmged*	*Intact*	*Dmged*				
Cargo	7.1.1 **BC-C**	<1.0	N	D & A	Y	NA	Y	NA	NA	NA	NA	Y
Cargo	7.1.2 **BC-B**	>1.0	N	D & A	Y	Y	Y	Y	NA	NA	NA	Y
Cargo	7.1.3 **BC-A**	>1.0	Y	D & A	Y	Y	Y	Y	NA	NA	NA	Y
	Topic	*Cond'n*										
Ballast	7.1.4(a) Capacity	Normal		D & A	Y	Y (1)	Y	NA	50%	Y	NA	Y
Ballast		Heavy		D & A	Y	Y (1)	Y	NA	60%	Y	Y	Y
Ballast	7.1.4(b) L. Strength	Normal		D & A	Y	Y (1)	Y	NA	N	N	NA (2)	N
Ballast		Heavy		D & A	Y	Y (1)	Y	NA	N	N	NA	N

Notes:

1. Except **BC-C** for which longitudinal strength requirements in damaged condition at ballast draft are not applicable.
2. At the lightest forward draft, slamming loads for assessment of structures of bottom forward are to be determined in accordance with the requirements of 5C-3-6/13.

7.3 Local Loading Conditions for Each Individual Hold

7.3.1 Definitions

The maximum allowable or minimum required cargo mass in a cargo hold, or in two adjacent holds, is related to the net load on the double bottom. The net load on the double bottom is a function of draft, cargo mass in the cargo hold, as well as the mass of any contents in double bottom tanks.

The following definitions apply:

M_H: the actual cargo mass in a cargo hold corresponding to a fully homogeneous cargo loaded condition at the molded summer draft (d). See also 3-2-A2/Table 1 item 2.2.4.

M_{Full}: $= M_H$, except that in calculating M_{Full}, the homogeneous cargo density is not to be taken as less than 1.0 tonne/m^3 (62.4 lb/ft^3)

M_{HD}: the maximum cargo mass allowed to be carried in a cargo hold according to design loading condition(s) with specified holds empty at the molded summer draft (d).

7.3.2 General Conditions for All Ships

7.3.2(a)

i) Any cargo hold is to be capable of carrying at least M_{Full} with fuel oil tanks in double bottom in way of the cargo hold, if any, 100% full and ballast water tanks in the double bottom in way of the cargo hold empty, at d.

ii) The maximum allowable hold mass for a draft less than d may be obtained by adjusting the value obtained by 5C-3-A6/7.3.2(a)i) for the loss of buoyancy due to the decrease in draft.

7.3.2(b)

i) Any cargo hold is to be capable of being immersed to d with a mass in hold not exceeding $0.5M_H$ and with all double bottom tanks in way of the cargo hold empty.

ii) The minimum required hold mass for a draft less than d may be obtained by adjusting the value obtained by 5C-3-A6/7.3.2(b)i) for the loss of buoyancy due to the decrease in draft, subject to 5C-3-A6/7.3.2(d).

7.3.2(c)

i) Any cargo hold is to be capable of being immersed to the deepest ballast draft (d_B) with the cargo hold and all double bottom tanks in way of the cargo hold empty.

ii) The minimum required mass for a draft greater than d_B may be obtained by adjusting the value obtained by 5C-3-A6/7.3.2(c)i) for the added buoyancy due to the increase in draft, subject to 5C-3-A6/7.3.2(d).

7.3.2(d) The final minimum required mass in the draft range in 5C-3-A6/7.3.2(b)ii), 5C-3-A6/7.3.2(c)ii) or, where applicable, 5C-3-A6/7.3.3(b)ii) is the least of the two (or three).

7.3.2(e)

i) Any two adjacent cargo holds are to be capable of carrying at least M_{Full} in each cargo hold with fuel oil tanks in double bottom in way of each cargo hold, if any, 100% full and ballast water tanks in the double bottom in way of each cargo hold empty, at d.

ii) The maximum allowable hold mass for any two adjacent holds at a draft less than d may be obtained by adjusting the value obtained by 5C-3-A6/7.3.2(e)i) for the loss of buoyancy due to the decrease in draft.

7.3.2(f)

i) Any two adjacent cargo holds are to be capable of being immersed to *d* with a mass not exceeding $0.5M_H$ in each cargo hold and with all double bottom tanks in way of each cargo hold empty.

ii) The minimum required hold mass for any two adjacent holds at a draft less than *d* may be obtained by adjusting the value obtained by 5C-3-A6/7.3.2(f)i) for the loss of buoyancy due to the decrease in draft, if that is less than that obtained from 5C-3-A6/7.3.3(d)ii).

7.3.3 Conditions for all Ships without Additional Notation **(no MP)**

All bulk carriers are to be designed for partial loading conditions in 5C-3-A6/7.3.3(a) through 5C-3-A6/7.3.3(d), unless the additional notation **(no MP)** is desired.

7.3.3(a)

i) Any cargo hold is to be capable of carrying at least M_{Full} with fuel oil tanks in double bottom in way of the cargo hold, if any, 100% full and ballast water tanks in the double bottom in way of the cargo hold empty, at 0.67*d*.

ii) The maximum allowable hold mass for a draft less than 0.67*d* may be obtained by adjusting the value obtained by 5C-3-A6/7.3.3(a)i) for the loss of buoyancy due to the decrease in draft.

7.3.3(b)

i) Any cargo hold is to be capable of being immersed to 0.83*d* with the hold and all double bottom tanks in way of the cargo hold empty.

ii) The minimum required hold mass for a draft greater than 0.83*d* may be obtained by adjusting the value obtained by 5C-3-A6/7.3.3(b)i) for the added buoyancy due to the increase in draft, subject to 5C-3-A6/7.3.2(d).

7.3.3(c)

i) Any two adjacent cargo holds are to be capable of carrying at least M_{Full} with fuel oil tanks in double bottom in way of the cargo holds, if any, 100% full and ballast water tanks in the double bottom in way of the cargo hold empty, at 0.67*d*. This requirement regarding the mass of cargo and fuel oil in double bottom tanks in way of the cargo hold applies also to the condition where the adjacent hold is fitted with ballast, if applicable.

ii) The maximum allowable hold mass for any two adjacent holds at a draft less than 0.67*d* may be obtained by adjusting the value obtained by 5C-3-A6/7.3.3(c)i) for the loss of buoyancy due to the decrease in draft.

7.3.3(d)

i) Any two adjacent cargo holds are to be capable of being immersed to 0.75*d*, with the cargo holds and all double bottom tanks in way of the cargo holds empty.

ii) The minimum required hold mass for any two adjacent holds at a draft greater than 0.75*d* may be obtained by adjusting the value obtained by 5C-3-A6/7.3.3(d)i) for the added buoyancy due to the increase in draft, if that is less than that obtained from 5C-3-A6/7.3.2(f)ii).

7.3.4 Additional Conditions Applicable for **BC-A** Notation

7.3.4(a) Cargo holds, which are intended to be empty at *d*, are to be capable of being empty with all double bottom tanks in way of the cargo hold also empty.

7.3.4(b)

i) Cargo holds, which are intended to be loaded with high density cargo, are to be capable of carrying at least $M_{HD} + 0.1M_H$ in each cargo hold, with fuel oil tanks in the double bottom in way of the cargo holds, if any, 100% full and ballast water tanks in the double bottom empty in way of the cargo hold, at *d*.

ii) In operation the maximum allowable cargo mass, with the contents of double bottom tanks as described above, is to be limited to M_{HD} for draft above d_1, where d_1 is the draft corresponding to maximum summer draft *d* after adjustment for $0.1M_H$.

iii) The maximum allowable hold mass for a draft less than d_1 may be obtained by adjusting the value obtained by 5C-3-A6/7.3.4(b)i) for the loss of buoyancy due to the decrease in draft.

7.3.4(c)

i) Any two adjacent cargo holds which according to a design loading condition may be loaded with the adjacent third and fourth holds (or any other spaces) empty, are to be capable of carrying 10% of M_H in each hold in addition to the maximum cargo mass according to that design loading condition, with fuel oil tanks in the double bottom in way of the cargo holds, if any, 100% full and ballast water tanks in the double bottom in way of the cargo holds empty, at *d*.

ii) In operation the maximum allowable mass in each hold, with the contents of double bottom tanks as described above, is to be limited to the maximum cargo mass according to that design loading condition for draft above d_1 where d_1 is the draft corresponding to maximum summer draft *d* after adjustment for $0.1M_H$.

iii) The maximum allowable hold mass for any two adjacent holds at a draft less than d_1 may be obtained by adjusting the value obtained by 5C-3-A6/7.3.4(c)i) for the loss of buoyancy due to the decreased draft.

7.3.5 Additional Conditions Applicable for At-sea Ballast Holds

7.3.5(a) Cargo holds, including hatchways, which are designed as ballast water holds at sea, are to be capable of being 100% full of ballast water with all double bottom tanks in way of the cargo hold being 100% full at any heavy ballast draft. For at-sea ballast holds adjacent to topside wing, hopper and double bottom tanks, the local strength is to be satisfactory with the hold full with ballast and the topside wing, hopper and double bottom tanks empty.

7.3.6 Additional Conditions Applicable during Loading and Unloading in Harbor

7.3.6(a)

i) In harbor condition, any single cargo hold is to be capable of holding, at 0.67*d*, at least the maximum allowable seagoing mass (M_{MAX}).

where:

M_{MAX} = $M_{HD} + M_{DBF}$ for loaded hold on **BC-A**

= $M_{FULL} + M_{DBF}$ for all other holds

M_{DBF} = mass of fuel oil in double bottom tank *ii)* The maximum allowable hold mass for a draft less than 0.67d may be obtained by adjusting the value obtained by 5C-3-A6/7.3.6(a)i) for the loss of buoyancy due to the decrease in draft, subject to 5C-3-A6/7.3.6(c)i).

7.3.6(b)

i) In harbor condition, any two adjacent cargo holds are to be capable of carrying at least M_{Full}, with fuel oil tanks in the double bottom in way of the cargo holds, if any, 100% full and ballast water tanks in the double bottom in way of the cargo holds empty, at 0.67d.

ii) The maximum allowable hold mass for any two adjacent holds at a draft less than 0.67d may be obtained by adjusting the value obtained by 5C-3-A6/7.3.6(b)i) for the loss of buoyancy due to the decrease in draft.

7.3.6(c)

i) The maximum allowable cargo mass in harbor condition, at a draft less than d [see 5C-3-A6/7.3.2(a)ii)], d_1 (see 5C-3-A6/7.3.4(b)iii) et al) or 0.67d (see 5C-3-A6/7.3.3(a)ii) et al), may be obtained by adding 0.15M_{HD} for loaded holds on **BC-A** or 0.15M_{FULL} for all other holds to the allowable seagoing mass at that draft where it is greater than the allowable mass obtained by 5C-3-A6/7.3.6(a), subject to the maximum of M_{MAX}.

ii) Likewise, the minimum required mass in harbor condition, at a draft greater than d_B [see 5C-3-A6/7.3.2(c) ii)], 0.83d [see 5C-3-A6/7.3.3(b)ii)] or 0.75d [see 5C-3-A6/7.3.3(d) ii)] may be obtained by subtracting 0.15M_{HD} for loaded holds on **BC-A** or 0.15M_{FULL} for all other holds from the allowable seagoing cargo mass at that draft, subject to the minimum of M_{MIN}, where M_{MIN} is the minimum required seagoing cargo mass at a draft less than those values mentioned.

7.3.7 Hold Mass Curves

7.3.7(a) Hold mass curves, prepared based on the design loading criteria for local strength in 5C-3-A6/7.3.2 to 5C-3-A6/7.3.6 above, and showing maximum allowable and minimum required mass as a function of draft, are to be included in the loading manual and the loading instrument. The design loading criteria in 5C-3-A6/7.3.5 is not be used to prepare hold mass curves of dry cargo for a hold adapted for the carriage of water ballast.

7.3.7(b) Hold mass curves are to be prepared for each single hold, as well as for any two adjacent holds, each further divided into sea-going condition and during loading and unloading in harbor. [See 3-2-A3/5.1.1(c) and 3-2-A3/5.1.1(d)].

7.3.7(c) At drafts other than those specified in the design loading conditions above, the maximum allowable and minimum required mass is to be adjusted for the change in the buoyancy acting on the bottom as specified in the respective paragraphs.

7.3.7(d) Each hold mass curve is to contain instructions for use with varying amount of contents in double bottom tanks.

7.3.8 Quick Reference to 5C-3-A6/7.3

A quick reference to local loading conditions in 5C-3-A6/7.3 (except for ballast hold in 5C-3-A6/7.3.5) is shown in 5C-3-A6/Tables 2A and 2B. For detailed requirements, the respective text is to be referred to.

TABLE 2A
Cargo Hold Loads (5C-3-A6/7.3) – Single Hold

notation	*L or E*	*Cond'n*	*Maximum Allowable*			*Minimum Required*		
			summer draft (d)	*shallower draft*	*@*	*summer draft*	*shallower draft*	*@*
BC-A	Loaded Hold	at sea	5.2.1 (7.3.2a): $M_{FULL} + M_{DBF}$ 5.4.2 (7.3.4b): $M_{HD} + (0.1M_H) + M_{DBF}$	5.4.2 (7.3.4b): $M_{HD} + M_{DBF}$ *5.3.1 (7.3.3a): $M_{FULL} + M_{DBF}$	d_1 *0.67d	5.2.2 (7.3.2b): $0.5M_H$	5.2.3 (7.3.2c): 0 *5.3.2 (7.3.3b): 0	d_B *0.83d
		No MP		(at sea) - * marked req't			(at sea) - * marked req't	
		harbor		5.6.1 (7.3.6a): $M_{MAX} = M_{HD}(M_{FULL}) + M_{DBF}$ 5.6.3 (7.3.6c): (max @sea) = $0.15M_{MAX}$	0.67d <d,d_1,0.67d		5.6.3 (7.3.6c): (min @sea) – $0.15M_{MIN}$	>dB, 0.83d, 0.75d
	Empty Hold	at sea	5.2.1 (7.3.2a): $M_{FULL} + M_{DBF}$	*5.3.1 (7.3.3a): $M_{FULL} + M_{DBF}$	*0.67d	5.4.1 (7.3.4a): 0		
		No MP		(at sea) - * marked req't				
		harbor		5.6.1 (7.3.6a): $M_{MAX} = M_{HD}(M_{FULL}) + M_{DBF}$ 5.6.3 (7.3.6c): (max @sea) = $0.15M_{MAX}$	0.67d <d,d_1,0.67d			
BC-B		at sea	5.2.1 (7.3.2a): $M_{FULL} + M_{DBF}$	*5.3.1 (7.3.3a): $M_{FULL} + M_{DBF}$	*0.67d	5.2.2(7.3.2b): $0.5M_H$	5.2.3 (7.3.2c): 0 *5.3.2 (7.3.3b): 0	d_B *0.83d
		No MP		(at sea) - * marked req't			(at sea) - * marked req't	
		harbor		5.6.1 (7.3.6a): $M_{MAX} = M_{HD}(M_{FULL}) + M_{DBF}$ 5.6.3 (7.3.6c): (max @sea) = $0.15M_{MAX}$	0.67d <d,d_1,0.67d		5.6.3 (7.3.6c): (min @sea) – $0.15M_{MIN}$	>dB, 0.83d, 0.75d
BC-C		at sea	5.2.1 (7.3.2a): $M_{FULL} + M_{DBF}$	*5.3.1 (7.3.3a): $M_{FULL} + M_{DBF}$	*0.67d	5.2.2(7.3.2b): $0.5M_H$	5.2.3 (7.3.2c): 0 *5.3.2 (7.3.3b): 0	d_B *0.83d
		No MP		(at sea) - * marked req't			(at sea) - * marked req't	
		harbor		5.6.1 (7.3.6a): $M_{MAX} = M_{HD}(M_{FULL}) + M_{DBF}$ 5.6.3 (7.3.6c): (max @sea) = $0.15M_{MAX}$	0.67d <d,d_1,0.67d		5.6.3 (7.3.6c): (min @sea) – $0.15M_{MIN}$	>dB, 0.83d, 0.75d

TABLE 2B
Cargo Hold Loads (5C-3-A6/7.3) *(loads in each hold shown)*

notation	*L or E*	*Cond'n*	*Maximum Allowable*			*Minimum Required*		
			summer draft (d)	*shallower draft*	*@*	*summer draft*	*shallower draft*	*@*
BC-A	Two Loaded Holds	at sea	5.4.3 (7.3.4c): $M_{HD} + (0.1M_H) + M_{DBF}$ None, (7.3.2e): $M_{FULL} + M_{DBF}$	*5.3.3 (7.3.3c): $M_{FULL} + M_{DBF}$	*0.67d	None, (7.3.2f): $0.5M_H$	*5.3.4 (7.3.3d): 0	*0.75d
		No MP		(at sea) - * marked req't			(at sea) - * marked req't	
		harbor		5.6.2 (7.3.6b): $M_{FULL} + M_{DBF}$	0.67d			
	All Holds	at sea	None, (7.3.2e): $M_{FULL} + M_{DBF}$	*5.3.3 (7.3.3c): $M_{FULL} + M_{DBF}$	*0.67d		*5.3.4 (7.3.3d): 0	*0.75d
		No MP		(at sea) - * marked req't			(at sea) - * marked req't	
		harbor		5.6.2 (7.3.6b): $M_{FULL} + M_{DBF}$	0.67d			
BC-B		at sea	None, (7.3.2e): $M_{FULL} + M_{DBF}$	*5.3.3 (7.3.3c): $M_{FULL} + M_{DBF}$	*0.67d		*5.3.4 (7.3.3d): 0	*0.75d
		No MP		(at sea) - * marked req't			(at sea) - * marked req't	
		harbor		5.6.2 (7.3.6b): $M_{FULL} + M_{DBF}$	0.67d			
BC-C		at sea	None, (7.3.2e): $M_{FULL} + M_{DBF}$	*5.3.3 (7.3.3c): $M_{FULL} + M_{DBF}$	*0.67d		*5.3.4 (7.3.3d): 0	*0.75d
		No MP		(at sea) - * marked req't			(at sea) - * marked req't	
		harbor		5.6.2 (7.3.6b): $M_{FULL} + M_{DBF}$	0.67d			

PART

5C

CHAPTER 4 Vessels Intended to Carry Ore or Bulk Cargoes (Under 150 meters (492 feet) in Length)

CONTENTS

PART

5C

CHAPTER 4 **Vessels Intended to Carry Ore or Bulk Cargoes (Under 150 meters (492 feet) in Length)**

SECTION 1 **Introduction**

Note: Vessels with Freeboard Length L_f, as defined in 3-1-1/3.3, of 150 m (492 ft) or more are to comply with SOLAS Chapter XII. Part 5C, Chapter 3 of these Rules may be used for that purpose.

1 General

1.1 Classification

In accordance with 1-1-3/3, the classification ✠ **A1 Bulk Carrier** or ✠ **A1 Ore Carrier** is to be assigned to vessels designed for the carriage of bulk cargoes, or ore cargoes, and built to the requirements of this section and other relevant sections of the Rules. Where the vessel has been specially reinforced for the carriage of heavy-density cargoes, special loading arrangements, or both, it will be distinguished in the *Record* with a notation describing the special arrangements. Full particulars of the loading conditions and the maximum density of the cargoes to be provided for are to be given on the basic design drawings.

1.3 Application

These requirements are intended to apply to vessels having machinery aft, one deck and a complete or partial double bottom. They are intended to apply to vessels generally of welded construction, of usual form and having proportions in accordance with 3-1-2/7. They are applicable to vessels having longitudinal framing and that have topside tanks and side tanks, or two continuous longitudinal bulkheads. Transverse side framing will also be acceptable. These Rules are also intended to apply to other vessels of similar type and arrangement.

1.5 Arrangement

Watertight and strength bulkheads, in accordance with Section 3-2-9, are to be provided. Where this is impracticable, the transverse strength and stiffness of the hull is to be effectively maintained by deep webs or partial bulkheads. Where it is intended to carry liquid in any of the spaces, additional bulkheads or swash bulkheads may be required. Tank bulkheads are to be in accordance with the requirements of Section 3-2-10 or Section 5C-2-2, as appropriate. The depth of double bottom at the centerline is not to be less than the height for center girders, as obtained from Section 3-2-4. Tanks forward of the collision bulkhead are not to be arranged for the carriage of oil or other liquid substances that are flammable.

1.7 Scantlings

It is recommended that compliance with the following requirements be accomplished through detailed investigation of the magnitude and distribution of the imposed longitudinal and transverse forces by using an acceptable method of engineering analysis. Where the structural members are highly stressed, their stability characteristics are to be investigated. In any case, the following paragraphs are to be used as a guide in determining scantlings.

1.9 Higher-strength Materials

In general, applications of higher-strength materials for vessels intended to carry ore or bulk cargoes are to meet the requirements of this chapter, but may be modified generally in accordance with the following sections: Section 3-2-4 for deep longitudinal members, Section 3-2-4 and Section 3-2-7 for longitudinals, Section 3-2-10 for bulkhead plating, Section 3-2-2 for shell plating and Section 3-2-3 for deck plating

1.11 Protection of Structure

For the protection of structure, see 3-2-18/5.

3 Carriage of Oil Cargoes

3.1 General

Ore carriers and bulk carriers intended also for the carriage of oil cargoes, as defined in 5C-2-1/1, are to comply with the applicable parts of Section 5C-2-1 as well as this section.

3.3 Gas Freeing

Prior to and during the handling of bulk or ore cargoes, all spaces except slop tanks are to be free of cargo oil vapors.

3.5 Slop Tanks

Slop tanks are to be separated from spaces that may contain sources of vapor ignition by oiltight and adequately vented cofferdams, as defined in 5C-2-1/5.3, or by cargo oil tanks which are maintained gas free.

5 Special Requirements for Deep Loading

Bulk carriers or ore carriers to which freeboards are assigned based on the subdivision requirements of the International Convention on Load Lines, 1966, are to comply with those regulations.

7 Forecastle *(2004)*

7.1 General

These requirements apply to all bulk carriers, ore carriers and combination carriers. These vessels are to be fitted with an enclosed forecastle on the freeboard deck in accordance with the requirements in this section.

7.3 Arrangements *(2007)*

The forecastle is to be located on the freeboard deck with its aft bulkhead fitted in way or aft of the forward bulkhead of the foremost hold, as shown in 5C-4-1/Figure 1. However, if this requirement hinders hatch cover operation, the aft bulkhead of the forecastle may be fitted forward of the forward bulkhead of the foremost cargo hold provided the forecastle length is not less than $0.07L_f$ (L_f: see 3-1-1/3.3) abaft the forward perpendicular.

A breakwater is not to be fitted on the forecastle deck with the purpose of protecting the hatch coaming or hatch covers. If fitted for other purposes, it is to be located such that its upper edge at center line is not less than H_B /tan 20° forward of the aft edge of the forecastle deck, where H_B is the height of the breakwater above the forecastle (see 5C-4-1/Figure 1).

7.5 Dimensions

7.5.1 Heights

The forecastle height, H_F, above the main deck at side is to be not less than:

- The standard height of a superstructure as specified in the International Convention on Load Line 1966 and its Protocol of 1988, or
- H_C + 0.5 m, where H_C is the height of the forward transverse hatch coaming of cargo hold No. 1,

whichever is the greater.

7.5.2 Location of Aft Edge of Forecastle Deck

All points of the aft edge of the forecastle deck are to be located at a distance ℓ_F:

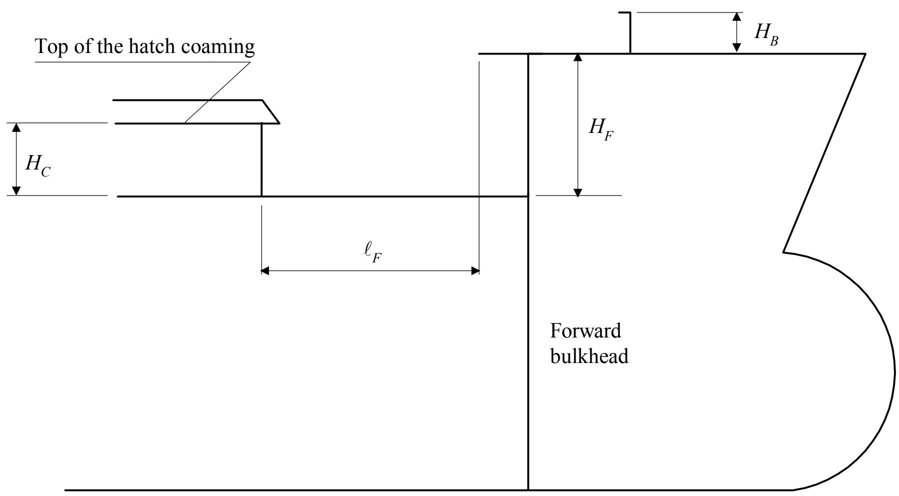
$$\ell_F \leq 5\sqrt{H_F - H_C}$$

from the No.1 hatch forward coaming plate in order to apply the reduced loading to the No. 1 forward transverse hatch coaming and No. 1 hatch cover in applying 5C-4-2/13.

7.7 Structural Arrangements and Scantlings

The structural arrangements and scantlings of the forecastle are to comply with the applicable requirements of 3-2-2/5.7, 3-2-5/5, 3-2-7/3, 3-2-11/1.3 and 3-2-11/9.

FIGURE 1



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PART

5C

CHAPTER 4 Vessels Intended to Carry Ore or Bulk Cargoes (Under 150 meters (492 feet) in Length)

SECTION 2 Hull Structure

1 Hull Girder Strength

1.1 Normal-strength Standard

The longitudinal hull girder strength is to be as required by the equations given in Section 3-2-1.

1.3 Hull Girder Shear and Bending Moments

For shear and bending moment calculation requirements, see Section 3-2-1.

1.5 Loading Guidance

Loading Guidance is to be as required by 3-2-1/7.

3 Transverse Bulkheads in Hold *(1995)*

Transverse bulkheads in holds are to be in accordance with 5C-4-1/1.5. For corrugated bulkheads, the distance, ℓ, between supporting members, may be measured between the upper and lower stools, except that the credit for upper stools of rectangular cross section is not to exceed twice the width of the cross section.

5 Shell Plating *(1 July 1998)*

Shell plating is to be not less in thickness than required by Section 3-2-1 and Section 3-2-2. In addition, the thickness of the side shell plating in way of cargo holds of single side skin bulk carriers is not to be less than given by:

$t_{min} = (L)^{1/2}$ mm $\qquad$ $t_{min} = 0.02175(L)^{1/2}$ in.

where L is the length of the vessel, as defined in 3-1-1/3.1, in m (ft).

7 Deck Plating

Deck plating is to be not less in thickness than required by Section 3-2-1 and Section 3-2-3.

9 Double-bottom and Tank Structure

9.1 General

The double bottom is generally to be arranged with a centerline girder, or equivalent, and full-depth side girders, in accordance with Section 3-2-4, except that the side girders are to be spaced approximately 3 m (10 ft). The scantlings of the double-bottom structure are to be in accordance with Section 3-2-4, except as modified in this section. Increases may be required when cargo is to be carried in alternate holds. It is recommended that the depth of double bottom forward be increased where subject to slamming forces and that unnecessary openings in the floors and girders be avoided. See also 5C-4-1/1.5. Where ducts forming a part of the double bottom structure are used as a part of the piping system for transferring cargo oil or ballast, the structural integrity of the duct is to be safeguarded by suitable relief valves or other arrangement to limit the pressure in the system to the value for which it is designed. See also 5C-4-1/1.5.

9.3 Floors and Transverses

In general, transverse floors under the cargo holds are to be spaced not more than 3 m (10 ft) and their thickness is to be as required by Section 3-2-4. Closely spaced transverses or floors fitted in the lower wing tanks are to have thickness as required by 3-2-4/5 for floors, intercostals and brackets elsewhere.

9.5 Bottom Longitudinals and Side Tank Framing

Bottom longitudinals are to be in accordance with 3-2-4/11.3. Side members in lower wing tanks or side tanks in bulk carriers, as well as shell frames and longitudinal bulkhead-stiffeners in ore carriers, are to have a section modulus *SM* not less than that obtained from the following equation:

$SM = 7.8chs\ell^2$ cm^3 $\qquad$ $SM = 0.0041chs\ell^2$ in^3

where

c = 1.00 for vertical side shell frames and vertical stiffeners on bulkheads

= 0.95 for side shell longitudinals

= 0.90 for horizontal stiffeners on bulkheads

h = for frames, the distance, in m (ft), from the longitudinal or from the middle of ℓ for vertical members, to the load line, or to a point located two-thirds of the distance from the keel to the bulkhead or freeboard deck, whichever is greater.

= for bulkhead stiffeners, the distance measured to a point located two-thirds of the distance from the top of the tank to the top of the overflow, and in no case is h to be less than the distance measured to a point located above the top of the tank as given in column (e) of 3-2-7/Table 1, appropriate to the vessel's length

s = spacing of the members, in m (ft)

ℓ = length of unsupported span, in m (ft)

Longitudinals around the bilge are to be graded in size from that required for the lowest side longitudinal to that required for bottom longitudinals. Shell longitudinals are to be at least as required by Section 3-2-9 or Section 3-2-10 for bulkhead stiffeners and by 3-2-5/3.17 for side longitudinals.

9.7 Inner-bottom Longitudinals

The section modulus *SM* of each inner-bottom longitudinal is not to be less than 85% of that required for bottom longitudinals, nor is to be less than that obtained from the following equation:

$SM = kcnhs\ell^2$ cm³ (in³)

where

k	=	7.8 (0.0041)		
c	=	1.12 for vessels intended for bulk cargo		
	=	1.75 for vessels specially reinforced for ore cargo or for loading in alternate holds		
n	=	0.40 (1 + V/1041)	for vessels intended for bulk cargo	*SI and MKS Units*
	=	V/2403	for vessels specially reinforced for ore cargo or for loading in alternate holds	
	=	0.40 (1 + V/65)	for vessels intended for bulk cargo	*US Units*
	=	V/150	for vessels specially reinforced for ore cargo or for loading in alternate holds	

In no case is n to be less than 0.80.

V = cargo deadweight, in kg (lb), divided by the total volume of the holds, in m³ (ft³). Where the cargo is not uniformly distributed in all holds, the value of V is to be checked for each hold [cargo deadweight of each hold, in kg (lb), divided by the volume of the hold, in m³ (ft³)], and where in any one hold it exceeds the mean value calculated as directed above, the longitudinals of that hold are to be increased accordingly.

h = distance, in m (ft), from the inner bottom to the deck at centerline, or for inner bottom longitudinals located directly under upper wing tanks to the underside of the upper wing tank.

s = spacing of longitudinals, in m (ft)

ℓ = spacing of the floors, in m (ft)

9.9 Inner-bottom Plating

The inner-bottom plating is to be not less than required by 3-2-4/9.1 and 3-2-4/9.3 and is to be flush throughout the cargo space.

Where ore or heavy bulk cargoes are carried or where cargo is handled by grabs, the requirements of 3-2-4/9.1 are to be suitably increased, but the increase need not exceed 5 mm (0.20 in.).

For vessels specially designed as ore carriers, it is recommended that the minimum thickness of inner bottom be 19 mm (0.75 in.) at 510 mm (20 in.) spacing of longitudinals.

9.11 Tank Bulkhead Plating

The thickness of the transverse and longitudinal bulkheads of side or wing tanks is not to be less than that required by 3-2-10/3.1 for the spacing of stiffeners and the distance h, in m (ft), measured from the lower edge of the plating to a point located at two-thirds of the distance from the top of the tank to the top of the overflow. In no case is h to be less than the distance measured to a point located above the top of the tank as given in column (e) of 3-2-7/Table 1, appropriate to the vessel's length.

For vessels intended to carry cargo oil, the thickness of the transverse or longitudinal bulkheads of side or wing tanks is to be not less than required by 5C-2-2/7.1.

Where a sloped part of the tank bulkhead plating is within or near the line of the cargo hatch, it is recommended that the part of the sloping bulkhead within or near the line of the cargo hatch be suitably reinforced.

9.13 Lower Wing Tank Stiffeners

The section modulus for each stiffener on the lower wing tank bulkheads is to be in accordance with 5C-4-2/9.5, or as determined by the equation in 5C-4-2/9.7, except that for the latter, h is to be measured from the longitudinal or, in the case of vertical stiffeners, from the middle of ℓ.

9.15 Transverse Webs

Each transverse web in the lower wing tanks, where fitted in bulk carriers, is to have a section modulus SM not less than that obtained from the following equation:

$SM = 4.74chs\ell^2$ cm^3 $\qquad$ $SM = 0.0025chs\ell^2$ in^3

where

c = 1.5 for side-shell, bottom-shell and wing-tank bulkheads.

s, h, ℓ are as defined under 5C-4-2/9.5

Transverse webs are to be in line with the solid floors and are to have depths of not less than 0.145ℓ (1.75 in/ft of span ℓ). In general, the depth is to be not less than two times the depth of the slots. See also 5C-4-2/9.3.

9.17 Carriage of Water Ballast or Liquid Cargoes in Cargo Holds

Where a cargo hold is intended to be used for the carriage of water ballast or liquid cargoes, the hold is in general to be assumed completely filled and the scantlings of the inner bottom, side structure, transverse bulkheads, deck and hatch covers are also to be in accordance with Section 3-2-10. The hatch cover and securing devices are to be suitable for the internal loading. See 3-2-15/9.

Special consideration may be given to the scantlings of cargo holds partially filled with water ballast or liquid cargoes, and full particulars are to be submitted.

11 Framing

11.1 Transverse Hold Framing *(1 July 1998)*

11.1.1 Frames

Transverse hold frames are to meet the requirements in Section 3-2-5, as modified below.

For a bulk carrier having upper and lower wing tanks with adequately spaced transverse strength bulkheads, the section modulus SM is not to be less than that obtained from the following equation.

$SM = 3.5sh_1\ell^2$ cm^3 $\qquad$ $SM = 0.00185sh_1\ell^2$ in^3

where

h_1 = $h + P$

s = frame spacing, in m (ft)

ℓ = unsupported span of frames, in m (ft), as indicated in 5C-4-2/Figure 1

h = vertical distance, in m (ft), from the middle of ℓ to the load line

P = $C_1(1.09 - 0.65h/d)$ m

= $3.28C_1(1.09 - 0.65h/d)$ ft

C_1 = as defined in 3-2-1/3.5.1

d = molded draft, as defined in 3-1-1/9

The web depth to thickness ratio is to comply with the requirements of 5C-1-A2/11.9.

The ratio of outstanding flange breadth to thickness is not to exceed $10\sqrt{Q}$ where Q is as defined in 3-2-1/5.5.

11.1.2 Frame Brackets *(1998)*

11.1.2(a) The section modulus SM_E of the frame and bracket measured at the heels of the frame attachment is to be at least 2.0 times the *SM* required by 5C-4-2/11.1.1 above. See 5C-4-2/Figure 1.

11.1.2(b) Side frames of higher tensile steels are to be symmetrical sections with integral upper and lower brackets. The brackets are to be soft toed.

The flange of the frame is to be curved (not knuckled) at the transition to the integral brackets and the radius of curvature is not to be less than r, in mm (in.), given by:

$r = 0.4\, b_f^2/t_f$

where

t_f = flange thickness of the bracket, in mm (in.)

b_f = flange width, in mm (in.)

11.1.2(c) Where frames and brackets are of ordinary strength steel, the frames may be asymmetric or rolled sections and fitted with separate brackets. The brackets are to be soft toed at their heels and the face plate or flange sniped at both ends.

11.1.2(d) Integral or separate frame brackets are to extend at least for a length of $0.125h_3$ onto the frame, and the depth of the bracket plus frame measured at the heel of the frame is generally to be at least 1.5 times that of the frame. Where the hull form renders this impracticable, equivalent strength in shear and bending is to be provided. The brackets are to be arranged with "soft" toes. See 5C-4-2/Figure 2 and 5C-4-2/Figure 3.

11.1.3 Minimum Thickness

11.1.3(a) Frames and Upper Brackets. The thickness of upper brackets and the web portions of the frames are not to be less than that obtained from the following equations:

$t = 0.03L_1 + 7$ mm

$t = 0.00036L_1 + 0.28$ in.

L_1 = scantling length of the vessel, in m (ft), as defined in 3-1-1/3.1

In the foremost cargo hold, the thickness given in 5C-4-2/11.1.3(a) above is to be increased by a factor of 1.15.

11.1.3(b) Lower Brackets. The thickness of the brackets at the lower end of frames is to be at least 2 mm (0.08 in.) greater than the minimum thickness of web portions of frames required by 5C-4-2/11.1.3(a) above or the actual thickness of the web of the frame being supported, whichever is greater.

11.1.4 Supporting Brackets

Brackets are to be fitted in the lower and upper wing tanks in line with every side frame. These brackets are to be stiffened against buckling.

11.1.5 Longitudinals at the Toe of Brackets

The section moduli of side longitudinals and sloping bulkhead longitudinals at the toe of brackets are to be determined as per 5C-4-2/9.5, 5C-4-2/9.13 and 5C-4-2/11.3, with length ℓ equal to the unsupported span between transverses and spacing s equal to "b", as indicated in 5C-4-2/Figure 3.

11.1.6 Tripping Brackets

When the frames in the foremost hold are asymmetric sections, tripping brackets are to be fitted at every two frames at approximately mid-span, as shown in 5C-4-2/Figure 4.

11.1.7 Side Frame Aft of Collision Bulkhead

In order to prevent large relative deflection of the side shell plating, e.g., panels just aft of the collision bulkhead, the section modulus of the first two frames aft of this bulkhead is to be at least 2.5 times the requirement in 5C-4-2/11.1.1 above. Other means of achieving this, such as brackets in line with forepeak structures, will be considered.

11.3 Upper Wing Tank Framing

Each structural section for the side shell and wing tank stiffener and deck longitudinal in way of upper wing tanks is to have a section modulus SM not less than that obtained from the following equation:

$SM = 7.8chs\ell^2$ cm^3 $\qquad$ $SM = 0.0041chs\ell^2$ in^3

where

c = 0.95 for side-shell longitudinals

= 0.90 for bulkhead longitudinals

= 1.00 for vertical side frames and bulkhead stiffeners

= 1.05 for deck longitudinals

h = distance, in m (ft), from the center of the area supported to a point located two-thirds of the distance from the top of the tank to the top of the overflow, and in no case is h to be less than the distance measured to a point located above the top of the tank, as given in column (e) of 3-2-7/Table 1, appropriate to the vessel's length, except for deck members where column (a) of 3-2-7/Table 1 applies

s = spacing of member, in m (ft)

ℓ = unsupported span, in m (ft)

11.5 Transverse Webs

Each transverse web in the upper wing tanks, where fitted, is to have a section modulus SM not less than that obtained from the following equation:

$SM = 4.74chs\ell^2$ cm^3 $\qquad$ $SM = 0.0025chs\ell^2$ in^3

where

c = 1.50 for shell and sloping-bulkhead webs and deck transverses

s, h, ℓ are as defined under 5C-4-2/11.3.

The webs in the upper wing tanks are to have depths of not less than 0.0832ℓ (1 in. per ft of span). Thickness is to be not less than 1 mm per 100 mm (0.01 in. per in.) of depth plus 4 mm (0.16 in.), but is to be not less than 8 mm (0.31 in.) and need not exceed 11 mm (0.44 in.). In general, the depth is to be not less than twice the depth of the slots.

13 Cargo Hold Hatch Covers, Coamings and Closing Arrangements *(2004)*

13.1 General

On all bulk carriers, ore carriers and combination carriers, all cargo hold hatch covers, hatch coamings and closing arrangements for cargo hold hatches in position 1, as defined in 3-2-15/3.1, are to meet the requirements in 5C-3-4/19 using the design pressures as indicated in 5C-4-2/13.3.

13.3 Hatch Cover Design Pressures

The following hatch cover design pressure, p, is to be used in conjunction with 5C-3-4/19:

For ships of 100 m (328 ft) in length and above:

$$p = p_0 + (p_{FP} - p_0)(0.25 - x/L_f)/0.25 \qquad \text{kN/m}^2 \text{ (tf/m}^2\text{, Ltf/ft}^2\text{)}$$

For ships less than 100 m (328 ft) in length:

$$p = R\{15.8 + (L_f/N)[1 - (5/3)(x/L_f)] - 3.6x/L_f\} \qquad \text{kN/m}^2 \text{ (tf/m}^2\text{, Ltf/ft}^2\text{)}$$

where

p_0 = 34.3 (3.5, 0.32) kN/m^2 (tf/m^2, Ltf/ft^2)

p_{FP} = pressure at the forward perpendicular

= $49.0 + a(L_f - 100)$ kN/m^2 for L_f in meters

= $5 + a(L_f - 100)$ tf/m^2 for L_f in meters

= $0.457 + a(L_f - 328)$ Ltf/ft^2 for L_f in feet

a = 0.0726 (0.0074, 0.000206) kN/m^2 (tf/m^2, Ltf/ft^2), for type B freeboard ships

= 0.356 (0.0363, 0.00101) kN/m^2 (tf/m^2, Ltf/ft^2), for ships with reduced freeboard

L_f = freeboard length, in m (ft), as defined in 3-1-1/3.3

x = distance, in m (ft), from the mid length of the hatch cover under examination to the forward end of L_f, or $0.25L_f$, whichever is less.

R = 1.0 (0.102, 0.00932)

N = 3 (3, 9.84)

For ships of 100 m (328 ft) in length and above, where a position 1 hatchway is located at least one superstructure standard height higher than the freeboard deck, the pressure p may be 34.3 kN/m^2 (3.5 tf/m^2, 0.32 Ltf/ft^2).

Special consideration is to be given for design pressures of ships less than 24 m (79 ft).

15 Testing

Requirements for testing are contained in Section 3-7-1.

17 Self-unloading Gear

Requirements for self-unloading gear are contained in 5C-3-7/7.

FIGURE 1
Length of Hold Frame *(1 July 1998)*

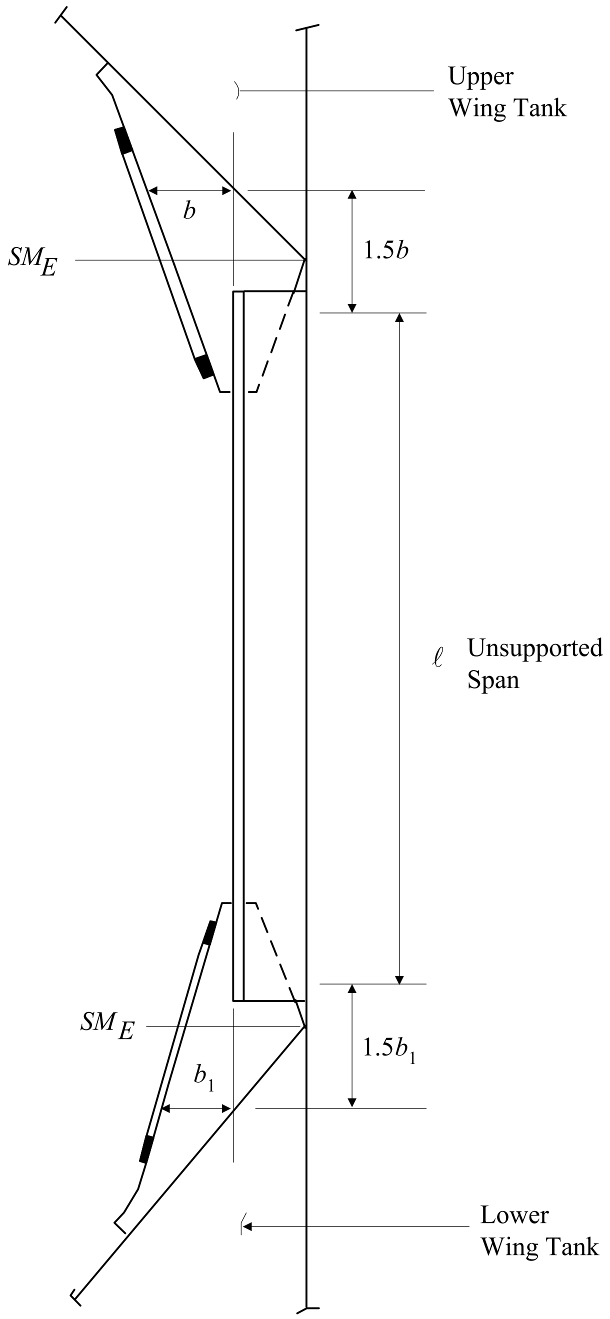


FIGURE 2 *(1 July 1998)*

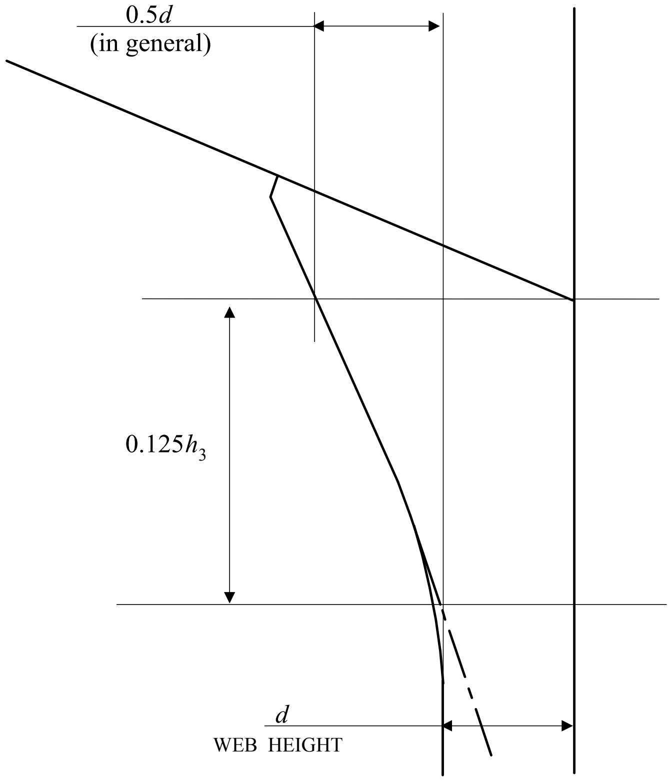


FIGURE 3 *(1 July 1998)*

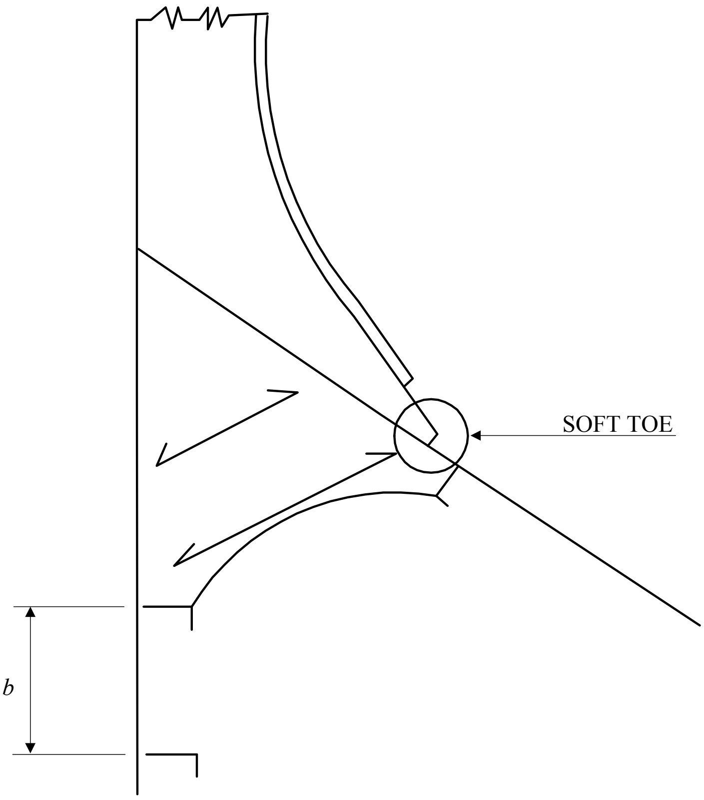
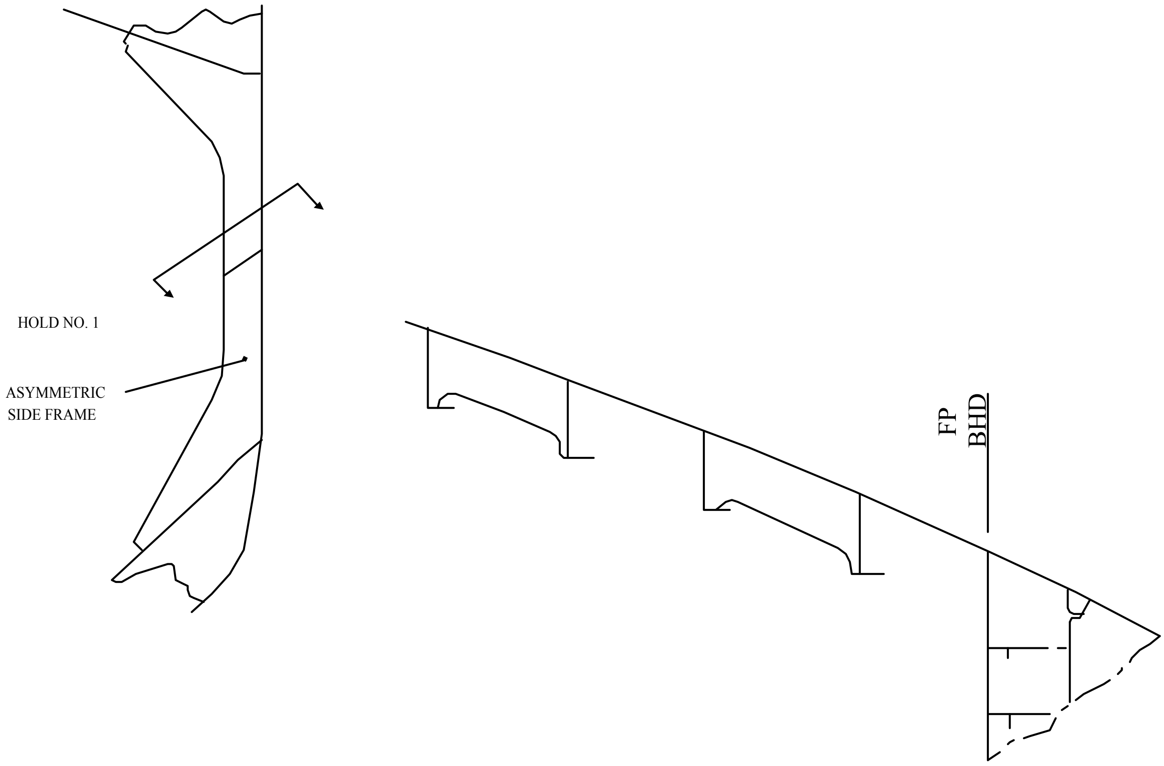


FIGURE 4 *(1 July 1998)*



PART

5C

CHAPTER 4 Vessels Intended to Carry Ore or Bulk Cargoes (Under 150 meters (492 feet) in Length)

SECTION 3 Cargo Safety and Vessel Systems

See Section 5C-3-7.

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PART

5C

CHAPTER **5 Vessels Intended to Carry Containers (130 meters (427 feet) to 450 meters (1476 feet) in Length)**

CONTENTS

PART

5C

CHAPTER 5 Vessels Intended to Carry Containers (130 meters (427 feet) to 450 meters (1476 feet) in Length)

SECTION 1 Introduction

1 General

1.1 Classification *(1 July 2001)*

In accordance with 1-1-3/3 and 1-1-3/25, the classification notation ✠ **A1 Container Carrier, SH, SHCM** is to be assigned to vessels designed primarily for the carriage of containers in holds or on deck or both, with structures for that purpose, such as cell guides, pedestals, etc., and built to the requirements of this Chapter and other relevant Sections of the Rules.

1.2 Optional Class Notation for Design Fatigue Life *(2003)*

Vessels designed and built to the requirements in this Chapter are intended to have a structural fatigue life of not less than 20 years. Where a vessel's design calls for a fatigue life in excess of the minimum design fatigue life of 20 years, the optional class notation **FL (year)** will be assigned at the request of the applicant. This optional notation is eligible, provided the excess design fatigue life is verified to be in compliance with the criteria in Appendix 1 of this Chapter, "Guide for Fatigue Strength Assessment of Container Carriers." Only one design fatigue life value is published for the entire structural system. Where differing design fatigue life values are intended for different structural elements within the vessel, the **(year)** refers to the least of the varying target lives. The 'design fatigue life' refers to the target value set by the applicant, not the value calculated in the analysis.

The notation **FL (year)** denotes that the design fatigue life assessed according to Appendix 1 of this Chapter is greater than the minimum design fatigue life of 20 years. The **(year)** refers to the fatigue life equal to 25 years or more (in 5-year increments), as specified by the applicant. The fatigue life will be identified in the *Record* by the notation **FL (year)**; e.g., **FL(30)** if the minimum design fatigue life assessed is 30 years.

1.3 Application *(1998)*

1.3.1 Size and Proportions *(1 July 2005)*

The requirements contained in this Chapter are applicable to container carriers in the range of 130 to 450 meters (427 to 1476 feet) in length, having proportions within the range as specified in 3-2-1/1 and are intended for unrestricted service.

1.3.2 Vessel Types

The equations and formulae for determining design load and strength requirements as specified in Section 5C-5-3 and Section 5C-5-4 are applicable to container carriers with either double-sided or single-sided construction. In general, the strength assessment procedure and failure criteria as specified in Section 5C-5-5 are applicable to all types of container carriers.

1.3.3 Direct Calculations *(1 July 2005)*

For a vessel with length greater than 250 meters (820 feet), the torsional response and critical structural details beyond $0.4L$ amidships are to be evaluated using a full ship finite element model unless a proven design or an equivalent analysis result is available.

For a vessel with length in excess of 350 meters (1148 feet), the hull structure and critical structural details are to comply with the requirements of the Dynamic Loading Approach and Spectral Fatigue Analysis. For analysis using the Dynamic Loading Approach, acceptance of an equivalent method can be considered by the Bureau. The vessel will be identified in the *Record* by the notations **SH-DLA** and **SFA**.

Direct calculations with respect to the determination of design loads and the establishment of alternative strength criteria based on first principles will be accepted for consideration, provided all the supporting data, analysis procedures and calculated results are fully documented and submitted for review. In this regard, due consideration is to be given to the environmental conditions, probability of occurrence, uncertainties in load and response predictions, and reliability of the structure in service. For long term prediction of wave loads, realistic wave spectra covering the North Atlantic Ocean and a probability level of 10^{-8} are to be employed.

1.3.4 SafeHull Construction Monitoring Program *(1 July 2001)*

For the class notation **SH, SHCM,** a Construction Monitoring Plan for critical areas, prepared in accordance with the requirements of Part 5C, Appendix 1, is to be submitted for approval prior to comencement of fabrication. See Part 5C, Appendix 1 "Guide for SafeHull Construction Monitoring Program."

1.5 Arrangement

Strength bulkheads or combined deep webs and substantial partial bulkheads are to be provided in accordance with 3-2-9/1.7. Upper wing torsional boxes or double hull side construction are to be provided in way of container holds having wide deck openings.

1.7 Submission of Plans

In addition to the plans listed elsewhere in the Rules (see Section 1-1-7), the following plans are to be submitted. Stowage arrangement of containers including stacking loads and height. Location of container supports and their connection to hull.

3 Section Properties of Structural Members *(1 July 2008)*

The geometric properties of structural members may be calculated directly from the dimensions of the section and the associated effective plating (see 3-1-2/13.3 or 5C-5-4/Figure 6, as applicable). For structural members with angle θ between web and associated plating not less than 75 degrees, the section modulus, web sectional area and moment of inertia of the "standard" (θ = 90 degrees) section may be used without modification. Where the angle θ is less than 75 degrees, the sectional properties are to be directly calculated about an axis parallel to the associated plating. (See 5C-5-1/Figure 1)

For longitudinals, frames and stiffeners, the section modulus may be obtained by the following equation:

$$SM = \alpha_\theta SM_{90}$$

where

α_θ = $1.45 - 40.5/\theta$

SM_{90} = the section modulus at θ = 90 degrees

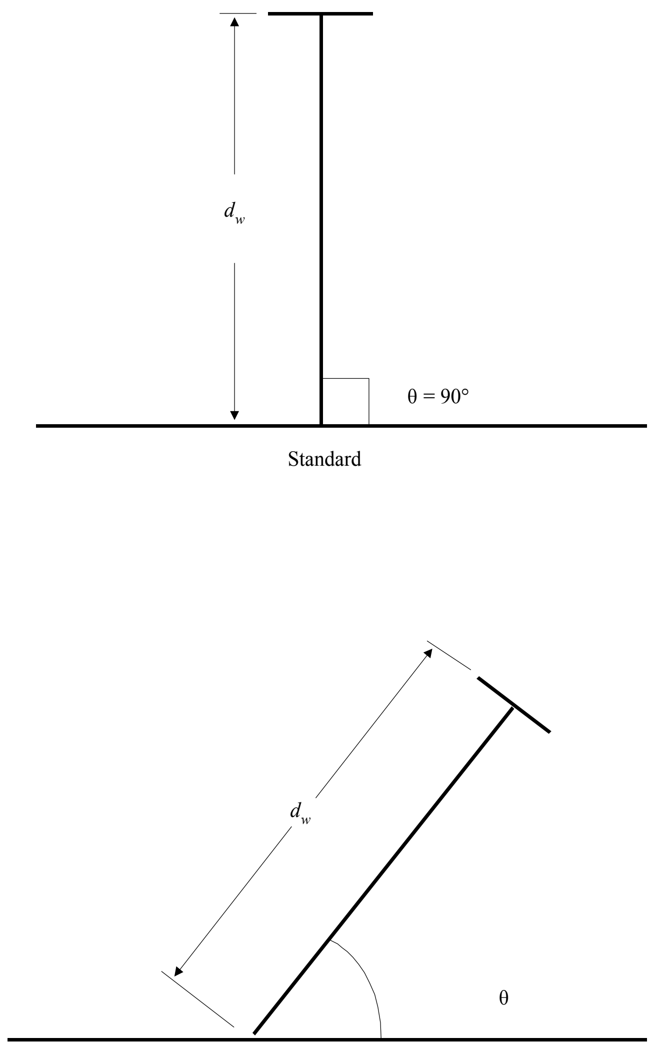
The effective section area may be obtained from the following equation:

$$A = A_{90} \sin \theta$$

where

A_{90} = effective shear area at θ = 90 degrees

FIGURE 1 *(1998)*



PART

5C

CHAPTER **5 Vessels Intended to Carry Containers (130 meters (427 feet) to 450 meters (1476 feet) in Length)**

SECTION **2 Design Considerations and General Requirements**

1 General Requirements *(1998)*

1.1 General *(1998)*

The strength requirements specified in this Chapter are based on a "net" ship approach. In determining compliance with the required scantlings, and performing structural analyses and strength assessments, the nominal design corrosion values given in 5C-5-2/Table 1 are to be deducted from the offered scantlings.

1.3 Initial Scantling Requirements *(1998)*

The initial plating thicknesses, section moduli of longitudinals/stiffeners and the scantlings of the main supporting structures are to be determined in accordance with Section 5C-5-4 for the "net" ship for further assessment, as required in the following paragraph. The relevant nominal design corrosion values are then added to obtain the full scantling requirements.

1.5 Strength Assessment-Failure Modes *(1998)*

A total assessment of the structures determined on the basis of the initial strength criteria in Section 5C-5-4 is to be carried out against the following three failure modes.

1.5.1 Material Yielding

The calculated stress intensities are not to be greater than the yielding state limit given in 5C-5-5/3 for all load cases specified in 5C-5-3/9.

1.5.2 Buckling and Ultimate Strength

For each individual member, plate or stiffened panel, the buckling and ultimate strength are to be in compliance with the requirements specified in 5C-5-5/5. In addition, the hull girder ultimate strength is to be in accordance with 5C-5-5/5.13.

1.5.3 Fatigue

The fatigue strength of structural details and welded joints in highly stressed regions is to be in accordance with 5C-5-5/7.

1.7 Structural Redundancy and Residual Strength *(1998)*

Consideration is to be given to structural redundancy and hull girder residual strength in the early design stages.

Vessels which have been built in accordance with the procedures and criteria for calculating and evaluating the residual strength of hull structures in the ABS *Guide for Assessing Hull-Girder Residual Strength*, in addition to other requirements of these Rules, will be classed and distinguished in the *Record* by the symbol **RES** placed after the appropriate hull classification notation.

3 Nominal Design Corrosion Values (NDCV) *(1998)*

As indicated in 5C-5-2/1.1, the strength criteria specified in this Chapter are based on a "net" ship approach, wherein the nominal design corrosion values are deducted.

The "net" thickness or scantlings correspond to the minimum strength requirements acceptable for classification, regardless of the design service life of the vessel. In addition to the coating protection specified in the Rules, minimum corrosion values for plating and structural members, as given in 5C-5-2/Table 1 and 5C-5-2/Figure 1, are to be applied. These minimum corrosion values are being introduced solely for the above purpose, and are not to be construed as renewal standards.

In view of the anticipated higher corrosion rates for structural members in some regions, such as highly stressed areas, it is advisable to consider additional design margins for the primary and critical structural members to minimize repairs and maintenance costs. The beneficial effects of these design margins on reduction of stresses and increase of the effective hull girder section modulus can be appropriately accounted for in the design evaluation.

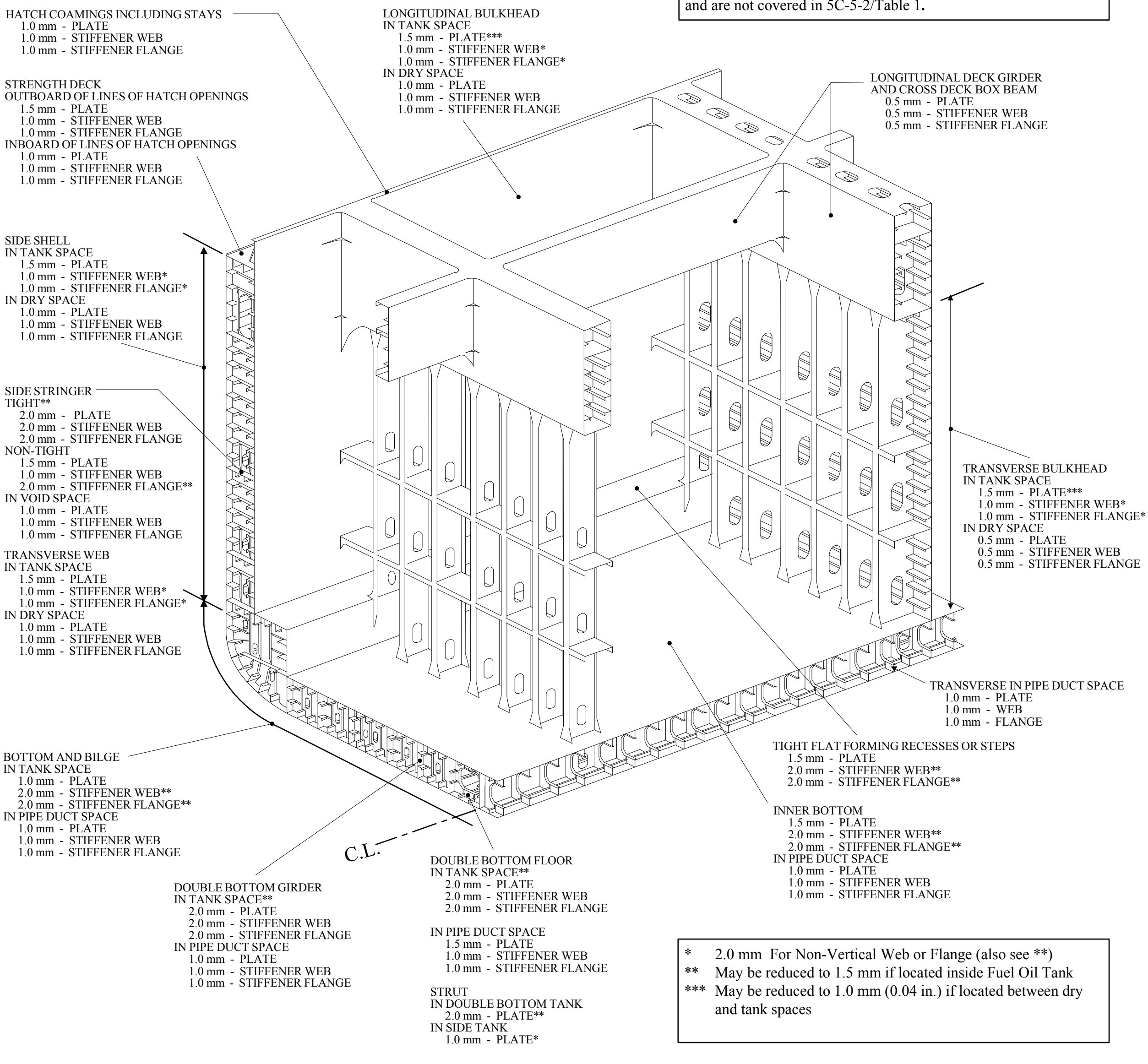
FIGURE 1
Nominal Design Corrosion Values (NDCV) *(2007)*

NOTES

1) In splash zone (1.5 meters down from 2nd deck), use uniform corrosion value of 2.0 mm (0.08 in.) for all internal members within this zone. Boundary plating of tank is considered according to 5C-5-2/Table 1.

2) It is recognized that corrosion depends on many factors including coating properties, cargo and temperature of carriage and that actual wastage rates observed may be appreciably different from those given here.

3) Pitting and grooving are regarded as localized phenomena and are not covered in 5C-5-2/Table 1.



* 2.0 mm For Non-Vertical Web or Flange (also see **)
** May be reduced to 1.5 mm if located inside Fuel Oil Tank
*** May be reduced to 1.0 mm (0.04 in.) if located between dry and tank spaces

TABLE 1
Nominal Design Corrosion Values (NDCV) for Container Carriers *(2007)*

Structural Element/Location		*Nominal Design Corrosion Values in mm (in.)*		
		Plate	*Attached Stiffeners* *Web*	*Attached Stiffeners* *Flange*
Strength Deck	Outboard of Lines of Hatch Openings	1.5 (0.06)	1.0 (0.04)	1.0 (0.04)
	Inboard of Lines of Hatch Openings	1.0 (0.04)	1.0 (0.04)	1.0 (0.04)
Side Shell	In Tank Space	1.5 (0.06)	1.0 (0.04) *	1.0 (0.04) *
	In Dry Space	1.0 (0.04)	1.0 (0.04)	1.0 (0.04)
Bottom and Bilge	In Tank Space	1.0 (0.04)	2.0 (0.08) **	2.0 (0.08) **
	In Pipe Duct Space	1.0 (0.04)	1.0 (0.04)	1.0 (0.04)
Inner Bottom	In Tank Space	1.5 (0.06)	2.0 (0.08) **	2.0 (0.08) **
	In Pipe Duct Space	1.0 (0.04)	1.0 (0.04)	1.0 (0.04)
Longitudinal Bulkhead	In Tank Space	1.5 (0.06) ***	1.0 (0.04) *	1.0 (0.04) *
	In Dry Space	1.0 (0.04)	1.0 (0.04)	1.0 (0.04)
Transverse Bulkhead (except for Cross Deck Box Beam)	In Tank Space	1.5 (0.06) ***	1.0 (0.04) *	1.0 (0.04) *
	In Dry Space	0.5 (0.02)	0.5 (0.02)	0.5 (0.02)
Transverse Web	In Tank Space	1.5 (0.06)	1.0 (0.04) *	1.0 (0.04) *
	In Dry Space	1.0 (0.04)	1.0 (0.04)	1.0 (0.04)
Tight Flat forming Recesses or Steps (except 2nd deck)		1.5 (0.06)	2.0 (0.08) **	2.0 (0.08) **
Side Stringer	Tight **	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)
	Non-Tight	1.5 (0.06)	1.0 (0.04)	2.0 (0.08) **
	In Void Space	1.0 (0.04)	1.0 (0.04)	1.0 (0.04)
Double Bottom Girder	In Tank **	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)
	In Pipe Duct Space	1.0 (0.04)	1.0 (0.04)	1.0 (0.04)
Double Bottom Floor	In Tank **	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)
	In Pipe Duct Space	1.0 (0.04)	1.0 (0.04)	1.0 (0.04)
Transverse in Pipe Duct Space		1.5 (0.06)	1.0 (0.04)	1.0 (0.04)
Longitudinal Deck Girder and Box Beam		0.5 (0.02)	0.5 (0.02)	0.5 (0.02)
Hatch Coamings including Stays		1.0 (0.04)	1.0 (0.04)	1.0 (0.04)
Hatch Cover		1.0 (0.04)	1.0 (0.04)	1.0 (0.04)
Strut	In Double Bottom Tank	--	2.0 (0.08) **	
	In Side Tank	--	1.0 (0.04) *	

* 2.0 mm (0.08 in.) for non vertical members (also see ***)

** May be reduced to 1.5 mm (0.06 in.) if located inside fuel oil tank

*** May be reduced to 1.0 mm (0.04 in.) if located between dry and tank spaces

Notes:

1. In splash zone (1.5 meters down from 2nd deck), use uniform corrosion value of 2.0 mm (0.08 in.) for all internal members within this zone. Boundary plating of tank is considered according to the above table.
2. It is recognized that corrosion depends on many factors including coating properties, cargo and temperature of carriage and that actual wastage rates observed may be appreciably different from those given here.
3. Pitting and grooving are regarded as localized phenomena and are not covered in this table.

PART

5C

CHAPTER **5 Vessels Intended to Carry Containers (130 meters (427 feet) to 450 meters (1476 feet) in Length)**

SECTION **3 Load Criteria**

1 General

1.1 Load Components *(1998)*

In the design of the hull structure of container carriers, all load components with respect to the hull girder and local structure as specified in this Chapter and Section 3-2-1 are to be taken into account. These include static loads in still water, wave-induced hull girder loads, wave-induced internal and external loads, slamming, impact loads and other loads, where applicable.

3 Static Loads *(1998)*

The sign convention for bending, M_H, and torsional moments, T_S, and shear forces, F_H, is as follows in 5C-5-3/Figure 1.

3.1 Still-water Bending Moments, Shear Forces and Torsional Moment *(1 July 2005)*

For still-water bending moment and shear force calculations, see 3-2-1/3.3.

Envelope curves are also to be provided for the still-water bending moments (hogging and sagging) and shear forces (positive and negative).

Except for special loading cases, the loading patterns shown in 5C-5-3/Figure 3 are to be considered in determining local static loads.

Still-water torsional moment due to uneven distribution of cargo and other weights is to be considered. Unless the maximum still-water torsional moment is specified in the loading manual, the following equation may be used to calculate still-water torsional moment amidships:

$$T_S = \pm\, k\, B\, W_T \quad \text{kN-m (tf-m, Ltf-ft)}$$

where

k = 0.004

B = breadth of vessel, as defined in 3-1-1/5, in m (ft)

W_T = maximum total container weight of vessel, kN (tf, Ltf)

The sign convention for bending, M_H, and torsional moments, T_S, and shear forces, F_H, is shown in 5C-5-3/Figure 1.

The still-water torsional moment along the length of the vessel L may be obtained by multiplying the midship value by the distribution factor m_T as given in 5C-5-3/Figure 6.

FIGURE 1
Sign Conventions

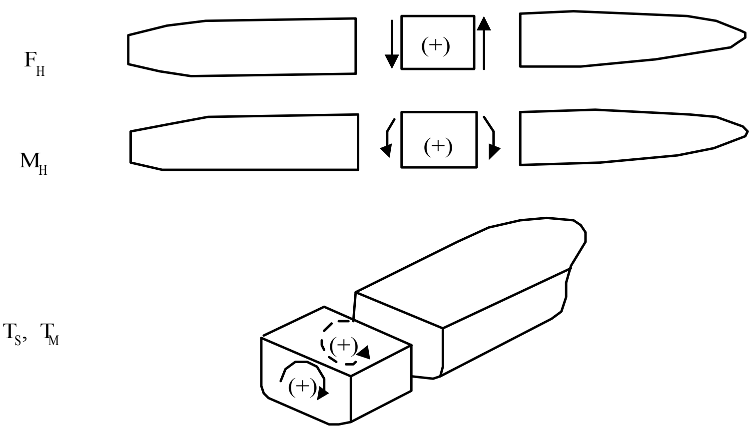


FIGURE 2
Distribution Factor f_{MV}

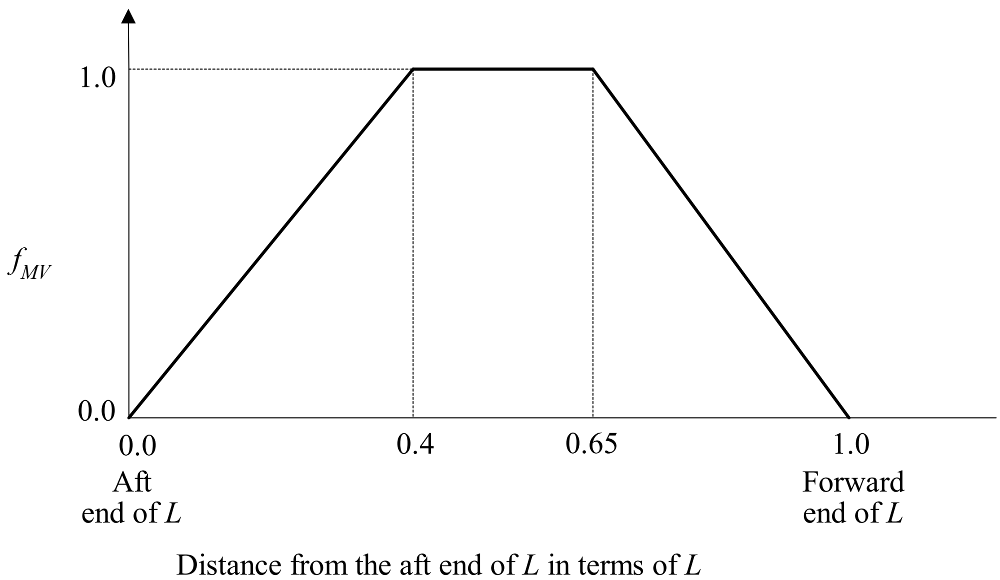
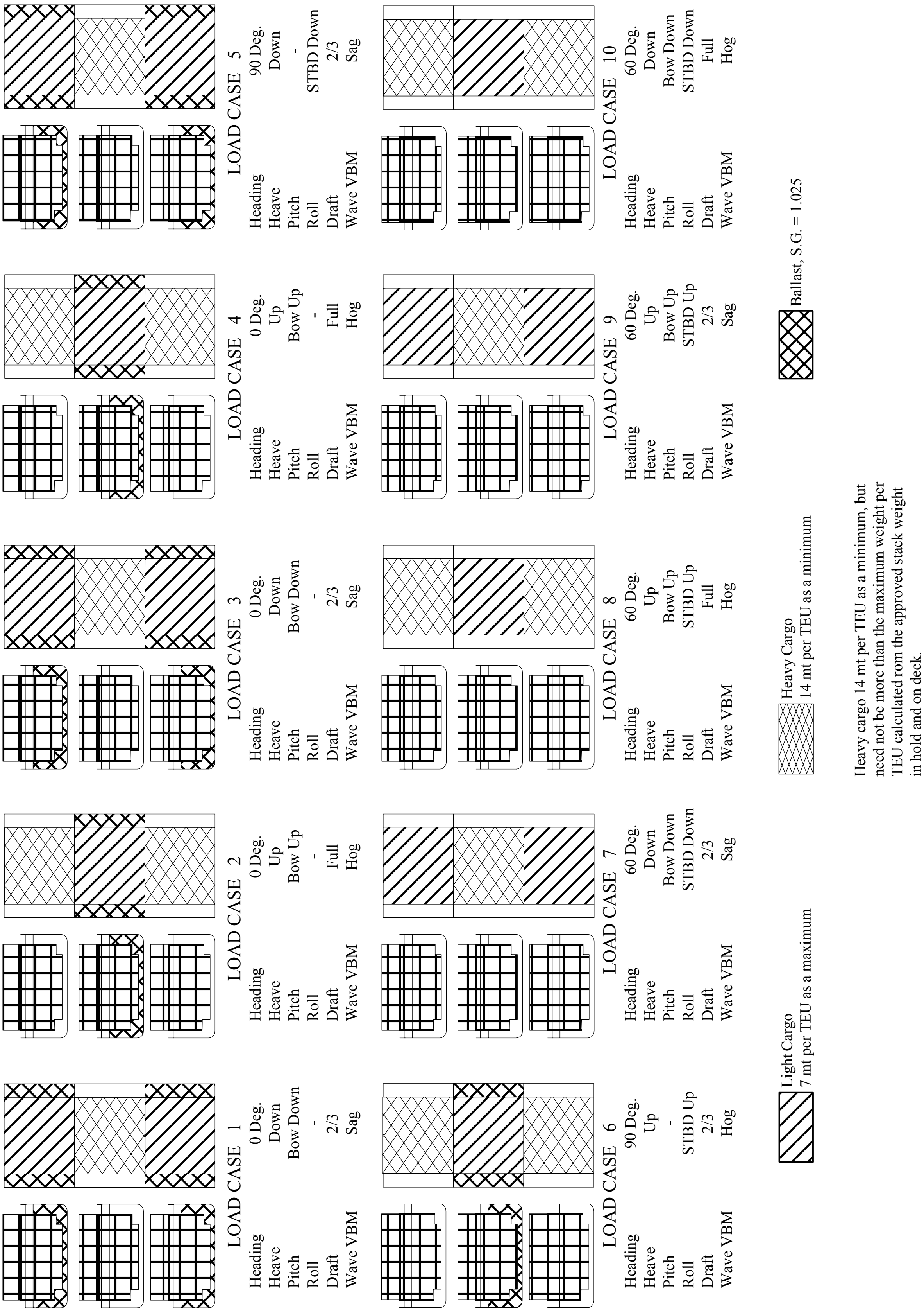


FIGURE 3
Loading Pattern of Container Carrier *(1 July 2005)*



3.3 Cargo Container Loads *(1998)*

The cargo container loads acting on the supporting structure in still water may be determined based on the weight of containers and may be distributed as given in 5C-5-3/5.5.2. The stowage arrangement of containers including stacking loads and heights is to be submitted for review.

5 Wave-induced Loads *(1998)*

Where a direct calculation of the wave-induced loads [i.e., longitudinal bending moments and shear forces, hydrodynamic pressures (external) and inertial forces and added pressure heads (internal)] is not available, the approximation equations given below and specified in 3-2-1/3.5 may be used to calculate the design loads.

When a direct calculation is performed, envelope curves for the combined wave and still-water bending moments and shear forces, covering all the anticipated loading conditions, are to be submitted for review.

5.1 Wave-induced Longitudinal Bending and Torsional Moments and Shear Forces

5.1.1 Vertical Wave Bending Moment *(1 July 2005)*

The vertical wave bending moment amidships, expressed in kN-m (tf-m, Ltf-ft), may be obtained from the following equations:

$M_w = k_w M_{ws}$ Wave Sagging Moment

$M_w = k_w M_{wh}$ Wave Hogging Moment

where

k_w = 1.0 for the nominal wave bending moment in the determination of the hull girder section modulus in 5C-5-4/3.1.1 and the bowflare slamming effects on hull girder sagging bending moment in 5C-5-3/11.3.3

= $(1.84 - 0.56C_b)$ for wave sagging bending moment used in strength formulation and assessment of local structural elements and members in Section 5C-5-4, 5C-5-5/1, 5C-5-5/3 and 5C-5-5/5

= 1.0 for wave hogging bending moment used in strength formulation and assessment of local structural elements and members in Section 5C-5-4, 5C-5-5/1, 5C-5-5/3 and 5C-5-5/5

= $(1.09 + 0.029V - 0.47C_b)^{1/2}$ for wave hogging and sagging bending moments used in fatigue strength formulation in 5C-5-5/7 and Appendix 5C-5-A1

V = 75% of the design speed, V_d, in knots.

V need not to be taken greater than 24 knots.

V_d = the design speed, as defined in 3-2-14/3

M_{ws}, M_{wh} and C_b are as defined in 3-2-1/3.5.1.

5.1.2 Vertical Wave Shear Force *(1 July 2005)*

The envelopes of the maximum wave-induced shearing forces, F_w, expressed in kN (tf, Ltf), may be obtained from the following equations:

$F_w = k_w F_{wp}$ for positive shear force (upward front section)

$F_w = k_w F_{wn}$ for negative shear force (downward front section)

where

k_w = 1.0 for the nominal wave-induced positive and negative shear forces in determination of shearing strength in 5C-5-4/5 and bowflare slamming effects on hull girder positive shear force in 5C-5-3/11.3.3

k_w = k_{wp} for positive shear force (upward front section)

k_w = k_{wn} for negative shear force (downward front section)

k_{wp} and k_{wn} are for wave-induced shear forces used in strength formulation and assessment of local structural elements and members in Section 5C-5-5, Linear interpolation may be used for intermediate values.

k_{wp} = 1.0 at AP

= $(1.61 - 0.47\ C_b)^{1/2}$ from 0.2L to 0.3L from AP

= 1.0 from 0.4L to 0.6 L from AP

= 1.5 from 0.7L to 0.85L from AP

= 1.0 at FP

k_{wn} = 1.0 at AP

= 1.5 from 0.2L to 0.3L from AP

= 1.0 from 0.4L to 0.6L from AP

= $1.1(1.61 - 0.47\ C_b)^{1/2}$ from 0.7L to 0.85L from AP

= 1.0 at FP

k_w = $(1.09 + 0.029V - 0.47C_b)^{1/2}$ for positive and negative wave-induced shear forces used in fatigue strength formulation in 5C-5-5/7 and Appendix 5C-5-A1

F_{wp}, F_{wn} are the envelopes of maximum wave-induced vertical shearing forces, as defined in 3-2-1/3.5.3, wherein C_b is not to be taken less than 0.6. V is as defined in 5C-5-3/5.1.1.

5.1.3 Horizontal Wave Bending Moment *(1 July 2005)*

The horizontal wave bending moment amidships, expressed in kN-m (tf-m, Ltf-ft), positive (tension port) or negative (tension starboard), may be obtained from the following equation:

$$M_H = \pm k_s K_3 C_1 L^2 D (C_b + 0.7) \times 10^{-3}$$

where

k_s = $(1.61 - 0.47\ C_b)^{1/2}$ for strength formulation and assessment of local structural elements and members in Sections 5C-5-4 and 5C-5-5

= $(1.09 + 0.029V - 0.47C_b)^{1/2}$ for fatigue strength formulation in 5C-5-5/7 and Appendix 5C-5-A1

K_3 = 104.2 (10.62, 0.973)

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

D = depth of vessel, as defined in 3-1-1/7, in m (ft)

C_1 is as given in 3-2-1/3.5.1.

C_b is as defined in 3-2-1/3.5.1 and is not to be taken less than 0.6.

V is as defined in 5C-5-3/5.1.1.

The horizontal wave bending moment along the length of the vessel L may be obtained by multiplying the midship value by the distribution factor m_h, as given in 5C-5-3/Figure 4.

5.1.4 Horizontal Wave Shear Force *(1 July 2005)*

The envelope of the horizontal wave shear force, F_H, expressed in kN (tf, Ltf), positive (toward port front section) or negative (toward starboard front section), may be obtained from the following equation:

$$F_H = f_h\, k_s\, k\, C_1\, L\, D\, (C_b + 0.7) \times 10^{-2} \qquad \text{kN (tf, Ltf)}$$

where

k_s = $(1.61 - 0.47\, C_b)^{1/2}$ for strength formulation and assessment of local structural elements and members in Sections 5C-5-4 and 5C-5-5

= $(1.09 + 0.029V - 0.47C_b)^{1/2}$ for fatigue strength formulation in 5C-5-5/7 and Appendix 5C-5-A1.

f_h = distribution factor, as given in 5C-5-3/Figure 5

k = 36 (3.67, 0.34)

C_1, L, D and C_b are as defined in 5C-5-3/5.1.3 above. V is as defined in 5C-5-3/5.1.1.

5.1.5 Wave-induced Torsional Moment

5.1.5(a) Nominal Wave-induced Torsional Moment (1 July 2005). The nominal wave-induced torsional moment amidships, in kN-m (tf-m, Ltf-ft), positive clockwise looking forward, may be determined as follows:

$$T_M = k_s\, k\, L\, B^2 d\, [(C_w - 0.5)^2 + 0.1]\, [0.13 - (e/D)(c_o/d)^{1/2}]$$

where

k_s = $(1.61 - 0.47C_b)^{1/2}$ for strength formulation and assessment of local structural elements and members in Sections 5C-5-4 and 5C-5-5

= $(1.09 + 0.029V - 0.47C_b)^{1/2}$ for fatigue strength formulation in 5C-5-5/7 and Appendix 5C-5-A1.

k = 2.7 (0.276, 0.077)

c_o = 0.14 (0.14, 0.459)

d = draft, as defined in 3-1-1/9, in m (ft); its value is not to be taken less than 12.5 m (41 ft)

e = the vertical distance, in m (ft), of the effective shear center of the hull girder within cargo space, measured from the baseline of the vessel, positive upward.

The effective shear center may be calculated by considering an open section of the cargo hold nearest to midship.

C_w = waterplane coefficient for the draft d. If not available, it may be approximated by $C_w = C_b + 0.2$, but need not to be taken greater than 0.9 for typical container carriers

L, B and D are as defined in 3-1-1/3.1, 3-1-1/5, and 3-1-1/7, respectively.

C_b is as defined in 3-2-1/3.5.1 and is not to be taken less than 0.6.

V is as defined in 5C-5-3/5.1.1.

5.1.5(b) Distribution of Wave-induced Torsional Moment. The nominal wave induced torsional moment along the length of the vessel L may be obtained by multiplying the midship value by the distribution factor m_T, as given in 5C-5-3/Figure 6.

5.1.5(c) Simultaneous Distribution of Wave-induced Torsional Moment. When a direct calculation is not available, the wave-induced torsional moment, $T(x)$, along the length of vessel at an instantaneous time may be approximated by the following equations. For assessing the structural response to torsion, i.e., distortions and warping stresses, at least two different torsional moment distribution curves in a critical region, such as in front of the engine room, are to be considered. One curve gives approximately a peak value of the torsional moment, one shows a maximum slope of the moment curve. Three sample torsional moment distribution curves are shown in 5C-5-3/Figure 7. These three curves should be considered as the least set to assess torsional responses for the engine room region, amidships, and the forward quarter length region, respectively.

A: $T(x) = T_M\,[0.8 \sin[2\pi(x/L - 0.025)] + 0.2]$, for $0.05L \le x \le 0.95L$

B: $T(x) = T_M\,[0.7 \cos[2.72\pi(x/L - 0.5)] + 0.3]$, for $0.05L \le x \le 0.95L$

C: $T(x) = -T_M\,[0.75 \sin(2\pi x/L) + 0.05]$, for $0.05L \le x \le 0.95L$

$T(x) = 0$, at $x = 0$ and $x = 1.0L$

where

T_M is as defined in 5C-5-3/5.1.5(a) above.

x is the distance from the aft end of L to station considered, in m (ft).

L is as defined in 3-1-1/3.1.

5.3 External Pressures and Impact Loads *(1998)*

5.3.1 Pressure Distribution *(1 July 2005)*

The external pressures, p_e, positive toward inboard, imposed on the hull in a seaway can be expressed by the following equation at a given location:

$$p_e = \rho g(h_s + k_u h_{de}) \ge 0 \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

ρg = specific weight of sea water

= 1.005 N/cm²-m (0.1025 kgf/cm²-m, 0.4444 lbf/in²-ft)

h_s = hydrostatic pressure head in still water, in m (ft)

k_u = load factor, and may be taken as unity unless otherwise specified

h_{de} = hydrodynamic pressure head induced by the wave, in m (ft), may be calculated as follows

$h_{de} = k_c h_{di}$

where

k_c = correlation factor for a specific combined load, as given in 5C-5-3/Table 1 and 5C-5-3/Table 2

h_{di} = hydrodynamic pressure head, in m (ft), at location i, (i = 1, 2, 3, 4 or 5; see 5C-5-3/Figure 8)

= $k_\ell \alpha_i h_{do}$, in m (ft)

k_ℓ = distribution factor along the length of the vessel

= $1 + (k_{\ell o} - 1) \cos \mu$, $k_{\ell o}$ is as given in 5C-5-3/Figure 9

= 1.0 amidships

h_{do} = $1.36\, k_s C_1$

k_s = 1.0 for strength formulation and assessment of local structural elements and members in Sections 5C-5-4 and 5C-5-5

= $(1.09 + 0.029V - 0.47C_b)^{1/2}$ for fatigue strength formulation in 5C-5-5/7 and Appendix 5C-5-A1

C_1 = as defined in 3-2-1/3.5.1

α_i = distribution factor around the girth of vessel at location "i", linearly interpolated at other locations

=	$1.00 - 0.25 \cos \mu$,	for i = 1,	at WL, starboard
=	$0.40 - 0.10 \cos \mu$,	for i = 2,	at bilge, starboard
=	$0.30 - 0.20 \sin \mu$,	for i = 3,	at bottom centerline
=	$2\,\alpha_3 - \alpha_2$,	for i = 4,	at bilge, port
=	$0.75 - 1.25 \sin \mu$,	for i = 5,	at WL, port

μ = wave heading angle in degrees, to be taken from 0° to 90° (0° for head sea, 90° for beam sea for wave coming from starboard)

The distribution of the total external pressure including static and hydrodynamic pressures is illustrated in 5C-5-3/Figure 10.

C_b is as defined in 3-2-1/3.5.1 and is not to be taken less than 0.6. V is as defined in 5C-5-3/5.1.1.

5.3.2 Extreme Pressures

In determining the required scantlings of local structural members, the extreme external pressure, p_e, as defined in 5C-5-3/5.3.1 with k_u and k_c given in 5C-5-3/7 and 5C-5-3/9, is to be used.

5.3.3 Simultaneous Pressures

For performing 3D structural analysis, the simultaneous pressure along any portion of the hull girder may be obtained from:

$$p_{es} = \rho g (h_s + k_f k_u h_{de}) \geq 0 \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

k_f is the distribution function of h_{de} corresponding to a designated wave profile along the vessel's length, and may be determined as follows:

5.3.3(a) For the combined load cases, L.C.1 through L.C.6 specified in 5C-5-3/Table 1

$$k_f = k_{fo} \{1 - [1 - \cos 2\pi (x/L - x_o/L)] \cos \mu\}$$

5.3.3(b) For the combined load cases, L.C.7 and L.C.8 specified in 5C-5-3/Table 1

$$k_f = k_{fo} \cos \{4\pi (x/L - x_o/L - 0.25) \cos \mu\}$$

5.3.3(c) For the combined load cases, L.C.9 and L.C.10 specified in 5C-5-3/Table 1

$$k_f = k_{fo} \cos \{4\pi (x/L - x_o/L + 0.25) \cos \mu\}$$

5.3.3(d) For the combined load cases, L.C. F1 and L.C. F2 specified in 5C-5-A1/Table 3

$$k_f = k_{fo} \cos \{4\pi (x/L - x_o/L) \cos \mu\}$$

where

x = distance from AP to the station considered, in m (ft)

x_o = distance from AP to the reference station, in m (ft).

The reference station is the point along the vessel length where the wave trough or crest is located in head seas, and may be taken as the mid-point of the middle hold of tbe three hold model.

L is the vessel length, as defined in 3-1-1/3.1, in m (ft).

μ is the wave heading angle, in degrees, as defined in 5C-5-3/5.3.1.

k_{fo} = ± 1.0, as specified in 5C-5-3/Table 1 and 5C-5-A1/Table 3

The simultaneous pressure distribution around the girth of the vessel is to be determined based on the wave heading angles specified in 5C-5-3/Table 1 and 5C-5-A1/Table 3.

5.3.4 Impact Loads on Bow and Deck

5.3.4(a) Bow Pressures. When experimental data or direct calculation is not available, nominal wave-induced bow pressures above the load waterline (*LWL*) in the region from the forward end to the collision bulkhead may be obtained from the following equations:

$$p_{bij} = k\, C_k\, C_{ij}\, V_{ij}^2 \sin \gamma_{ij} \qquad \text{kN/m}^2 \text{ (tf/m}^2\text{, Ltf/ft}^2\text{)}$$

where

k = 1.025 (0.1045, 0.00888)

C_{ij} = $\{1 + \cos^2 [90 (F_{bi} - 2\alpha_{ij})/F_{bi}]\}^{1/2}$

V_{ij} = $\omega_1 V \sin \alpha_{ij} + \omega_2 (L)^{1/2}$

ω_1 = 0.515 (1.68) for m (ft)

ω_2 = 1.0 (1.8) for m (ft)

V = as defined in 5C-5-3/5.1.1. V is not taken less than 10 knots.

γ_{ij} = local bow angle measured from the horizontal, not to be taken less than 50°

= $\tan^{-1} (\tan \beta_{ij} / \cos \alpha_{ij})$

α_{ij} = local waterline angle between the tangent line and the centerline, see 5C-5-3/Figure 11, not taken less than 35°

β_{ij} = local body plan angle measured from the horizontal, see 5C-5-3/Figure 11, not taken less than 35°

F_{bi} = freeboard from the highest deck at side to the *LWL* at station *i*, in m (ft), see 5C-5-3/Figure 11

α_{ij} = vertical distance from the *LWL* to *j*-th *WL*, in m (ft), see 5C-5-3/Figure 11

C_k = 0.7 at collision bulkhead and 0.9 at 0.0125L aft of the FP, with linear interpolation for intermediate locations

= 0.9 between 0.0125L aft of the FP and the FP

= 1.0 at and forward of the FP

i, *j* = station and waterline, to be taken to correspond to the locations as required by the forward body strength requirements

L = vessel length, as defined in 3-1-1/3.1, in m (ft).

5.3.4(b) Green Water. When experimental data or direct calculation is not available, nominal green water pressures imposed on deck in the region forward of 0.3L from the FP may be obtained from the following equations. p_{gi} is not to be taken less than 20.6 kN/m^2 (2.1 tf/m^2, 0.192 Ltf/ft^2).

$$p_{gi} = k\,F_n \sin(\delta_j)(M_{Ri} - k_1 F_{bi})^{1/2} \qquad \text{kN/m}^2\ (\text{tf/m}^2,\ \text{Ltf/ft}^2)$$

where

k = 128.16 (13.063, 0.3584)

k_1 = 1.5 (4.92) for m (ft)

F_n = $V_d/(gL)^{1/2} \geq 0.225$, V_d is design speed as defined in 3-2-14/3, in m/s (ft/s)

F_{bi} = freeboard at station *i*, in m (ft)

M_{Ri} = as defined in 5C-5-3/11.1, if $M_{Ri} < k_1F_{bi}$, then $p_{gi} = 0$

δ_j = the angle between the horizontal and a line connecting the highest deck at the side and the half beam at the still waterline of station *i*, see 5C-5-3/Figure 11

g = acceleration due to gravity = 9.807 m/sec^2 (32.2 ft/sec^2)

5.5 Cargo Loads and Liquid Pressure *(1998)*

5.5.1 Ship Motions and Accelerations

In determining the cargo loads and liquid pressure, the dominant ship motions, pitch and roll, and the resultant accelerations induced by the wave are required. When a direct calculation is not available, the approximate equations given below may be used:

5.5.1(a) Pitch. (1998) The pitch amplitude: (positive bow up)

$$\phi = k_1(V/C_b)^{1/4}/L \qquad \text{in deg.,}$$

but need not to be taken more than 10 deg.

The pitch natural period:

$$T_p = k_2\,(C_b\,d_i)^{1/2} \qquad \text{in sec.}$$

where

k_1 = 1030 (3378) for L, in m (ft)

k_2 = 3.5 (1.932) for d_i, in m (ft)

V = as defined in 5C-5-3/5.1.1

d_i = draft amidships for the relevant loading conditions

The vessel length L is as defined in 3-1-1/3.1, in m (ft).

C_b is as defined in 3-2-1/3.5.1 and is not to be taken less than 0.6.

5.5.1(b) Roll. (1998) The roll amplitude: (positive starboard down)

$\theta = C_R\,(28.4 - k_\theta\, C_{di}\, \Delta/1000)$ if $T_r > 20$ sec.

$\theta = C_R\,(28.4 - k_\theta\, C_{di}\, \Delta/1000)(1.5375 - 0.027\, T_r)$ if $12.5 \le T_r \le 20$ sec.

$\theta = C_R\,(28.4 - k_\theta\, C_{di}\, \Delta/1000)\ 1.2$ if $T_r < 12.5$ sec.

where

k_θ = 0.002 (0.02, 0.02)

θ, in degrees, but need not to be taken greater than 30 degrees.

C_R = $1.0 - 0.00625V$

V = as defined in 5C-5-3/5.1.1

C_{di} = $1.25\,(d_i/d) - 0.25$

d_i = draft amidships for the relevant loading conditions, in m (ft)

d = draft as defined in 3-1-1/9, in m (ft)

Δ = $k_d\, C_b\, L\, B\, d$ kN (tf, Ltf)

k_d = 10.05 (1.025, 0.0286)

L, B are as given in 3-1-1/3.1 and 3-1-1/5.

C_b is as defined in 3-2-1/3.5.1 and is not to be taken less than 0.6.

The roll natural motion period:

$T_r = k_4\, k_r / GM^{1/2}$ in sec.

where

k_4 = 2 (1.104) for k_r, GM in m (ft)

k_r = roll radius of gyration, in m (ft), and may be taken as $0.35B$ for full load conditions and $0.40B$ for $^2/_3$ draft conditions.

GM = metacentric height, to be taken as:

= GM(full) for $d_i = d$

= 3.0 GM(full) for $d_i = {}^2/_3\, d$

GM(full) = metacentric height for fully loaded condition

If GM(full) is not available, GM(full) can be taken as $0.06B$.

5.5.1(c) Accelerations (1 July 2005). The vertical, longitudinal and transverse accelerations of tank contents (cargo or liquid), a_v, a_ℓ and a_t may be obtained from the following formulae:

$a_v = C_v\, k_v\, a_o\, g$	m/sec^2 (ft/sec^2)	positive downward
$a_\ell = C_\ell\, k_\ell\, a_o\, g$	m/sec^2 (ft/sec^2)	positive forward
$a_t = C_t\, k_t\, a_o\, g$	m/sec^2 (ft/sec^2)	positive starboard

where

a_o	=	$k_0\,(2.4/L^{1/2} + 34/L - 600/L^2)$	for L in m
	=	$k_0\,(4.347/L^{1/2} + 111.55/L - 6458/L^2)$	for L in ft
k_0	=	$(1.3 - 0.47C_b)$ for strength formulation and assessment of local structural elements and members in Sections 5C-5-4 and 5C-5-5	
	=	$(1.09 + 0.029V - 0.47C_b)$ for fatigue strength formulation in 5C-5-5/7, Appendix 5C-5-A1	
V	=	as defined in 5C-5-3/5.1.1	
C_b	=	as defined in 3-2-1/3.5.1 and is not to be taken less than 0.6	
C_v	=	$\cos^2\mu + (1 + 1.0\, z/B)(\sin\mu)/k_v$	
μ	=	wave heading angle in degrees, 0° for head sea, and 90° for beam sea for wave coming from starboard	
k_v	=	$[1 + 0.65(5.3 - 45/L)^2\,(x/L - 0.45)^2]^{1/2}$	for L in m
	=	$[1 + 0.65(5.3 - 147.6/L)^2\,(x/L - 0.45)^2]^{1/2}$	for L in ft
C_ℓ	=	$0.35 - 0.0005\,(L - 200)$	for L in m
	=	$0.35 - 0.00015\,(L - 656)$	for L in ft
k_ℓ	=	$0.5 + 8y/L$	
C_t	=	$1.27[1 + 1.52(x/L - 0.45)^2]^{1/2}$	
k_t	=	$(0.35 + 0.5\, y/B)\sin\mu$	
x	=	longitudinal distance from the AP to the station considered, in m (ft)	
y	=	vertical distance from the waterline to the point considered, in m (ft), positive upward	
z	=	transverse distance from the centerline to the point considered in m (ft), positive starboard	
g	=	acceleration due to gravity = 9.807 m/sec^2 (32.2 ft/sec^2)	

L, B are the length and breadth of vessel, as defined in 3-1-1/3.1 and 3-1-1/5, respectively, in m (ft).

5.5.2 Cargo Container Loads

5.5.2(a) General. For the design and evaluation of hull structure, the following forces due to the loaded containers are to be considered:

- Static weight in upright condition
- Dynamic forces due to roll and pitch of vessel
- Inertial force due to acceleration.

For the design and evaluation of the hull structure, all containers are considered to be stowed by stacks in the cargo hold and above the deck. All containers in the hold are to be restrained by cell guides, which are a series of vertical steel angles, suitably spaced according to the container length and width, which provide alignment and horizontal restraint for container stacks. The static and dynamic forces due to loaded containers are to be applied to supporting structures, such as web, girders, pillars, etc., as concentrated forces through the cell guide and to bottom corners of the container stack.

The container loads from the containers stored above the deck are to be applied to hatch coamings, bulwark or other supporting structures at the bottom of the container stack.

5.5.2(b) Loads. The forces from individual containers are to be calculated at the center of gravity of each container. The center of gravity of the container may be normally considered as the mid point of the container.

$$F_v = W + k_u F_{dv} \qquad \text{kN (tf, Ltf)}$$

$$F_t = k_u F_{dt} \qquad \text{kN (tf, Ltf)}$$

$$F_\ell = k_u F_{d\ell} \qquad \text{kN (tf, Ltf)}$$

where

F_v = vertical container load due to each container, positive downward

F_t = transverse container load due to each container, positive starboard

F_ℓ = longitudinal container load due to each container, positive forward

W = gross weight of the container, in kN (tf, Ltf)

F_{dv} = dynamic vertical container load due to ship motion

= $k_c W[\cos\phi_e \cos\theta_e + a_{ve}/g - 1]$

F_{dt} = dynamic transverse container load due to ship motion, positive starboard

= $k_c W[\sin\theta_e + a_{te}/g]$

$F_{d\ell}$ = dynamic longitudinal container load due to ship motion, positive forward

= $k_c W[-\sin\phi_e + a_{\ell e}/g]$

k_c = correlation coefficient and may be taken as unity unless otherwise specified

k_u = dynamic load factor and may be taken as unity unless otherwise specified

θ_e = effective angle of roll = $0.71\ C_\theta\theta$

ϕ_e = effective angle of pitch = $0.71\ C_\phi\phi$

a_{ve} = effective vertical acceleration = $0.71\ c_v a_v$

a_{te} = effective transverse acceleration = $0.71\ c_T a_t$

$a_{\ell e}$ = effective longitudinal acceleration = $0.71\ c_L a_\ell$

c_v, c_T, c_L, C_θ and C_ϕ are as specified in 5C-5-3/Table 1, 5C-5-3/Table 2 and 5C-5-A1/Table 3.

a_v, a_t, and a_ℓ are as specified in 5C-5-3/5.5.1(c).

ϕ and θ are pitch and roll amplitudes, as given in 5C-5-3/5.5.1(a) and 5C-5-3/5.5.1(b).

The container loads F_v, F_t, and F_ℓ may be distributed equally to the four corners of the container in the direction of the load component, as shown in 5C-5-3/Figure 12. The transverse and longitudinal container loads acting on the cell guide may be transmitted to supporting structural members by statically distributing the loads to adjacent supporting points along the cell guide, as shown in 5C-5-3/Figure 13.

All vertical container loads are to be transmitted to the bottom corners of each container stack.

All container loads above the deck are to be transmitted to the bottom corners of each container stack, and then distributed to supporting structures such as hatch coaming, bulwark or stanchions.

5.5.3 Internal Liquid Pressures

5.5.3(a) Distribution of Internal Pressures (1 July 2005). The internal liquid pressures, p_i, positive toward tank boundaries for a fully filled ballast or other tank may be obtained from the following formula:

$$p_i = \rho g(\eta + \Delta\eta + k_u h_d) \geq 0 \qquad \text{in N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

ρg = specific weight of the fluid in N/cm^2-m (kgf/cm^2-m, lbf/in^2-ft), but not to be taken less than the specific weight of sea water

η = local coordinate in vertical direction for tank boundaries measuring from the top of the tank to the point considered, as shown in 5C-5-3/Figure 14, in m (ft)

$\Delta\eta$ = 0 for the upper tank whose tank top extends to the strength deck

= a distance equivalent to $^2/_3$ of the distance from tank top to the top of the overflow (The exposed height is minimum 760 mm above freeboard deck or 450 mm above superstructure deck.) for the lower tank whose tank top does not extend to the strength deck.

Where a side shell wing tank top extends to the underdeck passageway (second deck), this distance need not be greater than $^1/_3$ of the distance from the second deck to the top of the overflow

k_u = load factor and may be taken as unity unless otherwise specified.

h_d = wave induced pressure head, including inertial force and added pressure head

= $k_c(\eta a_i/g + \Delta h_i)$, m (ft)

k_c = correlation factor and may be taken as unity unless otherwise specified.

a_i = effective resultant acceleration, in m/sec^2 (ft/sec^2), at the point considered, may be approximated by $0.71C_{dp}[w_v a_v + w_\ell(\ell/h)\, a_\ell + w_t(b/h)a_t]$

g = acceleration due to gravity

= 9.807 m/sec^2 (32.2 ft/sec^2)

C_{dp} is specified in 5C-5-3/5.5.3(d).

a_v, a_ℓ and a_t are as given in 5C-5-3/5.5.1(c).

w_v, w_ℓ and w_t are weighted coefficients, showing directions, as specified in 5C-5-3/Table 1, 5C-5-3/Table 2, and 5C-5-A1/Table 3.

Δh_i = added pressure head due to pitch and roll motions at the point considered, in m (ft).

In general, the added head may be calculated based on the vertical distance from the reference point of the tank to the point considered. The reference point is (i) the highest point of the tank boundary after roll and pitch, or (ii) the average height of the points after roll and pitch, which are $\Delta\eta$ above the top of the tank at the overflow, whichever is greater.

For prismatic tanks on the starboard side, whose tank top extends to the strength deck, the added pressure head may be calculated as follows:

i) *for bow down and starboard down* ($\phi_e < 0$, $\theta_e > 0$)

$$\Delta h_i = \xi \sin(-\phi_e) + C_{ru} (\zeta_e \sin \theta_e \cos \phi_e + \eta_e \cos \theta_e \cos \phi_e - \eta)$$

$$\zeta_e = b - \zeta$$

$$\eta_e = \eta$$

ii) *for bow up and starboard up* ($\phi_e > 0$, $\theta_e < 0$)

$$\Delta h_i = (\ell - \xi)\sin \phi_e + C_{ru} \{\zeta_e \sin(-\theta_e) \cos \phi_e + \eta_e \cos \theta_e \cos \phi_e - \eta\}$$

$$\zeta_e = \zeta - \delta_b$$

$$\eta_e = \eta - \delta_h$$

C_{ru} is specified in 5C-5-3/5.5.3(d).

ξ, ζ, η are the local coordinates, in m (ft), for the point considered with respect to the origin shown in 5C-5-3/Figure 14; b and h are the local coordinate adjustments, in m (ft), for a rounded tank corner, as shown in 5C-5-3/Figure 14.

where

$$\theta_e = 0.71\ C_\theta \theta$$

$$\phi_e = 0.71\ C_\phi \phi$$

ℓ = length of the tank, in m (ft)

b = breadth of the tank considered, in m (ft)

h = height of the tank considered, in m (ft)

ϕ and θ are pitch and roll amplitudes, as given in 5C-5-3/5.5.1(a) and 5C-5-3/5.5.1(b).

C_ϕ and C_θ are weighted coefficients showing directions, as given in 5C-5-3/Table 1, 5C-5-3/Table 2 and 5C-5-A1/Table 3.

For prismatic lower tanks on starboard side whose tank top does not extend to the strength deck, added pressure head may be calculated as follows, assuming the reference point based on the average height of the overflow.

i) *for bow down and starboard down* ($\phi_e < 0$, $\theta_e > 0$)

$$\Delta h_i = (\xi - \ell/2) \sin(-\phi_e) + C_{ru} (\zeta_e \sin \theta_e \cos \phi_e + \eta_e \cos \theta_e \cos \phi_e - \eta_e)$$

$$\zeta_e = b_a - \zeta$$

$$\eta_e = \eta + \Delta\eta$$

ii) *for bow up and starboard up* ($\phi_e > 0$, $\theta_e < 0$)

$$\Delta h_i = (\ell/2 - \xi) \sin \phi_e + C_{ru} \{\zeta_e \sin(-\theta_e) \cos \phi_e + \eta_e \cos \theta_e \cos \phi_e - \eta_e\}$$

$$\zeta_e = \zeta - b_a$$

$$\eta_e = \eta + \Delta\eta$$

b_a is the transverse distance of overflow from ξ axis. All other parameters are as defined above.

5.5.3(b) Extreme Internal Liquid Pressure. For assessing local structures at a tank boundary, the extreme internal liquid pressure with k_u, as specified in 5C-5-3/7, is to be considered.

5.5.3(c) Simultaneous Internal Liquid Pressures. In performing a structural analysis, the internal liquid pressures may be calculated in accordance with 5C-5-3/5.5.3(a) and 5C-5-3/5.5.3(b) above for tanks in the midbody. For tanks in the fore or aft body, the pressures are to be determined based on linear distributions of accelerations and ship motions along the length of the vessel.

5.5.3(d) Definition of Tank Shape and Associated Coefficients

i) *Rectangular Tank*

The following tank is considered as a rectangular tank:

$b/b_1 \leq 3.0$ or $h/h_1 \leq 3.0$

where

b = extreme breadth of the tank considered

b_1 = least breadth of wing tank part of the tank considered

h = extreme height of the tank considered

h_1 = least height of double bottom part of the tank considered

as shown in 5C-5-3/Figure 14

The coefficients C_{dp} and C_{ru} of the tank are as follows:

$C_{dp} = 1.0$

$C_{ru} = 1.0$

ii) *J-shaped Tank*

A tank having the following configurations is considered as a "J-shaped" tank.

$b/b_1 \geq 5.0$ and $h/h_1 \geq 5.0$

The coefficients C_{dp} and C_{ru} are as follows:

$C_{dp} = 0.7$

$C_{ru} = 1.0$

iii) *U-shaped Tank*

A half of a "U-shaped" tank, divided at the centerline, should satisfy the condition of a "J-shaped" tank.

The coefficients C_{dp} and C_{ru} are as follows:

$C_{dp} = 0.5$

$C_{ru} = 0.7$

a_i, defined in 5C-5-3/5.5.3(a), for U-shaped tank is not to be taken less than that calculated for J-shaped tank.

iv) In a case where the minimum tank ratio of b/b_1 or h/h_1, whichever is lesser, is greater than 3.0 but less than 5.0, the coefficients C_{dp} and C_{ru} of the tank are to be determined by the following interpolation:

An intermediate tank between rectangular and J-shaped tank:

(Rectangular - J-shaped like tank)

$C_{dp} = 1.0 - 0.15$ (the min. tank ratio - 3.0)

$C_{ru} = 1.0$

An intermediate tank between rectangular and U-shaped tank:

(Rectangular - U-shaped like tank)

$C_{dp} = 1.0 - 0.25$ (the min. tank ratio - 3.0)

$C_{ru} = 1.0 - 0.15$ (the min. tank ratio - 3.0)

a_i, defined in 5C-5-3/5.5.3(a), for a rectangular – "U" shape like tank is not to be taken less than that calculated for a rectangular – "J" shape like tank.

v) For non-prismatic tanks mentioned in Note 4 of 5C-5-3/Table 2, b_1, h and h_1 are to be determined based on the extreme section.

FIGURE 4
Distribution Factor m_h (1998)

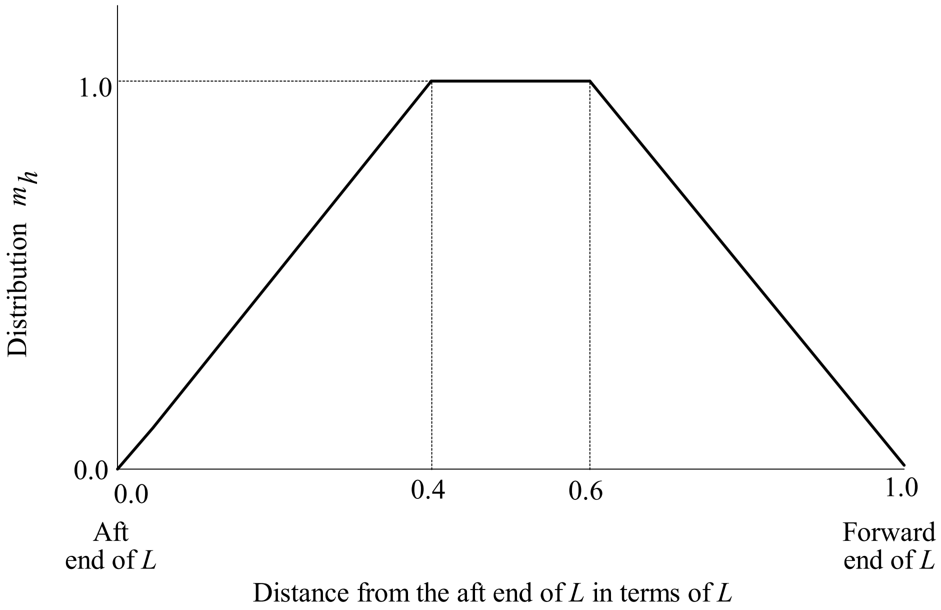


FIGURE 5
Distribution Factor f_h (1998)

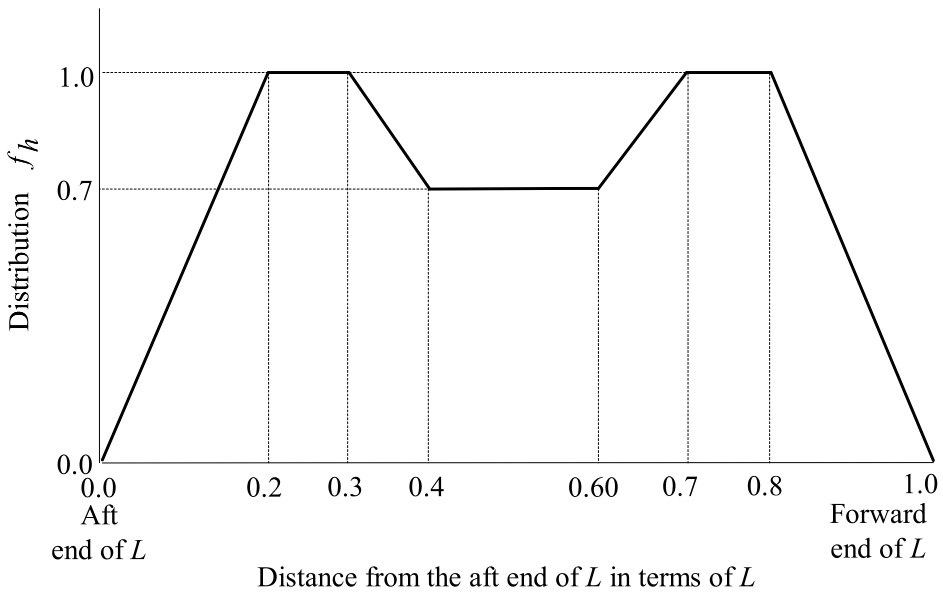


FIGURE 6
Distribution Factor m_T *(1998)*

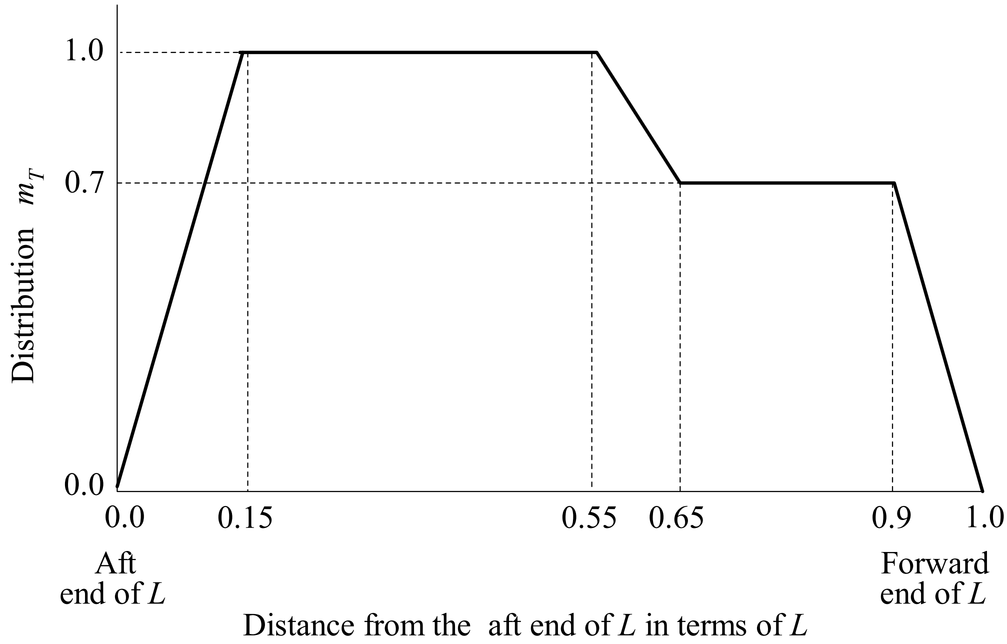


FIGURE 7
Torsional Moment Distribution Curves *(1998)*

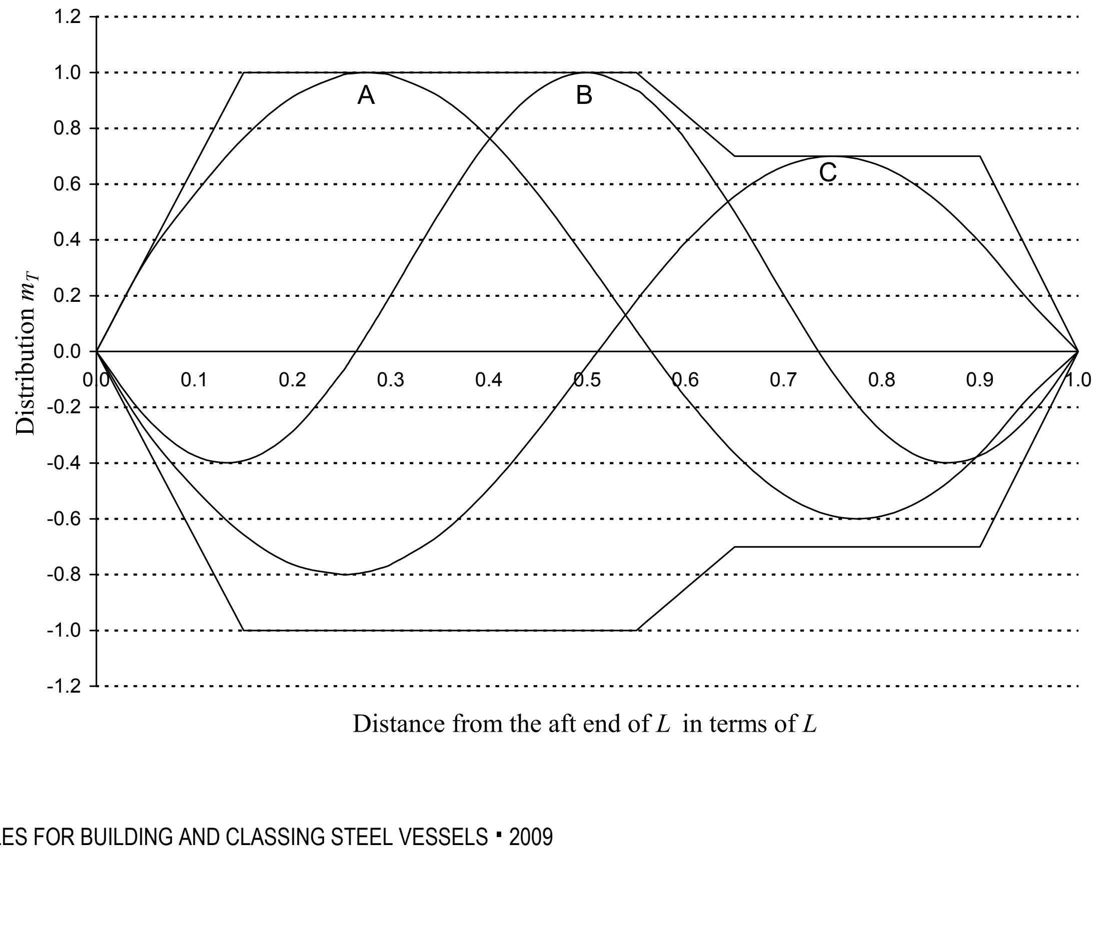


FIGURE 8
Distribution of Hydrodynamic Pressure *(1998)*

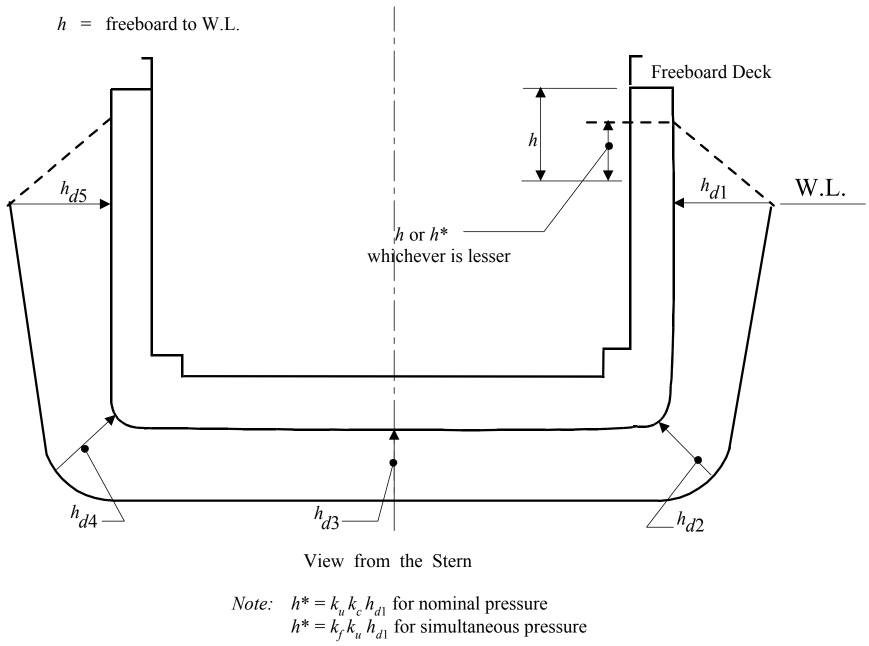


FIGURE 9
Hydrodynamic Pressure Distribution Factor $k_{\ell o}$ *(1998)*

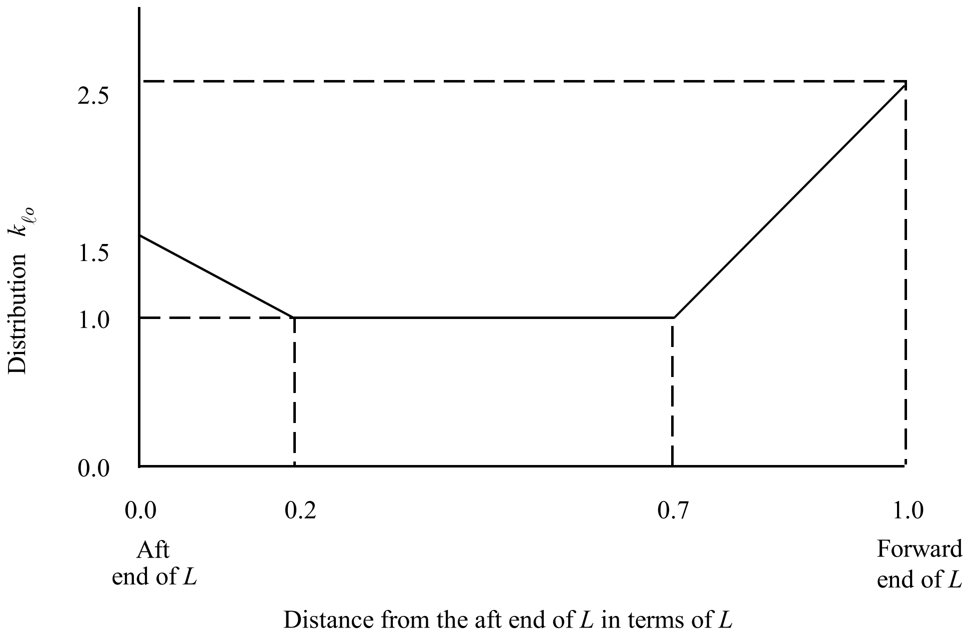
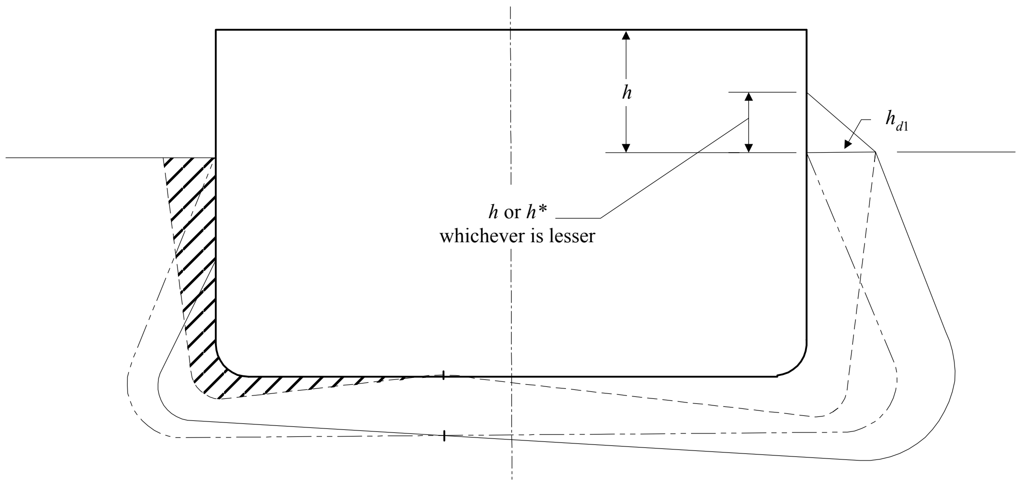


FIGURE 10
Illustration of Determining Total External Pressure



h_d : Hydrodynamic Pressure Head (indicates negative)

h_s : Hydrostatic Pressure Head in Still Water

: Total External Pressure Head

Note: $h^* = k_u k_c h_{d1}$ for nominal pressure
$h^* = k_f k_u h_{d1}$ for simultaneous pressure

FIGURE 11
Definition of Bow Geometry *(1 July 2008)*

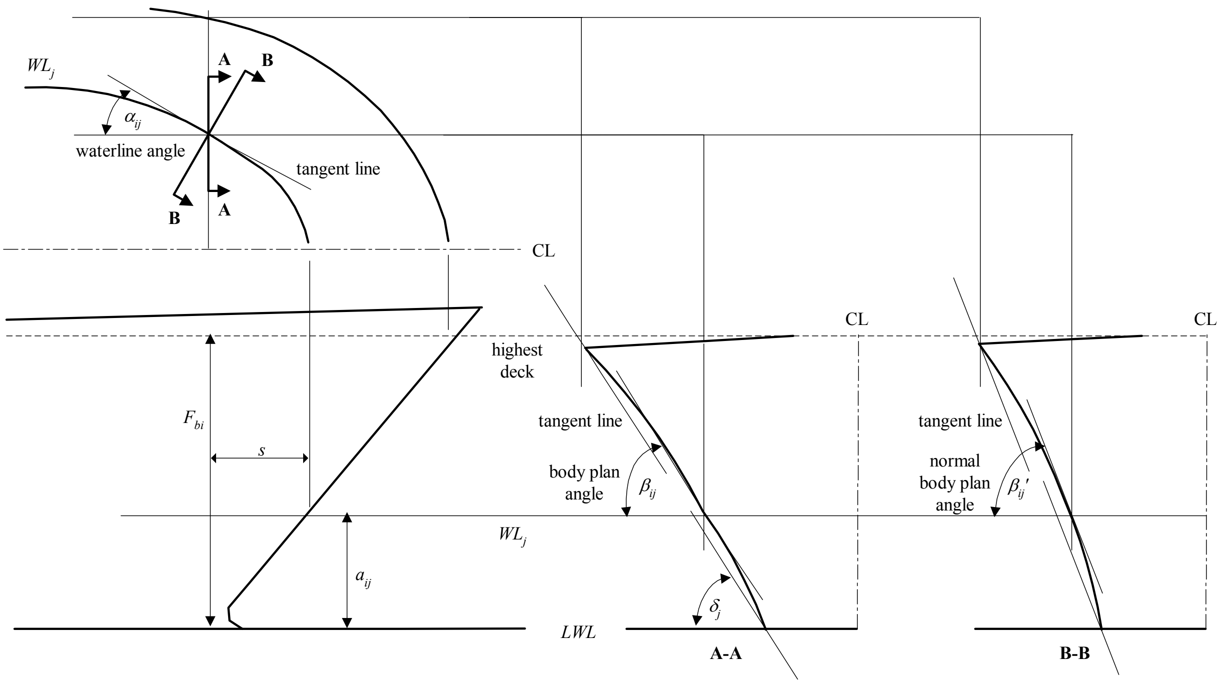


FIGURE 12
Distribution of Container Loads to Corners in Hold

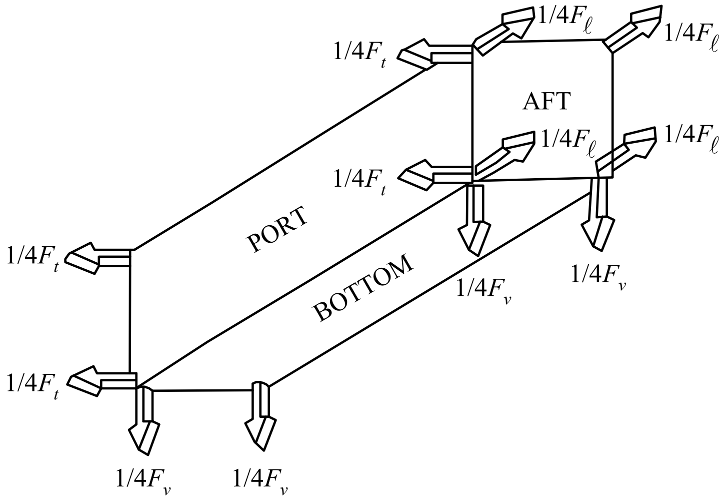
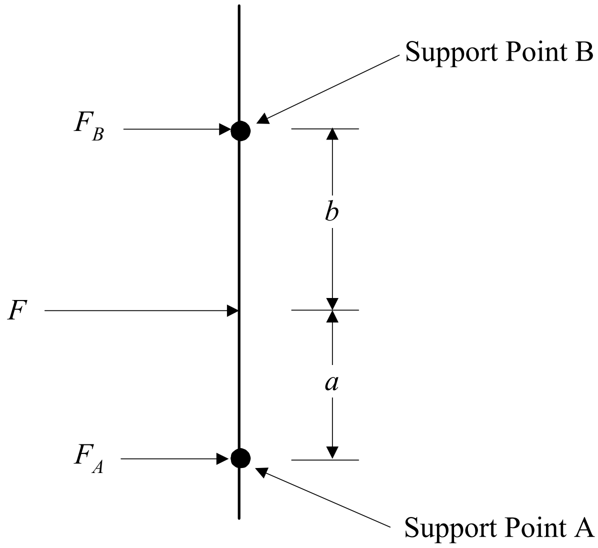


FIGURE 13
Transfer of Container Corner Loads on the Cell Guide to Support Points



$$F_A = \frac{b}{a+b} F$$

$$F_B = \frac{a}{a+b} F$$

FIGURE 14
Definition of Tank Geometry

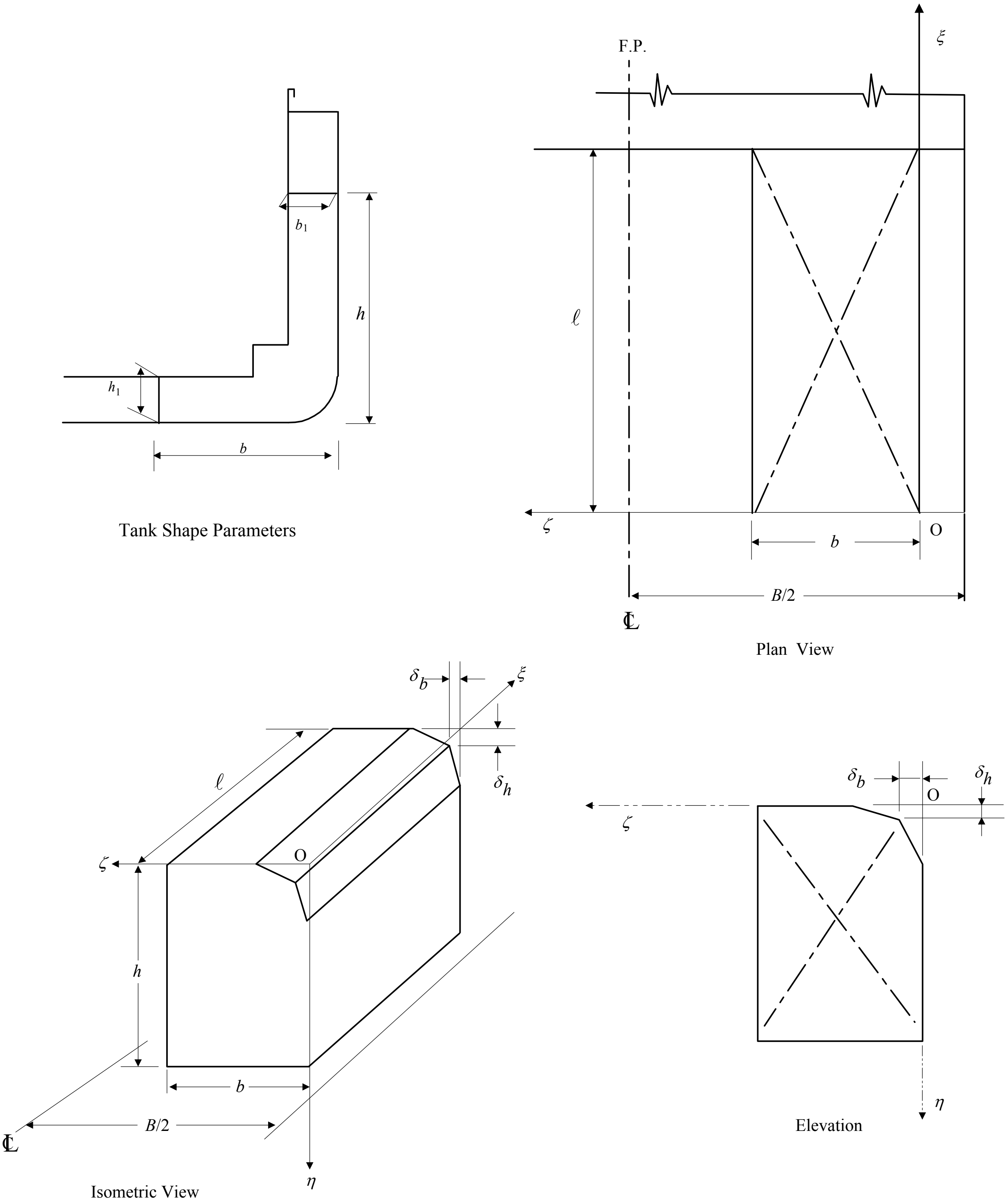


TABLE 1A
Combined Load Cases for Yielding and Buckling Strength Formulation *(2007)*

	L.C. 1	*L.C. 2*	*L.C. 3*	*L.C. 4*	*L.C. 5*	*L.C. 6*	*L.C. 7*	*L.C. 8*	*L.C. 9*	*L.C. 10*
A. Hull Girder Loads (2)										
Vertical B.M.(3) k_c	Sag (–) 1.0	Hog (+) 1.0	Sag (–) 0.7	Hog (+) 0.7	Sag (–) 0.3	Hog (+) 0.3	Sag (–) 0.4	Hog (+) 0.4	Sag (–) 0.4	Hog (+) 0.4
Vertical S.F. k_c	(+) 0.5	(–) 0.5	(+) 1.0	(–) 1.0	(+) 0.3	(–) 0.3	(+) 0.4	(–) 0.4	(–) 0.4	(+) 0.4
Horizontal B.M k_c	0.0	0.0	0.0	0.0	Stbd Tens (–) 0.3	Port Tens (+) 0.3	Stbd Tens (–) 0.5	Port Tens (+) 0.5	Port Tens (+) 0.7	Stbd Tens (–) 0.7
Horizontal S.F. k_c	0.0	0.0	0.0	0.0	(+) 1.0	(–) 1.0	(+) 0.5	(–) 0..5	(–) 0.7	(+) 0.7
Torsional Mt.(4) k_c	0.0	0.0	0.0	0.0	(–) $0.55\alpha_s$	(+) $0.55\alpha_s$	(–) α_s	(+) α_s	(–) α_s	(+) α_s
B. External Pressure										
k_c	0.5	0.5	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0
k_{fo}	-1.0	1.0	-1.0	1.0	-1.0	1.0	-1.0	1.0	1.0	-1.0
C. Container Cargo Load										
k_c	0.4	0.4	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5
C_v	0.8	-0.8	0.8	-0.8	0.4	-0.4	0.7	-0.7	-0.7	0.7
C_L	Fwd Bhd 0.6 Aft Bhd 0.0	Fwd Bhd 0.0 Aft Bhd -0.6	Fwd Bhd 0.6 Aft Bhd 0.0	Fwd Bhd 0.0 Aft Bhd -0.6	-- --	-- --	Fwd Bhd 0.7 Aft Bhd 0.0	Fwd Bhd 0.0 Aft Bhd -0.7	Fwd Bhd 0.0 Aft Bhd -0.7	Fwd Bhd 0.7 Aft Bhd 0.0
C_T	-- --	-- --	-- --	-- --	Port Wall 0.0 Stbd Wall 0.9	Port Wall -0.9 Stbd Wall 0.0	Port Wall 0.0 Stbd Wall 0.7	Port Wall -0.7 Stbd Wall 0.0	Port Wall -0.7 Stbd Wall 0.0	Port Wall 0.0 Stbd Wall 0.7
C_ϕ, Pitch	-0.35	0.35	-0.70	0.70	0.0	0.0	-0.30	0.30	0.30	-0.30
C_θ, Roll	0.0	0.0	0.0	0.0	1.0	-1.0	0.30	-0.30	-0.30	0.30

TABLE 1A (continued)
Combined Load Cases for Yielding and Buckling Strength Formulation *(2007)*

	L.C. 1	*L.C. 2*	*L.C. 3*	*L.C. 4*	*L.C. 5*	*L.C. 6*	*L.C. 7*	*L.C. 8*	*L.C. 9*	*L.C. 10*
D. Internal Ballast Tank Pressure										
k_c	0.4	0.4	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5
w_v	0.75	-0.75	0.75	-0.75	0.25	-0.25	0.4	-0.4	-0.4	0.4
w_ℓ	Fwd Bhd 0.25 Aft Bhd -0.25	Fwd Bhd -0.25 Aft Bhd 0.25	Fwd Bhd 0.25 Aft Bhd -0.25	Fwd Bhd -0.25 Aft Bhd 0.25	-- --	-- --	Fwd Bhd 0.2 Aft Bhd -0.2	Fwd Bhd -0.2 Aft Bhd 0.2	Fwd Bhd -0.2 Aft Bhd 0.2	Fwd Bhd 0.2 Aft Bhd -0.2
w_L	-- --	-- --	-- --	-- --	Port Wall -0.75 Stbd Wall 0.75	Port Wall 0.75 Stbd Wall -0.75	Port Wall -0.4 Stbd Wall 0.4	Port Wall 0.4 Stbd Wall -0.4	Port Wall 0.4 Stbd Wall -0.4	Port Wall -0.4 Stbd Wall 0.4
C_ϕ, Pitch	-0.35	0.35	-0.70	0.70	0.0	0.0	-0.30	0.30	0.30	-0.30
C_θ, Roll	0.0	0.0	0.0	0.0	1.0	-1.0	0.30	-0.30	-0.30	0.30
E. Reference Wave Heading and Position										
Heading Angle	0	0	0	0	90	90	60	60	60	60
Heave	Down	Up	Down	Up	Down	Up	Down	Up	Up	Down
Pitch	Bow Down	Bow Up	Bow Down	Bow Up	--	--	Bow Down	Bow Up	Bow Up	Bow Down
Roll	--	--	--	--	Stbd Down	Stbd Up	Stbd Down	Stbd Up	Stbd Up	Stbd Down
Draft	$^2/_3$	1	$^2/_3$	1	$^2/_3$	$^2/_3$	$^2/_3$	1	$^2/_3$	1

1 k_u = 1.0 for all load components.

2 Boundary forces are to be applied to produce the above specified hull girder bending moment at the middle of the structural model, and specified hull girder shear force at one end of the middle hold of the model. The sign convention for the shear force corresponds to the forward end of middle hold. The specified torsional moment is to be produced at the aft bulkhead of the middle hold for L.C. 5-8, and at the forward bulkhead of the middle hold for L.C. 9-10.

3 *(1 July 2005)* The following still water bending moment (SWBM) is to be used for structural analysis.

L.C. 1, 3, 5, 7 and 9: Minimum hogging SWBM amidships of the actual container cargo loading conditions. This SWBM is not be more than 20% of the wave-induced sagging moment.

L.C. 2, 4, 6, 8 and 10: Maximum hogging SWBM.

TABLE 1A (continued)
Combined Load Cases for Yielding and Buckling Strength Formulation *(2007)*

4 *(1999)* α_s is to be obtained by the following equation:

$$\alpha_s = (T_m + T_s)/T_m$$

where

T_m = nominal wave-induced torsional moment amidships, in kN-m (tf-m, Ltf-ft), as defined in 5C-5-3/5.1.5(a)

T_s = still-water torsional moment amidships, in kN-m (tf-m, Ltf-ft), as defined in 5C-5-3/3.1

5 *(2007)* For the lower tanks whose tank top does not extend to the second deck, $\Delta\eta$ is to be the distance equivalent to $^1/_2$ of the distance from the tank top to the top of the overflow (the exposed height is minimum 760 mm above the freeboard deck or 450 mm above the superstructure deck). However, $\Delta\eta$ need not be greater than the distance between the tank top and second deck.

6 *(2007)* L.C. 9 & 10 are applicable to the structural model representing the cargo hold immediately forward of the engine room.

TABLE 1B
Combined Load Cases for Fatigue Strength Formulation *(2007)*

	L.C. 1	*L.C. 2*	*L.C. 3*	*L.C. 4*	*L.C. 5*	*L.C. 6*	*L.C. 7*	*L.C. 8*	*L.C. 9*	*L.C. 10*
A. Hull Girder Loads (2)										
Vertical B.M.(3) k_c	Sag (–) 1.0	Hog (+) 1.0	Sag (–) 0.7	Hog (+) 0.7	Sag (–) 0.3	Hog (+) 0.3	Sag (–) 0.4	Hog (+) 0.4	Sag (–) 0.4	Hog (+) 0.4
Vertical S.F. k_c	(+) 0.5	(–) 0.5	(+) 1.0	(–) 1.0	(+) 0.3	(–) 0.3	(+) 0.4	(–) 0.4	(–) 0.4	(+) 0.4
Horizontal B.M k_c	0.0	0.0	0.0	0.0	Stbd Tens (–) 0.3	Port Tens (+) 0.3	Stbd Tens (–) 0.5	Port Tens (+) 0.5	Port Tens (+) 0.7	Stbd Tens (–) 0.7
Horizontal S.F. k_c	0.0	0.0	0.0	0.0	(+) 1.0	(–) 1.0	(+) 0.5	(–) 0.5	(–) 0.7	(+) 0.7
Torsional Mt.(4) k_c	0.0	0.0	0.0	0.0	(–) $0.55\alpha_s$	(+) $0.55\alpha_s$	(–) α_s	(+) α_s	(–) α_s	(+) α_s
B. External Pressure										
k_c	0.5	0.5	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0
k_{fo}	-1.0	1.0	-1.0	1.0	-1.0	1.0	-1.0	1.0	1.0	-1.0
C. Container Cargo Load										
k_c	0.4	0.4	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5
C_v	0.8	-0.8	0.8	-0.8	0.4	-0.4	0.7	-0.7	-0.7	0.7
C_L	Fwd Bhd 0.6 Aft Bhd 0.0	Fwd Bhd 0.0 Aft Bhd -0.6	Fwd Bhd 0.6 Aft Bhd 0.0	Fwd Bhd 0.0 Aft Bhd -0.6	-- --	-- --	Fwd Bhd 0.7 Aft Bhd 0.0	Fwd Bhd 0.0 Aft Bhd -0.7	Fwd Bhd 0.0 Aft Bhd -0.7	Fwd Bhd 0.7 Aft Bhd 0.0
C_T	-- --	-- --	-- --	-- --	Port Wall 0.0 Stbd Wall 0.9	Port Wall -0.9 Stbd Wall 0.0	Port Wall 0.0 Stbd Wall 0.7	Port Wall -0.7 Stbd Wall 0.0	Port Wall -0.7 Stbd Wall 0.0	Port Wall 0.0 Stbd Wall 0.7
C_ϕ, Pitch	-1.0	1.0	-1.0	1.0	0.0	0.0	-0.7	0.7	0.7	-0.7
C_θ, Roll	0.0	0.0	0.0	0.0	1.0	-1.0	0.7	-0.7	-0.7	0.7

TABLE 1B (continued)
Combined Load Cases for Fatigue Strength Formulation *(2007)*

	L.C. 1	*L.C. 2*	*L.C. 3*	*L.C. 4*	*L.C. 5*	*L.C. 6*	*L.C. 7*	*L.C. 8*	*L.C. 9*	*L.C. 10*
D. Internal Ballast Tank Pressure										
k_c	0.4	0.4	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5
w_v	0.75	-0.75	0.75	-0.75	0.25	-0.25	0.4	-0.4	-0.4	0.4
w_ℓ	Fwd Bhd 0.25 Aft Bhd -0.25	Fwd Bhd -0.25 Aft Bhd 0.25	Fwd Bhd 0.25 Aft Bhd -0.25	Fwd Bhd -0.25 Aft Bhd 0.25	-- --	-- --	Fwd Bhd 0.2 Aft Bhd -0.2	Fwd Bhd -0.2 Aft Bhd 0.2	Fwd Bhd -0.2 Aft Bhd 0.2	Fwd Bhd 0.2 Aft Bhd -0.2
w_L	-- --	-- --	-- --	-- --	Port Wall -0.75 Stbd Wall 0.75	Port Wall 0.75 Stbd Wall -0.75	Port Wall -0.4 Stbd Wall 0.4	Port Wall 0.4 Stbd Wall -0.4	Port Wall 0.4 Stbd Wall -0.4	Port Wall -0.4 Stbd Wall 0.4
C_ϕ, Pitch	-1.0	1.0	-1.0	1.0	0.0	0.0	-0.7	0.7	0.7	-0.7
C_θ, Roll	0.0	0.0	0.0	0.0	1.0	-1.0	0.7	-0.7	-0.7	0.7
E. Reference Wave Heading and Position										
Heading Angle	0	0	0	0	90	90	60	60	60	60
Heave	Down	Up	Down	Up	Down	Up	Down	Up	Up	Down
Pitch	Bow Down	Bow Up	Bow Down	Bow Up	--	--	Bow Down	Bow Up	Bow Up	Bow Down
Roll	--	--	--	--	Stbd Down	Stbd Up	Stbd Down	Stbd Up	Stbd Up	Stbd Down
Draft	$^2/_3$	1	$^2/_3$	1	$^2/_3$	$^2/_3$	$^2/_3$	1	$^2/_3$	1

1 k_u = 1.0 for all load components.

2 Boundary forces are to be applied to produce the above specified hull girder bending moment at the middle of the structural model, and specified hull girder shear force at one end of the middle hold of the model. The sign convention for the shear force corresponds to the forward end of middle hold. The specified torsional moment is to be produced at the aft bulkhead of the middle hold for L.C. 5-8, and at the forward bulkhead of the middle hold for L.C. 9-10.

3 The following still water bending moment (SWBM) is to be used for structural analysis.

L.C. 1, 3, 5, 7 and 9: Minimum hogging SWBM amidships of the actual container cargo loading conditions. This SWBM is not be more than 20% of the wave-induced sagging moment.

L.C. 2, 4, 6, 8 and 10: Maximum hogging SWBM.

TABLE 1B (continued)
Combined Load Cases for Fatigue Strength Formulation *(2007)*

4 α_s is to be obtained by the following equation:

$$\alpha_s = (T_m + T_s)/T_m$$

where

T_m = nominal wave-induced torsional moment amidships, in kN-m (tf-m, Ltf-ft), as defined in 5C-5-3/5.1.5(a)

T_s = still-water torsional moment amidships, in kN-m (tf-m, Ltf-ft), as defined in 5C-5-3/3.1

5 For the lower tanks whose tank top does not extend to the second deck, $\Delta\eta$ is to be the distance equivalent to $^1/_2$ of the distance from the tank top to the top of the overflow (the exposed height is minimum 760 mm above the freeboard deck or 450 mm above the superstructure deck). However, $\Delta\eta$ need not be greater than the distance between the tank top and second deck.

6 L.C. 9 & 10 are applicable to the structural model representing the cargo hold immediately forward of the engine room.

TABLE 2
Design Pressure for Local and Supporting Members *(2007)*

A. Local Structures - Plating & Long'ls/Stiffeners

The nominal pressure (4, 5), $p = |p_i - p_e|$, is to be determined from load cases "a" & "b" below, whichever is greater, with k_u = 1.1 and k_c = 1.0 unless otherwise specified in the table (1)

Structural Members/ Components	*Case "a" At Forward end of the tank or hold*				*Case "b" At Forward end of the tank or hold*			
	Draft/Wave Heading Angle	*Location (2, 3) and Loading Pattern*	*Coefficients* p_i	*Coefficients* p_e	*Draft/Wave Heading Angle*	*Location (2, 3) and Loading Pattern*	*Coefficients* p_i	*Coefficients* p_e
1. Bottom Plating and Long'l	2/3draft/0°	Full double bottom & wing tanks	A_i	A_e	Full draft/0°	Empty double bottom & wing tanks	--	B_e
2. Inner Bottom Plating and Long'l	2/3 draft/0°	Full double bottom & wing tanks, cargo holds empty	A_i	--				--
3. Side Shell Plating & Long'l/Frame	2/3 draft/60°	Starboard side (6) of full double bottom & wing tank	B_i	A_e	Full draft/60°	Empty double bottom & wing tanks	--	B_e
4. Main Deck Plating & Long'l	2/3 draft/0°	Full wing tank (7)	C_i	--				
5. Long'l Bulkhead Plating & long'l/Stiffeners	2/3 draft/60°	Starboard side (6) of full double bottom & wing tanks, cargo hold empty	B_i	--	Flooded Condition	Flooded (8) cargo hold, double bottom & wing tanks empty	D_i	--
6. Transverse Bulkhead Plating & Stiffeners								
(i) Tank Boundaries	2/3 draft/0°	Forward Bulkhead of full double bottom & wing tanks	A_i					
(ii) Cargo Hold Boundaries	Flooded Condition	Flooded (8) cargo hold	D_i					
7. Double Bottom Structure								
(i) Watertight Girder Plating & Stiffeners	2/3 draft/60°	Starboard side (6) of full double bottom or wing tanks, adjacent tanks empty	B_i					
(ii) Tank End Floor Plating & Stiffeners	2/3 draft/0°	Forward tank end floor of full double bottom or side tank, adjacent tanks empty	A_i					
8. Watertight Side Stringer	2/3 draft/60°	Full double bottom or side tank, adjacent tanks empty	B_i					

TABLE 2 (continued)
Design Pressure for Local and Supporting Members *(2007)*

B. Main Supporting Members

The nominal pressure, $p = |p_i - p_e|$, is to be determined from load cases "a" & "b" below, whichever is greater, with k_u = 1.0 and k_c = 1.0 unless otherwise specified in the table

Structural Members/ Components	*Case "a" Mid-Tank*				*Case "b" Mid-Tank*			
	Draft/Wave Heading Angle	*Location and Loading Pattern*	*Coefficients*		*Draft/Wave Heading Angle*	*Location and Loading Pattern*	*Coefficients*	
			p_i	p_e			p_i	p_e
9. Double Bottom Floors & Girders Bottom Transverse in Pipe Duct Space	Full draft/0°	Mid-tank, cargo holds and ballast tanks empty	---	B_e				
10. Transverses and Stringers	Full draft/90°	Starboard side of mid-tank, cargo hold and ballast tanks empty	---	B_e				
11. Horizontal Girders and Vertical Webs on Transverse Watertight Bulkhead	Flooded Condition	Flooded (8) cargo hold	D_i					
12. Transverse Webs on Longitudinal Watertight Bulkhead	Flooded Condition	Flooded (8) cargo hold, double bottom & wing tanks empty	D_i					
13. Deck Transverse	$^2/_3$ draft/0°	Full wing tank (7)	C_i					
14. Vertical Web on Double Bottom Watertight Girder	$^2/_3$ draft/60°	Starboard side (6) of full double bottom or wing tanks, adjacent tanks empty	B_i					

TABLE 2 (continued)
Design Pressure for Local and Supporting Members *(1 July 2005)*

Notes:

1 For calculating p_i and p_e, the necessary coefficients are to be determined based on the following designated groups:

a) for p_i

	w_v	w_ℓ		w_t		C_ϕ	C_θ
		Forward Bulkhead	AFt Bulkhead	Starboard side	Port side		
A_i	0.75	0.25	-0.25	0.0	0.0	-0.35	0.0
B_i	0.40	0.20	-0.20	0.4	-0.4	-0.30	0.30
C_i	-0.75	0.25	--	0.0	0.0	-0.35	0.0
D_i	0.0	0.0	0.0	0.0	0.0	0.0	0.0

b) for p_e

A_e: $k_{\ell o} = 1.0$, $k_u = 1.0$, $k_c = -0.5$

B_e: $k_{\ell o} = 1.0$

2 For structures within 0.4*L* amidships, the nominal pressure is to be calculated for a hold or tank located amidships.
The net scantlings of the structural members within 0.4L amidships are to be determined for each cargo hold or tank in the region, based on the assumption that the cargo hold or tank is located amidships as shown 5C-5-3/Figure 15.

3 For structures outside 0.4*L* amidships, the nominal pressure is to be calculated for members in a hold or tank under consideration.

4 The nominal pressure of a non-prismatic tank is to be calculated based on the extreme tank boundary section which is assumed constant lengthwise as illustrated in 5C-5-3/Figure 16. This calculated pressure is not applicable to members outside the actual tank boundary.

5 In calculation of the nominal pressure, ρg of the liquid or ballast is not to be taken less than 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.4444 lbf./in^2-ft).

6 "Starboard side" and "Port side" designate the desired half portion of the tank, respectively. When calculating the nominal pressure for case a of item 5 and 11, the pressure at the other half portion of the tank is to be examined.

7 The nominal deck pressure is to be not less than 2.06 N/cm^2 (0.21 kgf/cm^2, 2.99 lbf/in^2) in Position 1 and 1.57 N/cm^2 (0.16 kgf/cm^2, 2.28 lbf/in^2) in Position 2. Position 1 and Position 2 are defined in 3-2-15/3 of the Rules.

8 *(1 July 2005)* The nominal pressure for watertight requirement for flooding condition may be taken as the cargo hold filled up to the deepest equilibrium waterline in the one compartment damaged condition. This is not to be less than the cargo hold filled up to the bulkhead deck at center unless a deck lower than the uppermost continuous deck is designed as freeboard deck, as allowed in 3-1-1/13.1. In such case, the nominal pressure may be taken as the cargo hold filled up to freeboard deck at center.

9 Application items for typical sections are illustrated in 5C-5-3/Figure 17. See also Note 6 for members marked with (*).

FIGURE 15
Location of Hold for Nominal Pressure Calculation

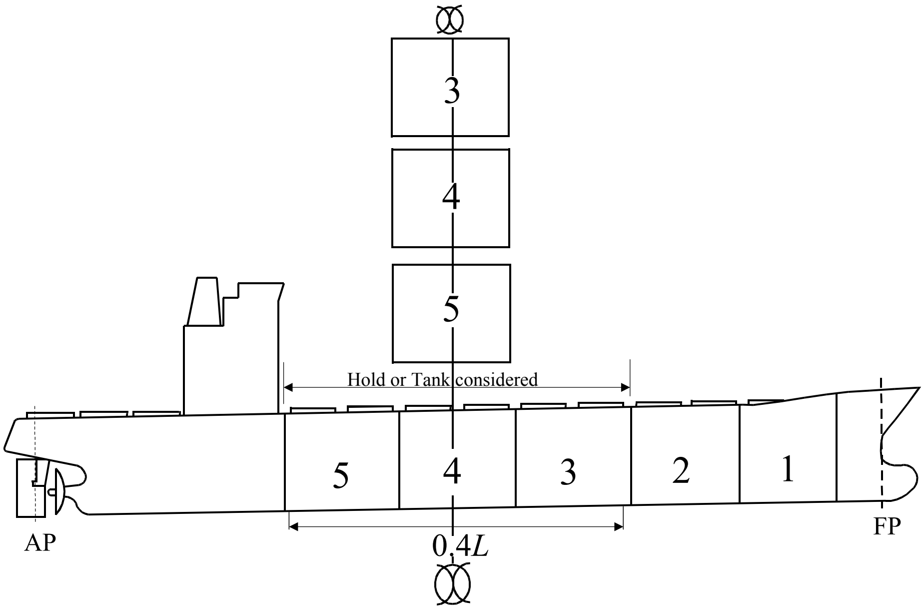


FIGURE 16
Nominal Pressure Calculation Procedure for Non-Prismatic Tank

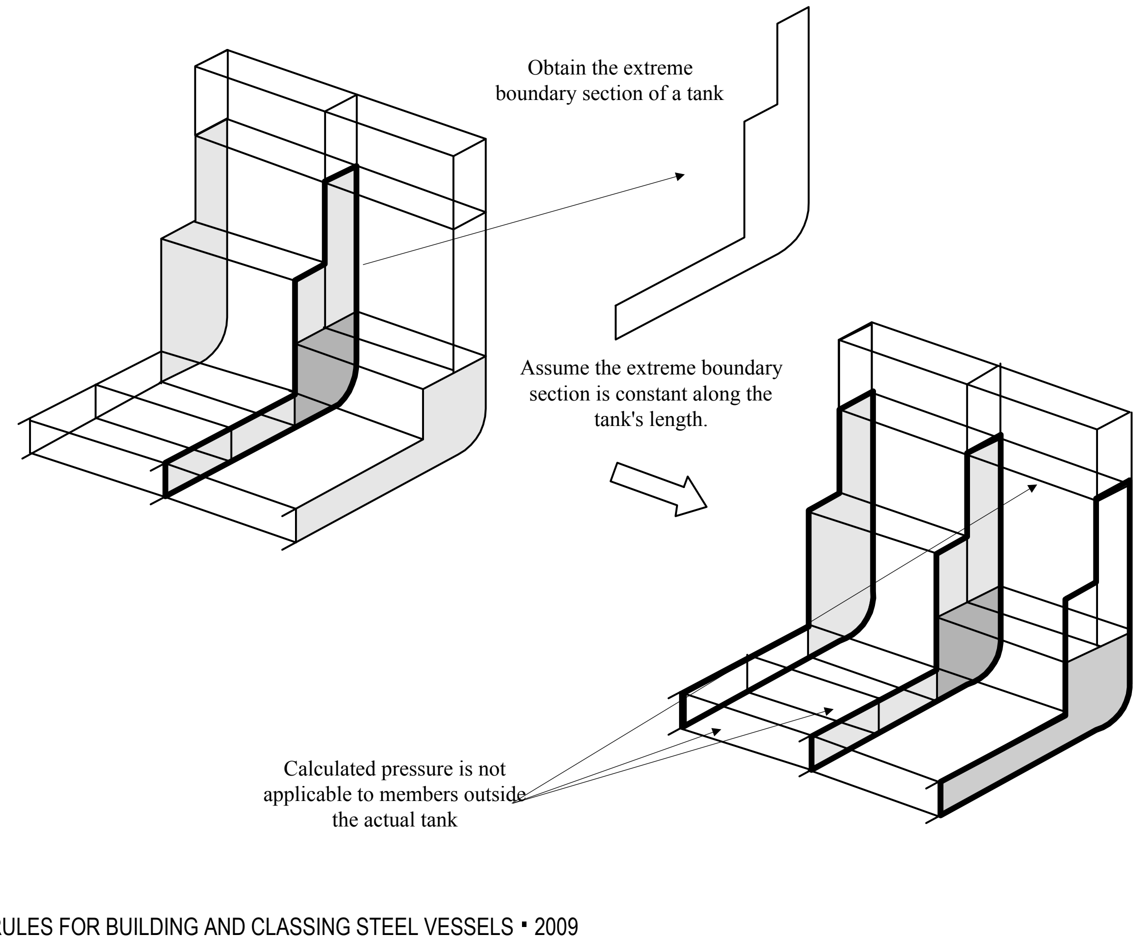
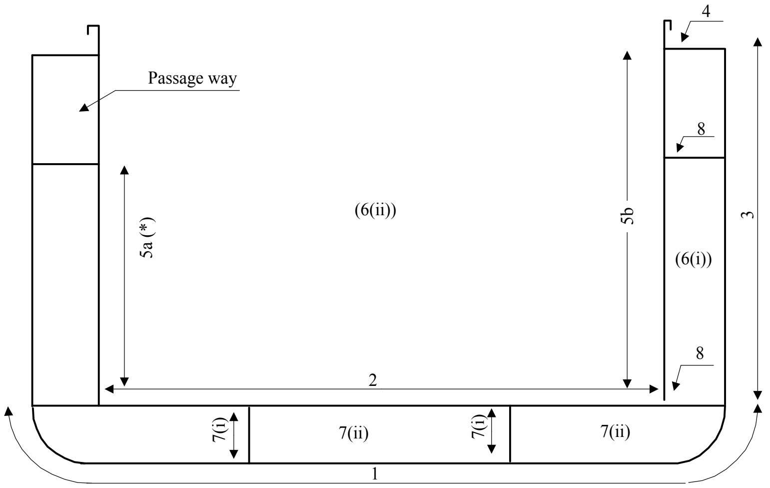
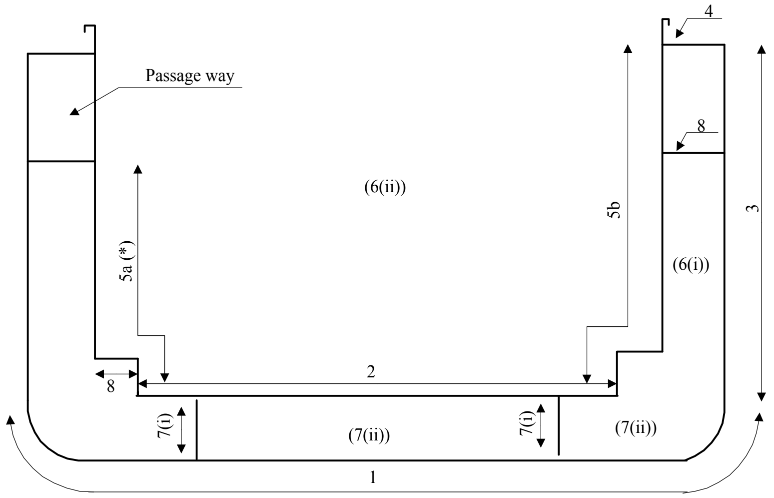


FIGURE 17
Applicable Areas of Design Pressures

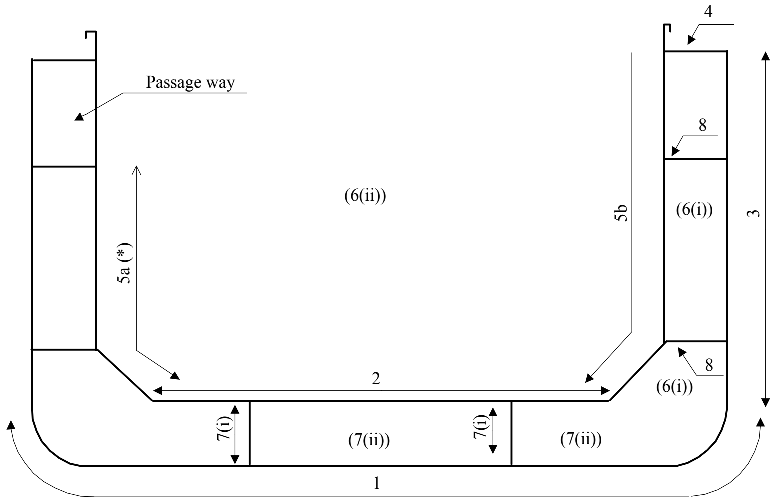
Type A



Type B



Type C



7 Nominal Design Loads *(1998)*

The nominal design loads specified below are to be used for determining the required scantlings of hull structures in conjunction with the specified permissible stresses given in Section 5C-5-4.

7.1 Hull Girder Loads – Longitudinal Bending Moments, Shear Forces and Torsional Moment *(1998)*

7.1.1 Total Vertical Bending Moment and Shear Force

The total longitudinal vertical bending moment and shear force may be obtained from the following equations:

$M_t = M_s + k_u\, k_c\, M_w$ kN-m (tf-m, Ltf-ft)

$F_t = F_s + k_u\, k_c\, F_w$ kN (tf, Ltf)

where

M_s and M_w are the stillwater bending moment and vertical wave-induced bending moment, respectively, as specified in 5C-5-3/3.1 and 5C-5-3/5.1, for either hogging or sagging conditions.

F_s and F_w are the stillwater and the vertical wave-induced shear forces, respectively, as obtained from 5C-5-3/3.1 and 5C-5-3/5.1 for either positive or negative shears.

k_u is a load factor and may be taken as unity unless otherwise specified.

k_c is a correlation factor and may be taken as unity unless otherwise specified.

The total bending moment is to be obtained based on the envelope curves, as specified in 5C-5-3/3.1 and 5C-5-3/5. For this purpose, k_u = 1.0, and k_c = 1.0.

7.1.2 Horizontal Wave Bending Moment and Shear Force

For non-head sea conditions, the horizontal wave bending moment and the horizontal shear force, as specified in 5C-5-3/5.1, are to be considered as additional hull girder loads, especially for the design of the side shell and inner skin structures within the range of 0.35D above and below the mid-depth of vessel. The effective horizontal bending moment and shear force, M_{HE} and F_{HE}, may be determined by the following equations:

$M_{HE} = k_u\, k_c\, M_H$ kN-m (tf-m, Ltf-ft)

$F_{HE} = k_u\, k_c\, F_H$ kN (tf, Ltf)

M_H and F_H are as specified in 5C-5-3/5.1.

7.1.3 Wave-Induced Torsional Moment

The effective wave-induced torsional moment for non-head sea conditions is to be considered in addition to the hull girder loads specified in 5C-5-3/7.1.1 and 5C-5-3/7.1.2 above.

$T_{ME} = k_u\, k_c\, T_M$ kN-m (tf-m, Ltf-ft)

where

T_M is as specified in 5C-5-3/5.1.5.

where k_u and k_c are load factor and correlation factor, respectively, which may be taken as unity unless otherwise specified. For this purpose, k_u = 1.0 and k_c = 1.0.

7.3 Local Loads for Design of Supporting Structures *(1998)*

In determining the required scantlings of the main supporting structures, such as girders, transverses, stringers, floors and deep webs, the nominal loads induced by the external pressures, ballast pressures and cargo loads distributed over both sides of the structural panel within the cargo hold boundaries are to be considered for the worst possible load combinations. In general, consideration is to be given to the following two loading cases accounting for the worst effects of the dynamic load components.

7.3.1

Maximum internal cargo loads or pressures for a fully loaded cargo hold with the adjacent holds empty and minimum external pressures, where applicable.

7.3.2

Empty cargo hold with the fore and aft holds full and maximum external pressures, where applicable.

The specified design loads for main supporting structures are given in 5C-5-3/Table 2.

7.5 Local Pressures for Design of Plating and Longitudinals *(1998)*

In calculating the required scantlings of plating, longitudinals and stiffeners, the nominal pressures are to be considered for the two load cases given in 5C-5-3/7.3, using k_u = 1.1 instead of k_u = 1.0, as shown above.

The necessary details for calculating the nominal pressures are given in 5C-5-3/Table 2.

9 Combined Load Cases

9.1 Combined Load Cases for Structural Analysis *(1998)*

For assessing the strength of the hull girder structures and in performing a structural analysis as outlined in Section 5C-5-5, the ten combined load cases specified in 5C-5-3/Table 1 are to be considered. Additional combined load cases may be required as warranted. The loading patterns are shown in 5C-5-3/Figure 3 for three cargo hold lengths. It is to be noted that the midship section should be located within the mid-hold of the three hold FE model. The necessary factors and coefficients for calculating hull girder and local loads are given in 5C-5-3/Table 1. The total external pressure distribution including static and hydrodynamic pressures is illustrated in 5C-5-3/Figure 10.

If deemed necessary, another three hold length model consisting of the engine room and two adjacent cargo holds forward is to be analyzed to assess the torsional response of the deck structures immediately forward of the engine room. For this purpose, four load cases, Load Cases 7 through 10 of 5C-5-3/Table 1, are to be considered using the loading patterns of cargo holds specified in 5C-5-3/Figure 3.

9.3 Combined Load Cases for Strength Assessment *(1998)*

For assessing the failure modes with respect to material yielding, buckling and ultimate strength, the following combined load cases are to be considered:

9.3.1 Ultimate Strength of Hull Girder

For assessing ultimate strength of the hull girder, the combined effects of the following primary and local loads are to be considered.

9.3.1(a) Primary Loads, Longitudinal Bending Moments and Shear Forces in Head Sea Conditions

($M_H = 0$, $F_H = 0$, $T_M = 0$)

M_t = $M_s + k_u\, k_c\, M_w$, $k_c = 1.0$ hogging and sagging

F_t = $F_s + k_u\, k_c\, F_w$, $k_c = 1.0$ positive and negative

k_u = 1.15 for vessels without bowflare

For vessels having significant bowflare, k_u is to be increased as specified in 5C-5-3/11.3.3.

M_s, M_w, F_s and F_w are as defined in 5C-5-3/3 and 5C-5-3/5.

9.3.1(b) Local loads for large stiffened panels. Internal and external pressure loads as given in 5C-5-3/Table 2 are to be considered.

9.3.2 Yielding, Buckling and Ultimate Strength of Local Structures

For assessing the yielding, buckling and ultimate strength of local structures, the ten combined load cases given in 5C-5-3/Table 1 are to be considered.

9.3.3 Fatigue Strength

For assessing the fatigue strength of structural joints, the ten combined load cases given in 5C-5-3/9.1 and two additional load cases given in 5C-5-A1/Table 3 are to be used for fatigue strength assessment, as described in Appendix 5C-5-A1.

11 Impact Loads

11.1 Bottom Slamming Pressure *(2002)*

For container carriers with a heavy ballast draft forward less than 0.04L, bottom slamming loads are to be considered for assessing strength of the flat of bottom plating forward and the associated stiffening system in the fore body region.

The equivalent bottom slamming pressure for the strength assessment is to be determined based on well documented experimental data or analytical studies. When these direct calculations are not available, nominal bottom slamming pressures may be determined by the following equations:

$$P_{si} = k\, k_i\, [v_0^2 + M_{Vi}\, E_{ni}]\, E_f \qquad \text{kN/m}^2\ (\text{tf/m}^2,\ \text{Ltf/ft}^2)$$

where

P_{si} = equivalent bottom slamming pressure for section i

k = 1.025 (0.1045, 0.000888)

k_i = $2.2\, b^*/d_0 + \alpha \le 40$

b^* = half width of flat of bottom at the i-th ship station, see 5C-5-3/Figure 18

d_0 = $^1/_{10}$ of the section draft at the heavy ballast condition, see 5C-5-3/Figure 18

α = a constant as given in 5C-5-3/Table 3

E_f = $f_1 = \omega_1\, (L)^{1/2}$

f_1 = 0.004 (0.0022), m (ft)

ω_1 = natural angular frequency of the hull girder 2-node vertical vibration of the vessel in the wet mode and the heavy ballast draft condition, in rad/second. If not known, the following equation may be used:

= $\mu[B\,D^3/(\Delta_S\,C_b^{\,3}\,L^3)]^{1/2} + 1.0 \quad \geq 3.7$

μ = 23400 (7475, 4094)

Δ_S = $\Delta_b[1.2 + B/(3d_b)]$

Δ_b = vessel displacement at the heavy ballast condition, in kN (tf, Ltf)

d_b = mean draft of vessel at the heavy ballast condition, in m (ft)

V = 75% of design speed, V_d, in knots. V is not to be taken less than 10 knots.

V_d = the design speed as defined in 3-2-14/3

v_0 = $c_0\,L^{1/2}$, m/s (ft/s)

c_0 = 0.29 (0.525), m (ft)

L = vessel's length, as defined in 3-1-1/3.1, in m (ft)

E_{ni} = natural log of n_i

n_i = $5730\,(M_{Vi}/M_{Ri})^{1/2}\,G_{ei}$, if $n_i < 1$ then $P_{si} = 0$

G_{ei} = $e^{[-(v_0^2/M_{Vi} + d_i^2/M_{Ri})]}$

d_i = local section draft, in m (ft)

M_{Vi} = $B_i\,M_{Ri}$

M_{Ri} = $c_1\,A_i\,(VL/C_b)^{1/2}$

c_1 = 0.44 (2.615), m (ft)

A_i and B_i are as given in 5C-5-3/Table 4.

C_b is as defined in 3-2-1/3.5.1 and is not to be less than 0.6.

where b represents the half breadth at the $^1/_{10}$ draft of the section, see 5C-5-3/Figure 18. Linear interpolation may be used for intermediate values.

11.3 Bowflare Slamming

Bowflare slamming loads are to be considered for assessing the strength of the side plating and the associated stiffening system in the forebody region of the vessel at its load waterline.

11.3.1 Nominal Bowflare Slamming *(1 July 2008)*

When experimental data or direct calculation is not available, nominal bowflare slamming pressures above the load waterline (LWL) may be determined by the following equations:

$P_{ij} = P_{0ij}$ or P_{bij} as defined below, whichever is greater

$P_{0ij} = k_1(9M_{Ri} - h_{ij}^{\,2})^{1/2}$ kN/m² (tf/m², Ltf/ft²)

$P_{bij} = k_2\,k_3\{c_2 + K_{ij}\,M_{Vi}\,(1 + E_{ni})\}$ kN/m² (tf/m², Ltf/ft²)

where

k_1 = 9.807 (1, 0.0278)

k_2 = 1.025 (0.1045, 0.000888)

k_3 = 1 for $h_{ij} \leq h_b^*$

= $1 + (h_{ij}/h_b^* - 1)^2$ for $h_b^* < h_{ij} < 2h_b^*$

= 2 for $h_{ij} \geq 2\,h_b^*$

c_2 = 39.2 (422.46) for m (ft)

E_{ni} = natural log of n_{ij}

n_{ij} = $5730\,(M_{Vi}/M_{Ri})^{1/2}\,G_{ij} \geq 1.0$

G_{ij} = $\exp\,(-h_{ij}^2/M_{Ri})$

M_{vi} = $B_i\,M_{Ri}$, where B_i is given in 5C-5-3/Table 4

M_{Ri} = $c_1\,A_i\,(VL/C_b)^{1/2}$, where A_i is given in 5C-5-3/Table 4, if $9M_{Ri} < h_{ij}^2$, then $P_{oij} = 0$

c_1 = 0.44 (2.615) for m (ft)

h_{ij} = vertical distance measured from the load waterline (LWL) at station i to WL_j on the bowflare. The value of h_{ij} is not to be taken less than h_b^*. P_{bij} at a location between LWL and h_b^* above LWL need not be taken greater than p_{bij}^*.

h_b^* = $0.005(L - 130) + 3.0$ (m) for $L < 230$ m

= $0.005(L - 426.4) + 9.84$ (ft) for $L < 754$ ft

= $7.143 \times 10^{-3}(L - 230) + 3.5$ (m) for 230 m $\leq L <$ 300 m

= $7.143 \times 10^{-3}(L - 754.4) + 11.48$ (ft) for 754 ft $\leq L <$ 984 ft

= 4.0 m (13.12 ft) for $L \geq$ 300 m (984 ft)

p_{bij}^* = $P_{bi}^*\sqrt{\beta_i^* / \beta_{ij}'}$

P_{bi}^* = P_{bij} at h_b^* above LWL

K_{ij} = $f_{ij}\,[r_j/(bb_{ij} + 0.5h_{ij})]^{3/2}\,[\ell_{ij}/r_j]\,[1.09 + 0.029V - 0.47\,C_b]^2$

r_j = $(M_{Ri})^{1/2}$

bb_{ij} = $b_{ij} - b_{i0}$ > 2.0 m (6.56 ft)

b_{ij} = local half beam of location j at station i

b_{i0} = load waterline half beam at station i

ℓ_{ij} = longitudinal distance of station i at j-th WL measured from amidships, based on the scantling length

f_{ij} = $[90/\beta_{ij}' - 1]^2\,[\tan^2(\beta_{ij}')/9.86]\cos\gamma$

β'_{ij} = normal local body plan angle

= $\tan^{-1}[\tan(\beta_{ij})/\cos(\alpha_{ij})]$

α_{ij} = waterline angle as in 5C-5-3/Figure 11

β_{ij} = local body plan angle, in degrees, measured from the horizontal, as in 5C-5-3/Figure 11, not to be taken greater than 75 degrees

β_i^* = β'_{ij} at h_b^* above LWL

γ = ship stem angle at the centerline plane measured from the horizontal, as in 5C-5-3/Figure 19, in degrees, not to be taken greater than 75 degrees.

V = as defined in 5C-5-3/11.1

L = as defined in 3-1-1/3.1, in m (ft)

C_b = as defined in 3-2-1/3.5.1 and not to be less than 0.6.

11.3.2 Simultaneous Bowflare Slamming Pressure

For performing structural analyses to determine overall responses of the hull structures, the spatial distribution of instantaneous bowflare pressures on the fore body region of the hull may be expressed by multiplying the calculated maximum bowflare slamming pressures, P_{ij}, at forward ship stations by a factor of 0.71 for the region between the stem and 0.3L from the FP.

11.3.3 Effects of Bowflare Slamming on Vertical Hull Girder Bending Moment and Shear Force *(1 July 2005)*

For container carriers having a forebody parameter, A_r d_k, greater than 70 m^2 (753 ft^2), the buckling strength of the hull girder structure in the forward half-length is to be evaluated using the following hull girder bending moment and shear force.

The still water bending moment used to calculate the total bending moment may be determined from the minimum hogging bending moment or maximum sagging bending moment, whichever is applicable in the container cargo loading conditions.

The maximum bending moment due to bowflare slamming and regular waves may be determined by the following equation:

$$M_{wbi} = k[\alpha_i L^2 A_r d_k F_n{}^{1/3}/(\omega_1 C_b{}^2 d)]$$

where

M_{wbi} = maximum bending moment due to bowflare slamming and regular waves ending moment at station i, where station 10 denotes the midship and station 20 is the AP, not to be less than $|M_{wi}|$

$|M_{wi}|$ = absolute value of wave induced bending moment at station i, as specified in 5C-5-3/5.1.1 for sagging condition, where station 10 denotes the midship and station 20 is the AP

k = 10.3 (1.05, 3.44) for kN-m (tf-m, Ltf-ft)

α_i = envelope curve factors: 0.6, 1.2, 1.8, 2.05, 2.1 and 2.0, corresponding to stations at 0.1, 0.2, 0.3, 0.35, 0.4, and 0.5L from the FP, respectively. Linear interpolation may be used for intermediate values

ω_1 = natural frequency of the 2-node hull girder vibration of the vessel in the wet mode, in rad/second. If not known, the following equation may be used

= $\mu\,[B\,D^3/(\Delta_s\,C_b\,L^3)]^{1/2} + 1.4 \geq 3.7$

where

μ = 23400 (7475, 4094)

Δ_s = $\Delta\{1.2 + B/(3d)\}$

Δ = displacement as defined in 5C-5-3/5.5.1(b) in kN (tf, Ltf)

d = draft as defined in 3-1-1/9 in m (ft)

A_r = the maximum value of A_{ri} in the forebody region

A_{ri} = bowflare shape parameter at station i forward of the quarter length, up to the FP of the vessel, to be determined between the LWL and the highest deck, as follows:

= $(b_{Ti}/H_i) \sum\left[b_j^2 + s_j^2\right]^{1/2}, \quad j = 1, n \quad n \geq 4$

d_k = $0.2 \sum_i^5 b_{Ti}$

= nominal half deck width based on forward five stations of the FP, 0.05L, 0.1L, 0.15L and 0.2L, (see 5C-5-3/Figure 21)

where

b_{Ti} = Σb_j at station i

H_i = Σs_j at station i

b_j = local change (increase) in beam for the j-th segment at station i (see 5C-5-3/Figure 20)

s_j = local change (increase) in freeboard up to the highest deck for the j-th segment at station i forward (see 5C-5-3/Figure 20)

The still water shear force used to calculate the total shear force can be determined from the maximum negative shear force or minimum positive shear force whichever is applicable in the container cargo loading conditions.

The shear force due to bowflare slamming and regular waves may be determined by the following equation:

$$F_{wbi} = K_{si}[c_2 L A_r d_k F_n^{1/3} /(\omega_1 C_b^2 d)]$$

where

F_{wbi} = maximum positive wave induced shear force due to bowflare slamming and regular waves at station i, where station 10 denotes the midship, kN (tf, Ltf), not to be less than F_{wi}

F_{wi} = positive wave induced shear force (see 5C-5-3/5.1.2) at station i, where station 10 denotes the midship, kN (tf, Ltf)

c_2 = 66.95 (6.825, 22.386) for kN (tf, Ltf)

K_{si} = shear envelope curve factor at station i

= 0.0 for the forward perpendicular

= 1.0 for 0.7L to 0.85L from the aft end of L

= 0.5 for 0.5L to 0.6L from the aft end of L

Linear interpolation may be used for intermediate values.

$$F_n = 0.514\, V_d/(gL)^{1/2}, \quad \text{for SI and MKS units}$$

$$= 1.688\, V_d/(gL)^{1/2}, \quad \text{for US units}$$

V_d is the design speed, as defined in 3-2-14/3, in knots. g is the acceleration due to gravity (9.807 m/sec^2, 32.2 ft/sec^2). F_n is not to be taken less than 0.225.

L, B, D and C_b are as defined in Section 3-1-1. C_b is not to be taken less than 0.6.

TABLE 3
Values of α

b/d_o	α	b/d_o	α
≤ 1.00	0.00	4.00	20.25
1.50	9.00	5.00	22.00
2.00	11.75	6.00	23.75
2.50	14.25	7.00	24.50
3.00	16.50	7.50	24.75
3.50	18.50	≥ 25.0	24.75

TABLE 4
Values* of A_i and B_i

	A_i	B_i
-0.05L	1.25	0.3600
FP	1.00	0.4000
0.05L	0.80	0.4375
0.10L	0.62	0.4838
0.15L	0.47	0.5532
0.20L	0.33	0.6666
0.25L	0.22	0.8182
0.30L	0.22	0.8182

* Linear interpolation may be used for intermediate values

FIGURE 18
Distribution of Bottom Slamming Pressure Along the Section Girth

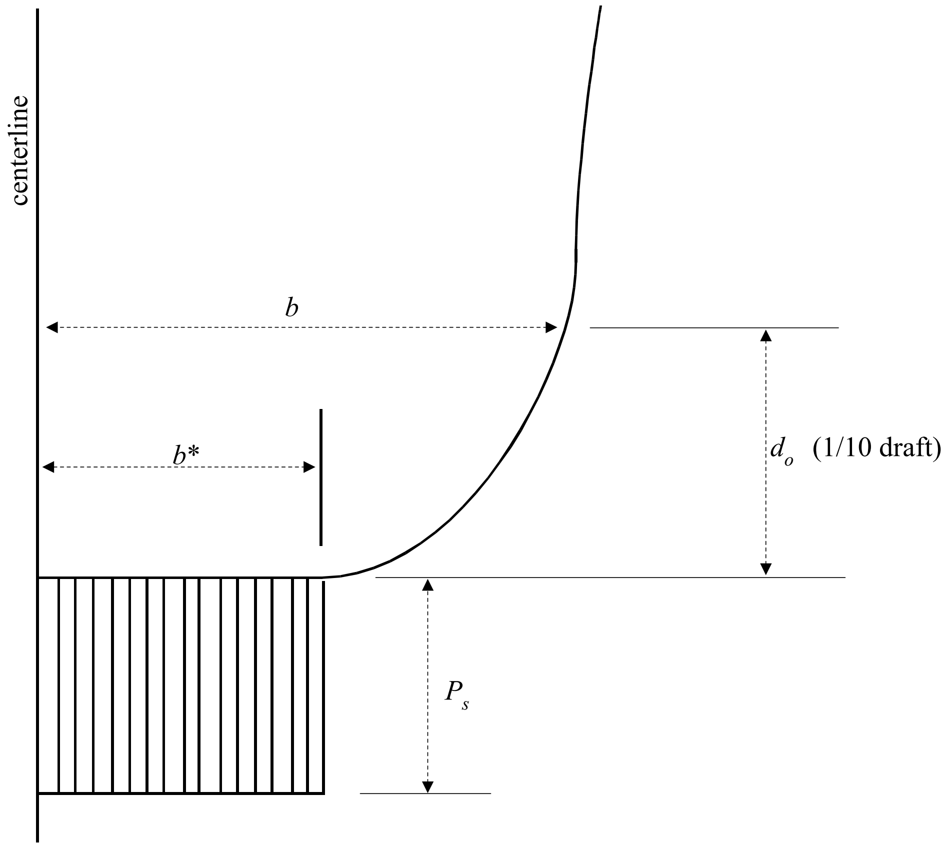


FIGURE 19
Ship Stem Angle, γ

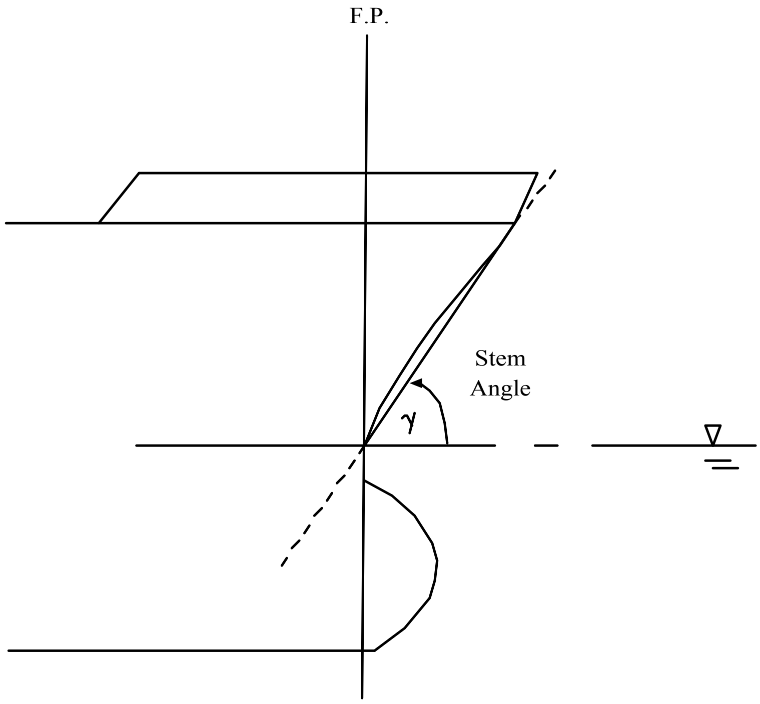


FIGURE 20
Definition of Bow Flare Geometry for Bow Flare Shape Parameter

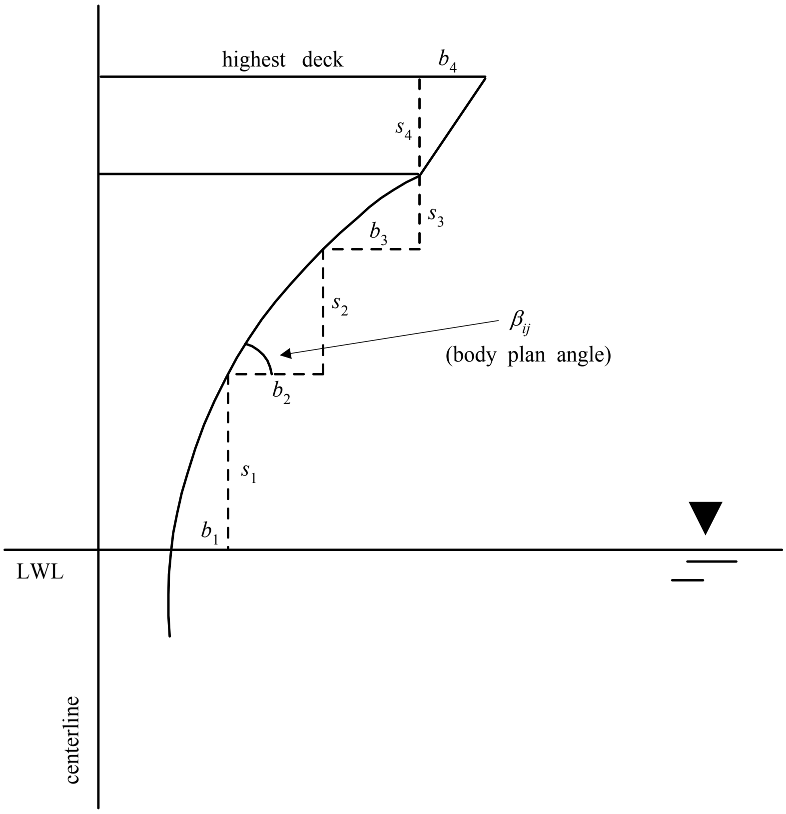
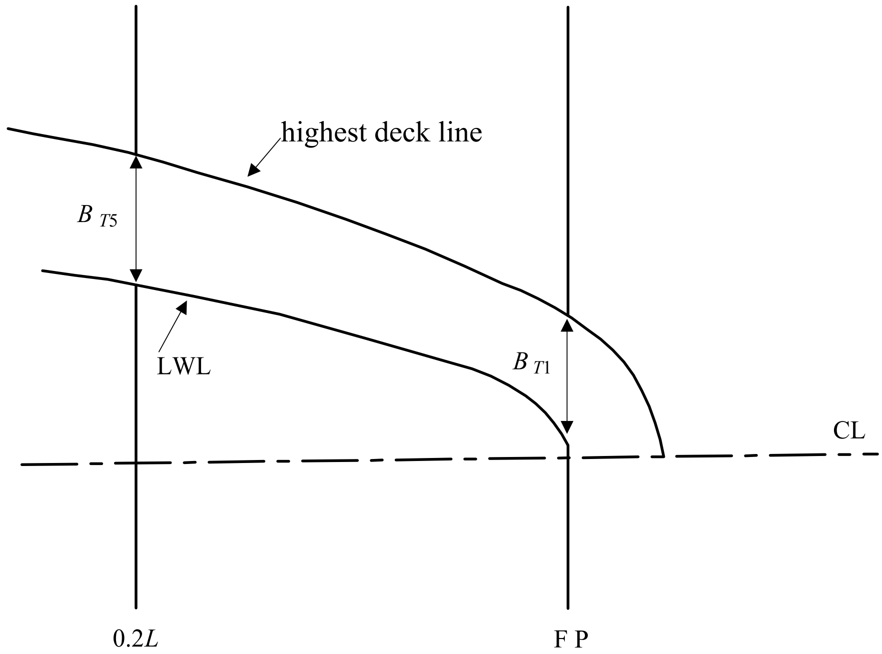


FIGURE 21
Definition of Half Deck Width



13 Other Loads

13.1 Vibrations

In addition to the vibratory hull girder loads induced by bottom and bow slamming specified in 5C-5-3/11, vibratory responses of hull structures induced by the propulsion system and waves are also to be examined, as applicable.

13.3 Ice Loads

For vessels intended for special services, such as navigating in cold regions, consideration is to be given to the effects of ice loads in assessing the strength of the hull structure.

In this case, the limits of the ice loads are to be furnished and analyzed by the designer.

13.5 Accidental Loads

The effects of possible accidental loads on the stiffening systems in the design of the main supporting members of the side and bottom shell structures are to be considered. The pressures for the flooded condition, as specified in Note 8 of 5C-5-3/Table 2 for watertight bulkheads, and nominal magnitudes of the accidental loads with respect to collision or grounding, as outlined in the ABS *Guide for Assessing Hull-Girder Residual Strength*, may be applied for this purpose.

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PART

5C

CHAPTER 5 Vessels Intended to Carry Containers (130 meters (427 feet) to 450 meters (1476 feet) in Length)

SECTION 4 Initial Scantling Criteria

1 General

1.1 Strength Requirements *(1998)*

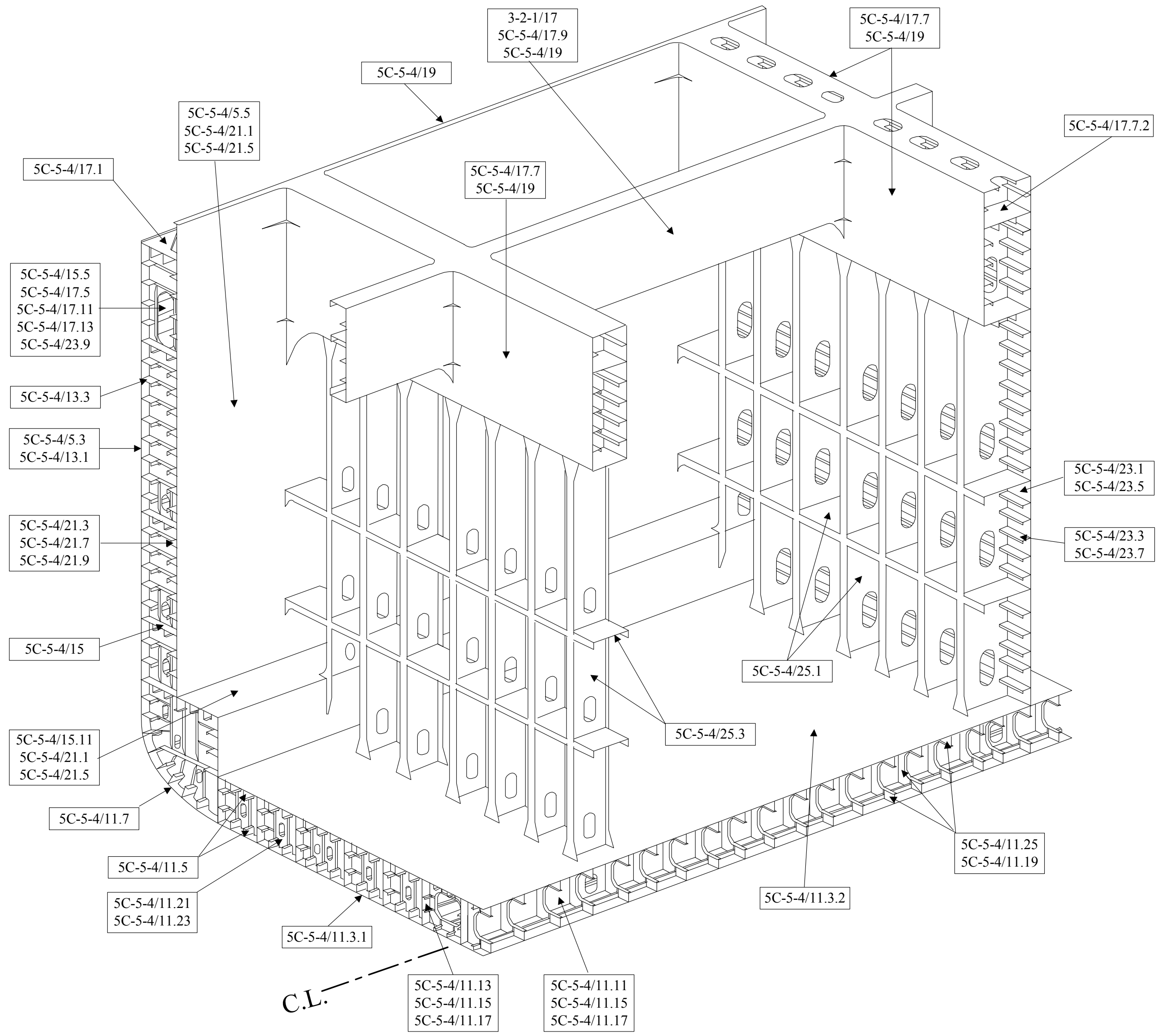
This section specifies the minimum strength requirements for the hull structure with respect to the determination of initial scantlings, including the hull girder, shell and bulkhead plating, frames/stiffeners and main supporting members. Once the minimum scantlings are determined, the strength of the resulting design is to be assessed in accordance with Section 5C-5-5. The assessment is to be carried out by means of an appropriate structural analysis, as per 5C-5-5/9, in order to establish compliance with the failure criteria in 5C-5-5/3, 5C-5-5/5 and 5C-5-5/7. Structural details are to comply with 5C-5-5/1.7.

The requirements for the hull girder strength are specified in 5C-5-4/3. The requirements in 5C-5-4/7 and 5C-5-4/9 are applicable to container carriers having upper wing torsional boxes and special consideration is to be given to vessels without upper wing torsional boxes. The required scantlings of double bottom structures, side structures, deck structures, longitudinal bulkheads and transverse bulkheads structures are specified in 5C-5-4/11, 5C-5-4/13, 5C-5-4/15, 5C-5-4/17, 5C-5-4/19, 5C-5-4/21, 5C-5-4/23 and 5C-5-4/25, respectively. 5C-5-4/Figure 1 shows the paragraph numbers giving scantling requirements for the various structural components of typical container carriers. For hull structures beyond 0.4L amidships, the initial scantlings are to be determined in accordance with Section 5C-5-6.

1.3 Calculation of Load Effects *(1998)*

Approximation equations are given in 5C-5-4/11 through 5C-5-4/25 and Section 5C-5-6 for calculating the maximum bending moments and shear forces for main supporting members clear of the end brackets for typical structural arrangements and configurations. For designs with different structural configurations, these local load effects may be determined from a proper 3D structural analysis at the early design stages, as outlined in 5C-5-5/9, for the combined load cases specified in 5C-5-3/9, excluding the hull girder load components. In this case, the results of detailed stress analysis are to be submitted for review.

FIGURE 1
Scantling Requirement Reference by Subsection



1.5 Structural Details *(1 July 2008)*

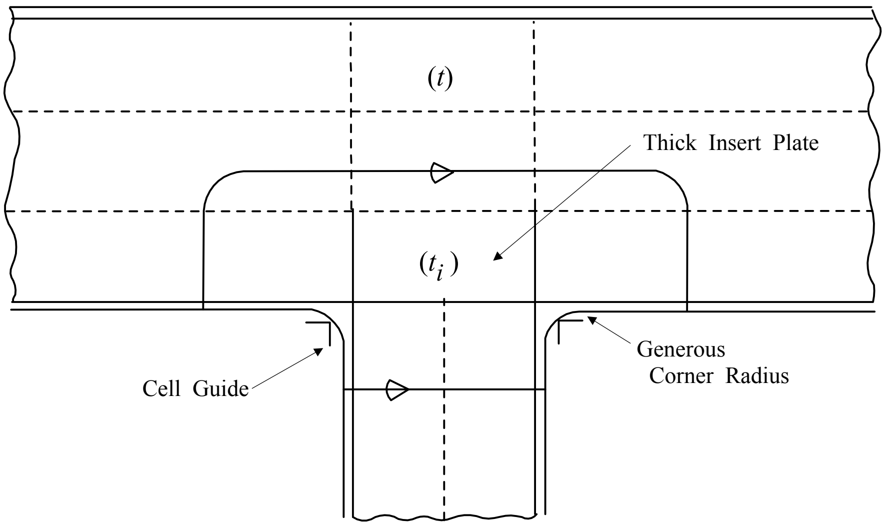
See 5C-5-5/1.7 and 5C-5-4/Figure 2.

Stiffening members, cell guides and doublers for container fittings are not to be directly welded to hatch corners. During construction, hatch corners are not to be altered to create space to accommodate cell guides. Where container fittings are fitted for container securing, doubler pads are to be welded at least 100 mm (4 in.) away from curved edges of hatch corners.

1.7 Evaluation of Grouped Stiffeners *(1 July 2005)*

Where several members in a group with some variation in requirement are selected as equal, the section modulus requirement may be taken as the average of each individual requirement in the group. However, the section modulus requirement for the group is not to be taken less than 90% of the largest section modulus required for individual stiffeners within the group. Sequentially positioned stiffeners of equal scantlings may be considered a group.

FIGURE 2
Improvement of Hatch Corners and Heavy Insert Deck Plate



3 Hull Girder Strength

3.1 Hull Girder Section Modulus *(1998)*

3.1.1 Hull Girder Section Modulus Amidships

The required hull girder section modulus amidships is to be calculated in accordance with 3-2-1/3.7, 3-2-1/5, and 3-2-1/9 where the calculation of the total vertical bending moment, M_t, is in accordance with 5C-5-3/7.1.1. For the assessment of the ultimate strength as specified in Section 5C-5-5 and the determination of initial net structural scantlings, the net hull girder section modulus amidships, SM_n, is to be calculated in accordance with 5C-5-4/3.1.2 below.

3.1.2 Effective Longitudinal Members

The hull girder section modulus calculation is to be carried out in accordance with 3-2-1/9 as modified below. To suit the strength criteria based on a "net" ship concept, the nominal design corrosion values specified in 5C-5-2/Table 1 are to be deducted in calculating the net section modulus, SM_n.

3.1.3 Extent of Midship Scantlings

The items included in the hull girder section modulus amidships are to be extended as necessary to meet the hull girder section modulus required at the location being considered. The required hull girder section modulus can be obtained as M_t/f_p at the location being considered, except if $(M_t)_{max}/f_p$ is less than SM_{min} in 3-2-1/3.7.1(b). In this case, the required section modulus is to be obtained by multiplying SM_{min} by the ratio of $M_{ti}/(M_t)_{max}$ where M_{ti} is the total bending moment at the location under consideration and $(M_t)_{max}$ is the maximum total bending moment amidships.

3.3 Hull Girder Moment of Inertia *(1998)*

The hull girder moment of inertia is to be not less than required by 3-2-1/3.7.2.

3.5 Transverse Strength *(1998)*

To ensure adequate transverse strength of the hull girder, the requirements for the sizes and scantlings of the primary transverse supporting members, such as the cross deck box beams on top of watertight and mid-hold strength transverse bulkheads, specified in this section, as well as the requirements for the arrangement of transverse bulkheads given in other sections of the Rules are to be satisfied

5 Hull Girder Shearing Strength *(1998)*

5.1 General

The net thicknesses of the side shell and longitudinal bulkhead plating are to be determined based on the total vertical shear force, F_t, and the permissible shear stress f_s, given below.

$F_t = F_S + k_u\, k_c\, F_W$ kN (tf, Ltf)

f_s = $11.96/Q$ kN/cm^2 ($1.220/Q$ tf/cm^2, $7.741/Q$ Ltf/in^2) at Sea

= $10.87/Q$ kN/cm^2 ($1.114/Q$ tf/cm^2, $7.065/Q$ Ltf/in^2) in Port

where

F_S = still-water shear force based on the envelope curve required by 5C-5-3/3.1 for all anticipated loading conditions at the location considered, in kN (tf, Ltf).

F_W = vertical wave shear force, as given in 5C-5-3/5.1.2, with k_w = 1.0, in kN (tf, Ltf).

F_W for in-port condition may be taken as zero.

For vessels having significant bow flare, the value of F_W at the forebody is subject to special consideration, as specified in 5C-5-3/11.3.3.

Q = material conversion factor

= 1.0 for ordinary strength steel

= 0.78 for Grade H32 steel

= 0.72 for Grade H36 steel

= 0.68 for Grade H40 steel

k_u, k_c may be taken as unity unless otherwise specified.

The shear stresses in the side shell and longitudinal bulkhead plating (net thickness) may be calculated using a direct analysis to determine the general shear distribution. When a direct calculation is not available and the longitudinal bulkhead is located at any point not less than $0.045B$ but no further than $0.12B$ from the side shell, the net thickness of the side shell and longitudinal bulkhead plating may be obtained from the equations given in 5C-5-4/5.3 and 5C-5-4/5.5 below.

The nominal design corrosion values, as given in 5C-5-2/Table 1, for the side shell and longitudinal bulkhead plating are to be added to the "net" thickness.

5.3 Net Thickness of Side Shell Plating

$t_s \geq F_t D_s m/I f_s$ cm (in.)

where

F_t and f_s are as defined above.

D_s = shear distribution factor for side shell

= $0.515 (A_s/A)(-0.143 + 2.109 A_s/A)(1.021 - 0.363 b/B)$ for Type A

= $0.515 (A_s/A)(-0.266 + 2.449 A_s/A)(1.029 - 0.692 b/B)$ for Type B

= $0.515 (A_s/A)(-0.032 + 1.934 A_s/A)(0.981 - 0.538 b/B)$ for Type C

A_b = total projected area of the net longitudinal bulkhead plating above inner bottom (one side), in cm^2 (in^2)

A_s = total projected area of the net side shell plating (one side), in cm^2 (in^2)

A = $A_b + A_s$

b = distance between outer longitudinal bulkhead and side shell, in m (ft)

B = breadth of the vessel, in m (ft), as defined in 3-1-1/5

Sections of Types A, B and C are defined in 5C-5-3/Figure 17.

I = moment of inertia of the "net" hull girder section at the position considered in, cm^4 (in^4)

m = first moment of the "net" hull girder section, in cm^3 (in^3), about the neutral axis, of the area between the vertical level at which the shear stress is being determined and the vertical extremity of the section under consideration.

5.5 Net Thickness of the Longitudinal Bulkhead Plating

$t_b \geq F_t D_b m/I f_s$ cm (in.)

where

D_b = shear distribution factor for longitudinal bulkhead plating

= $0.550 (A_b/A)(-0.120 + 2.445 A_b/A)(0.975 + 0.431 b/B)$ for Type A

= $0.550 (A_b/A)(-0.198 + 2.480 A_b/A)(0.969 + 0.741 b/B)$ for Type B

= $0.550 (A_b/A)(0.098 + 1.934 A_b/A)(1.022 + 0.612 b/B)$ for Type C

All other parameters are as defined in 5C-5-4/5.3 above.

7 Hull Girder Torsional Stiffness *(1998)*

The strength criteria are based on the following assumptions and limitations to prevent excessive hull girder distortion in operation.

i) $b_0 \leq 0.905\, B$

ii) $L_0 \leq 0.75\, L$

iii) $\alpha_M\, \Gamma_M \geq 32\, C_n\, (T_M + T_S)\, L_0^2\, (2\, \omega_M + h_e\, b_0)\ell_0/[E\, (\, \ell_0^2\, +\, b_0^2\,)]$

where

b_0 = width of the hatch opening amidships, measured between the inboard edges of the strength deck, in m (ft)

L, B, D = length, breadth, depth of the vessel, in m (ft), as defined in Section 3-1-1

C_n = 1.0 for vessel without deck girders or with a centerline deck girder inboard of lines of hatch openings

= 0.95 for vessel with two continuous longitudinal deck girders inboard of lines of hatch openings

T_M = nominal wave-induced torsional moment amidships, in kN-m (tf-m, Ltf-ft), as defined in 5C-5-3/5.1.5

T_S = still-water torsional moment amidships, in kN-m (tf-m, Ltf-ft), as defined in 5C-5-3/3.1

L_0 = effective length, in m (ft), of the consecutive hatch openings between engine room and forepeak space, as defined in 5C-5-4/9.3

ℓ_0 = length of the hatch opening amidships, in m (ft)

E = modulus of elasticity of the material, may be taken as 2.06×10^8 kN/m^2 (2.1×10^7 tf/m^2, 1.92×10^6 Ltf/ft^2) for steel.

h_e = $D - e$

α_M = $1 + 0.04\, L_0^2\, J_M\, /\, \Gamma_M$

Γ_M = warping constant of the net hull girder section amidships, in m^6 (ft^6), (see Appendix 5C-5-A3)

J_M = St. Venant torsional constant of the net hull girder section amidships, in m^4 (ft^4), (see Appendix 5C-5-A3)

ω_M = warping function (see Appendix 5C-5-A3)of the net hull girder section amidships at the inboard edge of the strength deck plating, clear of hatch corner, in m^2 (ft^2)

e is as defined in 5C-5-3/5.1.5, measured from the baseline of the vessel, positive upward.

For designs which do not satisfy these assumptions, an appropriate hull girder analysis to verify the offered torsional stiffness is to be submitted for review.

9 Torsion-induced Longitudinal Stress *(1998)*

9.1 Total Torsion-induced Longitudinal Stress, (Warping Stress)

The total warping stress in deck structures may be obtained from the following equation:

$$f_{LW} = f_{LWW} + f_{LWS} \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

f_{LWW} = wave-induced warping stress in N/cm² (kgf/cm², lbf/in²), as specified in 5C-5-4/9.3

f_{LWS} = still-water warping stress in N/cm² (kgf/cm², lbf/in²), as specified in 5C-5-4/9.5

The total warping stress is not to be greater than the permissible warping stress, f_w, as specified in 5C-5-4/9.7.

9.3 Wave-induced Warping Stress

When a direct calculation using finite element analysis is not available, the wave-induced warping stress may be determined as specified below:

9.3.1 For Cargo Space Forward of Engine Room

9.3.1(a) The Maximum Wave Induced Warping Stress in the Strength Deck Plating in way of Hatch Opening. The maximum wave-induced warping stress, f_{LWW}, in the strength deck plating in way of hatch opening may be obtained from the following equation:

$$f_{LWW} = k\, C_w T_M\, L_0\, b_0 \omega_M /(B \alpha_M\, \Gamma_M) \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

k = 0.0123 (0.0123, 0.583)

C_w = $C_n\,(1 + \eta\, C_\ell)$

C_n is as defined in 5C-5-4/7.

C_ℓ is a parameter, as given in 5C-5-4/Figure 5, for the specified stations in function of η, $\Gamma_{E/R}$, Γ_{FC}, $\ell_{E/R}$, ℓ_{FC}, I_{CB}, I, b_0 and ℓ_0, as defined below.

T_M = nominal wave-induced torsional moment amidships, in kN-m (tf-m, Ltf-ft), as defined in 5C-5-3/5.1.5

L_0 = effective length, in m (ft), of the consecutive hatch openings at the strength deck level between the aft end of the hatch opening immediately forward of the engine room and the forward end of the foremost hatch opening

= $\ell_1 + \delta\ell_2$

ℓ_1 = length measured between the aft end of the hatch opening immediately forward of the engine room and the forward end of the first hatch opening that has the same width as that amidships, in m (ft), as shown in 5C-5-4/Figure 3

ℓ_2 = length of the fore-end hatch opening area, in m (ft), as shown in 5C-5-4/Figure 3

δ = $(b_0'/B')_f/(b_0/B)_M \leq 1.0$

$(b_0'/B')_f$ = average ratio of the hatch opening width to the mean vessel's breadth for all hatch openings in the fore-end hatch opening region, ℓ_2

$(b_0/B)_M$ = ratio of the hatch opening width to the vessel's breadth amidships

b_0, b_0' = width, in m (ft), of the strength deck hatch opening amidships and the mean width of the fore-end hatch opening region, ℓ_2, respectively, measured between the inboard edges of the strength deck, as shown in 5C-5-4/Figure 3

B, B' = vessel's breadth, in m (ft), amidships and the mean vessel's breadth of the fore-end hatch opening region, ℓ_2, respectively, as shown in 5C-5-4/Figure 3

η = $[(\alpha_M\,\Gamma_M)/(\,\alpha\,\Gamma)]\,(\omega\,/\omega_M)$

α = $1 + 0.04\,L_0^2\,J/\Gamma$

Γ = warping constant of the net hull girder section under consideration, in m^6 (ft^6), (see Appendix 5C-5-A3)

J = St. Venant torsional constant of the net hull girder section under consideration, in m^4 (ft^4), (see Appendix 5C-5-A3)

ω = warping function, (see Appendix 5C-5-A3), of the net hull girder section under consideration at the inboard edge of the strength deck plating, clear of hatch corner, in m^2 (ft^2)

α_M, J_M, Γ_M and ω_M are as defined in 5C-5-4/7.

$\Gamma_{E/R}$, Γ_{FC} = warping constant, in m^6 (ft^6), determined in way of the closed hull girder section immediately abaft of the forward bulkhead of the engine room, and in way of the closed hull girder section immediately forward of the foremost hatch opening, respectively.

$\ell_{E/R}$, ℓ_{FC} = length, in m (ft), of the closed hull girder section in the engine room and in the fore-end region, respectively

I_{CB}, I = net moment of inertia, in m^4 (ft^4), about the vertical axis z of the cross deck box beam at the vessel's centerline and of the side longitudinal deck box, respectively, under consideration (5C-5-4/Figure 4)

ℓ_0 = as defined in 5C-5-4/7

The following items may be included in the calculation of the moment of inertia I_{CB} of the cross deck box beam:

- Transverse hatch end coaming plate and continuous stiffeners (above the strength deck)
- Cross deck plating and continuous beams at the strength deck level
- Bottom and top plating and continuous stiffeners of the cross deck box beam
- Side transverse plates and continuous stiffeners of cross deck box beam

The following items may be included in the calculation of the moment of inertia I of the side longitudinal deck box:

- Strength deck plating and continuous longitudinals
- Side shell and longitudinal bulkhead plating and continuous longitudinals. Effective depth of side shell and longitudinal bulkhead is equal to the distance between the strength deck and the second deck, but not to be more than $0.22D$
- Second deck plating and continuous longitudinals, if the distance between strength and second decks does not exceed $0.22D$
- Continuous longitudinal hatch side coaming (plate and continuous longitudinal stiffeners)

9.3.1(b) The Maximum Wave Induced Warping Stress at the Top of a Continuous Longitudinal Hatch Coaming. The maximum wave-induced warping stress, f_{LWW}, for the top of the continuous longitudinal hatch coaming may be obtained from the equation given in 5C-5-4/9.1 above by substituting the warping function ω by ω_c as defined below, and using C_ℓ as given in 5C-5-4/Figure 5 for the hatch coaming top.

$$\omega_c = \omega + 0.5\, h\, b_0$$

where

h = height, in m (ft), of the continuous longitudinal hatch coaming of the hull girder section under consideration

b_0 = width, in m (ft), of the hatch opening of the hull girder section under consideration

9.3.2 For Cargo Space Abaft Engine Room

The maximum wave-induced warping stress, f_{LWW}, in the strength deck plating in way of hatch opening may be obtained from the following equation:

$$f_{LWW} = k\, C_w'\, T_M'\, L_0'\, b_0'\, \omega'/(B'\, \alpha'\, \Gamma') \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

k = 0.0123 (0.0123, 0.583)

C_w' = $C_n (1 + \eta' C_\ell)$

η' = $[(\alpha' \Gamma')/(\alpha \Gamma)]\,(\omega/\omega')$

ω, α and Γ are as defined in 5C-5-4/9.3.1 above and are to be determined at the hull girder section under consideration.

ω', α' and Γ' are as defined in 5C-5-4/9.3.1 above for ω, α and Γ and are to be determined at the hull girder section immediately abaft the engine room (station B in 5C-5-4/Figure 5).

$\Gamma_{E/R}'$ = warping constant in way of the closed hull girder section immediately forward of the aft bulkhead of the engine room

T_M' = nominal wave-induced torsional moment, in kN-m (tf-m, Ltf-ft), in way of the hull girder section immediately abaft the engine room, as defined in 5C-5-3/5.1.5

L_0' = length, in m (ft), of the consecutive hatch openings at the strength deck level abaft the engine room

b_0', B' = width, in m (ft), of hatch opening immediately abaft the engine room and the vessel's breadth, respectively, at the mid-length of that hatch opening, in m (ft)

C_n is as defined in 5C-5-4/7.

C_ℓ is a parameter as given in 5C-5-4/Figure 5.

9.3.3 For Hatch Openings in Forecastle Deck

For vessels with hatch openings in the forecastle deck, the maximum wave-induced warping stress, f_{LWW}, in the forecastle deck plating in way of hatch opening may be obtained from the equation specified in 5C-5-4/9.3.1 above with the appropriate coefficients given in 5C-5-4/Figure 5.

9.5 Still-water Warping Stress

The still-water warping stresses at the inboard edge of strength deck plating and at the top of continuous longitudinal hatch coaming may be obtained from the equations in 5C-5-4/9.3 using T_S in lieu of T_M, or T_S' in lieu of T_M', where T_S is as specified in 5C-5-3/3.1 and T_S' is still-water torsional moment, in kN-m (tf-m, Ltf-ft), at the section corresponding to T_M'.

T_M' is as specified in 5C-5-4/9.3.2.

9.7 Permissible Warping Stress

9.7.1

Permissible warping stress may be obtained from the following equation:

$$f_w = C\,S_m f_y - (f_V + f_H + f_2) \qquad \text{N/cm}^2\ (\text{kgf/cm}^2,\ \text{lbf/in}^2)$$

where

C = 0.90 for the inboard edge of the strength deck

= 0.95 for the top of the continuous longitudinal hatch side coaming

S_m = strength reduction factor, as defined in 5C-5-4/11.3.1

f_y = minimum specified yield point of the material of the member for which the warping stress is calculated, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_V = stress due to vertical still-water and wave-induced hull girder bending moments, as specified in 5C-5-4/9.7.2 below, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_H = stress due to horizontal wave-induced bending moment, as specified in 5C-5-4/9.7.3 below, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_2 = secondary stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $f_P + f_B$

f_P = stress due to external water pressure on side shell, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-5-4/17.5.2

f_P may be taken as zero when a vessel is under hogging condition.

f_B = stress due to dynamic container load on transverse bulkhead, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-5-4/17.5.3

f_B may be taken as zero at Stations A, B, C, G, F′ and G′ shown in 5C-5-4/Figure 5.

9.7.2

Stress due to vertical hull girder bending moment may be obtained from the following equation:

$f_V = k\,M_V/SM_V$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

k	=	1000 (1000, 2240)
M_V	=	vertical hull girder bending moment at the section under consideration, in kN-m (tf-m, Ltf-ft)
	=	$M_S + 0.40\,f_{MV}\,M_W$
M_S	=	still-water bending moment at the section under consideration, in kN-m (tf-m, Ltf-ft), as specified in 5C-5-3/3.1
M_W	=	vertical wave-induced bending moment amidships, in kN-m (tf-m, Ltf-ft), as specified in 5C-5-3/5.1.1
f_{MV}	=	distribution factor, as shown in 5C-5-3/Figure 2
S_{MV}	=	vertical hull girder net section modulus at the strength deck or at the top of continuous longitudinal hatch coaming at the section under consideration, in m-cm^2 (ft-in^2), determined based on 5C-5-4/3.1.2

9.7.3

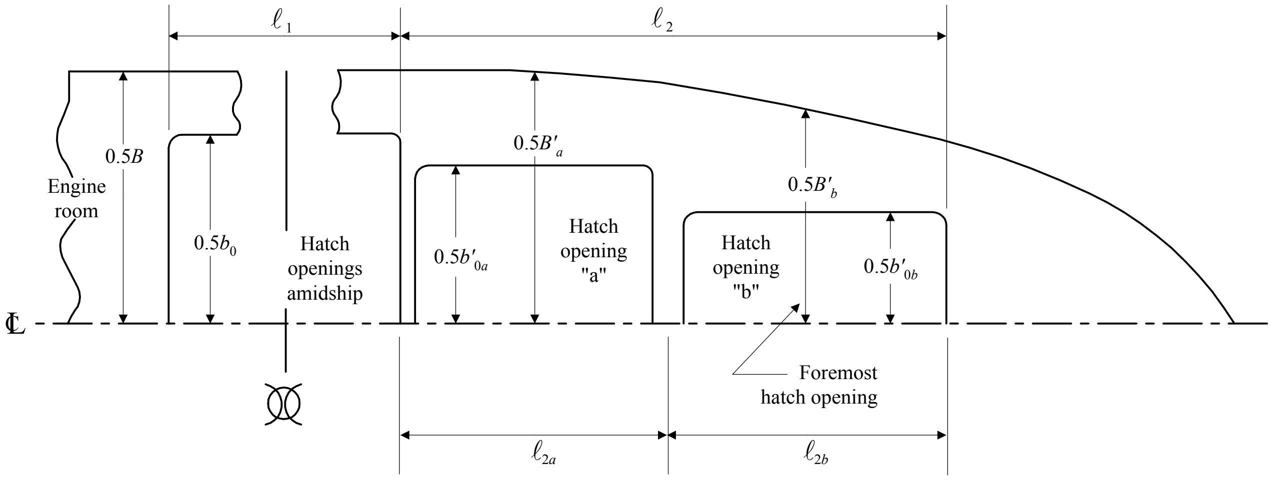
Stress due to horizontal hull girder bending moment may be obtained from the following equation:

$f_H = k\,M_h/SM_H$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

k	=	1000 (1000, 2240)
M_h	=	horizontal wave-induced bending moment, in kN-m (tf-m, Ltf-ft), at the section under consideration
	=	$0.7\,m_h\,M_H$
M_H	=	horizontal wave-induced bending moment amidships, in kN-m (tf-m, Ltf-ft), as specified in 5C-5-3/5.1.3
m_h	=	distribution factor, as specified in 5C-5-3/5.1.3
SM_H	=	$2\,I_z/b_0$ = horizontal hull girder net section modulus, in m-cm^2 (ft-in^2)
I_z	=	hull girder net moment of inertia of the section under consideration about the vertical axis through the centerline of the vessel, in cm^2-m^2 (in^2-ft^2)
b_0	=	width of the hatch opening measured between the inboard edges of the strength deck at the section under consideration, in m (ft)

FIGURE 3
Strength Deck Definition of ℓ_1, ℓ_2, b_0, b_0', B and B'



L_0	=	$\ell_1 + \delta\ell_2$
δ	=	$(b_0'/B')_f/(b_0/B)_M \leq 1.0$
$(b_0'/B')_f$	=	$(b_{0a}'/B_a')\,(\ell_{2a}/\ell_2) + (b_{0b}'/B_b')\,(\ell_{2b}/\ell_2)$
$(b_0/B)_M$	=	b_0/B

Note: b_0, b_{0a}', b_{0b}', B_a', and B_b' are to be measured at midpoint of the hatch opening under consideration

FIGURE 4
Deck Structure

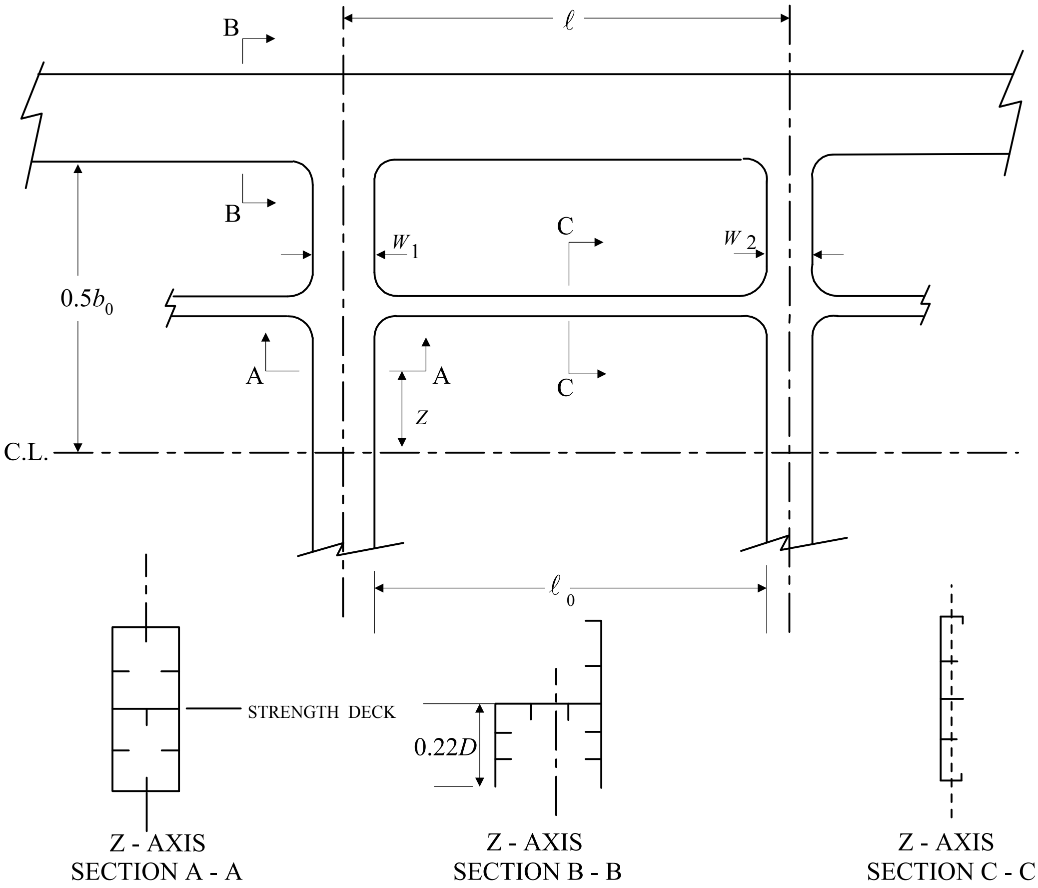
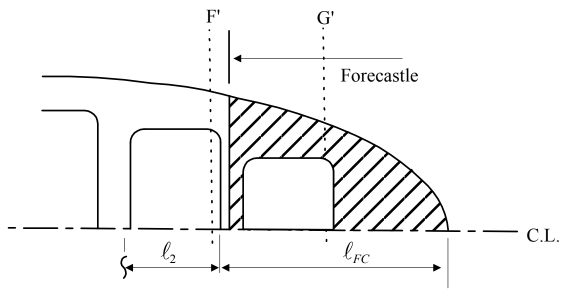


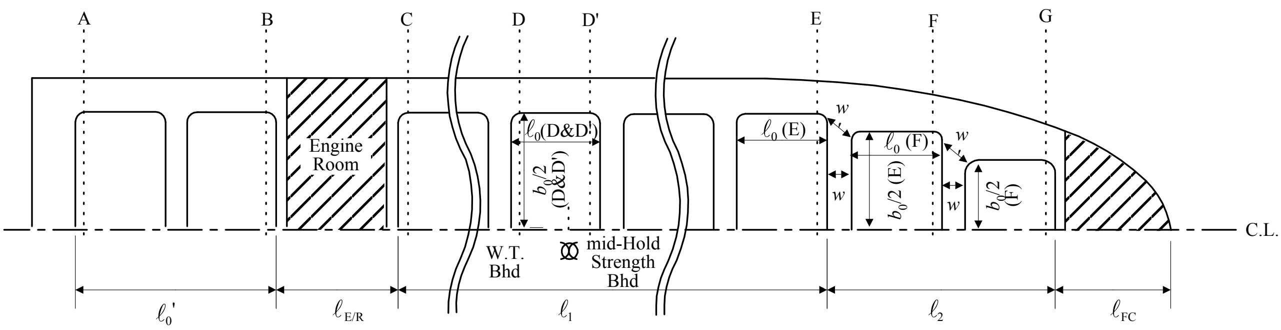
FIGURE 5
Specified Stations and Coefficients for Warping Stress Calculation

Station E : the forward end of the hatch that has the same width of b_0 as that amidships
Station F : the forward ends of hatches where there is a change of b_0, other than station E or G
Station G : the forward end of the foremost hatch

Vessels with hatch opening in forecastle deck



w' = distance between the hatch corners of two adjacent hatch opening as shown below
w = width of cross deck



Vessels without hatch opening in forecastle deck
or
Vessels without forecastle

FIGURE 5 (continued)
Specified Stations and Coefficients for Warping Stress Calculations

	Hatch Opening on strength Deck Level																*Hatch Opening on Forecastle Deck*			
Station	A		B		C		D		D′		E		F		G		F′		G′	
Coefficients & Parameters	α_3	C_ℓ	α_3	C_ℓ	α_1	C_ℓ	α_4	C_ℓ	α_4	C_ℓ	α_5	C_ℓ	α_5	C_ℓ	α_2	C_ℓ	α_2	C_ℓ	α_2	C_ℓ
Strength Deck	0.05	0.45	0.25	1.75	20	1.90	0.010	0.900	0.010	0.750	0.020	0.52	0.100	0.50	2.5	0.45	7.00	0.97	2.00	1.06
	0.2	0.55	1.00	2.25	40	2.00	0.024	0.950	0.024	0.870	0.060	0.53	0.300	0.51	10.0	0.55	9.00	0.98	2.20	1.08
	0.40	0.63	2.00	2.60	60	2.05	0.030	0.975	0.030	0.910	0.120	0.56	0.500	0.53	20.0	0.62	11.00	1.04	2.40	1.27
	0.70	0.72	3.00	2.80	80	2.08	0.036	1.000	0.036	0.930	0.300	0.68	0.700	0.56	30.0	0.65	13.00	1.10	2.60	1.44
	1.00	0.77	4.00	2.95	100	2.10	0.042	1.025	0.042	0.950	0.480	0.86	0.900	0.57	40.0	0.66	15.00	1.16	2.70	1.53
	1.30	0.79	5.00	2.98	120	2.12	0.048	1.035	0.048	0.960	0.720	1.09	1.200	0.58	60.0	0.67	17.00	1.22	2.80	1.62
	2.40	0.80	12.00	3.00	200	2.15	0.100	1.050	0.100	0.970	0.960	1.20	1.600	0.59	95.0	0.68	19.00	1.22	3.00	1.62
Coaming Top	0.05		0.25		5		0.010	0.60	0.010	0.48	0.020	0.40	0.025	0.15	2.5					
							0.024	0.62	0.024	0.58	0.060	0.41	0.050	0.16						
				1.75*		1.4*	0.030	0.64	0.030	0.60	0.120	0.42	0.100	0.18						
	↓	.05**	↓	(0.7**)	↓	(0.7**)	0.036	0.67	0.036	0.62	0.300	0.47	0.300	0.21	↓	0.1**				
							0.042	0.69	0.042	0.63	0.480	0.56	0.500	0.22						
							0.048	0.70	0.048	0.64	0.720	0.62	0.700	0.23						
	3.00		20.00		250		0.100	0.72	0.100	0.65	0.960	0.64	1.600	0.24	100.0					

$\alpha_1 = (\Gamma \cdot L_0)/(\Gamma_{E/R} \cdot \ell_{E/R})$ $\alpha_2 = (\Gamma \cdot L_0)/(\Gamma_{FC} \cdot \ell_{FC})$ $\alpha_3 = (\Gamma \cdot L_0')/(\Gamma_{E/R}' \cdot \ell_{E/R})$

$\alpha_4 = [(I_{CB}/b_0)/(I/\ell_0)]/\eta$ $\alpha_5 = (w'/w)^2\,\alpha_4$

Notes:

1 Defintition of parameters and coefficients are specified in 5C-5-4/9.3, except otherwise noted.
For calculation of α_4, b_0 and ℓ_0 are as shown in the figure.
b_0 is to be measured at the midpoint of the hatch opening.

2 For different value of parameter, C_ℓ may be linearly interpolated or extrapolated.

3 C_ℓ may be taken as zero where blank.

4 * -- Fully connected to the deck house; ** -- End bracket only.

11 Double Bottom Structures

11.1 General *(1998)*

11.1.1 General

The arrangement of bottom girders, solid floors, stiffening systems and access openings, and the depth of the double bottom are to be in compliance with the Rules. Centerline and side girders are to be fitted, as necessary, to provide sufficient stiffness and strength for docking loads as well as those specified in Section 5C-5-3.

11.1.2 Framing

Generally, bottom and inner bottom plating is to be longitudinally framed, except for limited areas such as those in way of pipe tunnels and the bilge areas.

11.1.3 Keel Plate Thickness

The thickness of the flat keel plate is to be not less than that required for the bottom shell plating at that location by 5C-5-4/11.3.1, increased by 1.5 mm (0.06 in.), except where the submitted docking plan specifies all docking blocks be arranged away from the keel.

11.1.4 Definition of Bottom Shell Plating

The term "bottom shell plating" refers to the plating from the keel to the upper turn of the bilge amidships, but the upper turn of the bilge is not to be taken more than $0.2D$ above the baseline.

11.1.5 Non-prismatic Double Bottom Structures

See Note in 5C-5-4/Figure 8 for non-prismatic double bottom structures where the breadths of the forward and aft ends are different.

11.3 Bottom Shell and Inner Bottom Plating *(1998)*

The net thicknesses of the bottom shell and inner bottom plating, over the midship $0.4L$, are to satisfy the hull girder section modulus requirements in 5C-5-4/3.1, the buckling and ultimate strength requirements in 5C-5-5/5, and are to be not less than that obtained from the following.

11.3.1 Bottom Shell Plating *(1 July 2005)*

The net thickness of the bottom shell plating, t_n, is to be not less than t_1, t_2 and t_3, specified as follows:

$$t_1 = 0.73s(k_1\, p/f_1)^{1/2} \quad \text{mm (in.)}$$

$$t_2 = 0.73s(k_2\, p/f_2)^{1/2} \quad \text{mm (in.)}$$

$$t_3 = c\, s(S_m f_y/E)^{1/2} \quad \text{mm (in.)}$$

where

s = spacing of bottom longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.500

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-5-3/Table 2. For pipe tunnel, pressure is to be taken as that of the adjacent tank.

f_1 = permissible bending stress, in longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $(0.95 - 0.67\alpha_1 SM_{RB}/SM_B)S_m f_y \leq K_p\, S_m f_y$

K_p = 0.40 for load case 1-"a" in 5C-5-3/Table 2

= 0.36 for $L > 210$ m (689 ft) for load case 1-"b" in 5C-5-3/Table 2

= $0.36 + (210 - L)/900$ for $L \leq 210$ m [$0.36 +(689 - L)/2950$ for $L \leq 689$ ft] for load case 1-"b" in 5C-5-3/Table 2

SM_{RB} = reference net hull girder section modulus based on material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

= $0.9\, SM$

SM = required gross hull girder section modulus amidships, in accordance with 5C-5-4/3.1.1, with k_w defined in 5C-5-3/5.1.1 for the purpose of calculating M_w (sagging and hogging), based on material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

SM_B = design (actual) net hull girder section modulus at the bottom, amidships in cm^2-m (in^2-ft)

α_1 = $S_{m1} f_{y1}/S_m f_y$

S_m = strength reduction factor for plating under consideration

=	1.0	for ordinary mild steel
=	0.95	for Grade H32 steel
=	0.908	for Grade H36 steel
=	0.875	for Grade H40 steel

S_{m1} = strength reduction factor for the bottom flange of the hull girder

f_y = minimum specified yield point of the material, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{y1} = minimum specified yield point of the bottom flange of the hull girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_2 = permissible bending stress, in the transverse direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.80\, S_m f_y$

E = modulus of elasticity of the material, may be taken as 2.06×10^7 N/cm^2 (2.1×10^6 kgf/cm^2, 30×10^6 lbf/in^2) for steel

c = $0.7N^2 - 0.2$, not to be taken less than $0.4Q^{1/2}$

N = $R_b\, (Q/Q_b)^{1/2}$

R_b = $(SM_{RBH}/SM_B)^{1/2}$

SM_{RBH} = reference net hull girder section modulus for hogging bending moment based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

= $0.9SM_H$

SM_H = required gross hull girder section modulus amidships in accordance with 5C-5-4/3.1.1 for hogging total bending moment, with k_w defined in 5C-5-3/5.1.1 for the purpose of calculating M_w (hogging), based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

Q, Q_b = material conversion factor in 5C-5-4/5 for the bottom plating and the bottom flange of the hull girder, respectively

Bottom shell plating may be transversely framed in pipe tunnels or bilge areas, provided the net thickness of the bottom shell plating, t_n, is not less than t_4 specified below:

$$t_4 = 0.73\, s\, k\, (k_2\, p/f_1)^{1/2} \qquad \text{mm (in.)}$$

where

s = spacing of bottom transverse frame, in mm (in.)

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

k_2 = 0.500

All other parameters are as defined above.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

In addition to the foregoing, the net thickness of the bottom shell plating, outboard of 0.3B from the centerline of the vessel, is to be not less than that of the lowest side shell plating required by 5C-5-4/13.1, adjusted for the spacing of the bottom/bilge longitudinals or frames and the material factors. For a curved plate where girth spacing is greater than that of the adjacent bottom plating, the spacing may be modified by the equations, as specified in 5C-5-4/11.7.

11.3.2 Inner Bottom Plating *(1999)*

The net thickness of the inner bottom plating, t_n, is to be not less than t_1, t_2 and t_3, specified as follows:

$$t_1 = 0.73s(k_1\, p/f_1)^{1/2} \qquad \text{mm (in.)}$$

$$t_2 = 0.73s(k_2\, p/f_2)^{1/2} \qquad \text{mm (in.)}$$

$$t_3 = c\, s\, (S_m f_y/E)^{1/2} \qquad \text{mm (in.)}$$

where

s = spacing of inner bottom longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.500

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-5-3/Table 2. For pipe tunnel, internal pressure is to be taken as that of the adjacent tank.

f_1 = permissible bending stress, in longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $(0.95 - 0.50\alpha_1 SM_{RB}/SM_B)\, S_m f_y \le 0.55 S_m f_y$, where SM_B/SM_{RB} is not to be taken more than 1.4

f_2 = permissible bending stress, in the transverse direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.85\, S_m f_y$

α_1 = $S_{m1} f_{y1}/S_m f_y$

S_m = strength reduction factor, as defined in 5C-5-4/11.3.1, for the inner bottom plating

S_{m1} = strength reduction factor, as defined in 5C-5-4/11.3.1, for the bottom flange of the hull girder

f_y = minimum specified yield point of the inner bottom plating, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{y1} = minimum specified yield point of the bottom flange of the hull girder, in N/cm^2 (kgf/cm^2, lbf/ in^2)

c = $0.7N^2 - 0.2$, not to be taken less than $0.4Q^{1/2}$

N = $R_b[(Q/Q_b)\,(y/y_n)]^{1/2}$

Q, Q_b = material conversion factor in 5C-5-4/5 for the inner bottom plating and the bottom flange of the hull girder, respectively

y = vertical distance, in m (ft), measured from the inner bottom to the neutral axis of the hull girder section

y_n = vertical distance, in m (ft), measured from the bottom to the neutral axis of the section

SM_{RB}, SM_B and E are as defined in 5C-5-4/11.3.1.

Inner bottom plating may be transversely framed in pipe tunnels, provided the net thickness of the inner bottom plating, t_n, is not less than t_4, as specified below:

$$t_4 = 0.73\, s\, k(k_2\, p/f_1)^{1/2} \qquad \text{mm (in.)}$$

where

s = spacing of inner bottom transverse frames, in mm (in.)

k_2 = 0.500

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$ $\quad (1 \le \alpha \le 2)$

= 1.0 $\quad (\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

All other parameters are as defined above.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

11.5 Bottom and Inner Bottom Longitudinals *(2007)*

The net section modulus of each bottom or inner bottom longitudinal or each transverse frame in pipe tunnels, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equations:

$S_M = M/f_b$ cm^3 (in^3)

$M = cps\ell^2\, 10^3/k$ N-cm (kgf-cm, lbf-in.)

where

c = 1.0 without struts

= 0.65 with effective struts

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-5-3/Table 2 for bottom and inner bottom plating, respectively. For pipe tunnel, pressure is to be taken as that of the adjacent tank.

s = spacing of longitudinals or transverse frames, in mm (in.)

ℓ = span of longitudinals or transverse frames between effective supports, as shown in 5C-5-4/Figure 6, in m (ft)

k = 12 (12, 83.33)

f_b = permissible bending stresses, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $1.2[1.0 - 0.65\alpha_1 SM_{RB}/SM_B]S_m f_y \le 0.60 S_m f_y$ for bottom longitudinals

= $1.1[1.0 - 0.50\alpha_1 SM_{RB}/SM_B]S_m f_y \le 0.65 S_m f_y$ for inner bottom longitudinals

= $0.70\, S_m f_y$ for transverse frames

α_1 = $S_{m1} f_{y1}/S_m f_y$

S_m = strength reduction factor, as defined in 5C-5-4/11.3.1, for the material of longitudinals or transverse frames considered

S_{m1} = strength reduction factor, as defined in 5C-5-4/11.3.1, for the bottom flange material of the hull girder

f_y = minimum specified yield point for the material of longitudinals or transverse frames considered, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{y1} = minimum specified yield point of the bottom flange of the hull girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

SM_{RB} and SM_B are as defined in 5C-5-4/11.3.1.

The net section modulus of the bottom longitudinals, outboard of 0.3B from the centerline of the vessel, is also to be not less than that of the lowest side longitudinal required by 5C-5-4/13.3, adjusted for the span and spacing of the longitudinals and the material factors.

Where effective struts are fitted between bottom and inner bottom longitudinals, the net section modulus of the inner bottom longitudinals is also to be not less than 90% of that required for the bottom longitudinals.

When determining compliance with the foregoing, an effective breadth, b_e, of the attached plating is to be used in the calculation of the section modulus of the design longitudinal. b_e is to be calculated from section a) of 5C-5-4/Figure 7.

11.7 Bilge Plate and Longitudinals/Frames *(1 July 2005)*

In general, the bilge plate is to be longitudinally stiffened. The net thickness of the bilge plate is to be not less than required in 5C-5-4/11.3.1, adjusted for the spacing of the bilge longitudinals or frames and the material factors. Where girth spacing of bilge longitudinals is greater than that of the adjacent bottom plating, the spacing may be modified by the following equation in calculations of t_1 and t_2:

$s = k_{r1}\, s_g$ mm (in.)

but not to be taken less than the spacing of the longitudinals of the adjacent bottom plating

where

s_g = girth spacing of bilge longitudinals, in mm (in.)

k_{r1} = $(1 - 0.5\, s_g/R)^2$ but not less than 0.55

R = radius of bilge, in mm (in.)

Longitudinals around the bilge are to be graduated in size from that required for the lowest side longitudinal to that required for the most outboard bottom longitudinals. The permissible bending stresses are to be calculated at the lowest side longitudinal and the most outboard bottom longitudinal.

For container carriers with length over 250 m in length, bilge longitudinals of asymmetric cross section below $^1/_3 d$ from the waterline are to have double-sided support connections to side transverses. Alternatively, the fatigue strength of the welded connections of the slot connections is to be evaluated using a fine mesh finite element model.

$\alpha = k_{r2}\, s_g/s$ but not less than 1.0

where

s = spacing of bilge transverse frames, in mm (in.)

s_g = longer edge (girth) of the panel under consideration, in mm (in.)

k_{r2} = $15/(1 + 40\, s_g/R)$

R = radius of bilge, in mm (in.)

In no case is the net thickness of the bilge plate to be less than that of the adjacent bottom plating.

The net thickness of the web part of the transverse frame or of the web plate is to be not less than t_1, as required in 5C-5-4/11.21, for the bottom floor.

In addition, the net section modulus of the frame is to be not less than that required in 5C-5-4/11.5 for transverse frames nor less than that required for side frames with a nominal pressure at the upper turn of the bilge in 5C-5-4/13.3, adjusted for the span and spacing of the frames and the material factors.

11.9 Bottom Struts *(1998)*

Where struts are fitted as an effective supporting system for bottom and inner bottom longitudinals, they are to be positioned so as to divide the span into approximately equal intervals. They are to have net area not less than A_{r1} or A_{r2}, whichever is greater, obtained from the following equations:

$A_{r1} = k\, p_a\, b\, s/w_a$ cm^2 (in^2)

$A_{r2} = k\, p_b\, b\, s/w_b$ cm^2 (in^2)

where

k = 0.01 (0.01, 1.0)

b = mean length of longitudinals supported, in mm (in.)

s = spacing of longitudinals, in mm (in.)

p_a = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the strut considered as specified in Case "a" of 5C-5-3/Table 2 for inner bottom longitudinals

p_b = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the strut considered as specified in Case "b" of 5C-5-3/Table 2 for bottom longitudinals

w_a = $0.45\, S_m f_y$

w_b = $0.45 f_y[1 - 0.0254(f_y/E)(\ell/r)^2]$

ℓ = unsupported span of the strut, in cm (in.)

r = least radius of gyration of the strut, in cm (in.)

f_y = minimum specified yield point of the struts, in N/cm^2 (kgf/cm^2, lbf/in^2)

E is as defined in 5C-5-4/11.3.1.

11.11 Centerline Girder in way of Cargo Holds *(2004)*

The net thickness of the centerline girder in cargo holds is to be not less than t_1 and t_2, as defined below, whichever is greater:

t_1	=	$(0.045L + 4.5)R$	mm	for SI or MKS Units
	=	$(0.00054L + 0.177)R$	in.	for U.S. Units
t_2	=	$10F_1/(d_b f_s)$	mm	for SI or MKS Units
	=	$F_1/(d_b f_s)$	in.	for U.S. Units

where F_1 is the maximum shear force of the centerline girder, as obtained from the equations given below (see also 5C-5-4/1.3). Alternatively, F_1 may be determined from finite element analyses, as specified in 5C-5-5/9 with the combined load cases in 5C-5-3/9. However, in no case is F_1 to be taken less than 85% of that determined from the equations below.

$F_1 = k\, 750\, \alpha_1\, \gamma_1\, n_1\, n_2\, p\, \ell_s\, s_1$ N (kgf, lbf) for $\lambda \le 1.5$

$F_1 = k\, 259\, \gamma_1\, n_1\, n_2\, p\, b_s\, s_1$ N (kgf, lbf) for $\lambda > 1.5$

where

k = 1.0 (1.0, 2.24)

α_1 = $0.505 - 0.183\lambda$

λ = ℓ_s/b_s

ℓ_s = unsupported length of the double bottom structures under consideration, in m (ft), as shown in 5C-5-4/Figure 8

b_s = unsupported width of the double bottom structures under consideration, in m (ft), as shown in 5C-5-4/Figure 8

γ_1 = $|2.67x/(\ell_s - s_f) - 0.33| \le 1.0$

n_1 = $0.0374(s_1/s_f)^2 - 0.326\,(s_1/s_f) + 1.289$

n_2 = $1.3 - (s_f/12)$ for SI or MKS Units

= $1.3 - (s_f/39.37)$ for U.S. Units

s_1 = sum of one-half of girder spacings on both sides of the centerline girder, in m (ft)

s_f = average spacing of floors, in m (ft)

x = longitudinal distance from the mid-span of length ℓ_s to the location on the girder under consideration, in m (ft)

p = nominal pressure, in kN/m^2 (tf/m^2, Ltf/ft^2), as specified in 5C-5-3/Table 2

d_b = depth of the double bottom structure, in cm (in.)

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.50\ S_m f_y$

R = 1.0 for ordinary mild steel

= $f_{ym}/S_m f_{yh}$ for higher strength material

f_{ym} = specified minimum yield point for mild steel, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{yh} = specified minimum yield point for higher tensile steel, in N/cm^2 (kgf/cm^2, lbf/in^2)

L = length of vessel, in m (ft), as defined in 3-1-1/3.1

S_m and f_y are as defined in 5C-5-4/11.3.1

Pipe tunnels may be substituted for centerline girders, provided the tunnel is suitably stiffened by fitting deep, closely spaced transverse webs. The thickness of each girder forming the pipe tunnel and center girder within the pipe tunnel, if any, is not to be less than that required for the bottom side girder (see 5C-5-4/11.13).

11.13 Bottom Side Girders

The net thickness of the bottom side girders is to be not less than t_1 and t_2, as defined below.

t_1	=	$(0.026L + 4.5)R$	mm	for SI or MKS Units
	=	$(0.00031L + 0.177)R$	in.	for U.S. Units
t_2	=	$10F_2/(d_b f_s)$	mm	for SI or MKS Units
	=	$F_2/(d_b f_s)$	in.	for U.S. Units

where F_2 is the maximum shear force of the side girder under consideration, as obtained from the equations given below (see also 5C-5-4/1.3). Alternatively, F_2 may be determined from finite element analyses, as specified in 5C-5-5/9 with the combined load cases in 5C-5-3/9; however, in no case is F_2 to be taken less than 85% of that determined from the equations below.

$F_2 = k\ 750\ \alpha_2\ \beta_1\ \gamma_1\ n_3\ n_4\ p\ \ell_s\ s_2$ N (kgf, lbf) for $\lambda \leq 1.5$

$F_2 = k\ 214\ \beta_1\ \gamma_1\ n_3\ n_4\ p\ b_s\ s_2$ N (kgf, lbf) for $\lambda > 1.5$

where

k = 1.0 (1.0, 2.24)

α_2 = $0.445 - 0.17\lambda$

β_1 = $1.25 - (2z_1/b_s) \geq 0.6$

n_3 = $1.072 - 0.0715(s_2/s_f)$

n_4 = $1.2 - (s_f/18)$ for SI or MKS Units

= $1.2 - (s_f/59.1)$ for U.S. Units

s_2 = sum of one-half of girder spacings on both sides of side girder, in m (ft)

z_1 = transverse distance from the centerline of the vessel to the location of the girder under consideration, in m (ft).

γ_1, ℓ_s, b_s, s_f, λ, p, d_b, f_s, L and R are as defined in 5C-5-4/11.11.

11.15 Longitudinally Stiffened Bottom Girders *(1999)*

In addition to 5C-5-4/11.11 or 5C-5-4/11.13, the net thickness of longitudinally stiffened bottom girders is to be not less than t_3, as defined below:

$$t_3 = c\, s\, (S_m f_y/E)^{1/2} \quad \text{mm (in.)}$$

where

s = space of stiffeners, in mm (in.)

c = $0.7N^2 - 0.2$, not to be taken less than $0.4Q^{1/2}$

N = $R_b[(Q/Q_b)\,(y/y_n)]^{1/2}$

Q, Q_b = material conversion factor in 5C-5-4/5 for the bottom girder plating and the bottom flange of the hull girder, respectively

y = vertical distance, in m (ft), measured from the lower edge of the bottom girder plating to the neutral axis of the hull girder section.

y_n = vertical distance, in m (ft), measured from the bottom to the neutral axis of the section

S_m, f_y, SM_{RB}, SM_B, R_b and E are defined in 5C-5-4/11.3.1.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

11.17 Bottom Tank Boundary Girders *(2007)*

The net thickness of the double bottom girders forming boundaries of deep tanks, in addition to complying with 5C-5-4/11.11, 5C-5-4/11.13 and 5C-5-4/11.15, is to be not less than obtained from the following equations:

$$t_1 = 0.73s(k_1\, p/f_1)^{1/2} \quad \text{mm (in.)}$$

$$t_2 = 0.73s(k_2\, p/f_2)^{1/2} \quad \text{mm (in.)}$$

where

s = spacing of longitudinals or vertical stiffeners, in mm (in.)

k_1 = 0.342 for longitudinally stiffened plating

= $0.500k^2$ for vertically stiffened plating

k_2 = 0.50

k = $(3.075\,\alpha^{1/2} - 2.077)/(\alpha + 0.272)$ $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as specified in 5C-5-3/Table 2

f_1 = permissible bending stress in longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $1.25[1 - 0.33(z_1/B) - 0.52\ \alpha_1\ (SM_{RB}/SM_B)\ (y/y_n)]\ S_m f_y \leq 0.75 S_m f_y$

f_2 = permissible bending stress in vertical direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.95\ S_m f_y$

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the lower edge of each plate where the plating is longitudinally stiffened

= vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the mid-depth of the double bottom height where the plating is vertically stiffened

B = vessel's breadth, in m (ft), as defined in 3-1-1/5

SM_{RB} and SM_B are as defined in 5C-5-4/11.3.1.

S_m, f_y and α_1 are as defined in 5C-5-4/11.5.

z_1 and y_n are as defined in 5C-5-4/11.13 and 5C-5-4/11.15, respectively.

11.19 Vertical Web on Bottom Tank Boundary Girder

Vertical webs on double bottom watertight girders, if fitted, are to have scantlings not less than obtained from the following equations.

$SM = M/f_b$ cm^3 (in^3)

$M = p\,s\ell^2\,10^5/k_1$ N-cm (kgf-cm, lbf-in)

$A_s = F/f_s$ cm^2 (in^2)

$F = k_2\,500\,ps\ell$ N (kgf, lbf)

where

k_1 = 12 (12, 44.64)

k_2 = 1.0 (1.0, 2.24)

p = nominal pressure at the midspan of the vertical web, in kN/m^2 (tf/m^2, Ltf/ft^2), as specified in 5C-5-3/Table2.

s = spacing of the vertical web, in m (ft)

ℓ = span of the vertical web, in m (ft)

ℓ may be modified in accordance with 5C-5-4/Figure 9

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.7\ S_m f_y$

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.4\ S_m f_y$

S_m = strength reduction factor for the vertical web, as defined in 5C-5-4/11.3.1

f_y = minimum specified yield point for the vertical web, in N/cm^2 (kgf/cm^2, lbf/in^2)

The net thickness of the web plate of the vertical web is to be not less than t_1, obtained in 5C-5-4/11.15, as adjusted for the material of the web plate.

11.21 Bottom Floors *(1 July 2005)*

The net thickness of the floors is to be not less than t_1 and t_2, as defined below, whichever is greater:

$t_1 = (0.025L + 4.0)R$ mm for SI or MKS Units

$= (0.0003L + 0.157)R$ in. for U.S. Units

$t_2 = 10F_3/(d_b f_s)$ mm for SI or MKS Units

$= F_3/(d_b f_s)$ in. for U.S. Units

where

L = length of the vessel, in m (ft), as defined in Section 3-1-1, but need not exceed 240 m (787 feet)

F_3 = maximum shear force at the floor under consideration, as obtained from the equation given below (see also 5C-5-4/1.3). Alternatively, F_3 may be determined from finite element analyses, as specified in 5C-5-5/9 with the combined load cases in 5C-5-3/9. However, in no case is F_3 to be taken less than 85% of that determined from the equation below:

= $k\, 650\, \alpha_3\, \beta_2\, \gamma_2\, p\, b_s\, s_3$ N (kgf, lbf)

k = 1.0 (1.0, 2.24)

α_3 = $0.5\,\eta\,(0.66 - 0.08\eta)$

β_2 = $2z_2/b_s \geq 0.4$

γ_2 = $(\ell_s - 2x)/(3\, s_f) \leq 1.0$

η = $(\ell_s/b_s)(s_g/s_f)^{1/4}$

s_g = average spacing of girders, in m (ft)

s_3 = sum of one-half of floor spacings on both sides of floor, in m (ft)

x = longitudinal distance from the mid-span of lengths ℓ_s to the location of the floor under consideration, in m (ft)

z_2 = transverse distance from the centerline of the vessel to the location on the floor under consideration, in m (ft)

ℓ_s, b_s, s_f, p, d_b, f_s, and R are as defined in 5C-5-4/11.11.

11.23 Tank End Floors *(1998)*

The net thickness of the tank end floors is to be not less than required in 5C-5-4/23.1.

11.25 Transverses in Pipe Tunnel

Transverses in pipe tunnels are to have scantlings, SM and A_s, not less than obtained from the following equations:

$SM = M/f_b$ cm^3 (in^3)

$M = ps\ell^2\ 10^5/k_1$ N-cm (kgf-cm, lbf-in)

$A_s = F/f_s$ cm^2 (in^2)

$F = k_2\ 600ps\ell$ N (kgf, lbf)

where

k_1 = 10 (10, 37.2)

k_2 = 1.0 (1.0, 2.24)

p = nominal pressure for the bottom transverse, in kN/m^2 (tf/m^2, Ltf/ft^2), as specified in 5C-5-3/Table 2. p for the inner bottom transverse is to be taken 90% of that for the bottom transverse.

s = spacing of the transverse, in m (ft)

ℓ = span of the transverse, in m (ft)

ℓ may be modified in accordance with 5C-5-4/Figure 9

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.7\ S_m f_y$

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.4\ S_m f_y$

S_m = strength reduction factor for the transverses, as defined in 5C-5-4/11.3.1

f_y = minimum specified yield point for the transverses, in N/cm^2 (kgf/cm^2, lbf/in^2)

The net thickness of the web plate of the transverse is to be not less than t_1, obtained in 5C-5-4/11.21 above, adjusted for the material of the web plate.

11.27 Container Supporting Structures *(1998)*

Generally, bottom floors and girders are to be so arranged to support container loads. Where the container pads are not in line with these members, brackets or headers are to be provided to transmit the container loads to these members. Each bracket or header is to have a net section modulus, SM, in cm^3 (in^3), and a net sectional area, A_s, in cm^2 (in^2), of the web portion not less than that obtained from the following equations:

$SM = M/f_b$

$A_s = F/f_s$

where

M = maximum bending moment due to container loads, in N-cm (kgf-cm, lbf-in)

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.80\ S_m f_y$

F = shearing force at the location under consideration due to container loads, in N (kgf, lbf)

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.53\ S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

The container loads are to be obtained from the equations in 5C-5-3/5.5.2(b) in association with the maximum design container weight for load case 3 specified in 5C-5-3/Table 1C.

FIGURE 6
Unsupported Span of Longitudinals

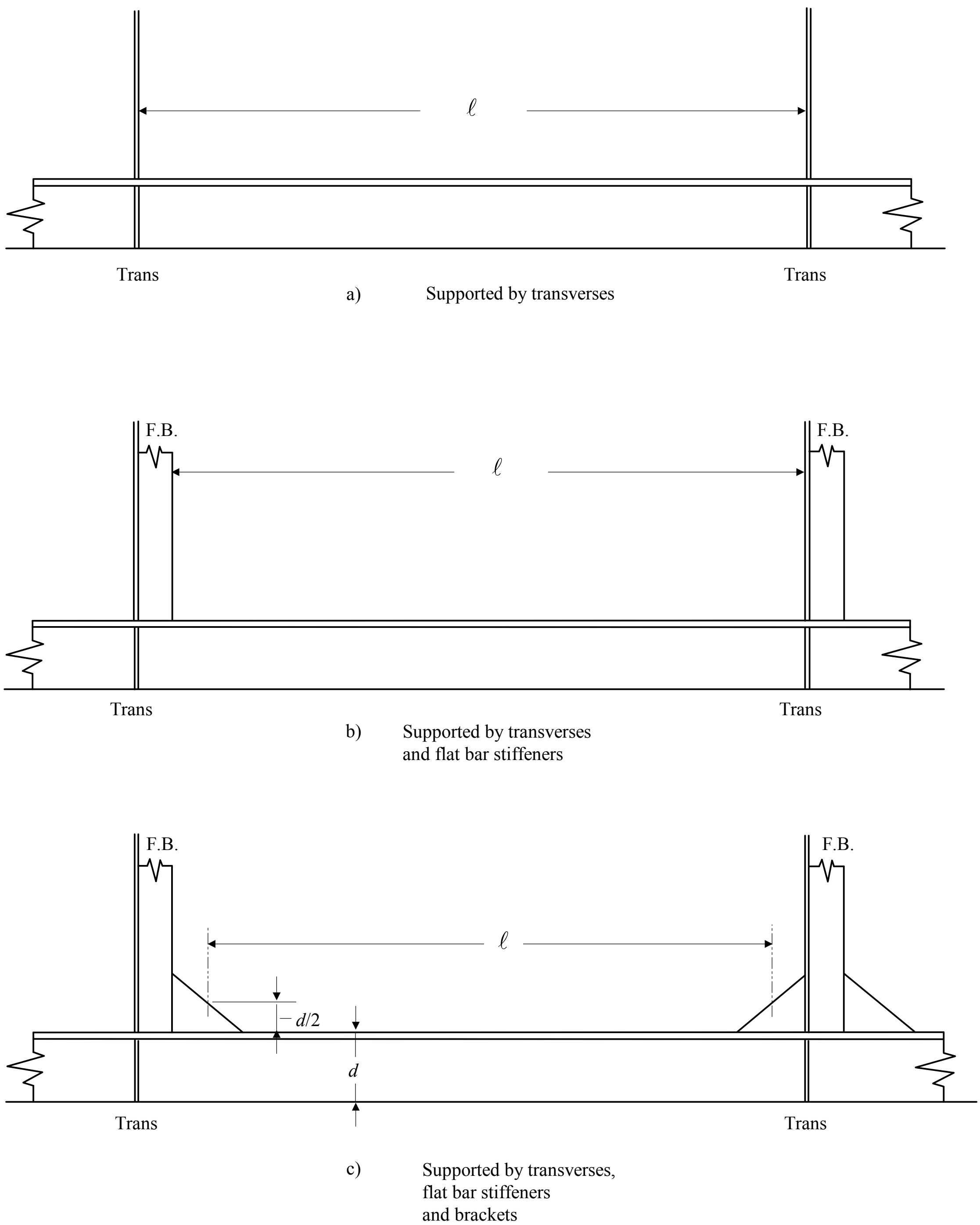
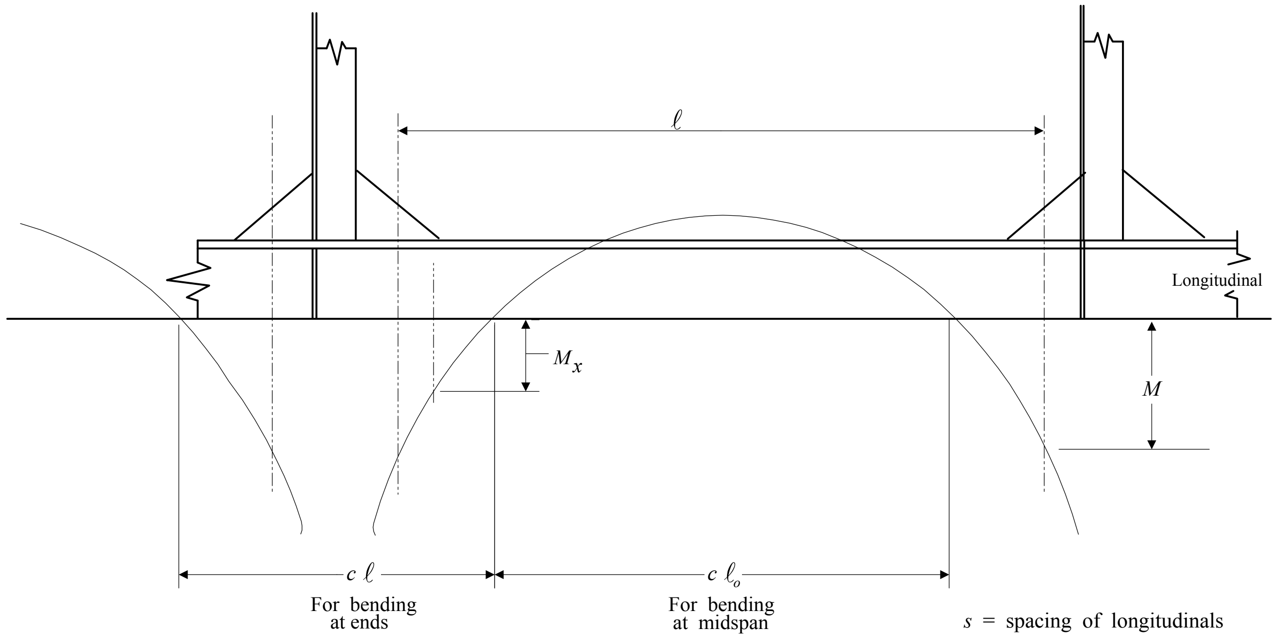


FIGURE 7
Effective Breadth of Plating b_e



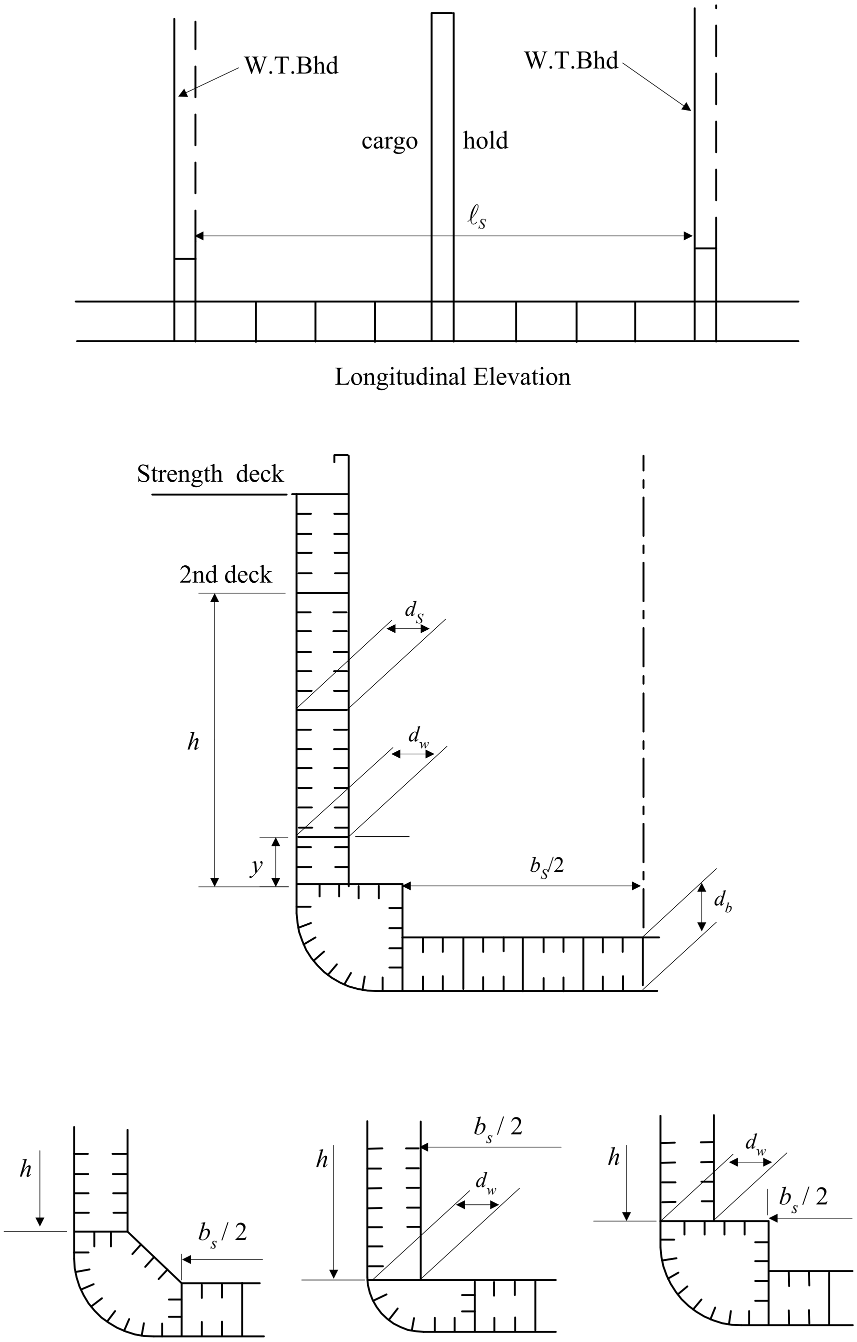
a) For bending at midspan

$c\ell_o/s$	1.5	2	2.5	3	3.5	4	4.5 and greater
b_e/s	0.58	0.73	0.83	0.90	0.95	0.98	1.0

b) For bending at ends [$b_e/s = (0.124c\ell/s - 0.062)^{1/2}$]

$c\ell/s$	1	1.5	2	2.5	3	3.5	4.0
b_e/s	0.25	0.35	0.43	0.5	0.55	0.6	0.67

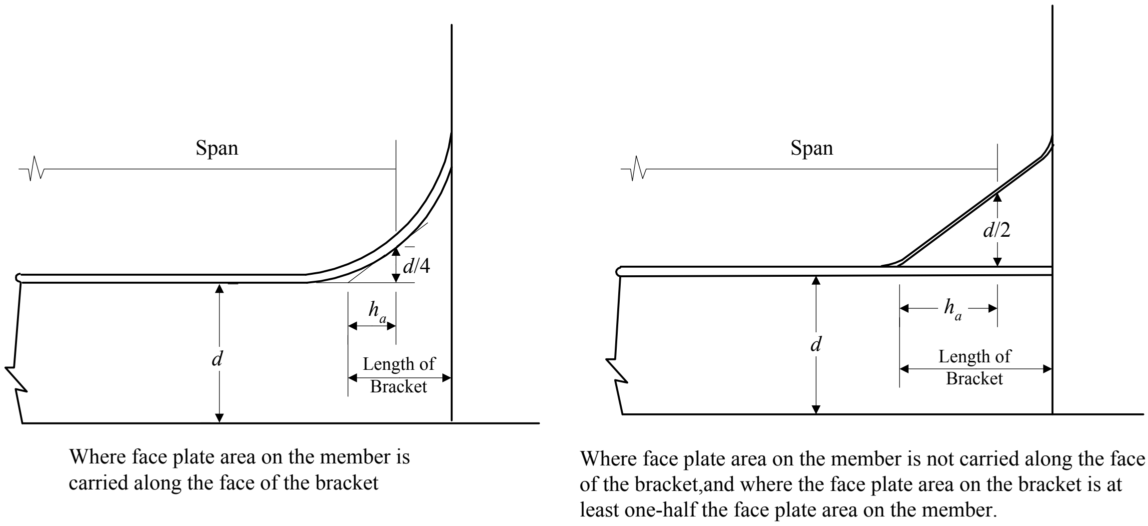
FIGURE 8
Definitions of ℓ_s, b_s, h, d_b, d_w, d_s and y



Note

Where the breadths of the forward and aft ends of double bottom structure are different, i.e., non-prismatic double bottom structure, b_s is to be taken as the actual breadth of double bottom structure depending upon the longitudinal distance (x) from the mid-span of length ℓ_s under consideration. For calculation of shear force for side girders, the actual length of side girders is to be used in lieu of ℓ_s. All other formulae and parameters are applicable to shear force calculations. (See 5C-5-4/11.11, 5C-5-4/11.13 and 5C-5-4/11.21.)

FIGURE 9
Effectiveness of Brackets for Main Supporting Members



Brackets are not to be considered effective beyond the point where the arm on the girder or web is 1.5 times the arm on the bulkhead or base.

13 Side Shell Plating and Longitudinals *(1998)*

13.1 Side Shell Plating *(1 July 2007)*

The net thickness of the side shell plating, in addition to compliance with 5C-5-4/5.3, is to be not less than t_1, t_2 and t_3 specified below for the midship 0.4L:

$$t_1 = 0.73s(k_1\, p/f_1)^{1/2} \qquad \text{mm (in.)}$$

$$t_2 = 0.73s(k_2\, p/f_2)^{1/2} \qquad \text{mm (in.)}$$

$$t_3 = c\, s\, (S_m f_y/E)^{1/2} \qquad \text{mm (in.)}$$

where

s = spacing of side longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.500

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate strake, as specified in 5C-5-3/Table 2, but is not to be taken less than 85% of the pressure at the upper turn of the bilge. The nominal pressure at the upper turn of bilge for case “a” in 5C-5-3/Table 2 is not to be taken less than that at bottom boundary of wing tank where the bottom boundary is located between the upper turn of bilge and 0.35D above the base line.

f_1 = permissible bending stress, in longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $[0.835 - 0.40\ \alpha_1\ (SM_{RB}/SM_B)(y/y_b)]S_m f_y$, below neutral axis, where SM_B/SM_{RB} is not to be taken more than 1.4

= $[0.835 - 0.52\alpha_2\ (SM_{RD}/SM_D)(y/y_n)]\ S_m f_y$, above neutral axis

f_1 is not to be taken greater than:

$0.43S_m f_y$	for $L \geq 210$ m (689 ft)
$[0.43 + (210 - L)/2600]S_m f_y$	for $L < 210$ m
$[0.43 + (689 - L)/8531]S_m f_y$	for $L < 689$ ft

f_2 = permissible bending stress, in the vertical direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.80\ S_m f_y$

α_1 = $S_{m1} f_{y1}/S_m f_y$

α_2 = $S_{m2} f_{y2}/S_m f_y$

S_m = strength reduction factor, as defined in 5C-5-4/11.3.1, of the side shell plating

S_{m1} = strength reduction factor, as defined in 5C-5-4/11.3.1, of the bottom flange of the hull girder

S_{m2} = strength reduction factor, as defined in 5C-5-4/11.3.1, of the strength deck flange of the hull girder

f_y = minimum specified yield point of the side shell plating, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{y1} = minimum specified yield point of the bottom flange of the hull girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{y2} = minimum specified yield point of the strength deck flange of the hull girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

SM_{RD} = reference net hull-girder section modulus based on the material factor of the strength deck flange of the hull girder, in cm^2-m (in^2-ft).

= $0.95\ SM$

SM = required gross hull girder section modulus amdiships, in accordance with 5C-5-4/3.1.1, with k_w defined in 5C-5-3/5.1.1 for the purpose of calculating M_w (sagging and hogging), based on the material factor of the strength deck flange of the hull girder, in cm^2-m (in^2-ft)

SM_D = design (actual) net hull girder section modulus at the strength deck amidships, in cm^2-m (in^2-ft)

c = $0.7N^2 - 0.2$, not to be taken less than $0.4Q^{1/2}$

N = $R_d\ (Q/Q_d)^{1/2}$ for the sheer strake

= $R_d\ [(Q/Q_d)\ (y_a/y_n)]^{1/2}$ for other locations above neutral axis

= $R_b\ [(Q/Q_b)\ (y_a/y_n)]^{1/2}$ for locations below neutral axis

R_d = $(SM_{RDS}/SM_D)^{1/2}$

R_b = $(SM_{RBH}/SM_B)^{1/2}$

SM_{RDS} = reference net hull girder section modulus for sagging bending moment based on the material factor of the strength deck flange of the hull girder, in cm^2-m (in^2-ft)

= 0.95 SM_s

SM_s = required gross hull girder section modulus amidships, in accordance with 5C-5-4/3.1.1, with k_w defined in 5C-5-3/5.1.1 for the purpose of calculating M_w (sagging), based on material factor of the strength deck flange of the hull girder, in cm^2-m (in^2-ft)

SM_{RBH} = reference net hull girder section modulus for hogging bending moment based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

= 0.9 SM_H

SM_H = required gross hull girder section modulus amidships, in accordance with 5C-5-4/3.1.1, with k_w defined in 5C-5-3/5.1.1 for the purpose of calculating M_w (hogging), based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

Q, Q_b, Q_d = material conversion factor in 5C-5-4/5 for the side shell plating, the bottom flange and the strength deck flange of the hull girder, respectively

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the lower edge of the side shell strake

y_a = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the lower edge (upper edge) of the side shell strake, when the strake under consideration is below (above) the neutral axis.

y_b = vertical distance, in m (ft), measured from the upper turn of bilge to the neutral axis of the section

y_n = vertical distance, in m (ft), measured from the bottom (deck) to the neutral axis of the hull girder transverse section, when the strake under consideration is below (above) the neutral axis

SM_{RB}, SM_B, and E are as defined in 5C-5-4/11.3.1.

t_1 and t_2, as calculated for each plate, need not to be taken in excess of those calculated at the upper turn of the bilge, respectively, as adjusted for the spacing of the longitudinals and the material factors.

In addition, the net thickness of the side shell plating is not to be taken less than t_4, obtained from the following equation:

$$t_4 = 90(s/1000 + 0.7)\,[Bd/(S_m f_y)^2]^{1/4} + t_k \quad \text{mm}$$

$$t_4 = 7.3(s/39.4 + 0.7)\,[Bd/(S_m f_y)^2]^{1/4} + t_k \quad \text{in.}$$

where

s = spacing of side frames, in mm (in.)

B = breadth of vessel, as defined in 3-1-1/5, in m (ft)

d = molded draft, as defined in 3-1-1/9, in m (ft)

t_k = 0.5 mm (0.02 in.) for mild steel

= 1.0 mm (0.04 in.) for Grade H32 steel

= 1.5 mm (0.06 in.) for Grade H36 steel

All other parameters are as defined above.

The net thickness, t_4, is to be applied to the following extent of the side shell plating:

Longitudinal extent: between a section aft of amidships where the breadth at the waterline exceeds $0.9B$, and a section forward of amidships where the breadth at the waterline exceeds $0.6B$,

Vertical extent: between 300 mm (12 in.) below the lowest ballast waterline to $0.25d$ or 2.2 m (7.2 ft), whichever is greater, above the summer load line.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

In general, the side shell is to be longitudinally framed within the regions of $0.15D$ from the baseline and $0.15D$ from the upper deck. Other parts of side shell plating may be transversely framed, provided the net thickness of the side shell plating is not less than t_5, as specified below, and is also not less than that of adjacent longitudinally framed shell:

$$t_5 = 0.73s\, k\, (k_2\, p/f\,)^{1/2} \quad \text{mm (in.)}$$

where

s = spacing of side frames, in mm (in.)

k_2 = 0.500

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \leq \alpha \leq 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

p = nominal pressure at side shell under consideration, in N/cm² (kgf/cm², lbf/in²), as specified in 5C-5-3/Table 2 for side structural members

f = permissible bending stress, in N/cm² (kgf/cm², lbf/in²)

= $[0.835 - 0.40\alpha_1\, (SM_{RB}/SM_B)(y/y_b)]S_m f_y \leq 0.55 S_m f_y$, below neutral axis, where $SM_B\, /SM_{RB}$ is not to be taken more than 1.4

= $0.55\, S_m f_y$, above neutral axis

All other parameters are as defined above.

For a curved plate where girth spacing is greater than that of the adjacent side plating, the spacing may be modified by the equations as specified in 5C-5-4/11.7.

The minimum width of the sheer strake for the midship $0.4L$ is to be obtained from the following equations:

b = $5L + 800$ mm for $L \leq 200$ m

= $0.06L + 31.5$ in. for $L \leq 656$ ft

b = 1800 mm for $200 < L \leq 350$ m

= 70.87 in. for $656 < L \leq 1148$ ft

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

b = width of sheer strake, in mm (in.)

The thickness of the sheer strake is to be increased 25% in way of breaks of superstructures, but this increase need not exceed 6.5 mm (0.25 in.).

13.3 Side Longitudinals and Side Frames *(1 July 2005)*

The net section modulus of each side longitudinal or side frame, in association with the effective plating, is to be not less than that obtained from the following equations:

$SM = M/f_b$ cm^3 (in^3)

$M = cps\ell^2 10^3/k$ N-cm (kgf-cm, lbf-in)

where

c = 1.0 without struts

= 0.65 with effective struts

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the side longitudinal considered, as specified in 5C-5-3/Table 2, but is not to be taken less than 2.25 N/cm^2 (0.23 kgf/cm^2, 3.27 lbf/in^2). For side frames, pressure is to be taken at the middle of the span of the side frame.

s = spacing of side longitudinals or side frames, in mm (in.)

ℓ = span of longitudinals or frames between effective supports, as shown in 5C-5-4/Figure 6, in m (ft)

k = 12 (12, 83.33)

f_b = permissible bending stresses, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $1.5\,[0.835 - 0.52\alpha_2\,(SM_{RDS}/SM_D)(y/y_n)]S_m f_y \le 0.85 S_m f_y$

for side longitudinals above neutral axis in load case 3-B in 5C-5-3/Table 2

= $1.0\,[0.835 - 0.52\alpha_1\,(SM_{RB}/SM_B)(y/y_n)]S_m f_y \le 0.75 S_m f_y$

for side longitudinals below neutral axis

= $1.5\,[0.835 - 0.52\alpha_2\,(SM_{RD}/SM_D)(y/y_n)]S_m f_y \le 0.85 S_m f_y$

for side longitudinals above neutral axis in load case 3-A in 5C-5-3/Table 2

= $0.90\,S_m f_y$ for side frames

α_2 = $S_{m2} f_{y2}/S_m f_y$

S_m, f_y and α_1 are as defined in 5C-5-4/11.3.1.

S_{m2} = strength reduction factor for the strength deck flange of the hull girder, as defined in 5C-5-4/11.3.1

f_{y2} = minimum specified yield point of the strength deck flange of the hull girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

SM_D and SM_{RDS} are as defined in 5C-5-4/13.1 and SM_{RDS} is to be taken not less than 0.5 SM_{RD}.

SM_{RB} and SM_B are as defined in 5C-5-4/11.3.1.

SM_{RD} = reference net hull girder section modulus based on material factor of the strength deck flange of the hull girder, in cm^2-m (in^2-ft)

= 0.95 SM

SM = reference gross hull girder section modulus amidships in accordance with 5C-5-4/3.1.1, with k_w defined in 5C-5-3/5.1.1 for the purpose of calculating M_w (sagging and hogging), based on material factor of the strength deck flange of the hull girder, in cm^2-m (in^2-ft)

y = vertical distance, in m (ft), measured from the neutral axis of the section to the side longitudinal under consideration at its connection to the associated plate

y_n = vertical distance, in m (ft), measured from the strength deck (bottom) to the neutral axis of the section, when the longitudinal under consideration is above (below) the neutral axis

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

The net moment of inertia of side longitudinals within the region of 0.1D from the strength deck, in association with the effective plating (b_{WL} t_n), is to be not less than that obtained from the following equation:

$$i_o = k A_e \ell^2 f_y / E \qquad \text{cm}^4 \text{ (in}^4\text{)}$$

where

k = 610 (610, 8.79)

A_e = net sectional area of the longitudinal with the associated effective plating (b_{WL} t_n), in cm^2 (in^2)

b_{WL} = $c_e s$

c_e = $2.25/\beta - 1.25/\beta^2$ for $\beta \geq 1.25$

= 1.0 for $\beta \leq 1.25$

β = $(f_y/E)^{1/2}\, s/t_n$

t_n = net thickness of the plate, in mm (in.)

D = depth of vessel, in m (ft), as defined in 3-1-1/7

ℓ, s and f_y are as defined in 5C-5-4/11.5.

E is as defined in 5C-5-4/11.3.1.

For container carriers with length over 250 m in length, side shell longitudinals of asymmetric cross section below $^1/_3 d$ from the waterline are to have lugged slot connections to side transverses. Alternatively, the fatigue strength of the welded connections of the slot connections is to be evaluated using a fine mesh finite element model.

13.5 Side Struts *(1998)*

Where struts are fitted as an effective supporting system for side tank structures, they are to be positioned so as to divide the span into approximately equal intervals. They are to have net area not less than A_{r1} or A_{r2}, whichever is greater, obtained from the following equations:

$$A_{r1} = kp_a bs/w_a \qquad \text{cm}^2 \text{ (in}^2\text{)}$$

$$A_{r2} = kp_b bs/w_b \qquad \text{cm}^2 \text{ (in}^2\text{)}$$

where

k = 0.01 (0.01, 1.0)

b = mean span of the side frames or side longitudinals supported, in mm (in.)

s	=	spacing of the side frames or side longitudinals, in mm (in.)	
p_a	=	nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the strut considered, as specified in Case "a" of 5C-5-3/Table 2 for side longitudinals	
p_b	=	nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the strut considered, as specified in Case "b" of 5C-5-3/Table 2 for side longitudinals	
w_a	=	$0.45\, S_m f_y$	
w_b	=	$0.56 f_y\, [1 - 0.0254\, (f_y/E)\, (\ell/r)^2]$	when $(\ell/r)^2\, (f_y/E) < 20$
	=	$5.55E\, (\ell/r)^2$	when $(\ell/r)^2\, (f_y/E) \geq 20$
ℓ	=	unsupported span of the strut, in cm (in.)	
r	=	least radius of gyration of the strut, in cm (in.)	
f_y	=	minimum specified yield point of the struts, in N/cm^2 (kgf/cm^2, lbf/in^2)	

E is as defined in 5C-5-4/11.3.1.

15 Side Transverses and Side Stringers *(1998)*

The minimum scantlings for the side transverses and side stringers are to be determined from 5C-5-4/15.1, 5C-5-4/15.3, 5C-5-4/15.5, 5C-5-4/15.7, 5C-5-4/15.9 and 5C-5-4/15.11, as follows. Alternatively, t_2 in 5C-5-4/15.1 and 5C-5-4/15.7 and the scantlings in 5C-5-4/15.3 and 5C-5-4/15.5 may be determined from finite element analyses, as specified in 5C-5-5/9 with the combined load cases in 5C-5-3/9. However, in no case are the scantlings to be taken less than 85% of those determined from the corresponding equations below. For this purpose, an additional load case is also to be investigated modifying load case 6 with a full draft.

15.1 Side Transverse in Double Side Structures *(1 July 2005)*

The net thickness of the side transverse in a double side is to be not less than t_1 and t_2, as defined below, whichever is greater.

t_1	$= 8.5$	mm	where $L \geq 200$ m
	$= 0.02L + 4.5$	mm	where $200 > L \geq 130$ m for SI or MKS Units
	$= 0.334$	in.	where $L \geq 656$ ft
	$= 0.00024L + 0.177$	in.	where 656 ft $> L \geq 427$ ft for US Units
t_2	$= 10F_1/(d_w f_s)$	mm	for SI or MKS Units
	$= F_1/(d_w f_s)$	in.	for U.S. Units

where F_1 is the maximum shear force of the side transverse under consideration, as obtained from the equations given below (see also 5C-5-4/1.3):

$$F_1 = k190\lambda\beta_1\gamma_1 phs_1 \qquad \text{N (kgf, lbf)}$$

where

k	=	1.0 (1.0, 2.24)
λ	=	ℓ_s/h, but need not be taken more than 2.5
β_1	=	$1 - 1.25\, y/h \geq 0.45$

ℓ_s = length of the cargo hold under consideration, in m (ft)

h = height of the double side structure, in m (ft), as shown in 5C-5-4/Figure 8

γ_1 = 1.25 if no stringer is installed

= 1.05 if a stringer or stringers are installed within the upper half of the side height h, but no stringer is installed within the lower half

= 0.93 if a stringer or stringers are installed up to 0.5h from the lower end of the side height h

s_1 = sum of one-half of transverse spacings on both sides of transverse, in m (ft)

y = vertical distance from the inner bottom or the lowest deck level to the location on the transverse under consideration, as shown in 5C-5-4/Figure 8, in m (ft)

d_w = width of the transverse web plate at elevation y, as shown in 5C-5-4/Figure 8, in cm (in.)

p = nominal pressure on the double side structure at an elevation of 0.2h above the lower end of h, as specified in 5C-5-3/Table 2, in kN/m^2 (tf/m^2, Ltf/in^2)

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.50\, S_m f_y$

L = length of vessel, in m (ft), as defined in 3-1-1/3.1

S_m and f_y are as defined in 5C-5-4/11.3.1.

The net thickness of the transverse in the bilge part is to be not less than t_1 as required above and the lower part is also to be not less than t_1 as required in 5C-5-4/11.21 for the bottom floor.

Where the shell is longitudinally framed, web stiffeners are to be fitted for the full depth of the transverses at every longitudinal. Other stiffening arrangement may be considered based on the structural stability of the web plates.

15.3 Side Transverse in Single Side Shell

Side transverse on single skin side shell is to have scantlings not less than that obtained from the following equations.

15.3.1 Section Modulus

The net section modulus of the side transverse is not to be less than obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

$M = 3350\lambda\gamma p s h^2/k$ N-cm (kgf-cm, lbf-in)

where

k = 1.0 (1.0, 3.72)

h = height of the single skin side structure, in m (ft)

λ = ℓ_s/h, but need not be taken more than 2.5

γ = 1.0 if no stringer is installed

= 0.8 if a stringer or stringers are installed within the upper half of the side height h , but no stringer is installed within the lower half

= 0.65 if a stringer or stringers are installed up to $0.5h$ from the lower end of side height h

p = nominal pressure on the single skin side structure at an elevation of $0.2h$ above the lower end of h, in kN/m^2 (tf/m^2, Ltf/ft^2), as specified in 5C-5-3/Table 2

s = spacing of the side transverse, in m (ft)

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.75\, S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1. ℓ_s is defined in 5C-5-4/15.1 above.

15.3.2 Web Thickness *(1 July 2005)*

The net web thickness of the side transverse is not to be less than that obtained from the following equations:

$t_1 = 8.5$	mm	where $L \geq 200$ m
$= 0.02L + 4.5$	mm	where $200 > L \geq 130$ m for SI or MKS Units
$= 0.334$	in.	where $L \geq 656$ ft
$= 0.00024L + 0.177$	in.	where 656 ft $> L \geq 427$ ft for U.S. Units
$t_2 = k_3F/(d_w f_s)$	mm (in.)	
$F = k160\lambda\beta_1\gamma_1 psh$	N (kgf, lbf)	

where

k_3 = 10 (10, 1.0)

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.50\, S_m f_y$

d_w = depth of the side transverse, in cm (in.)

β_1 = $1 - 1.25y/h \geq 0.45$

λ, p, s and h are as defined in 5C-5-4/15.3.1 above. k, γ_1 and y are defined in 5C-5-4/15.1 above.

15.3.3 Web Stiffeners

Web stiffeners extending to the full depth of the side transverses are to be fitted at every longitudinal. Other stiffening arrangements may be considered based on the structural stability of the web plates.

15.5 Side Transverse in Underdeck Passageway

Side transverses in the underdeck passageway forming an upper wing torsional box are to have scantlings not less than obtained from the following equations:

15.5.1 Section Modulus

The net section modulus of the side transverses is not to be less than that obtained from the following equation:

$SM = (M_1 + M_2)/f_b$ cm^3 (in^3)

$M_1 = c_1 p_u s \ell^2 10^5/k_1$ N-cm (kgf-cm, lbf-in)

$M_2 = k8\lambda\gamma_1 phs_1 y$ N-cm (kgf-cm, lbf-in)

where

k_1 = 12 (12, 44.64)

c_1 = $1 - 0.1\ell/p_u$

p_u = nominal pressure calculated at the mid-span of the side transverse under consideration, in kN/m^2 (tf/m^2, Ltf/ft^2), as specified in 5C-5-3/Table 2

s = spacing of the side transverses, in m (ft)

ℓ = span of the side transverse, in m (ft), ℓ may be modified in accordance with 5C-5-4/Figure 9

y = $k_2(\ell - h_u/2) \geq 0$

k_2 = 100 (100, 12)

h_u = height of the underdeck passageway, in m (ft)

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, Ibf/in^2)

= $0.85\ S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1. k, λ, γ_1, p, h and s_1 are as defined in 5C-5-4/15.1 above.

15.5.2 Depth of Side Transverse

The depth of the side transverse is not to be less than that obtained from the following equation:

$d = k\ell$ mm (in.)

where

k = 125 (1.5)

ℓ is as defined in 5C-5-4/15.5.1 above.

15.5.3 Web Thickness

The net web thickness of the side transverse is not to be less than that obtained from the following equation:

$t = k_3 (F_1 + F_2)/(d_w f_s)$ mm (in.) but not less than 8.0 mm (0.31 in.)

$F_1 = k500c_2 p_u s\ell$ N (kgf, lbf)

$F_2 = k14.25\lambda\gamma_1 phs_1$ N (kgf, lbf)

where

k_3 = 10 (10, 1.0)

c_2 = $1 - 0.2\ell/p_u$

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.50\ S_m f_y$

d_w = depth of the side transverse, in cm (in.)

p_u, s and ℓ are as defined in 5C-5-4/15.5.1 above. k, λ, γ_1, p, h and s_1 are as defined in 5C-5-4/15.1 above.

15.5.4 Web Stiffeners

Web stiffeners extending to the full depth of the side transverses are to be fitted at least every two longitudinals. Other stiffening arrangements may be considered based on the structural stability of the web plates.

15.7 Side Stringers in Double Side Structures *(1 July 2005)*

If longitudinal stringers are installed in the double side below the 2nd deck, the net thickness of the stringer plate is to be not less than t_1 and t_2, as defined below, whichever is greater.

$t_1 = 9.5$	mm	where $L \geq 200$ m	
$= 0.02L + 5.5$	mm	where $200 > L \geq 130$ m	for SI or MKS Units
$= 0.374$	in.	where $L \geq 656$ ft	
$= 0.00024L + 0.217$	in.	where 656 ft $> L \geq 427$ ft	for U.S. Units
$t_2 = 10F_2/(d_s f_s)$	mm	for SI or MKS Units	
$= F_2/(d_s f_s)$	in.	for U.S. Units	

where F_2 is the maximum shear force in the stringer under consideration, as obtained from the approximation equations given below (see also 5C-5-4/1.3).

$F_2 = k95\ \gamma_2\ p_s \ell_s s_2$ N (kgf, lbf)

where

k = 1.0 (1.0, 2.24)

γ_2 = $2x/\ell_s \geq 0.45$

s_2 = sum of the one-half of stringer spacings on both sides of each stringer, in m (ft)

x = longitudinal distance from the mid-span of length ℓ_s to the location on the stringer under consideration, m (ft)

d_s = width of the stringer, as shown in 5C-5-4/Figure 8, in cm (in.)

p_s = nominal pressure on the double side structure at the level of the stringer under consideration, as specified in 5C-5-3/Table 2, in kN/m^2 (tf/m^2, Ltf/in^2)

L, ℓ_s, and f_s are as defined in 5C-5-4/15.1.

In addition, the net thickness of the longitudinally framed plate is to be not less than that obtained from the following equation:

$$t_3 = c\, s\, (S_m f_s/E)^{1/2} \qquad \text{mm (in.)}$$

where

s = spacing of longitudinals, in mm (in.)

c = $0.7N^2 - 0.2$, not to be taken less than 0.2

N = $R_d\, [(Q/Q_d)\, (y/y_n)]^{1/2}$ for side stringers located above neutral axis

= $R_b\, [(Q/Q_b)\, (y/y_n)]^{1/2}$ for side stringers located below neutral axis

R_d = $(SM_{RDS}/SM_D)^{1/2}$

R_b = $(SM_{RBH}/SM_B)^{1/2}$

SM_{RDS} = reference net hull girder section modulus for sagging bending moment based on the material factor of the strength deck flange of the hull girder, in cm^2-m (in^2-ft)

= $0.95\, SM_S$

SM_S = reference gross hull girder section modulus in accordance with 5C-5-4/3.1.1 for sagging total bending moment, with k_w defined in 5C-5-3/5.1.1 for the purpose of calculating M_w (sagging), based on the material factor of the strength deck flange of the hull girder, in cm^2-m (in^2-ft)

SM_{RBH} = reference net hull girder section modulus for hogging bending moment based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

= $0.9SM_H$

SM_H = reference gross hull girder section modulus in accordance with 5C-5-4/3.1.1 for hogging total bending moment, with k_w defined in 5C-5-3/5.1.1 for the purpose of calculating M_w (hogging), based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)

Q, Q_b, Q_d = material conversion factor in 5C-5-4/5 for the side stringer plating, the bottom flange and the strength deck flange of the hull girder, respectively

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the side stringer.

y_n = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section, when the side stringer under consideration is below (above) the neutral axis

S_m and f_y are defined in 5C-5-4/11.3.1.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

Where the shell is transversely framed, web stiffeners are to be fitted for the full width of the side stringer at every frame. Other stiffening arrangements may be considered based on the structural stability of the web plates.

15.9 Transverses Forming Tank Boundaries

Where transverses form tank boundaries, the net thickness is also to be not less than as required in 5C-5-4/23.

15.11 Side Stringers Forming Tank Boundaries

15.11.1 Plating

Where the side stringer forms tank boundaries, the net thickness of the boundary plating is also to be not less than t_1 and t_2 specified as follows:

$t_1 = 0.73s(k_1\, p/f_1)^{1/2}$ mm (in.)

$t_2 = 0.73s(k_2\, p/f_2)^{1/2}$ mm (in.)

where

s = spacing of longitudinals or stiffeners, in mm (in.)

k_1 = 0.342, for longitudinally stiffened plating

= $0.500\, k^2$, for transversely stiffened plating

k_2 = 0.500

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-5-3/Table 2

f_1 = permissible bending stress, in longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $c[1.0 - 0.70\alpha_1 SM_{RB}/SM_B\,(y/y_n)]\, S_m f_y \le 0.85 S_m f_y$, below neutral axis

= $c[1.0 - 0.70\alpha_2 SM_{RD}/SM_D\,(y/y_n)]\, S_m f_y \le 0.85 S_m f_y$, above neutral axis

c = 1.1 for longitudinally stiffened plating

= 1.4 for transversely stiffened plating

f_2 = permissible bending stress, in the transverse direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.95\, S_m f_y$

α_1 = $S_{m1} f_{y1}/S_m f_y$

α_2 = $S_{m2} f_{y2}/S_m f_y$

S_m = strength reduction factor of the longitudinal bulkhead plating, as defined in 5C-5-4/11.3.1

f_y = minimum specified yield point of the longitudinal bulkhead plating, in N/cm^2 (kgf/cm^2, lbf/in^2)

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the side stringer under consideration

y_n = distance, in m (ft), measured from the main deck (bottom) to the neutral axis of the section

SM_{RB}, SM_B, and E are as defined in 5C-5-4/11.3.1.

S_{m1} and f_{y1} are as defined in 5C-5-4/11.5.

S_{m2}, SM_{RD} and f_{y2} are as defined in 5C-5-4/13.3.

SM_D is as defined in 5C-5-4/13.1.

15.11.2 Stiffeners on Side Stringer

The net section modulus of each longitudinal or stiffener on side stringer forming tank boundaries, in association with the effective plating, is to be not less than that obtained from the following equations:

$$SM = M/f_b \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

$$M = cps\ell^2 10^3/k \qquad \text{N-cm (kgf-cm, lbf-in)}$$

where

k = 12 (12, 83.33)

c = 1.0

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the longitudinal considered, as specified in 5C-5-3/Table 2

s = spacing of longitudinals or stiffeners, in mm (in.)

ℓ = span of longitudinals or stiffeners between effective supports, as shown in 5C-5-4/Figure 6, in m (ft)

f_b = permissible bending stresses, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $1.1[1.0 - 0.70\alpha_1(SM_{RB}/SM_B)(y/y_n)]S_m f_y \leq 0.80 S_m f_y$

for longitudinals below neutral axis

= $1.6[1.0 - 0.70\alpha_2(SM_{RD}/SM_D)(y/y_n)]S_m f_y \leq 0.80 S_m f_y$

for longitudinals above neutral axis

= $0.90\ S_m f_y$ for stiffeners

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the longitudinal under consideration at its connection to the associated plate

SM_{RB} and SM_B are as defined in 5C-5-4/11.3.1.

S_{m1} and f_{y1} are as defined in 5C-5-4/11.5.

SM_{RD}, S_{m2} and f_{y2} are as defined in 5C-5-4/13.3.

S_m, f_y, y_n, α_1 and α_2 are defined in 5C-5-4/15.11.1.

SM_D is as defined in 5C-5-4/13.1.

15.13 Container Supporting Structures *(1998)*

Where brackets or headers are provided to transmit the dynamic container loads due to ship's motion to the main supporting side structures, each bracket or header is to have a net section modulus, SM, in cm^3 (in^3), and a net sectional area, A_s, in cm^2 (in^2), of the web portion not less than that obtained from the following equations:

$$SM = M/f_b$$

$$A_s = F/f_s$$

where

M	=	maximum bending moment due to dynamic container load, N-cm (kgf-cm, lbf-in)
f_b	=	permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)
	=	$0.80\ S_m f_y$
F	=	shear force at the location under consideration due to dynamic container load, in N (kgf, lbf)
f_s	=	permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)
	=	$0.53\ S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.5.

The dynamic container loads are to be obtained from the equations in 5C-5-3/5.5.2(b) in association with the maximum design container weight for load case 5, as specified in 5C-5-3/Table 1C .

17 Deck Structures

17.1 Strength Deck Plating *(1 July 2005)*

In general, the strength deck is to be longitudinally framed. The net thickness of the strength deck plating is to be not less than that needed to meet the hull girder section modulus requirements in 5C-5-4/3.1 and the buckling and ultimate strength requirements in 5C-5-5/5, nor is the thickness to be less than t_1, t_2 and t_3, specified below for the midship $0.4L$:

$$t_1 = 0.73s(k_1\, p/f_1)^{1/2} \qquad \text{mm (in.)}$$

$$t_2 = 0.73s(k_2\, p/f_2)^{1/2} \qquad \text{mm (in.)}$$

$$t_3 = cs(S_m f_y /E)^{1/2} \qquad \text{mm (in.)}$$

where

s	=	spacing of deck longitudinals, in mm (in.)
k_1	=	0.342
k_2	=	0.500
p	=	nominal deck pressure, in N/cm^2 (kgf/cm^2, lbf/ in^2), as specified in 5C-5-3/Table 2.
f_1	=	permissible bending stress in longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)
	=	$0.15\ S_m f_y$
f_2	=	permissible bending stress, in the transverse direction, in N/cm^2 (kgf/cm^2, lbf/in^2)
	=	$0.80\ S_m f_y$

c	=	$0.5(0.6 + 0.0015L)$	for SI or MKS units
	=	$0.5(0.6 + 0.0046L)$	for U.S Units

c is to be taken not less than $0.7N^2 - 0.2$ for vessel less than 267 m (876 ft) in length.

L = length of vessel, in m (ft), as defined in 3-1-1/3.1

N = $R_d(Q/Q_d)^{1/2}$

R_d = $(SM_{RDS}/SM_D)^{1/2}$

SM_{RDS} = reference net hull girder section modulus for sagging bending moment based on the material factor of the strength deck flange of the hull girder, in cm^2-m (in^2-ft)

= $0.95SM_S$

SM_S = reference gross hull girder section modulus in accordance with 5C-5-4/3.1.1 for sagging total bending moment, with k_w defined in 5C-5-3/5.1.1 for the purpose of calculating M_w (sagging), based on the material factor of the strength deck flange of the hull girder, in cm^2-m (in^2-ft)

Q, Q_d = material conversion factor in 5C-5-4/5 for the deck plating and the strength deck flange of the hull girder, respectively

S_m, f_y and E are as defined in 5C-5-4/11.3.1.

SM_D is as defined in 5C-5-4/13.1.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

17.3 Strength Deck Longitudinals *(1998)*

The net section modulus of each individual deck longitudinal, in association with the effective plating, is to be not less than that obtained from the following equations:

$SM = M/f_b$ cm^3 (in^3)

$M = ps\ell^2 10^3/k$ N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 83.33)

s = spacing of deck longitudinals, in mm (in.)

ℓ = span of longitudinals between effective supports, as shown in 5C-5-4/Figure 6, in m (ft)

p = nominal deck pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-5-3/Table 2.

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.3\, S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.5.

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

The net moment of inertia of the deck longitudinal in association with the effective plating ($b_{WL}\, t_n$) is to be not less than i_o, as specified in 5C-5-4/13.3.

17.5 Upper Wing Torsional Box

17.5.1 Width of Torsional Box

In general, the width of the upper wing torsional box is not to be less than $0.009L_0$, where L_0 is as defined in 5C-5-4/9.3.

17.5.2 Calculation of Secondary Stress due to External Water Pressure on Side Shell

The stress at the strength deck and at the top of a continuous longitudinal hatch side coaming, induced by external water pressure on the side shell, may be obtained from the following equation:

$$f_P = M_P/SM \qquad \text{N/cm}^2\ (\text{kgf/cm}^2,\ \text{lbf/in}^2)$$

where

M_P = $kQ\ell 10^5$ N-cm (kgf-cm, lbf-in)

k = 0.15 (0.15, 0.0403)

Q = $k_1(0.94C_1k_\ell h_2 + 0.5\,h_2^2 + 0.67C_1k_\ell h_1)s$ kN (tf, Ltf)

k_1 = 9.807 (1, 0.028)

k_ℓ = $0.5(1 + k_{\ell o})$

s = spacing of side transverses, spacing, in m (ft), below the second deck

ℓ = $\ell_0 + 0.5(w_1 + w_2)$

ℓ_0 = length of the hatch opening amidships, in m (ft)

w_1, w_2 = widths of the cross deck box beams, in m (ft), clear of hatch corner, fore and aft of the hatch opening amidships, as shown in 5C-5-4/Figure 4

SM = net section modulus of the upper wing torsional box, in cm^3 (in^3), at the inboard edge of the strength deck or at the top of the continuous longitudinal hatch side coaming with respect to vertical axis z (5C-5-4/Figure 4) for the hull girder section under consideration.

C_1 is as defined in 3-2-1/3.5.

$k_{\ell o}$ is as defined in 5C-5-3/Figure 9.

h_1 and h_2 are as shown in 5C-5-4/Figure 10 for hull girder section under consideration, in m (ft).

The following items may be included in the calculation of the section modulus SM:

- Strength deck plating and continuous longitudinals
- Side shell and longitudinal bulkhead plating and continuous longitudinals. Effective depth of side shell and longitudinal bulkhead is equal to the distance between the strength deck and the second deck
- Second deck plating and continuous longitudinals
- Continuous longitudinal hatch coaming and continuous longitudinal stiffeners

17.5.3 Calculation of Secondary Stress due to Dynamic Container Load on Transverse Bulkhead

The stress at the strength deck and at the top of the continuous longitudinal hatch coaming, induced by container load on transverse bulkhead and transmitted through cross deck, may be obtained from the following equation:

$$f_B = M_B / SM \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

M_B	=	$kC_2R\, b_0 10^5/12$ N-cm (kgf-cm, lbf-in)
k	=	1.0 (1.0, 0.269)
R	=	$0.5Q_1 + 0.25Q_2\, n/(n + 1)$ kN (tf, Ltf)
Q_1	=	total dynamic container load in longitudinal direction on cross deck box beam (above the bottom of cross deck box beam), in kN (tf, Ltf)
	=	$m_1m_2W(1 - h_5/h_4)$ $(\sin(0.5\phi) + 0.5a_1/g)$
Q_2	=	total dynamic container load in longitudinal direction on transverse bulkhead, (below the bottom of cross deck box beam), in kN (tf, Ltf)
	=	$m_1m_2W(h_5/h_4)$ $(\sin(0.5\phi) + 0.5a_2/g)$
C_2	=	$1.72 - 0.26n^{0.5} \geq 1.0$
b_0	=	width of the strength deck hatch opening amidships, in m (ft), as specified in 5C-5-4/7
n	=	number of vertical webs on transverse bulkhead under consideration
m_1	=	tier number of container stacks in the cargo hold amidships
m_2	=	row number of container stacks in the cargo hold amidships
h_4	=	m_1h_C
h_C	=	height of container, in m (ft)
h_5	=	vertical distance between inner bottom and the bottom of cross deck box beam at center line, amidships, in m (ft)
W	=	maximum design weight of an equivalent 40 ft container in hold, not to be taken less than 274 kN (28 tf, 27.6 Ltf)
g	=	acceleration due to gravity = 9.807 m/sec^2 (32.2 ft/sec^2)
a_1	=	longitudinal acceleration a_ℓ, as specified in 5C-5-3/5.5.1(c) at a vertical height $0.5(h_4 + h_5)$, measured from inner bottom amidships, in m/sec^2 (ft/sec^2)
a_2	=	longitudinal acceleration a_ℓ, as specified in 5C-5-3/5.5.1(c) at a vertical height $0.5h_5$, measured from inner bottom amidships, in m/sec^2 (ft/sec^2)
ϕ	=	angle of pitch in degrees, as specified in 5C-5-3/5.5.1(a)

SM is as defined in 5C-5-4/17.5.2 with the following modification.

The following items may be included in the calculation of the section modulus SM:

- Strength deck plating and continuous longitudinals
- Side shell and longitudinal bulkhead plating and continuous longitudinals. Effective depth of side shell and longitudinal bulkhead is equal to the distance between the strength deck and the second deck, but not to be more than $0.22D$
- Second deck plating and continuous longitudinals, if the distance between strength and second decks does not exceed $0.22D$ as shown in 5C-5-4/Figure 4
- Continuous longitudinal hatch side coaming (plate and continuous longitudinal stiffeners)

17.7 Cross Deck Structure *(1998)*

17.7.1 Cross Deck Width

In general, the width of the cross deck box beam is not to be less than $0.04b_0$ for watertight bulkhead and $0.03b_0$ for mid-hold strength bulkhead where b_0 is as defined in 5C-5-4/7.

17.7.2 Cross Deck Plating

The net thickness of the cross deck plating at the strength deck level and at the bottom of the cross deck box is not to be less than that obtained from the following equation:

$$t = kF_o/(wf_s) \quad \text{mm (in.)}$$

but not to be taken less than 9.0 mm (0.35 in.).

where

k = 100 (100, 186.8)

F_o = $F + R$

F = $C_1(T_M + T_s)\,\omega_M L_0^2 I_{CB}/(b^3 \alpha_M \Gamma_M)$ kN (tf, Ltf)

C_1 = $70/(9 + \mu)$

μ = $10^7 I^*_{CB}/(b_0^3 \ell_0)$

I^*_{CB} = $0.5(I_{CB1} + I_{CB2})$

I_{CB1} and I_{CB2} = net moment of inertia of the cross deck box beam at the vessel's centerline, in m^4 (ft^4), fore and aft of the hatch opening amidships with respect to the vertical axis z, (5C-5-4/Figure 4)

I_{CB} = net moment of inertia of the cross deck box beam under consideration at the vessel's centerline, in m^4 (ft^4), about the vertical axis z (5C-5-4/Figure 4)

b = $0.5(B + b_0)$

b_0 = width, in m (ft), of the strength deck hatch opening amidships, measured between the inboard edges of the strength deck, as shown in 5C-5-4/Figure 4

ℓ_0 = length of the hatch opening amidships, in m (ft)

B = vessel's breadth, in m (ft), amidships

w = width of the cross deck structure under consideration, in m (ft)

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\,S_m f_y$

T_s is as defined in 5C-5-3/3.1.

T_M, ω_M, L_0, α_M and Γ_M are as defined in 5C-5-4/7.

R is as defined in 5C-5-4/17.5.3.

S_m and f_y are as defined in 5C-5-4/11.3.1.

For cross deck structures abaft engine room, L_0 may be taken as L_0', defined in 5C-5-4/9.3.2.

The net thicknesses t_1 and t_2 (5C-5-4/Figure 11) of the side plate of the cross deck box beam are not to be less than the following:

$t_1 = L/50 + 6$ mm ($L/4170 + 0.24$ in.), but need not be greater than 10 mm (0.39 in.)

$t_2 = 14$ mm (0.55 in.)

where

L = length of vessel, in m (ft), as defined in 3-1-1/3.1

The following minimum extent a_1 and a_2 of insert plates, (5C-5-4/Figure 11) are provided as guidance:

a_1 = $1.5b_r$

a_2 = $0.5b_s$

b_r = horizontal distance from the longitudinal bulkhead to the bracket end, as shown in 5C-5-4/Figure 11

b_s = width of the strength deck of the hull girder section under consideration, as shown in 5C-5-4/Figure 11

The required net thickness t_2 may be reduced, provided the strength of the resultant design is verified by fine mesh finite element analyses, as specified in 5C-5-5/9.5 or 5C-5-5/9.7 with the combined load cases 5C-5-3/9; however, in no case is the thickness to be taken less than t_1, obtained from the above equation.

The side plating above the strength deck is also to meet the requirement in 5C-5-4/19.1.1.

17.7.3 Cross Deck Beams

The net section modulus of each deck beam at the weather deck, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equations:

$SM = M/f_b$ cm^3 (in^3)

$M = ps\ell^2 10^3/k$ N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 83.33)

s = spacing of deck beams

ℓ = span of beam between effective supports, in m (ft)

p = nominal deck pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as specified in 5C-5-3/Table 2.

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.4 S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.3.1.

In general, the side plate of the cross deck box beam is to be horizontally stiffened. The net section modulus of stiffeners is to be not less than as required for watertight bulkhead stiffeners in 5C-5-4/23.7 in the same location. Pressure is not to be taken less than 2.25 N/cm^2 (0.23 kgf/ cm^2, 3.27 lbf/in^2).

17.7.4 Section Modulus of Cross Deck Box Beam

The net section modulus at any section of the cross deck box beam with respect to the vertical axis z (5C-5-4/Figure 4) is not to be less than obtained from the following equation:

$$SM = M/f_b \qquad \text{cm}^3\ (\text{in}^3)$$

where

M = $M_1 + M_2$

M_1 = $kFz10^5$ N-cm (kgf-cm, lbf-in)

M_2 = $k0.17C_2Rb_1\ 10^5$ N-cm (kgf-cm, lbf-in)

k = 1.0 (1.0, 0.269)

C_2 and R are as defined in 5C-5-4/17.5.3.

F is as defined in 5C-5-4/17.7.2.

b_1 = width, in m (ft), of the hatch opening for the hull girder section under consideration

z = horizontal distance from centerline of the vessel to the section of cross deck box beam under consideration, in m (ft), as shown in 5C-5-4/Figure 4. z need not be taken more than 0.5 b_1

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2) = 0.85 $S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

The following items may be included in the calculation of the cross deck box beam section modulus SM:

- Transverse hatch coaming (above the strength deck)
- Cross deck plating with stiffeners at the strength deck level
- Bottom and top plating of the cross deck box beam with stiffeners
- Side plates of cross deck box beam with stiffeners, (between strength deck and bottom of the cross deck box beam)

17.9 Longitudinal Deck Girders Inboard of Lines of Openings *(1 July 2005)*

The net scantlings of the longitudinal deck girders inside the lines of outer-most hatch openings are to satisfy the following condition and, in general, are to be maintained throughout its length:

$$f_{L1}/\eta \le f_{a1} \quad \text{and} \quad f_{L2} \le f_{a2}$$

where

f_{L1} = $H_o f_{LD1}$

f_{L2} = $H_o f_{LD2}$

f_{LD1} = calculated longitudinal hull girder compressive stress at the top flange of the longitudinal deck girder, in N/cm^2 (kgf/cm^2, lbf/in^2)

= CM_{sv}/SM

f_{LD2} = calculated maximum longitudinal hull girder bending stress at the top flange of the longitudinal deck structures, in N/cm^2 (kgf/cm^2, lbf/in^2)

= CM_t/SM

H_o = effectiveness of longitudinal deck structures, as specified in 3-2-1/17.3

M_{sv} = the maximum total vertical sagging bending moment amidships, in kN-m (tf-m, Ltf-ft), but is to be taken not less than M_w (sagging), as specified in 5C-5-3/5.1.1. For this purpose, M_w is to be calculated with k_w defined in 5C-5-3/5.1.1.

M_t = total hull girder vertical bending moment, as specified in 5C-5-3/7.1.1, with k_u = 1.0, k_c = 1.0 and k_w defined in 5C-5-3/5.1.1, in kN-m (tf-m, Ltf-ft),

SM = the offered net design hull girder vertical section modulus amidships at the top flange of the longitudinal deck girder, cm^2-m (in^2-ft)

C = 1000 (1000, 2240)

η = f_E/f_y for $f_E/f_y \le 0.6$

= $(1 - 0.24 f_y/f_E)$ for $f_E/f_y > 0.6$

f_{a1} = $S_m f_y - f_b$ N/cm^2 (kgf/cm^2, lbf/in^2)

f_{a2} = $0.9 S_m f_y - f_b$ N/cm^2 (kgf/cm^2, lbf/in^2)

S_m = strength reduction factor for the longitudinal deck girders, as defined in 5C-5-4/11.3.1

f_E = $\pi^2 E/(\ell_0/r)^2$ N/cm^2 (kgf/cm^2, lbf/in^2)

E = modulus of elasticity of the material, may be taken as 2.06×10^7 N/cm^2 (2.1×10^6 kgf/cm^2, 30×10^6 lbf/in^2) for steel

ℓ_0 = length of the strength deck hatch opening, in cm (in.)

r = least radius of gyration of the longitudinal deck girder, in cm (in.)

f_b = bending stress, N/cm^2 (kgf/cm^2, lbf/in^2). Where the longitudinal deck girder is effectively supported by pillars, f_b may be taken as zero

= M/SM_v

M = bending moment of the longitudinal deck girder induced by container loads on deck, in kN-cm (tf-cm, Ltf-in)

= $c m_{d1} m_{d2} W_d \ell_0$

c = 45 (45, 101.9) for a centerline longitudinal deck girder

= 30 (30, 67.2) for two longitudinal deck girders

m_{d1} = tier number of 20 ft container stacks on deck

m_{d2} = row number of 20 ft container stacks on deck

W_d = maximum design weight of a 20 ft container on deck, not to be taken less than 137.3 kN (14 tf, 13.8 Ltf).

SM_v = section modulus of the longitudinal deck girder about its horizontal neutral axis, in cm^3 (in^3)

f_y = specified minimum yield point of the longitudinal deck girders, in N/cm^2 (kgf/cm^2, lbf/in^2)

17.11 Deck Transverse in Underdeck Passageway *(1998)*

Deck transverses of the strength deck in the underdeck passageway are to have scantlings not less than that obtained from the following equations:

17.11.1

The net section modulus of the deck transverse is not to be less than that obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

$M = ps\ell^2 10^5/k$ N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 44.64)

p = nominal pressure in kN/m^2 (tf/m^2, Ltf/ft^2), as specified in 5C-5-3/Table 2

s = spacing of the deck transverse, in m (ft)

ℓ = span of the deck transverse, in m (ft)

ℓ may be modified in accordance with 5C-5-4/Figure 9.

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.7\, S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

17.11.2

The net section modulus of the deck transverse is not to be less than the section modulus of the side transverse in 5C-5-4/15.5. The depth and the net web thickness of the deck transverse are also not to be less than required for side transverse in 5C-5-4/15.3 nor for transverse web on longitudinal bulkhead in 5C-5-4/21.11.

17.13 Underdeck Passageway (Second Deck) *(1 July 2005)*

The net thickness of the passage deck is to be not less than t_1, as specified below:

$t_1 = 9.0$ mm for $L \geq 200$ m

$t_1 = 0.02\,L + 5.0$ mm for $200 \text{ m} \geq L \geq 130$ m

$t_1 = 0.354$ in. for $L \geq 656$ ft.

$t_1 = 0.00024\,L + 0.20$ in. for $656 \text{ ft} > L \geq 427$ ft.

In addition, the net thickness of the longitudinally framed passage deck plate is to be not less than that obtained from the following equation:

$t_2 = cs(S_m f_y/E)^{1/2}$ mm (in.)

where

s = spacing of longitudinals, in mm (in.)

c = $0.7N^2 - 0.2$, not to be taken less than 0.2

N = $R_d[(Q/Q_d)(y/y_n)]^{1/2}$

R_d = $(SM_{RDS}/SM_D)^{1/2}$

SM_{RDS} = reference net hull girder section modulus for sagging bending moment based on the material factor of the strength deck flange of the hull girder, in cm²-m (in²-ft)

= $0.95SM_S$

SM_S = reference gross hull girder section modulus in accordance with 5C-5-4/3.1.1 for sagging total bending moment, with k_w defined in 5C-5-3/5.1.1 for the purpose of calculating M_w (sagging), based on the material factor of the strength deck flange of the hull girder, in cm²-m (in²-ft)

SM_D = net design hull girder section modulus amidships at the strength deck, in cm²-m (in²-ft)

Q, Q_d = material conversion factor in 5C-5-4/5 for the side stringer plating, the bottom flange and the strength deck flange of the hull girder, respectively

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the passage deck

y_n = vertical distance, in m (ft), measured from the deck to the neutral axis of the hull girder transverse section,

S_m and f_y are defined in 5C-5-4/11.3.1.

The net thickness, t_2, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

In addition, the passage deck forming a tank boundary is to comply with the requirement for a side stringer in 5C-5-4/15.11. Where the passage deck forms a cargo hold boundary, the scantlings of the deck are also to comply with the requirements for watertight longitudinal bulkhead in 5C-5-4/21.5 and 5C-5-4/21.7.

FIGURE 10
Definitions of h_1 and h_2

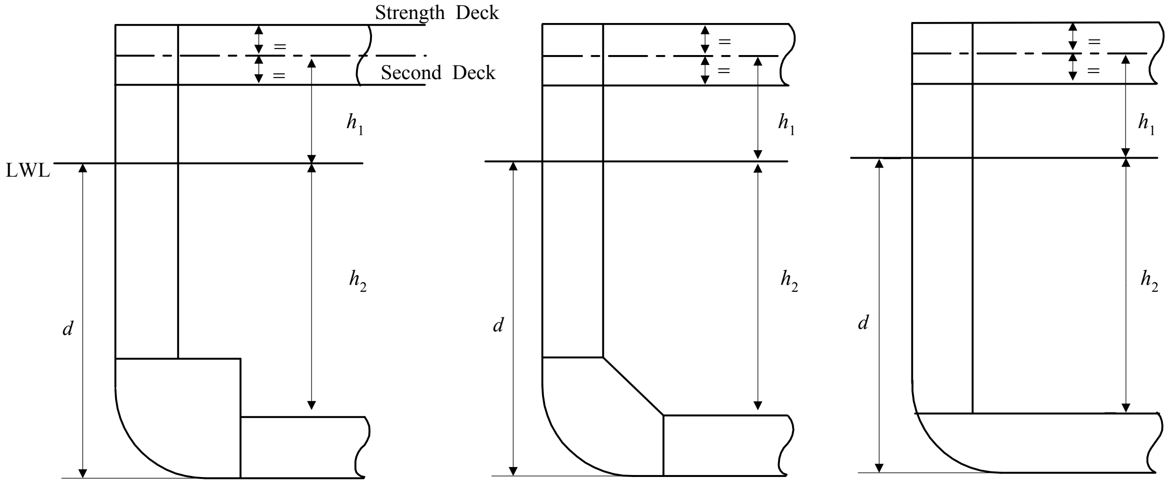
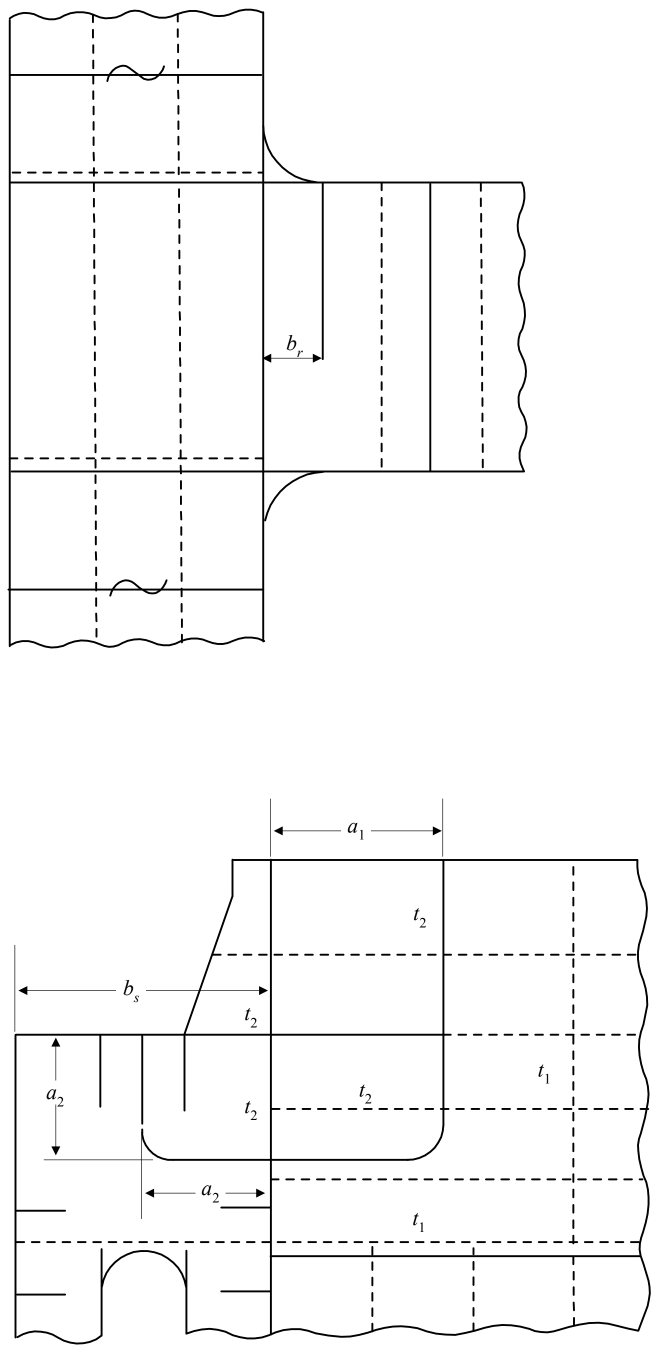


FIGURE 11
Sizes of Insert Plates



19 Hatch Coamings and Hatch Covers *(1998)*

19.1 Hatch Coamings

Hatch coamings are to satisfy the following requirements.

19.1.1 Thickness of Coamings

The net thickness of the coaming plates is to be not less than 10 mm (0.4 in.). Horizontal stiffeners are to be fitted on coamings. Effective brackets or stays are to be fitted at intervals of not more than 3.0 m (10 ft). Where coamings exceed 915 mm (36 in.) in height, the arrangement of stiffeners and brackets, or stays is to provide equivalent strength and stiffness. Consideration is to be given to provide additional strength for deep coamings fitted forward of 0.20L from the FP, which may be subject to impact loading from green water.

Where chocks are provided on the coaming to limit the horizontal movement of hatch cover, the strength of the coaming and deck structure is to be adequate to withstand the load on these chocks. Similar consideration is to be given to pads supporting the load from hatch covers.

19.1.2 Continuous Longitudinal Hatch Coamings

Continuous longitudinal hatch coamings on the strength dec,k which extend more than $^1/_7L$ and are effectively supported by underdeck structures, are to be longitudinally stiffened. The coaming thickness is to be not less than the value of t_3, given in 5C-5-4/17.1, adjusted for the spacing of the coaming stiffeners and the material conversion factor. The stiffeners are to comply with the requirements of 5C-5-4/17.3 where ℓ is the distance between brackets. The hull girder section modulus to the top of the coaming is to be as required by 5C-5-4/3.1.1 and 5C-5-4/3.1.3.

19.3 Hatch Covers *(2002)*

The strength and arrangements of hatch covers are generally to be determined in accordance with the applicable parts of 3-2-15/7 and 3-2-15/9.

For container loading, the description of the container stowage arrangement including the exact locations of the container pads, maximum design weight of a container and numbers of tiers and rows is to be submitted. Where the pads are not in line with supporting structures, headers are to be provided to transmit the container loads to these members. Each member intended to support containers is to meet the requirements in 3-2-15/9.9.

For dynamic container loading, the container load is to be obtained from the equations in 5C-5-3/5.5.2(b) with the maximum design container weight for load case 3, 5 and 7 specified in 5C-5-3/Table 1C .

21 Longitudinal Bulkheads *(1998)*

21.1 Tank Bulkhead Plating *(1 July 2005)*

The net thickness of the longitudinal bulkhead plating forming tank boundaries, in addition to compliance with 5C-5-4/5.5, is to be not less than t_1 and t_2, specified below:

$$t_1 = 0.73s(k_1\,p/f_1)^{1/2} \qquad \text{mm (in.)}$$

$$t_2 = 0.73s(k_2\,p/f_2)^{1/2} \qquad \text{mm (in.)}$$

but not less than 9.5 mm (0.37 in.) or L/60 + 6.0 mm (L/5000 + 0.24 in.), whichever is less.

where

s = spacing of longitudinal bulkhead longitudinals, in mm (in.)

k_1 = 0.342

k_2 = 0.500

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as specified in 5C-5-3/Table 2.

f_1 = permissible bending stress, in longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $1.1[1.0 - 0.33(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]S_m f_y \le 0.75 S_m f_y$ below neutral axis

= $1.1[1.0 - 0.33(z/B) - 0.52\alpha_2(SM_{RD}/SM_D)(y/y_n)]S_m f_y \le 0.75 S_m f_y$ above neutral axis

SM_B/SM_{RB} is not to be taken more than $1.2\alpha_1$ or 1.4, whichever is less.

f_2 = permissible bending stress, in the vertical direction in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.90 S_m f_y$

α_1 = $\mathrm{S}_{m1} f_{y1}/S_m f_y$

α_2 = $S_{m2} f_{y2}/S_m f_y$

S_m = strength reduction factor of the longitudinal bulkhead plating, as defined in 5C-5-4/11.3.1

f_y = minimum specified yield point of the longitudinal bulkhead plating, in N/cm^2 (kgf/cm^2, lbf/in^2)

z = transverse distance, in m (ft), measured from the centerline of the section to the longitudinal bulkhead strake under consideration

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the lower edge of the longitudinal bulkhead strake under consideration

y_n = vertical distance, in m (ft), measured from the strength deck (bottom) to the neutral axis of the section

L = vessel's length, in m (ft), as defined in 3-1-1/3.1

B = vessel's breadth, in m (ft), as defined in 3-1-1/5

SM_{RB}, SM_B, and E are as defined in 5C-5-4/11.3.1.

S_{m1} and f_{y1} are as defined in 5C-5-4/11.5.

SM_{RD}, S_{m2} and f_{y2} are as defined in 5C-5-4/13.3.

SM_D is as defined in 5C-5-4/13.1.

In general, the longitudinal bulkhead is to be longitudinally framed, except for the areas of 0.35D above and below mid-depth of the longitudinal bulkhead. These areas of longitudinal bulkhead plating may be transversely framed, provided the net thickness of the longitudinal bulkhead plating is not less than t, as specified below:

$t = 0.73sk(k_2 p/f)^{1/2}$ mm (in.)

where

s = spacing of vertical stiffener on the longitudinal bulkhead, in mm (in.)

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

f = permissible bending stress, in longitudinal direction, in N/cm² (kgf/cm², lbf/in²)

= $1.2[1.0 - 0.33(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]S_m f_y \le 0.85S_m f_y$
below neutral axis

= $1.2[1.0 - 0.33(z/B) - 0.52\alpha_2(SM_{RD}/SM_D)(y/y_n)]S_m f_y \le 0.85S_m f_y$
above neutral axis

All other parameters are as defined above.

Flats forming recesses or steps in the longitudinal bulkhead are also to be of not less net thickness than required for the side stringer in 5C-5-4/15.11.1.

In addition to the above tank requirements, the longitudinal bulkhead forming the cargo hold boundary is to comply with the requirements in 5C-5-4/21.5 for watertight bulkheads.

In addition to the above requirements, the net thickness of the longitudinally framed strakes is also to be not less than that obtained from the following equation:

$t_3 = cs(S_m f_y/E)^{1/2}$ mm (in.)

where

s = spacing of longitudinal bulkhead longitudinals, in mm (in.)

c = $0.7N^2 - 0.2$, not to be less than 0.2

c for the top strake is not to be taken less than $0.4Q^{1/2}$.

N = $R_d(Q/Q_d)^{1/2}$ for the top strake

= $R_d[(Q/Q_d)(y/y_n)]^{1/2}$ for other locations above neutral axis

= $R_b[(Q/Q_b)(y/y_n)]^{1/2}$ for locations below neutral axis

R_d = $(SM_{RDS}/SM_D)^{1/2}$

R_b = $(SM_{RBH}/SM_B)^{1/2}$

SM_{RDS} = reference net hull girder section modulus for sagging bending moment based on the material factor of the strength deck flange of the hull girder, in cm²-m (in²-ft)

= $0.95SM_s$

SM_s = reference gross hull girder section modulus in accordance with 5C-5-4/3.1.1, for sagging total bending moment, with k_w defined in 5C-5-3/5.1.1 for the purpose of calculating M_w (sagging), based on material factor of the strength deck flange of the hull girder, in cm²-m (in²-ft)

SM_{RBH} = reference net hull girder section modulus for hogging bending moment based on the material factor of the bottom flange of the hull girder, in cm²-m (in²-ft)

= $0.9SM_H$

SM_H	=	reference gross hull girder section modulus in accordance with 5C-5-4/3.1.1 for hogging total bending moment, with k_w defined in 5C-5-3/5.1.1 for the purpose of calculating M_w (hogging), based on the material factor of the bottom flange of the hull girder, in cm^2-m (in^2-ft)
Q, Q_b, Q_d	=	material conversion factor in 5C-5-4/5 for the bulkhead plating, the bottom flange and the strength deck flange of the hull girder, respectively
y	=	vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the lower edge (upper edge) of the bulkhead strake, when the strake under consideration is below (above) the neutral axis.
y_n	=	vertical distance, in m (ft), measured from the bottom (deck) to the neutral axis of the hull girder transverse section, when the strake under consideration is below (above) the neutral axis

S_m and f_y are defined in 5C-5-4/21.1 and E is defined in 5C-5-4/11.3.1.

The net thickness, t_3, may be determined based on S_m and f_y of the hull girder strength material required at the location under consideration.

The minimum width of the top strake for the midship 0.4L is to be obtained from the following equations:

$b =$	$5L + 800$	mm	for $L \leq 200$ m
$=$	$0.06L + 31.5$	in.	for $L \leq 656$ ft
$b =$	1800	mm	for $200 < L \leq 500$ m
$=$	70.87	in.	for $656 < L \leq 1640$ ft

L = length of vessel as defined in 3-1-1/3.1, in m (ft)

b = width of top strake, in mm (in.)

21.3 Tank Bulkhead Longitudinals/Stiffeners *(1 July 2005)*

The net section modulus of each longitudinal or each vertical stiffener on the longitudinal bulkhead and double bottom water-tight girder forming tank boundaries, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equations:

$$SM = M/f_b \qquad \text{cm}^3 \ (\text{in}^3)$$

$$M = c_1 c_2\, ps\ell^2 10^3/k \qquad \text{N-cm (kgf-cm, lbf-in)}$$

where

k	=	12 (12, 83.33)	
c_1	=	1.0	for longitudinals
	=	$1 + \gamma\ell/10p$	for vertical stiffeners
γ	=	specific weight of the liquid $\geq$ 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.444 lbf/in^2-ft)	
c_2	=	1.0	without struts
	=	0.65	with effective struts
s	=	spacing of longitudinals or vertical stiffeners, in mm (in.)	

ℓ = span of longitudinals or vertical stiffeners between effective supports, as shown in 5C-5-4/Figure 6, in m (ft)

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the longitudinal considered, as specified in 5C-5-3/Table 2. For vertical stiffeners, pressure is to be taken at the midspan of each stiffener.

f_b = permissible bending stresses, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $1.15[1.0 - 0.33(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]S_m f_y \leq 0.80 S_m f_y$

for longitudinals on the longitudinal bulkhead below neutral axis

= $1.3[1.0 - 0.33(z/B) - 0.52\alpha_2(SM_{RD}/SM_D)(y/y_n)]S_m f_y \leq 0.80 S_m f_y$

for longitudinals on the longitudinal bulkhead above neutral axis

= $1.4[1.0 - 0.33(z/B) - 0.52(\alpha_1 SM_{RB}/SM_B)(y/y_n)]S_m f_y \leq 0.80 S_m f_y$

for longitudinals on the double bottom tight girders

= $0.90\, S_m f_y$ for vertical stiffeners

y = vertical distance, in m (ft), measured from the neutral axis of the hull girder transverse section to the longitudinal under consideration at its connection to the associated plate

SM_{RB} and SM_B are as defined in 5C-5-4/11.3.1.

S_{m1} and f_{y1} are as defined in 5C-5-4/11.5.

SM_{RD}, S_{m2} and f_{y2} are as defined in 5C-5-4/13.3.

SM_D is as defined in 5C-5-4/13.1.

S_m, f_y, α_1, α_2, z, and y_n are defined in 5C-5-4/21.1.

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

Where side struts are fitted as an effective supporting system for side tank structures, the requirement for the vertical stiffeners on the longitudinal bulkhead is also to be not less than 90% of the side frame requirement in 5C-5-4/13.3.

Longitudinals or horizontal stiffeners on the flats forming recesses or steps in the longitudinal bulkhead are to comply with the requirements for stiffeners on the side stringer in 5C-5-4/15.11.2.

In addition to the above tank requirements, the longitudinal bulkhead forming a cargo hold boundary is to comply with the requirements in the following subsection for the watertight bulkhead.

21.5 Watertight Bulkhead Plating *(1 July 2005)*

The net thickness of the longitudinal bulkhead plating forming cargo hold boundaries, in addition to compliance with 5C-5-4/5.5, is to be not less than t_1 and t_2, specified below:

$$t_1 = 0.73s(k_1 p/f_1)^{1/2} \quad \text{mm (in.)}$$

$$t_2 = 0.73s(k_2 p/f_2)^{1/2} \quad \text{mm (in.)}$$

but not less than 9.0 mm (0.354 in.) or $L/60 + 4.0$ mm ($L/5000 + 0.157$ in.), whichever is less.

where

s = spacing of longitudinals or vertical stiffeners, in mm (in.)

k_1 = 0.342 for longitudinally stiffened plating

= $0.500k^2$ for vertically stiffened plating

k_2 = 0.500

p = nominal pressure, in N/cm² (kgf/cm², lbf/in²), at the lower edge of each plate, as specified in 5C-5-3/Table 2. Pressure is not to be taken less than 2.25 N/cm² (0.23 kgf/cm², 3.27 lbf/in²).

f_1 = permissible bending stress, in longitudinal direction, in N/cm² (kgf/cm², lbf/in²)

= $[1.0 - 0.33(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]S_m f_y \leq 0.75 S_m f_y$ below neutral axis

= $[1.0 - 0.33(z/B) - 0.52\alpha_2(SM_{RD}/SM_D)(y/y_n)]S_m f_y \leq 0.75 S_m f_y$ above neutral axis

SM_B/SM_{RB} is not to be taken more than $1.2\alpha_1$ or 1.4, whichever is less.

f_2 = permissible bending stress, in the vertical direction in N/cm² (kgf/cm², lbf/in²)

= $0.85\, S_m f_y$

All other parameters are defined in 5C-5-4/21.1.

In addition to the above requirement, the required net thickness t_3 of the longitudinally framed strakes and the minimum width of the top strake for the midship 0.4L are to be obtained from 5C-5-4/21.1.

21.7 Watertight Bulkhead Longitudinals/Stiffeners *(1 July 2005)*

The net section modulus of each longitudinal or vertical stiffener on the longitudinal bulkhead forming cargo hold boundaries, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equations:

$SM = M/f_b$ cm³ (in³)

$M = c_1 c_2\, p s \ell^2 10^3/k$ N-cm (kgf-cm, lbf-in)

where

p = nominal pressure, in N/cm² (kgf/cm², lbf/in²), at the longitudinal considered, as specified in 5C-5-3/Table 2. For vertical stiffeners, pressure is to be taken at the midspan of each stiffener. Pressure is not to be taken less than 2.25 N/cm² (0.23 kgf/cm², 3.27 lbf/in²).

f_b = permissible bending stresses, in N/cm² (kgf/cm², lbf/in²)

= $1.2[1.0 - 0.33(z/B) - 0.52\alpha_1(SM_{RB}/SM_B)(y/y_n)]S_m f_y \leq 0.85 S_m f_y$

for longitudinals below neutral axis

= $1.35[1.0 - 0.33(z/B) - 0.52\alpha_2(SM_{RD}/SM_D)(y/y_n)]S_m f_y \leq 0.85 S_m f_y$

for longitudinals above neutral axis

= $0.95 S_m f_y$ for vertical stiffeners

All other parameters are as defined in 5C-5-4/21.3 above.

21.9 Longitudinals in Upper Wing Torsional Box

The net section modulus of longitudinals on the longitudinal bulkhead forming the upper wing torsional box is to be not less than as required for watertight bulkhead longitudinals in 5C-5-4/21.7 above in the same location. Pressure is not to be taken less than 2.25 N/cm^2 (0.23 kgf/cm^2, 3.27 lbf/in^2). In addition, the net moment of inertia of longitudinals on the longitudinal bulkhead, within the region of 0.1D from the strength deck, in association with the effective plating (b_{WL} t_n), is to be not less than i_o, as specified in 5C-5-4/13.3.

21.11 Transverse Web on Longitudinal Bulkhead in Underdeck Passageway *(1 July 2005)*

Transverse webs on the longitudinal bulkhead in the underdeck passageway are to have scantlings not less than that obtained from the following equations.

21.11.1 Section Modulus of Web

The net section modulus of the side transverse web on the longitudinal bulkhead is not to be less than that obtained from the following equation:

$SM_1 = M/f_{b1}$ cm^3 (in^3)

$SM_2 = M_2/f_{b2}$ cm^3 (in^3)

$M_1 = p_u s\ell^2 10^5/k_1$ N-cm (kgf-cm, lbf-in)

$M_2 = k8\lambda\gamma_1\, phs_1\, y$ N-cm (kgf-cm, lbf-in)

where

k_1 = 12 (12, 44.64)

p_u = nominal pressure for flooding condition calculated at the mid-span of the transverse web under consideration, in kN/m^2 (tf/m^2, Ltf/ft^2), as specified in 5C-5-3/Table 2. Pressure is not to be taken less than 22.5 kN/m^2 (2.3 tf/m^2, 0.21 Ltf/ft^2)

s = spacing of the transverse webs, in m (ft)

ℓ = span of the transverse web, in m (ft)

ℓ may be modified in accordance with 5C-5-4/Figure 9

y = $k_2 h_u/2$

k_2 = 100 (100, 12)

h_u = height of the underdeck passageway, in m (ft)

f_{b1} = permissible bending stress, in N/cm^2 (kgf/cm^2 lbf/in^2)

= 0.85 $S_m f_y$

f_{b2} = permissible bending stress, in N/cm^2 (kgf/cm^2 lbf/in^2)

= 0.85 $S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

k, λ, γ_1, p, h and s_1 are as defined in 5C-5-4/15.1.

21.11.2 Depth of Web

The depth of the transverse web is not to be less than that obtained from the following equation:

$d = k\ell$ mm (in.)

where

k = 125 (1.5)

ℓ is as defined in 5C-5-4/21.11.1 above.

21.11.3 Web Thickness

The net web thickness of the transverse web is not to be less than that obtained from the following equations:

$t_1 = k_3F_1/(d_w f_s)$ mm (in.)

$t_2 = k_3F_2/(d_w f_s)$ mm (in.)

but not less than 8.0 mm (0.31 in.)

$F_1 = k500p_u s\ell$ N (kgf, lbf)

where

k_3 = 10 (10, 1.0)

k = 1.0 (1.0, 2.24)

f_s = permissible shear stress, in N-cm^2 (kgf-cm^2, lbf-in^2)

= $0.50\ S_m f_y$

d_w = depth of the side transverse, in cm (in.)

p_u, s and ℓ are as defined in 5C-5-4/21.11.1 above. F_2 is as defined in 5C-5-4/15.5.3.

23 Transverse Bulkheads – Plating and Stiffeners *(1998)*

23.1 Tank Bulkhead Plating *(2007)*

The net thickness of transverse bulkhead plating forming tank boundaries is to be not less than t, as specified below:

$t = 0.73sk(k_1\, p/f)^{1/2}$ mm (in.)

but not less than 9.0 mm (0.35 in.) or $L/60 + 5.0$ mm ($L/5000 + 0.20$ in.), whichever is less.

where

s = spacing of bulkhead stiffeners, in mm (in.)

k_1 = 0.500

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha \le 2)$

= 1.0, $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

p = nominal pressure, N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as specified in 5C-5-3/Table 2 for transverse bulkhead members

f = permissible bending stress

= $0.95\, S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

L = vessel's length, in m (ft), as defined in 3-1-1/3.1

S_m and f_y are as defined in 5C-5-4/11.3.1.

In addition to the above tank requirements, the transverse bulkhead forming a cargo hold boundary is to comply with the requirements in 5C-5-4/23.5 for the watertight bulkhead.

23.3 Tank Bulkhead Stiffeners

The net section modulus of each individual vertical/horizontal stiffener on the transverse bulkheads forming tank boundaries and tank end floors, in association with the effective plating, is to be not less than that obtained from the following equation:

$$SM = M/f_b \qquad \text{cm}^3\ (\text{in}^3)$$

$$M = c_1\, p s \ell^2 10^3/k \qquad \text{N-cm (kgf-cm, lbf-in)}$$

where

k = 12 (12, 83.33)

c_1 = 1.0 for horizontal stiffeners

= $1 + \gamma\ell/10p$ for vertical stiffeners

γ = specific weight of the liquid, 1.005 N/cm^2-m (0.1025 kgf/cm^2-m, 0.444 lbf/in^2-ft)

s = spacing of vertical/horizontal stiffeners, in mm (in.)

ℓ = span of stiffeners between effective supports, in m (ft)

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the stiffener considered, as specified in 5C-5-3/Table 2. For vertical stiffeners, pressure is to be taken at the midspan of each stiffener.

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.70\, S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

23.5 Watertight Bulkhead Plating *(1 July 2005)*

The net thickness of transverse bulkhead plating forming cargo hold boundaries is to be not less than t, as specified below:

$$t = 0.73 s k (k_1\, p/f)^{1/2} \qquad \text{mm (in.)}$$

but not less than 9.0 mm (0.354 in.) or $L/60$ + 4.0 mm ($L/5000$ + 0.157 in.), whichever is less.

where

s = spacing of bulkhead stiffeners, in mm (in.)

k_1 = 0.50

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the lower edge of each plate, as specified in 5C-5-3/Table 2. Pressure is not to be taken less than 2.25 N/cm^2 (0.23 kgf/cm^2, 3.27 lbf/in^2).

f = permissible bending stress

= $0.85\ S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

All other parameters are as defined in 5C-5-4/23.1 above.

23.7 Watertight Bulkhead Stiffeners *(1 July 2005)*

The net section modulus of each individual vertical/horizontal stiffener on the transverse bulkheads in cargo hold, in association with the effective plating to which they are attached, is to be not less than that obtained from the following equation:

$SM = M/f_b$ cm^3 (in^3)

$M = c_1\ ps\ell^2 10^3/k$ N-cm (kgf-cm, lbf-in)

where

p = nominal pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), at the longitudinal considered. as specified in 5C-5-3/Table 2. For vertical stiffeners, pressure is to be taken at the mid-span of each stiffener. Pressure is not to be taken less than 2.25 N/cm^2 (0.23 kgf/cm^2, 3.27 lbf/in^2).

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $S_m f_y$

All other parameters are as defined in 5C-5-4/23.3 above.

23.9 Underdeck Passageway *(1998)*

In a case where watertight transverse bulkheads are provided within the underdeck passageway, their scantlings are to be not less than required for watertight transverse bulkheads in cargo hold in 5C-5-4/23.5 and 5C-5-4/23.7.

25 Watertight Bulkhead Main Supporting Members *(1998)*

25.1 Transverse Watertight Bulkhead *(1 July 2005)*

For the service conditions with dynamic container load and relative displacements due to torsion, the minimum scantlings for the horizontal girders and vertical webs on the watertight bulkheads are to be determined in accordance with the subsequent paragraphs of this Section. Alternatively, these scantlings may be determined from the total strength assessment in Section 5C-5-5. However, in no case are the scantlings to be taken less than 85% of those determined from the corresponding equations below for the service conditions.

For the flooding conditions, the minimum scantlings for the horizontal and vertical webs on the watertight bulkhead are to be determined in accordance with the subsequent paragraphs of this Section. Alternatively, the horizontal and vertical webs may also be evaluated using a finite element model in conjunction with the design flooding pressures specified in 5C-5-3/Table 2 and the corresponding permissible bending and shear stresses in this Section. The mesh size of the finite element model should be sufficiently refined so that the openings in the horizontal girders and vertical webs can be properly modeled. For container carriers over 250 m in length, the watertight bulkhead main supporting members are to be evaluated by a finite element model.

25.1.1 Section Modulus of Horizontal Girder

The net section modulus of horizontal girders on watertight bulkheads is not to be less than SM_1 and SM_2, as defined below, whichever is greater (see also 5C-5-4/1.3):

$SM_1 = (M_1 + M_2)/f_{b1}$ cm^3 (in^3)

$SM_2 = M_3/f_{b2}$ cm^3 (in^3)

$M_1 = k_1 10{,}000 c_2 P_\ell \ell_b$ N-cm (kgf-cm, lbf-in)

$M_2 = k_2 6{,}000 EI\delta c_3/\ell_b^2$ N-cm (kgf-cm, lbf-in)

$M_3 = k_1 10{,}000 c_2\, ps\, \ell_b^2$ N-cm (kgf-cm, lbf-in)

where

k_1 = 1.0 (1.0, 0.269)

k_2 = 1.0 (1.0, 2.24)

P_ℓ = dynamic container load in longitudinal direction on horizontal girder, in kN (tf, Ltf)

= $Q/(n + 1)$

n = number of the horizontal girders

Q = $m_1 m_2 W(\ell_v/h_4)$ (sin (0.5ϕ) + 0.5a_ℓ/g)

ϕ = angle of pitch, in degrees, as specified in 5C-5-3/5.5.1(a)

a_ℓ = longitudinal acceleration, as specified in 5C-5-3/5.5.1(c) at the mid-span of the vertical web of span ℓ_v, in m/sec^2 (ft/sec^2)

ℓ_v = span of vertical web, in m (ft), as defined in 5C-5-4/Figure 12 and 5C-5-4/Figure 13, as applicable

ℓ_b = span of the horizontal girders measured between the longitudinal bulkheads, in m (ft), as defined in 5C-5-4/Figure 12 and 5C-5-4/Figure 13, as applicable

p = pressure for flooding condition calculated at the mid-span of the horizontal girder under consideration, in kN/m^2 (tf/m^2, Ltf/ft^2), as specified in 5C-5-3/Table 2

s = spacing of the horizontal girders under consideration, in m (ft)

δ = relative displacement in longitudinal direction due to torsion at both ends of horizontal girder under consideration, in cm (in.)

= $60C_n(T_M + T_S)L_0^2\omega_M(y_h - d_b)/[E\alpha_M\Gamma_M(D - d_b)]$

T_M = nominal wave-induced torsional moment amidships, in kN (tf-m, Ltf-ft), as defined in 5C-5-3/5.1.5

T_S = still-water torsional moment amidships, in kN (tf-m, Ltf-ft), as specified in 5C-5-3/3.1

y_h = vertical distance from baseline to the horizontal girder under consideration, in m (ft)

d_b = depth of the double bottom, in m (ft)

D = vessel's depth, in m (ft), as defined in 3-1-1/7

c_2 = $0.316\alpha^2$ for $\alpha < 0.5$

= $0.204\alpha^2 + 0.028$ for $0.5 \le \alpha \le 1.0$

= $0.077\alpha + 0.16$ for $\alpha > 1.0$

c_2 is not to be taken less than 0.05

α = $0.9(\ell_v/\ell_b)\ [(I/I_v)(s_v/s)]^{1/4}$

if more than one vertical web is fitted on the bulkhead, average values of ℓ_v, s_v and I_v are to be used when these values are not the same for each web.

s_v = spacing of vertical webs, in m (ft)

I = moment of inertia of the horizontal girder at the mid-span, in m^4 (ft^4)

I_v = moment of inertia of the vertical web at the mid-span, in m^4 (ft^4)

c_3 = $2z/\ell_b$, ≥ 0.4

z = horizontal distance from the mid-span of the horizontal girder to the location under consideration, in m (ft), as defined in 5C-5-4/Figure 12 or 5C-5-4/Figure 13

E = modulus of elasticity of the material, may be taken as 2.06×10^8 kN/m^2 (2.1×10^7 tf/m^2, 1.92×10^6 Ltf/ ft^2) for steel

f_{b1} = permissible bending stress for service conditions, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.70\ S_m f_y$

f_{b2} = permissible bending stress for flooding condition, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.95\ S_m f_y$

C_n, α_M, Γ_M and ω_M are as defined in 5C-5-4/7.

L_0 is as defined in 5C-5-4/9.3.

m_1, m_2, W, h_4 and g are as defined in 5C-5-4/17.5.3.

S_m and f_y are as defined in 5C-5-4/11.3.1.

25.1.2 Web Sectional Area of Horizontal Girder

The net sectional area of the web portion of horizontal girders on watertight bulkheads is not to be less than A_1 and A_2, as defined below, whichever is greater (see also 5C-5-4/1.3);

$A_1 = (F_1 + F_2)/f_{s1}$ cm^2 (in^2)

$A_2 = F_3/f_{s2}$ cm^2 (in^2)

$F_1 = k_2 500 c_F P_\ell$ N (kgf, lbf)

$F_2 = k120EI\delta/\ell_b^3$ N (kgf, lbf)

$F_3 = k_2 500 c_F ps\ell_b$ N (kgf, lbf)

where

k = 1.0 (1.0, 18.67)

c_F = $0.51\alpha - 0.01$ for $\alpha < 0.7$

= $0.42\alpha^{1/2}$ for $0.7 \leq \alpha$

c_F is not to be taken less than 0.25.

f_{s1} = permissible shear stress for service conditions, in N/cm² (kgf/cm², lbf/in²)

= $0.45\ S_m f_y$

f_{s2} = permissible shear stress for flooding condition, in N/cm² (kgf/cm², lbf/in²)

= $0.54\ S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

k_2, α, P_ℓ, p, s, ℓ_b, E, I and δ are as defined in 5C-5-4/25.1.1 above.

25.1.3 Section Modulus of Vertical Web

The net section modulus of vertical webs on watertight bulkheads is not to be less than that obtained from the following equation (see also 5C-5-4/1.3):

$SM = M/f_b$ cm³ (in³)

$M = k_1 10{,}000 c_M p s_v \ell_v^2$ N-cm (kgf-cm, lbf-in)

where

k_1 = 1.0 (1.0, 0.269)

ℓ_v = span of vertical web, in m (ft), as defined in 5C-5-4/Figure 12 and 5C-5-4/Figure 13, as applicable

s_v = spacing of vertical webs, in m (ft)

p = pressure for flooding condition calculated at the mid-span of the vertical web under consideration, in kN/m² (tf/m², Ltf/ft²), as specified in 5C-5-3/Table 2

c_M = 0.637 for bulkhead without horizontal girder

= $0.637 - 0.4\alpha \geq 0.35$ for bulkhead with horizontal girder

α = as defined in 5C-5-4/25.1.1, except that the value of s, ℓ_b and I are to be averaged in case more than one horizontal girder is fitted on bulkhead

f_b = permissible bending stress for flooding condition, in N/cm² (kgf/cm², lbf/in²)

= $0.95\ S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

25.1.4 Web Sectional Area of Vertical Web

The net sectional area of the web portion of vertical webs on watertight bulkheads is not to be less than obtained from the following equation (see also 5C-5-4/1.3):

$A = F/f_s$ cm^2 (in^2)

$F = k_2 600 c_1 c_2\, p s_v \ell_v$ N (kgf, lbf)

where

c_1 = 0.678 for bulkhead without horizontal girder

= $0.678 - 0.36\alpha$, ≥ 0.45 for bulkhead with horizontal girder

c_2 = $1 - 0.4y/\ell_v$

y = vertical distance from the lower end of the vertical web to the location under consideration, in m (ft), as defined in 5C-5-4/Figure 12 or 5C-5-4/Figure 13

f_s = permissible shear stress for flooding condition, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.54\, S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

ℓ_v, s_v, p and α are as defined in 5C-5-4/25.1.3 above.

k_2 is as defined in 5C-5-4/25.1.1 above.

25.3 Mid-hold Strength Bulkhead

Where fitted in accordance with 3-2-9/1.7, mid-hold strength bulkheads are to meet the following requirements. The requirements of the net section modulus and net sectional area for horizontal girders and vertical webs may be reduced, provided the strength of the resultant design is verified with the subsequent total strength assessment in Section 5C-5-5. However, in no case are they to be taken less than 85% of those determined from the following equations.

25.3.1 Section Modulus of Horizontal Girder

The net section modulus of horizontal girders on mid-hold strength bulkheads is not to be less than obtained from the following equation (see also 5C-5-4/1.3):

$SM = (M_1 + M_2)/f_b$ cm^3 (in^3)

$M_1 = k_1 10{,}000 c_2 P_\ell \ell_b$ N-cm (kgf-cm, lbf-in)

$M_2 = k_2 6{,}000 EI\delta c_3/\ell_b^2$ N-cm (kgf-cm, lbf-in)

where

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.75 S_m f_y - 1{,}000 P_t/A$

P_t = dynamic container load in transverse direction on horizontal girder, in kN (tf, Ltf)

= $c_4 Q_t/(n + 1)$

c_4 = $0.5 + z/\ell_b$

n = number of the horizontal girders

Q_t = $m_1(m_2 - 1)W(\ell_v/h_4)(\sin(0.5\theta) + 0.5a_t/g)$

θ = angle of roll at *LWL* draft, in degrees, as specified in 5C-5-3/5.5.1(b)

a_t = transverse acceleration amidships, as specified in 5C-5-3/5.5.1(c) at the mid-span of vertical web of span ℓ_v for wave heading of 60°, in m/sec^2 (ft/sec^2)

A = net cross sectional area of the horizontal girder, in cm^2 (in^2)

S_m and f_y are as defined in 5C-5-4/11.3.1.

m_1, m_2, W, h_4 and g are as defined in 5C-5-4/17.5.3.

k_1, k_2, P_ℓ, ℓ_b, ℓ_v, E, I, δ, c_2, c_3 and z are as defined in 5C-5-4/25.1.1 above.

25.3.2 Web Sectional Area of Horizontal Girder

The net sectional area of the web portion of horizontal girders on mid-hold strength bulkheads is not to be less than that obtained from the following equation (see also 5C-5-4/1.3):

$A_1 = (F_1 + F_2)/f_s$ cm^2 (in^2)

$F_1 = k_2 500 c_F P_\ell$ N (kgf, lbf)

$F_2 = k120EI\delta/\ell_b^3$ N (kgf, lbf)

where

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\ S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

k_2, P_ℓ, ℓ_b, E, I and δ are as defined in 5C-5-4/25.1.1 above.

k and c_F are as defined in 5C-5-4/25.1.2 above.

25.3.3 Section Modulus of Vertical Web

The net section modulus of the vertical web on mid-hold strength bulkheads is not to be less than that obtained in 5C-5-4/25.3.3(a) and 5C-5-4/25.3.3(b) below.

25.3.3(a) Section Modulus Parallel to Transverse Section. The net section modulus of the vertical web on mid-hold strength bulkheads, about the neutral axis parallel to the transverse section of the vessel, is not to be less than that obtained from the following equation (see also 5C-5-4/1.3):

$SM = M/f_b$ cm^3 (in^3)

$M = k_1 10{,}000 c_M P_\ell \ell_v$ N-cm (kgf-cm, lbf-in)

where

P_ℓ = dynamic container load in longitudinal direction on vertical web, in kN (tf, Ltf)

= $Q_\ell/(n + 1)$

n = number of the vertical webs

Q_ℓ	=	$m_1 m_2 W(\ell_v/h_4)[\sin(0.71\phi) + 0.5a_\ell/g]$
ϕ	=	angle of pitch, in degrees, as specified in 5C-5-3/5.5.1(a).
a_ℓ	=	longitudinal acceleration, as specified in 5C-5-3/5.5.1(c), at the mid-span of the vertical web, in m/sec^2 (ft/sec^2)
f_b	=	permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)
	=	$0.75 S_m f_y - 1{,}000 P_v/A$
P_v	=	static and dynamic container load in vertical direction on vertical web, in kN (tf, Ltf)
	=	$Q_v/(n+1)$
Q_v	=	$m_{d1} m_{d2} W_d(1 + 0.57a_v/g)(\ell_b/B)$
m_{d1}	=	tier number of container stacks on deck
m_{d2}	=	row number of container stacks on deck
W_d	=	maximum design weight of an equivalent 40 ft container on deck, not to be taken less than 176.5 kN (18 tf, 17.7 Ltf)
a_v	=	vertical acceleration amidships, as specified in 5C-5-3/5.5.1(c) for wave heading angle of 0°, in m/sec^2 (ft/sec^2)
A	=	net sectional area of the vertical web, in cm^2 (in^2)
B	=	breadth of vessel, in m (ft), as defined in 3-1-1/5.

S_m and f_y are as defined in 5C-5-4/11.3.1.

m_1, m_2, W, h_4 and g are as defined in 5C-5-4/17.5.3.

k_1 and ℓ_b are as defined in 5C-5-4/25.1.1 above.

c_M and ℓ_v are as defined in 5C-5-4/25.1.3 above.

25.3.3(b) Section Modulus Parallel to Longitudinal Section. The net section modulus of the vertical web, about the neutral axis parallel to the center line of the vessel, is not to be less than that obtained from the following equation (see also 5C-5-4/1.3):

$SM = M/f_b$ cm^3 (in^3)

$M = k_1 c P_{t1} \ell_{v1}$ N-cm (kgf-cm, lbf-in)

where

k_1	=	1.0 (1.0, 0.269)	
ℓ_{v1}	=	span of vertical web between adjacent horizontal girders, in m (ft), as defined in 5C-5-4/Figure 12 and 5C-5-4/Figure 13 for bulkhead with horizontal girders	
	=	ℓ_v for bulkhead without horizontal girder	
c	=	12500	where two (2) containers are located between adjacent horizontal girders
	=	22200	where three (3) containers are located between adjacent horizontal girders
	=	$8330(m_1 - 1)$	where there is no horizontal girder

P_{t1} = $W[\sin(0.71\theta) + 0.64a_t/g]$, in kN (tf, Ltf)

θ = angle of roll at *LWL* draft, in degrees, as specified in 5C-5-3/5.5.1(b)

a_t = transverse acceleration amidships, as specified in 5C-5-3/5.5.1(c) at the level of the mid-span ℓ_{v1} of vertical web of span, ℓ_{v1} for wave heading angle of 90°, amidships, in m/sec^2 (ft/sec^2)

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.80\ S_m f_y$

m_1, W and g are as defined in 5C-5-4/17.5.3.

S_m and f_y are as defined in 5C-5-4/11.3.1.

25.3.4 Web Sectional Area of Vertical Web

The net sectional area of the web portion of the vertical web on mid-hold strength bulkhead is not to be less than that obtained from the following equation, (see also 5C-5-4/1.3):

$A = F/f_s$ cm^2 (in^2)

$F = k_2 500 c_1 P_\ell$ N (kgf, lbf)

where

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\ S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

k_2 is as defined in 5C-5-4/25.1.1 above.

c_1 is as defined in 5C-5-4/25.1.4 above.

P_ℓ is as defined in 5C-5-4/25.3.3(a) above.

25.5 Minimum Thickness and Stiffening Arrangement of Webs

The net thickness of the web plate of the main supporting members is to be not less than 8.5 mm (0.33 in.).

Suitable stiffening arrangements are to be considered based on the structural stability of the web plates. Tripping brackets are to be fitted at intervals of about 3 m (10 ft).

FIGURE 12
Transverse Watertight and Mid-hold Strength Bulkhead Definition of Spans for Bulkhead without Bottom Stool

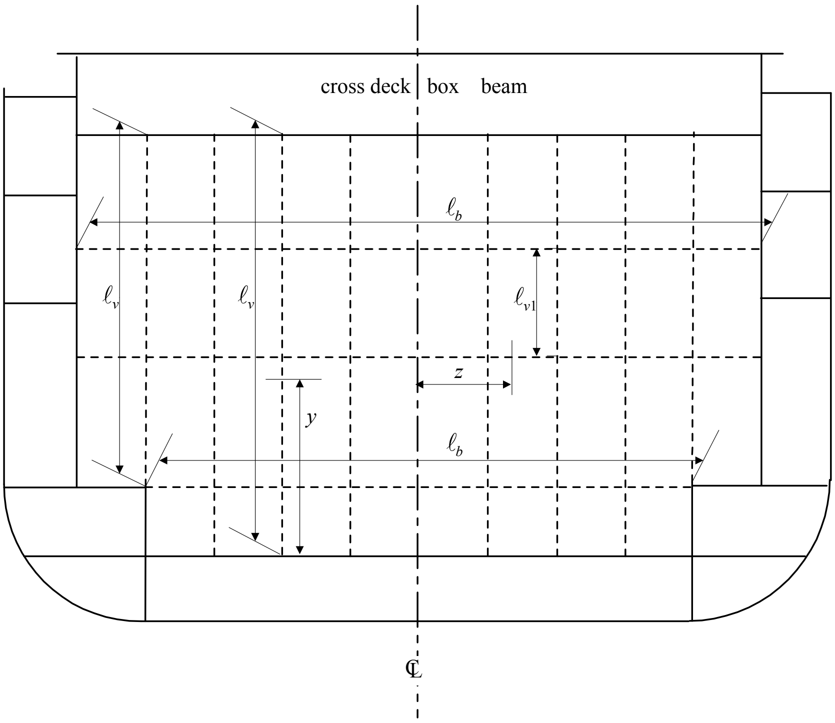
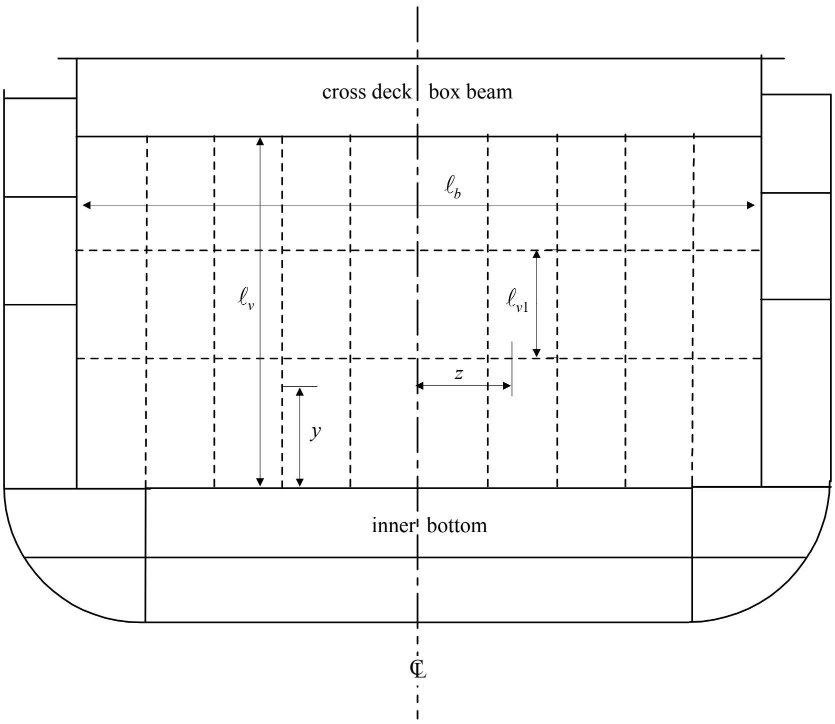


FIGURE 13
Transverse Watertight and Mid-hold Strength Bulkhead Definitions of Spans for Bulkhead with Bottom Stool



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PART

5C

CHAPTER 5 Vessels Intended to Carry Containers (130 meters (427 feet) to 450 meters (1476 feet) in Length)

SECTION 5 Total Strength Assessment *(1998)*

1 General Requirements

1.1 General *(1998)*

When assessing the adequacy of the structural configuration and the initially selected scantlings, the strength of the hull girder and the individual structural member or element is to be in compliance with the failure criteria specified in 5C-5-5/3, 5C-5-5/5 and 5C-5-5/7 below. In this regard, the structural response (load effects) is to be calculated by performing a structural analysis as specified in 5C-5-5/9 or by other equivalent and effective means. Due consideration is to be given to structural details as given in 5C-5-5/1.7.

1.3 Loads and Load Cases *(1998)*

In the determination of the structural response, the combined load cases given in 5C-5-3/9.3 are to be considered. Bottom slamming, bowflare slamming and other loads, as specified in 5C-5-3/11 and 5C-5-3/13, are also to be considered, as necessary.

1.5 Stress Components *(1998)*

The total stress in stiffened plate panels of the hull girder can be divided into the following three categories:

1.5.1 Primary

Primary stresses are those resulting from hull girder bending. The primary bending stresses may be determined by simple beam theory, using the specified total vertical and horizontal wave bending moments and the effective hull girder section modulus at the section considered. These primary stresses, designated by f_{L1} (f_{L1V}, f_{L1H} for vertical and horizontal bending, respectively), may be regarded as uniformly distributed across the thickness of plate elements at the same level, measuring from the relevant neutral axis of the hull girder.

In addition, warping stresses in the longitudinal direction, f_{LW}, are also to be considered for the deck structures, as specified in this Section.

1.5.2 Secondary

Secondary stresses are those resulting from bending of large stiffened panels between longitudinal and transverse bulkheads due to local loads. The secondary bending stresses designated by f_{L2} or f_{T2} are to be determined by performing a 3D FEM analysis, as outlined in this section.

For longitudinally stiffened hull structures, there is another secondary stress corresponding to bending of longitudinals with the associated plating between deep transverses or floors. These additional secondary stresses, designated by f^*_{L2}, may be approximated by simple beam theory.

The secondary stresses, f_{L2}, f_{T2} or f^*_{L2}, may be taken as uniformly distributed in the flange plating and face plates.

1.5.3 Tertiary

Tertiary stresses are those resulting from local bendings of the plate panels between stiffeners. The tertiary stresses, designated by f_{L3} or f_{T3}, can be calculated using classic plate theory. These stresses are referred to as point stresses at the surface of the plate.

1.7 Structural Details *(1998)*

The strength criteria specified in 5C-5-4/3 through 5C-5-4/25 and Section 5C-5-6 are based on assumptions that all structural joints and welded details are properly designed and fabricated and are compatible with the anticipated working stress levels at the locations considered. It is critical to closely examine the loading patterns, stress concentrations and potential failure modes of all structural joints and details during the design of highly stressed regions. In this exercise, failure criteria specified in 5C-5-5/3, 5C-5-5/5 and 5C-5-5/7 may be used to assess the adequacy of structural details.

To enhance the structural integrity and to prevent possible cracks at hatch corners, due consideration is to be given to the shapes of cut-outs and to the heavy insert plates as shown in 5C-5-4/Figure 2, of material with impact properties corresponding to the material class required for stringer plate in strength deck in 3-1-2/Tables 1 and 2.

3 Yielding Criteria

3.1 General

To prevent structural failure due to material yielding, the calculated stresses in the hull structure are to be within the limits given below for all of the combined load cases specified in 5C-5-3/9.3.

3.3 Structural Members and Elements

For all structural members and elements, such as longitudinals/stiffeners, web plates and flanges, the combined effects of all of the calculated stress components are to satisfy the following limit:

$$f_i \le S_m f_y \quad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

f_i = stress intensity

= $(f_L^2 + f_T^2 - f_L f_T + 3 f_{LT}^2)^{1/2}$

f_L = calculated total in-plane stress in the longitudinal direction including the primary, secondary and local load effects

= $f_{L1} + f_{L2} + f^*_{L2} + f_{LW}$ N/cm² (kgf/cm², lbf/in²)

f_{L1} = direct stress due to primary (hull girder) bending, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{L2} = direct stress due to secondary bending between bulkheads in the longitudinal direction N/cm^2 (kgf/cm^2, lbf/in^2)

f^*_{L2} = direct stress due to local bending of longitudinals or stiffeners between transverses in the longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{LW} = warping stresses in the longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_T = calculated total direct stress in the transverse/vertical direction, including the secondary and local load effects

= $f_{T2} + f^*_{T2}$ N/cm^2 (kgf/cm^2, lbf/in^2)

f_{LT} = calculated total in-plane shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{T2} = direct stress due to secondary bending between bulkheads in the transverse/vertical direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

f^*_{T2} = direct stress due to local bending of stiffeners in the transverse/vertical direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_y = specified minimum yield point, in N/cm^2 (kgf/cm^2, lbf/in^2)

S_m = strength reduction factor, as defined in 5C-5-4/11.3.1

For this purpose, f^*_{L2} and f^*_{T2} in the flanges of longitudinals and stiffeners, at the ends of their spans, may be obtained from the following equation:

$f^*_{L2} = 0.071 sp\ell^2/SM_L$ N/cm^2 (kgf/cm^2, lbf/in^2)

$f^*_{T2} = 0.071 sp\ell^2/SM_T$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

s = spacing of longitudinals (stiffeners), in cm (in.)

ℓ = unsupported span of the longitudinal (stiffener), in cm (in.)

p = net pressure load, in N/cm^2 (kgf/cm^2, lbf/in^2), for the longitudinal (stiffener)

SM_L (SM_T) = net section modulus, in cm^3 (in^3), of the longitudinal (stiffener)

3.5 Plating *(2007)*

For plating away from knuckle or cruciform connection of high stress concentrations and subject to both in-plane and lateral loads, the combined effects of all of the calculated stress components are to satisfy the limits specified in 5C-5-5/3.3 above with f_L and f_T modified as follows:

$f_L = f_{L1} + f_{L2} + f^*_{L2} + f_{LW} + f_{L3}$ N/cm^2 (kgf/cm^2, lbf/in^2)

$f_T = f_{T2} + f^*_{T2} + f_{T3}$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

f_{L3}, f_{T3} = equivalent plate bending stresses between stiffeners in the longitudinal and transverse directions, respectively, and may be approximated as follows:

f_{L3} = $k_L\, p(s/t_n)^2$ N/cm^2 (kgf/cm^2, lbf/in^2)

f_{T3} = $k_T\, p(s/t_n)^2$ N/cm^2 (kgf/cm^2, lbf/in^2)

k_L = 0.182 or 0.266 for stiffeners in the longitudinal or transverse direction, respectively

k_T = 0.266 or 0.182 for stiffeners in the longitudinal or transverse direction, respectively

p = net lateral pressures for the combined load case considered [see 5C-5-3/9.3.1(b)], in N/cm^2 (kgf/cm^2, lbf/in^2)

s = stiffeners spacing, in mm (in.)

t_n = net plate thickness, in mm (in.)

For plating within two longitudinals or stiffeners from knuckle or cruciform connections of high stress concentrations, the combined effects of the calculated stress components are to satisfy the following stress limit:

$$f_i \le 0.80\, S_m f_y$$

where

f_i = stress intensity

= $\left(f_L^2 + f_T^2 - f_L f_T + 3 f_{LT}^2\right)^{1/2}$

f_L = calculated total in-plane stress in the longitudinal direction including the primary and secondary stresses

= $f_{L1} + f_{L2} + f_{LW}$ N/cm^2 (kgf/cm^2, lbf/in^2)

f_T = calculated total direct stress in the transverse/vertical direction, including the secondary stresses

= f_{T2} N/cm^2 (kgf/cm^2, lbf/in^2)

In addition, the failure criteria for knuckle or cruciform connections in 5C-5-5/11 are to be complied with.

$f_{L1}, f_{L2}, f_{L2}^*, f_{LW}, f_{T2}$ and f_{T2}^* are as defined in 5C-5-5/3.3 above

5 Buckling and Ultimate Strength Criteria *(1998)*

5.1 General

5.1.1 Approach

The strength criteria given here correspond to either serviceability (buckling) state limit or ultimate state limit for structural members and panels, according to the intended functions and buckling resistance capability of the structure. For plate panels between stiffeners of decks, shell or plane bulkhead, buckling in the elastic range is acceptable, provided that the ultimate strength of the structure satisfies the specified design limits. The critical buckling stresses and ultimate strength of structural elements and members may be determined based on either well documented experimental data or a calibrated analytical approach. When a detailed analysis is not available, the equations given in Appendix 5C-5-A2 may be used to assess the buckling strength.

5.1.2 Buckling Control Concepts

The strength criteria, given in 5C-5-5/5.3 through 5C-5-5/5.11 below, are based on the following assumptions and limitations with respect to buckling control in the design.

5.1.2(a) The buckling strength of longitudinals and stiffeners is generally greater than that of the plate panels being supported by the stiffeners.

5.1.2(b) All of the longitudinals and stiffeners are designed to have moments of inertia with the associated effective plating not less than i_o given in 5C-5-A2/11.1.

5.1.2(c) The main supporting members, including transverses, girders and floors with the effective associated plating, are to have the moment of inertia not less than is given in 5C-5-A2/11.5.

5.1.2(d) Face plates and flanges of girders, longitudinals and stiffeners are proportioned such that local instability is prevented. (5C-5-A2/11.7).

5.1.2(e) Webs of longitudinals and stiffeners are proportioned such that local instability is prevented. (5C-5-A2/11.9).

5.1.2(f) Webs of girders, floors and transverses are designed with proper proportions and stiffening systems to prevent local instability. Critical buckling stresses of the webs may be calculated from equations given in 5C-5-A2/3.

For structures which do not satisfy these assumptions, a detailed analysis of buckling strength using an acceptable method is to be submitted for review.

5.3 Plate Panels

5.3.1 Buckling State Limit *(1 July 2005)*

The buckling state limit for plate panels between stiffeners is defined by the following equation:

$$(f_L/f_{cL})^2 + (f_T/f_{cT})^2 + (f_{LT}/f_{cLT})^2 \leq 1.0$$

where

f_L = calculated total compressive stress in the longitudinal direction for the plate, in N/cm^2 (kgf/cm^2, lbf/in^2), induced by bending and torsion of the hull girder and large stiffened panels between bulkheads

f_T = calculated total compressive stress in the transverse/vertical direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{LT} = calculated total shear stresses in the horizontal/vertical plane, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{cL}, f_{cT} and f_{cLT} are the critical buckling stresses corresponding to uniaxial compression in the longitudinal, transverse/vertical direction and edge shear, respectively, in N/cm^2 (kgf/cm^2, lbf/in^2), and may be determined from the equations given in Appendix 5C-5-A2.

f_L, f_T and f_{LT} are to be determined for the critical combined load cases specified in 5C-5-3/9.3 including the primary and secondary stresses as defined in 5C-5-5/3.3. f_L and f_T may be taken as zero when they are in tension.

5.3.2 Effective Width

When the buckling state limit specified in 5C-5-5/5.3.1 above is not satisfied, the effective width b_{wL} or b_{wT} of the plating given below is to be used instead of the full width between longitudinals, s, for determining the effective hull girder section modulus SM_e, specified in 5C-5-5/5.13.1 and also for verifying the ultimate strength as specified in 5C-5-5/5.3.3 below. When the buckling state limit in 5C-5-5/5.3.1 above is satisfied, the full width between longitudinals, s, may be used as the effective width b_{wL} for verifying the ultimate strength of longitudinals and stiffeners specified in 5C-5-5/5.5 and for determining the effective hull girder section modulus SM_e specified in 5C-5-5/5.13.1 below.

5.3.2(a) For long plate (Compression on the short edges)

$b_{wL}/s = C_e$

$C_e = 2.25/\beta - 1.25/\beta^2$ for $\beta > 1.25$

$= 1.0$ for $\beta \le 1.25$

$\beta = (f_y/E)^{1/2} s/t_n$

f_y = specified minimum yield point of the material, in N/cm^2 (kgf/cm^2, lbf/in^2)

s, t_n and E are as defined in 5C-5-5/5.3.1 above.

5.3.2(b) For wide plate (Compression on the long edges)

$b_{wT}/\ell = C_e s/\ell + 0.115\,(1 - s/\ell)\,(1 + 1/\beta^2)^2 \le 1.0$

where

ℓ = spacing of transverses/girders

C_e, s and ℓ are as defined in 5C-5-5/5.3.2(a) above.

5.3.3 Ultimate Strength *(1 July 2005)*

The ultimate strength of a plate panel between stiffeners is to satisfy all of the following equations:

$(f_L/f_{uL})^2 + (f_{LT}/f_{uLT})^2 \le S_m$;

$(f_T/f_{uT})^2 + (f_{LT}/f_{uLT})^2 \le S_m$;

$(f_L/f_{uL})^2 + (f_T/f_{uT})^2 - \eta(f_L/f_{uL})(f_T/f_{uT}) + (f_{LT}/f_{uLT})^2 \le S_m$

where

$\eta = (1/2)(3 - \beta) \ge 0$

f_L, f_T and f_{LT} are as defined in 5C-5-5/5.3.1 above.

β is as defined in 5C-5-5/5.3.2 above.

S_m is as defined in 5C-5-4/11.3.1.

f_{uL}, f_{uT} and f_{uLT} are the ultimate strengths with respect to uniaxial compression and edge shear, respectively, and may be obtained from the following equations and do not need to be taken less than the corresponding critical buckling stresses specified in 5C-5-5/5.3.1 above:

$f_{uL} = f_y\, b_{wL}/s \ge f_{cL}$, $f_{uT} = f_y\, b_{wT}/\ell \ge f_{cT}$

for plating longitudinally stiffened

$f_{uL} = f_y\, b_{wT}/\ell \ge f_{cL}$, $f_{uT} = f_y\, b_{wL}/s \ge f_{cT}$

for plating transversely stiffened

$f_{uLT} = f_{cLT} + 0.5\,(f_y - 1.73 f_{cLT})/(1 + \alpha + \alpha^2)^{1/2} \ge f_{cLT}$

where

$\alpha = \ell/s$

f_y, b_{wL}, b_{wT}, s, ℓ, f_{cL}, f_{cT} and f_{cLT} are as defined above.

When assessing the ultimate strength of plate panels between stiffeners, special attention is to be paid to the longitudinal bulkhead plating in the regions of high hull girder shear forces, and the bottom and inner bottom platings in the mid region of cargo holds subject to bi-axial compression.

5.5 Longitudinals and Stiffeners

5.5.1 Beam-Column Buckling State Limits and Ultimate Strength *(2007)*

The buckling state limit for longitudinals and stiffeners are considered as the ultimate state limit for these members and, in combination with the effective plating, are to be determined as follows:

$$f_a/(f_{ca}A_e/A) + m f_b/f_y \leq S_m$$

where

f_a	=	nominal calculated compressive stress
	=	P/A N/cm^2 (kgf/cm^2, lbf/in^2)
P	=	total compressive load, N (kgf, lbf)
f_{ca}	=	critical buckling stress, as given in 5C-5-A2/5.1, in N/cm^2 (kgf/cm^2, lbf/in^2)
A	=	total net sectional area, in cm^2 (in^2)
	=	$A_s + st_n$
A_s	=	net sectional area of the longitudinal, excluding the associated plating, in cm^2 (in^2)
A_e	=	effective net sectional area, in cm^2 (in^2)
	=	$A_s + b_{wL}t_n$
E	=	Young's modulus for steel, 2.06×10^7 N/cm^2 (2.1×10^6 kgf/cm^2, 30×10^6 lbf/in^2)
f_y	=	minimum specified yield point of the longitudinal or stiffener under consideration, N/cm^2 (kgf/cm^2, lbf/in^2)
f_b	=	effective bending stress, N/cm^2 (kgf/cm^2, lbf/in^2)
	=	M/SM_e
M	=	maximum total bending moment induced by lateral loads
	=	$C_m ps\ell^2/12$ N-cm (kgf-cm, lbf-in)
C_m	=	moment adjustment coefficient and may be taken as 0.75
p	=	lateral pressure for the region considered, in N/cm^2 (kgf/cm^2, lbf/in^2)
s	=	spacing of the longitudinals, cm (in.)
SM_e	=	effective net section modulus of the longitudinal at flange, including the effective plating b_e, in cm^3 (in^3).
b_e	=	effective breadth as specified in 5C-5-4/Figure 7, line b.
m	=	amplification factor
	=	$1/[1 - f_a/\pi^2E\,(r/\ell)^2] \geq 1.0$

t_n and b_{WL} are as defined in 5C-5-5/5.3, in cm (in.).

S_m is as defined in 5C-5-4/11.3.1.

r and ℓ are as defined in 5C-5-A2/5.1.

The above ultimate state limit need not be applied to the longitudinals having a relatively rigid support at one end provided that the bracket system at the rigid end is evaluated using a fine mesh finite element model and the following strength requirement is complied with:

$$f_a/(f_{ca} A_e/A) \le S_m$$

5.5.2 Torsional-Flexural Buckling State Limit *(2002)*

In general, the torsional-flexural buckling state limit of longitudinals and stiffeners is to satisfy the ultimate state limits given below:

$$f_a/(f_{ct} A_e/A) \le S_m$$

where

f_a = nominal calculated compressive stress, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in 5C-5-5/5.5.1 above

f_{ct} = critical torsional-flexural buckling stress, in N/cm^2 (kgf/cm^2, lbf/in^2), and may be determined by equations given in 5C-5-A2/5.5.

A_e and A are as defined in 5C-5-5/5.5.1 above and S_m is as defined in 5C-5-4/11.3.1.

5.7 Stiffened Panels

5.7.1 Large Stiffened Panels Between Bulkheads

For a vessel under the assumptions made in 5C-5-5/5.1 above with respect to the buckling control concepts, the large stiffened panels of the double bottom and double side structures between transverse bulkheads should automatically satisfy the design limits, provided each individual plate panel and longitudinally and uniaxially stiffened panel satisfy the specified ultimate state limits. Assessments of the buckling state limits are to be performed for large stiffened panels of the single side shell and plane transverse bulkheads. In this regard, the buckling strength is to satisfy the following condition for uniaxially or orthogonally stiffened panels.

$$(f_L/f_{cL})^2 + (f_T/f_{cT})^2 \le S_m$$

where

f_L, f_T = the calculated average compressive stresses in the longitudinal and transverse/vertical directions, respectively, in N/cm^2 (kgf/cm^2, lbf/in^2).

f_{cL}, f_{cT} = the critical buckling stresses for uniaxial compression in the longitudinal and transverse direction, respectively, and may be determined in accordance with 5C-5-A2/7, in N/cm^2 (kgf/cm^2, lbf/in^2)

S_m = strength reduction factor, as defined in 5C-5-4/11.3.1

5.7.2 Uniaxially Stiffened Panels between Transverses and Girders

The buckling strength of uniaxially stiffened panels between deep transverses and girders is also to be examined in accordance with the specifications given in 5C-5-5/5.7.1 above.

5.9 Deep Girders and Webs

5.9.1 Buckling Criteria *(2007)*

In general, the stiffness of the web stiffeners along the depth of the web plating is to be in compliance with the requirements 5C-5-A2/11.3. Web stiffeners which are oriented parallel to and near the face plate and thus subject to axial compression are also to satisfy the limits specified in 5C-5-5/5.5, considering the combined effect of the compressive and bending stresses in the web. In this case, the unsupported span of these parallel stiffeners may be taken between tripping brackets, as applicable.

The buckling strength of the web plate between stiffeners and flange/face plate is to satisfy the limits specified below:

5.9.1(a) For Web Plate

$$(f_L/f_{cL})^2 + (f_b/f_{cb})^2 + (f_{LT}/f_{cLT})^2 \le S_m$$

where

f_L = calculated uniform compressive stress along the length of the girder, in N/cm^2 (kgf/cm^2, lbf/in^2).

f_b = calculated ideal bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2).

f_{LT} = calculated total shear stress, including hull girder and local loads where applicable, in N/cm^2 (kgf/cm^2, lbf/in^2).

f_L, f_b and f_{LT} are to be calculated for the panel in question under the combined load cases specified in 5C-5-3/9.3 and these stresses may be calculated from the relative displacements of four corner nodes. This method is useful when the meshing within the panel is irregular. However, care should be taken when one corner of the panel is located in an area of high stress concentration. The calculated stresses from the above mentioned method tend to be on the conservative side. If the mesh is sufficiently refined, the plate panel stresses may be calculated from the displacements slightly away from the corner point in the said high stress concentration. For a regularly meshed plate panel, f_L, f_b and f_{LT} may be also directly calculated from the components stresses for the elements in the panel. f_{cL}, f_{cb} and f_{cLT} are critical buckling stresses with respect to uniform compression, ideal bending and shear, respectively, and may be determined in accordance with Appendix 5C-5-A2.

S_m is as defined in 5C-5-4/11.3.1.

In the determination of f_{cL} and f_{cLT}, the effects of openings are to be appropriately considered.

A practical method of determining the buckling strength is the well established eigenvalue analysis method with suitable edge constrains. If the predicted buckling stresses exceed the proportional linear elastic limit, which may be taken as $0.6 \times f_y$ for steel, plasticity correction is to be made.

5.9.1(b) For Face Plate and Flange. The breadth to thickness ratio of face plate and flange is to satisfy the limits given in 5C-5-A2/11.7.

5.9.1(c) For Large Brackets and Sloping Webs. The buckling strength is to satisfy the limits specified in 5C-5-5/5.9.1(a) above for web plate.

5.9.2 Tripping

Tripping brackets are to be provided in accordance with 5C-5-A2/9.5.

5.11 Longitudinal Deck Girders, Cross Deck Box Beams and Vertical Webs

The buckling and ultimate state limits for the longitudinal deck girders inboard of lines of hatch openings, the cross deck box beams where no longitudinal deck girder is installed, and the vertical webs of mid-hold strength bulkhead where no horizontal girder is installed are to be determined as follows:

$$f_a/f_{ua} + f_b/f_y \leq S_m$$

where

f_a	=	nominal calculated compressive stress = P/A, in N/cm^2 (kgf/cm^2, lbf/in^2)
P	=	total compressive load, in N (kgf, lbf)
f_{ua}	=	critical buckling stress, f_{ca} as given in 5C-5-A2/5.1 or f_{cT} as given 5C-5-A2/5.5, whichever is lesser, in N/cm (kgf/cm^2, lbf/in^2)
A	=	total net sectional area, in cm^2 (in^2)
f_b	=	effective bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)
	=	M/SM
M	=	maximum bending moment, as given in 5C-5-5/5.5.1. (See also 5C-5-A2/5.3.2.)
SM	=	effective section modulus, in cm^3 (in^3)

S_m and f_y are as defined in 5C-5-4/11.3.1.

5.13 Hull Girder Ultimate Strength

In addition to the strength requirements specified in 5C-5-4/3.1, the ultimate strength of the hull girder is to be assessed for the combined load cases given in 5C-5-3/9.3 and the specifications given in 5C-5-5/5.13.1 and 5C-5-5/5.13.2 below.

5.13.1 Maximum Longitudinal Bending Stresses

The maximum longitudinal bending stresses in the deck and bottom plating are not to be greater than that given in 5C-5-5/5.13.1(a), below.

5.13.1(a) (1 July 2005)

$$f_L \leq S_m f_y$$

where

f_L	=	total direct stress in the longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2)	
	=	$f_{b1} + f_{b2}$	
f_{b1}	=	effective longitudinal bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)	
	=	M_t/SM_e	
M_t	=	$M_s + k_u k_c M_w$	in N-cm (kgf-cm, lbf-in)
k_u	=	1.15	
k_c	=	1.0	

SM_e = the effective section modulus, as obtained from 5C-5-5/5.13.1(b) below, in cm^3 (in^3).

S_m = the strength reduction factor, as defined in 5C-5-4/11.3.1

f_y = minimum specified yield point of the material, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{b2} = secondary bending stress of large stiffened panel between longitudinal bulkheads and transverse bulkheads, in N/cm^2 (kgf/cm^2, lbf/in^2)

5.13.1(b) Calculation of SM_e. For assessing the hull girder ultimate strength, the effective section modulus is to be calculated, accounting for the buckling of plate panels. For vessels constructed of higher strength material, the effective width of the side, bottom shell and longitudinal bulkhead plating is to be used instead of the full width between longitudinals. The effective width, b_{wL}, is given in 5C-5-5/5.3.2 above.

5.13.2 Buckling and Ultimate Strength of Large Stiffened Panels

Under the combined effects of the normal stresses, f_L and f_T, and shear stresses, f_{LT}, the buckling strength and ultimate strength of the stiffened panel are to satisfy the requirements specified in 5C-5-5/5.7.

5.13.3 Hull Girder Shear Strength *(1 July 2005)*

The hull girder shear stress of the side shell and longitudinal bulkhead is not to be greater than that given below.

$$f_s \leq S_m f_{uLT}$$

where

f_s = hull girder shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2), may be calculated for F_t from the equations in 5C-5-4/5.3 and 5C-5-4/5.5, using the net thickness of the side shell and longitudinal bulkhead.

F_t = $F_s + k_c k_u F_w$, $k_u = 1.15$, $k_c = 1.0$, kN (tf, Ltf)

S_m = strength reduction factor, as defined in 5C-5-4/11.3.1

f_{uLT} = ultimate shear strength of panel, as defined in 5C-5-5/5.3.3

7 Fatigue Life *(1998)*

7.1 General

The fatigue strength of welded joints and details in highly stressed areas is to be analyzed, especially where higher strength steel is used. Special attention is to be given to structural notches, cut-outs and bracket toes and also to abrupt changes of structural sections. A simplified assessment of the fatigue strength of structural details may be accepted when carried out in accordance with Appendix 5C-5-A1.

The following subparagraphs are intended to emphasize the main points and to outline procedures where refined spectral analysis techniques are used to establish fatigue strength.

7.1.1 Workmanship

Most fatigue data available were experimentally developed under controlled laboratory conditions. Therefore, consideration is to be given to the workmanship expected during the construction.

7.1.2 Fatigue Data

In the selection of appropriate S-N curves and the associated stress concentration factors, attention is to be paid to the background of all design data and its validity for the details being considered. In this regard, recognized design data, such as those by AWS (American Welding Society), API (American Petroleum Institute), and DEn (Department of Energy), should be considered. Sample fatigue data and their applications are shown in Appendix 5C-5-A1, "Guide for Fatigue Strength Assessment of Container Carriers." If other fatigue data are to be used, the background and supporting data are to be submitted for review.

In this regard, clarification is required whether or not the stress concentration due to the weld profile, certain structural configurations and also the heat effects are accounted for in the proposed S-N curve. Considerations are also to be given to the additional stress concentrations.

7.1.3 Total Stress Range

For determining total stress ranges, the fluctuating stress components resulting from the load cases specified in 5C-5-A1/7.5.2 are to be considered.

7.1.4 Design Consideration

In design, consideration is to be given to the minimization of structural notches and stress concentrations. Areas subject to highly concentrated forces are to be properly configured and stiffened to dissipate the concentrated loads. See also 5C-5-5/1.7.

7.3 Procedures

The analysis of fatigue strength for a welded structural joint/detail may be performed in accordance with the following procedures.

7.3.1 Step 1 – Classification for Various Critical Locations

The class designations and associated load patterns are given in 5C-5-A1/Table 1

7.3.2 Step 2 – Permissible Stress Range Approach

Where deemed appropriate, the total applied stress range of the structural details classified in Step 1 may be checked against the permissible stress ranges as shown in Appendix 5C-5-A1.

7.3.3 Step 3 – Refined Analysis

Refined analyses are to be performed as outlined in 5C-5-5/7.3.3(a) or 5C-5-5/7.3.3(b) below for the structural details for which the total applied stress ranges obtained from Step 2 are greater than the permissible stress ranges, or for which the fatigue characteristics are not covered by the classified details and the associated S-N curves.

The fatigue life of the structure is generally not to be less than 20 years unless otherwise specified.

7.3.3(a) Spectral Analysis. Alternatively, a spectral analysis may be performed as outlined in 5C-5-5/7.5 below to directly calculate fatigue lives for the structural details in question.

7.3.3(b) Refined Fatigue Data. For structural details which are not covered by the detail classifications, proposed S-N curves and the associated SCFs, when applicable, may be submitted for consideration. In this regard, sufficient supporting data and background are also to be submitted for review. The refined SCFs may be determined by finite element analyses.

7.5 Spectral Analysis

Where the option in 5C-5-5/7.3.3(a) is exercised, a spectral analysis is to be performed in accordance with the following guidelines.

7.5.1 Representative Loading Patterns

Several representative loading patterns are to be considered to cover the worst scenarios anticipated for the design service life of the vessel with respect to the hull girder local loads.

7.5.2 Environmental Representation

Instead of the design wave loads specified in Section 5C-5-3, a wave scatter diagram (such as Walden Data) is to be employed to simulate a representative distribution of all of the wave conditions expected for the design service life of the vessel. In general, the wave data is to cover a time period of not less than 20 years. The probability of occurrence for each combination of significant wave height and mean period of the representative wave scatter diagram is to be weighted based on the transit time of the vessel at each wave environment within the anticipated shipping routes. The representative environment (the wave scatter diagram) is not to be taken less severe than the North Atlantic Ocean in terms of the fatigue damage.

7.5.3 Calculation of Wave Load RAOs

The wave load RAOs with respect to the wave induced bending moments, shear forces, motions, accelerations and hydrodynamic pressures can then be predicted by ship motion calculation for a selected representative loading condition.

7.5.4 Generation of Stress Spectrum

The stress spectrum for each critical structural detail (spot) may be generated by performing a structural analysis, accounting for all of the wave loads separately for each individual wave group. For this purpose, the 3D structural model and 2D models specified in Section 5C-5-3 may be used for determining structural responses. The additional secondary and tertiary stresses are also to be considered.

7.5.5 Cumulative Fatigue Damage and Fatigue Life

Based on the stress spectrum and the wave scatter diagram established above, the cumulative fatigue damage and the corresponding fatigue life can be estimated by the Palmgren-Miner linear damage rule.

9 Calculation of Structural Responses *(1998)*

9.1 Methods of Approach and Analysis Procedures *(1998)*

To verify the strength of the structure, the maximum stresses (load effects) in the structure are to be determined by performing appropriate structural analyses as outlined below. Guidelines on structural idealization, load application and structural analysis are given in ABS *Guidance for Finite Element Analysis of Container Carrier Structures*.

9.3 3D Finite Element Models *(1998)*

A simplified three-dimensional (3D) finite element model, usually representing three cargo holds within 0.4*L* amidships, is required to determine the load distribution in the structure.

Two or more 3D F.E. models may be required to simulate the actual design arrangements and scantlings to cover all critical regions for designs where the structural configuration and scantlings of the hold structure vary significantly among the cargo spaces. A separate 3D F.E. model is recommended to represent the forebody structures for the analysis when bottom slamming and bowflare slamming are to be considered, as specified in 5C-5-3/11.1 and 5C-5-3/11.3.

9.5 2D Finite Element Models *(1998)*

Two-dimensional fine mesh finite element models are required to determine the stress distribution in major supporting structures, particularly at intersections of two or more major structural members, for longitudinal and transverse/horizontal structural sections.

9.7 Refined 3D Local Structural Models *(1998)*

A 3D fine mesh model is to be used to examine stress concentrations, such as at hatch corners, connections of longitudinal hatch girders to cross deck box beams and at intersections of transverse bulkheads with longitudinal wing box girders.

9.9 Load Cases *(1998)*

When performing structural analyses, the ten combined load cases specified in 5C-5-3/9.1 are to be considered. In general, the structural responses for the still-water conditions are to be calculated separately to establish reference points for assessing the wave induced responses. Additional load cases may be required for special loading patterns and unusual design functions, such as impact loads as specified in 5C-5-3/11. Additional load cases may also be required for hull structures beyond the region of 0.4L amidships.

11 Critical Areas *(2007)*

The fatigue strength of the critical areas shown in 5C-5-5/Figure 1 is to be verified by fine mesh finite element models built in accordance with Appendix 5C-5-A1.

The mesh size in way of high stress concentration is to be of plate thickness dimension (t), and not to be greater than 50 mm × 50 mm. The element stress intensity of half plate thickness dimension (t/2) away from the weld toe is to satisfy the following stress limit:

$$f_i \le f_u$$

where

f_i = stress intensity

$= \left(f_L^2 + f_T^2 - f_L f_T + 3 f_{LT}^2\right)^{1/2}$

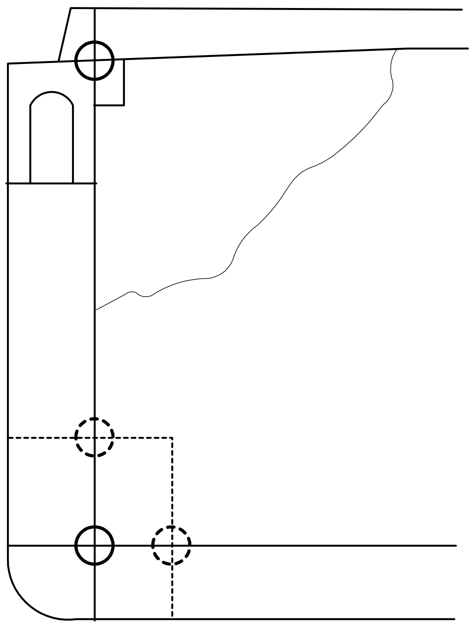
f_L = calculated total in-plane element stress in the longitudinal direction

f_T = calculated total in-plane element stress in the transverse/vertical direction

f_{LT} = calculated total in-plane element shear stress

f_u = the minimum tensile strength of the material

FIGURE 1
Critical Areas *(2007)*



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PART

5C

CHAPTER **5** **Vessels Intended to Carry Containers (130 meters (427 feet) to 450 meters (1476 feet) in Length)**

SECTION **6** **Hull Structure Beyond 0.4L Amidships**

1 General Requirements

1.1 General

The structural configurations, stiffening systems and design scantlings of the hull structures located beyond 0.4*L* amidships, including the forebody, aftbody and machinery spaces, are to be in compliance with the Rules.

The nominal design corrosion values for structural members within cargo spaces are to be in compliance with 5C-5-2/Table 1. For structural members located in other than cargo spaces, the corrosion values may be taken as below in establishing design scantlings.

1. 1.5 mm (0.06 in.) for side shell plating
2. 1.0 mm (0.04 in.) for bottom shell plating
3. 1.5 mm (0.06 in.) in the tank spaces and double bottom
4. 1.0 mm (0.04 in.) in dry spaces and decks

1.3 Structure within Cargo Spaces *(2002)*

The scantlings of longitudinal structural members in way of cargo spaces beyond the 0.4*L* amidships may be gradually reduced toward 0.1*L* from the ends, provided that the hull girder section modulus is in compliance with the requirements given in 5C-5-4/3.1.1 and that the strength of the structure satisfies the requirements specified in 5C-5-6/3 through 5C-5-6/21 and 5C-5-6/25 and the material yielding, buckling and ultimate strength criteria specified in 5C-5-5/3 and 5C-5-5/5.

In addition, consideration is to be given to the effects of the impact loads, as specified in 5C-5-3/5.3 and 5C-5-3/11, with respect to the local structures, as outlined in 5C-5-6/23.

The scantlings of transverse bulkheads in way of cargo spaces beyond 0.4*L* amidships may be determined in accordance with 5C-5-4/23.

3 Bottom Shell Plating and Stiffeners in Forebody

3.1 Bottom Shell Plating

The net thickness of the bottom shell plating is to be not less than t, obtained from the following equations and is not to extend for more than 0.1L at the fore end. Between the midship 0.4L and 0.1L from the FP, the thickness of the plating may be gradually tapered.

$$t = 0.03(L + 29) + 0.009s \quad \text{mm} \quad \text{for } L \le 305 \text{ m}$$

$$= (10.70 + 0.009s)\sqrt{D/35} \quad \text{mm} \quad \text{for } L > 305 \text{ m}$$

$$t = 0.00036(L + 95) + 0.009s \quad \text{in.} \quad \text{for } L \le 1000 \text{ ft}$$

$$= (0.421 + 0.009s)\sqrt{D/114.8} \quad \text{in.} \quad \text{for } L > 1000 \text{ ft}$$

where

s = fore peak frame spacing, in mm (in.)

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

D = molded depth, in m (ft), as defined in 3-1-1/7.1 or 35 m (114.8 ft), whichever is greater

The net bottom shell plating thickness, where constructed of higher-strength material, is to be not less than obtained from the following equation:

$$t_{hts} = [t_{ms} - C]\ [(Q + 2\sqrt{Q})/3] + C$$

where

t_{hts} = net thickness of higher-strength material, in mm (in.)

t_{ms} = net thickness, in mm (in.), of ordinary-strength steel, as required above.

Q = material conversion factor, as specified in 5C-5-4/5

C = 3.3 (0.13)

In determining the thickness of bottom shell plating constructed of higher-strength material and transversely framed, the critical buckling stress of the plating is to be checked in accordance with Appendix 5C-5-A2.

Shell plating is also not to be less in thickness than required by 5C-5-6/19 for deep tanks.

3.3 Bottom Longitudinals and Transverse Frames

Frames are not to have less strength than is required in 5C-5-6/3.3.1 and 5C-5-6/3.3.2 below, respectively. In way of deep tanks, they are not to have less strength than is required in 5C-5-6/19 for stiffeners on deep-tank bulkheads.

3.3.1 Bottom Longitudinals

The net section modulus of the bottom longitudinal required by 5C-5-4/11.5 for 0.4L amidships may be gradually reduced to the values required by 5C-5-6/5.11.1 toward 0.1L from the FP, provided that the hull girder section modulus at the location under consideration is in compliance with the requirements given in 5C-5-4/3.1.1. In no case is the net section modulus of each bottom shell longitudinal in association with the effective plating to be less than that obtained from the equations in 5C-5-6/5.11.1.

3.3.2 Bottom Transverse Frames

The bottom transverse frame, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equation:

$$SM = kc_1c_2hs\ell_2Q \qquad \text{cm}^3\ (\text{in}^3)$$

where

k = 7.8 (0.0041)

s = spacing of the frames, in m (ft)

c_1 = 1.0

c_2 = 0.85

h = the vertical distance, in m (ft), from the middle of ℓ to the load line, or two-thirds of the distance to the bulkhead deck or freeboard deck, whichever is greater.

ℓ = span of frames between effective supports, in m (ft), as shown in 5C-5-4/Figure 6.

Q = material conversion factor, as specified in 5C-5-4/5.

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

5 Side Shell Plating and Stiffeners in Forebody

5.1 Side Shell Plating

The net thickness of the side shell plating is to be not less than t, obtained from the following equations and is not to extend for more than 0.1L at the fore end. Between the midship 0.4L and 0.1L from the FP, the thickness of the plating may be gradually tapered.

$$t = 0.029(L + 29) + 0.009s \quad \text{mm} \quad \text{for } L \leq 305 \text{ m}$$

$$= (10.20 + 0.009s)\sqrt{D/35} \quad \text{mm} \quad \text{for } L > 305 \text{ m}$$

$$t = 0.00034(L + 95) + 0.009s \quad \text{in.} \quad \text{for } L \leq 1000 \text{ ft}$$

$$= (0.402 + 0.009s)\sqrt{D/114.8} \quad \text{in.} \quad \text{for } L > 1000 \text{ ft}$$

where

s = fore peak frame spacing, in mm (in.)

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

D = molded depth, in m (ft), as defined in 3-1-1/7.1 or 35 m (114.8 ft), whichever is greater

The net side shell plating thickness, where constructed of higher-strength material, is to be not less than obtained from the following equation:

$$t_{hts} = [t_{ms} - C][(Q + 2\sqrt{Q})/3] + C$$

where

t_{hts} = net thickness of higher-strength material, in mm (in.)

t_{ms} = net thickness, in mm (in.), of ordinary-strength steel, as required above

Q	=	material conversion factor, as specified in 5C-5-4/5
C	=	2.8 (0.11)

In determining the thickness of side shell plating constructed of higher-strength material and transversely framed, the critical buckling stress of the plating is to be checked in accordance with Appendix 5C-5-A2.

Shell plating is also not to be less in thickness than required by 5C-5-6/19 for deep tanks.

Also, see 5C-5-6/5.9 for shell plating below the load water line for 0.16L from the FP.

5.3 Forecastle Side Shell Plating

The net thickness, t, of the forecastle side shell plating is to be not less than that obtained from the following equation:

$$t = 0.0315(L + 154) + 0.006(s - S) \quad \text{mm}$$

$$t = 0.00038(L + 505) + 0.006(s - S) \quad \text{in.}$$

where

s	=	frame spacing, in mm (in.)		
S	=	standard frame spacing		
	=	$2.08L + 438$	mm	for $L \le 270$ m
	=	1000	mm	for $L > 270$ m
	=	610	mm	in way of the fore peak
S	=	$0.025L + 17.25$	in.	for $L \le 886$ ft
	=	39.4	in.	for $L > 886$ ft
	=	24	in.	in way of the fore peak
L	=	length of vessel, as defined in 3-1-1/3.1, in m (ft), but need not be taken more than 305 m (1000 ft.)		

Where constructed of higher-strength material, the plating thickness is to be not less than that obtained from the following equation:

$$t_{hts} = [t_{ms} - C][(Q + 2\sqrt{Q})/3] + C$$

where

t_{hts}	=	net thickness of higher-strength material, in mm (in.)
t_{ms}	=	net thickness, in mm (in.), of ordinary-strength steel, as required above
Q	=	material conversion factor, as specified in 5C-5-4/5
C	=	2.8 (0.11)

5.5 Stem Plating

The net thickness of plate stems at the design load waterline, where used, is not to be less than that required by the following equations:

$t = L/12$	mm	$L \le 246$ m
$t = 20.5$	mm	$L > 246$ m

$t = L/1000$ in. $L \le 807$ ft

$t = 0.807$ in. $L > 807$ ft

Above and below the design load waterline, the thickness may be tapered to the thickness required in 5C-5-6/5.1 at the freeboard deck and to the thickness of the flat-plate keel at the forefoot, respectively.

5.7 Bow Thruster Tunnel

The net thickness of the tunnel plating is to be not less than required in 5C-5-6/5.1 above, where s is to be taken as the standard frame spacing S given by the equation in 5C-5-6/5.3, nor is the thickness to be less than that obtained from the following equation:

$t = 0.008d + 1.8$ mm

$t = 0.008d + 0.07$ in.

d = inside diameter of the tunnel, in mm (in.), but is to be taken not less than 968 mm (38 in.)

Where the outboard ends of the tunnel are provided with bars or grids, the bars or grids are to be effectively secured.

5.9 Immersed Bow Plating *(1 July 2005)*

The net thickness of the plating below the load waterline for 0.16L from the FP is to be not less than t, given by the following equations, but need not be greater than the thickness of the side shell plating amidships.

$t = 0.045(L + 20) + 0.009s$ mm for $L \le 305$ m

$= 0.00054(L + 65.6) + 0.009s$ in. for $L \le 1000$ ft

$t = (14.75 + 0.009s)\sqrt{D/35}$ mm for $L > 305$ m

$= (0.58 + 0.009s)\sqrt{D/114.8}$ in. for $L > 1000$ ft

where

s = fore peak frame spacing, in mm (in.)

L = length of vessel, as defined in 3-1-1/3, in m (ft)

D = molded depth, in m (ft), as defined in 3-1-1/7 or 35 m (114.8 ft), whichever is greater

The net plating thickness, where constructed of higher-strength material, is to be not less than obtained from the following equation:

$$t_{hts} = [t_{ms} - C][(Q + 2\sqrt{Q})/3] + C$$

where

t_{hts} = net thickness of higher-strength material, in mm (in.)

t_{ms} = net thickness, in mm (in.), of ordinary-strength steel, as required above.

Q = material conversion factor, as specified in 5C-5-4/5

C = 2.8 (0.11)

5.11 Side Longitudinals and Transverse Frames

Frames are not to have less strength than is required in 5C-5-6/17.3 for bulkhead stiffeners in the same location in conjunction with heads to the bulkhead deck. In way of deep tanks, they are not to have less strength than is required in 5C-5-6/19.3 for stiffeners on deep-tank bulkheads. Framing sections are to have sufficient thickness and depth in relation to the spans between supports. See also 3-1-2/13.5.

5.11.1 Side Longitudinals

The net section modulus of each side longitudinal, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equation:

$$SM = k\, c_1 c_2\, h s \ell^2 Q \qquad \text{cm}^3\ (\text{in}^3)$$

where

k = 7.8 (0.0041)

s = spacing of side longitudinals, in m (ft)

c_1 = 0.95

c_2 = 0.85

h = above 0.5D from the keel, the vertical distance, in m (ft), from the longitudinal frame to the bulkhead deck but is not to be taken as less than 2.13 m (7.0 ft)

= at and below 0.5D from the keel, 0.75 times the vertical distance, in m (ft), from the longitudinal frame to the bulkhead deck, but is not less than 0.5D

D = depth of vessel, in m (ft), as defined in 3-1-1/7

ℓ = span of longitudinals between effective supports, in m (ft), as shown in 5C-5-4/Figure 6.

Q = material conversion factor, as specified in 5C-5-4/5.

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

The net section modulus of each longitudinal tween-deck frame forward of 0.125L from the stem is also to be not less than required by 5C-5-6/5.11.3 below, in the same location taking ℓ as the unsupported span along the frame length.

5.11.2 Fore-end Transverse Frames Forward of 0.3L to 0.125L from FP

The net section modulus SM of each transverse frame, in association with the effective plating to which it is attached, is to be not less than obtained from the following equation:

$$SM = sc_2\ell^2(h + bh_1/33)(7 + 45/\ell^3)Q \qquad \text{cm}^3$$

$$= sc_2\ell^2(h + bh_1/100)(0.0037 + 0.84/\ell^3)Q \qquad \text{in}^3$$

where

s = spacing of side frames, in m (ft)

c_2 = 0.85

ℓ = actual girth length along the frame, as shown in 5C-5-6/Figure 1. Where frames are supported by a system of web frames and side stringers of the size and arrangements obtained from Section 3-2-6, ℓ may be taken as the distance from the toe of the bracket to the lowest stringer plus 0.15 m (0.5 ft). The value of ℓ for use with the equation is not be less than 2.10 m (7 ft).

h = vertical distance, in m (ft), from the middle of ℓ to the load line or 0.4ℓ, whichever is the greater.

b = horizontal distance, in m (ft), from the outside of the frames to the first row of deck supports, as shown in 5C-5-6/Figure 1

h_1 = vertical distance, in m (ft), from the deck at the top of the frame to the bulkhead or freeboard deck plus the height of all cargo tween-deck spaces, or plus 2.44 m (8 ft). if that is greater. Where the cargo load differs from 715 kgf/m^3 (45 lbf/ft^3) multiplied by the tween-deck height in m (ft), the height of that tween-deck is to be proportionately adjusted in calculating h_1.

Q = material conversion factor, as specified in 5C-5-4/5

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

5.11.3 Transverse Tween-deck Frames

The net section modulus SM of each transverse tween-deck frame, in association with the effective plating, is to be not less than that obtained from the following equation:

$$SM = (7 + 45/\ell^3)sc_2\ell^2KQ \quad \text{cm}^3$$

$$= (0.0037 + 0.84/\ell^3)sc_2\ell^2KQ \quad \text{in}^3$$

where

s = spacing of side frames, in m (ft)

c_2 = 0.85

ℓ = tween deck height or unsupported span along the frame length, as shown in 5C-5-6/Figure 1, whichever is greater, in m (ft)

K = factor appropriate to the length of vessel and type of tween decks, as shown in 5C-5-6/Figure 1, defined as follows:

For L in m:

$K_A = 0.022L - 0.47$

$K_B = 0.034L - 0.56$

$K_C = 0.036L - 0.09$ for $L \le 180$ m

$= 0.031L + 0.83$ for $L > 180$ m

$K_D = 0.029L + 1.78$

For L in ft:

$K_A = 0.022L - 1.54$

$K_B = 0.034L - 1.84$

$K_C = 0.036L - 0.29$ for $L \le 590$ ft

$= 0.031L + 2.8$ for $L > 590$ ft

$K_D = 0.029L + 5.84$

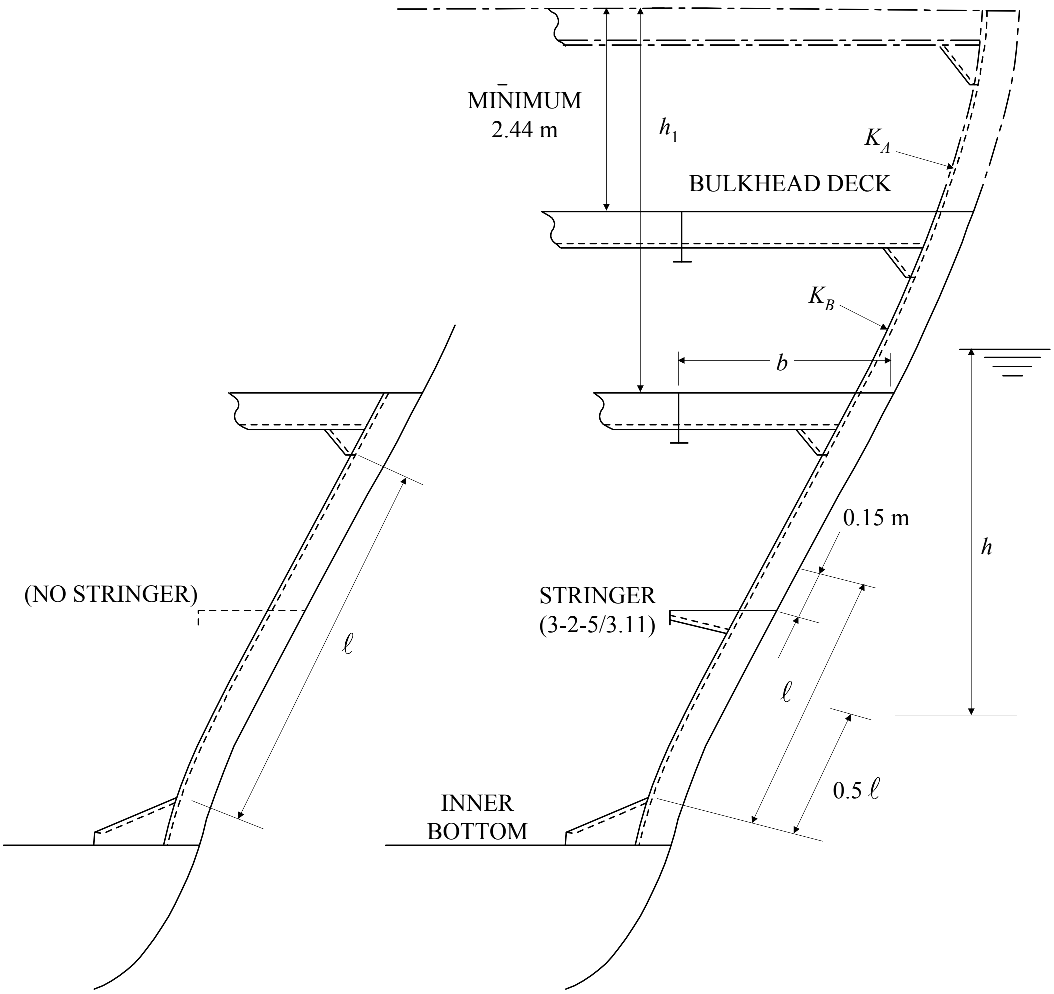
L = length of vessel, as defined in 3-1-1/3.1, in m (ft), but need not be taken as greater than 305 m (1000 ft)

Q = material conversion factor, as specified in 5C-5-4/5.

For tween-deck frames above the bulkhead deck forward of $0.125L$ from the FP, K is to be based on K_B.

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

FIGURE 1
Transverse Frames



7 Side Transverses and Stringers in Forebody

7.1 Transverse Web Frames

The net section modulus of each web frame, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equation:

$$SM = kc_1c_2s\ell^2\,(h + bh_1/45K)Q \qquad \text{cm}^3$$

$$= kc_1c_2s\ell^2\,(h + bh_1/150K)Q \qquad \text{in}^3$$

where

k = 4.74 (0.0025)

c_1 = 1.5

c_2 = 0.95

s = spacing of the web frames, in m (ft)

ℓ = span, in m (ft), measured from the line of the inner bottom (extended to the side of the vessel) to the deck at the top of the web frames. Where effective brackets are fitted, the length ℓ may be modified as shown in 5C-5-4/Figure 9.

h = vertical distance, in m (ft), from the middle of ℓ to the load line. $h \geq 0.5\ell$

h_1 = vertical distance, in m (ft), from the deck at the top of the frame to the bulkhead or freeboard deck plus the height of all cargo tween-deck spaces, or plus 2.44 m (8 ft). if that is greater. Where the cargo load differs from 715 kgf/m^3 (45 lbf/ft^3) multiplied by the tween-deck height, in m (ft), the height of that tween-deck is to be proportionately adjusted in calculating h_1

b = horizontal distance in, m (ft), from the outside of the frame to the first row of deck supports, as shown in 5C-5-6/Figure 2.

K = 1.0, where the deck is longitudinally framed and a deck transverse is fitted in way of each web frame

= number of transverse frame spaces between web frames where the deck is transversely framed

Q = material conversion factor, as specified in 5C-5-4/5.

The depth and net thickness of the web are not to be less than d_w and t_w, respectively, as defined below:

$$d_w = 125\ell \qquad \text{mm}$$

$$= 1.5\ell \qquad \text{in.}$$

$$t_w = d_w/100 + a \qquad \text{mm (in.)}$$

need not be greater than 13.0 mm (0.51 in.)

ℓ is as defined above.

Web frames in way of deep-tank are to comply with 5C-5-6/19.5.

a = 2.5 (0.1)

7.3 Stringers

The net section modulus of each side stringer, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equation:

$$SM = kc_1c_2hs\ell^2Q \qquad \text{cm}^3\ (\text{in}^3)$$

where

k = 4.74 (0.0025)

c_1 = 1.5

c_2 = 0.95

Q = material conversion factor, as specified in 5C-5-4/5

h = vertical distance, in m (ft), from the middle of s to the load line, or to two-thirds of the distance from the keel to the bulkhead deck, or 1.8 m (6 ft), whichever is greatest

s = sum of the half lengths, in m (ft), (on each side of the stringer) of the frames supported

ℓ = span, in m (ft), between web frames, or between web frame and bulkhead; where brackets are fitted, the length ℓ may be modified as shown in 5C-5-4/Figure 9

The depth and net thickness of the stringer are not to be less than d_w and t_w, respectively, as defined below:

$$d_w = 125\ell + 0.25d_s \qquad \text{mm}$$

$$= 1.5\ell + 0.25d_s \qquad \text{in.}$$

but need not exceed depth of the web frames to which they are attached

$$t_w = 0.014L + 6.2 \qquad \text{mm} \qquad \text{for } L \leq 200 \text{ m}$$

$$= 0.007L + 7.6 \qquad \text{mm} \qquad \text{for } L > 200 \text{ m}$$

$$t_w = 0.00017L + 0.244 \qquad \text{in.} \qquad \text{for } L \leq 656 \text{ ft}$$

$$= 0.00008L + 0.3 \qquad \text{in.} \qquad \text{for } L > 656 \text{ ft}$$

d_S is the depth of the slot, in mm (in.), for the frames and ℓ is as defined above. In general, the depth of the stringer is not to be less than three (3) times the depth of the slots or the slots are to be fitted with filler plates.

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

Stringers in way of deep-tank are also to comply with 5C-5-6/19.5.

7.5 Fore Peak-stringer

The peak stringer net plate thickness t and breadth b are not to be less than that obtained from the following equations, respectively:

$$t = 0.014L + 5.7 \qquad \text{mm} \qquad \text{for } L \leq 200 \text{ m}$$

$$t = 0.007L + 7.1 \qquad \text{mm} \qquad \text{for } L > 200 \text{ m}$$

$$t = 0.00017L + 0.224 \qquad \text{in.} \qquad \text{for } L \leq 656 \text{ ft}$$

$$t = 0.00008L + 0.28 \qquad \text{in.} \qquad \text{for } L > 656 \text{ ft}$$

$b = 2.22L + 600$ mm

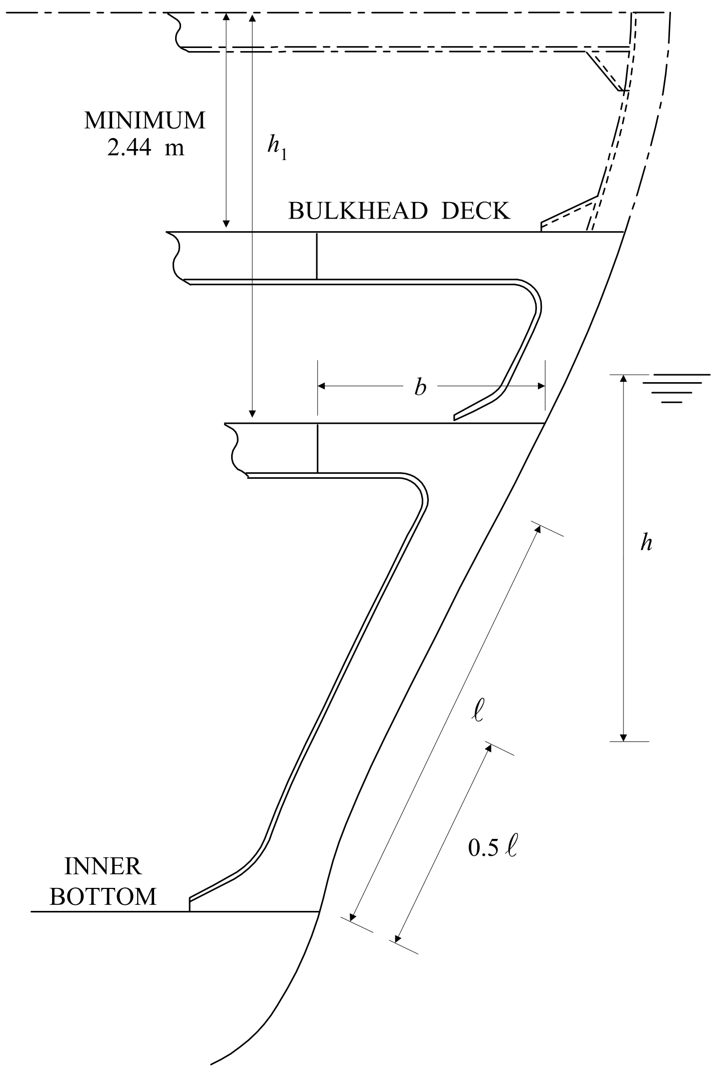
$= 0.027L + 23.5$ in.

where

L = length of vessel, as defined 3-1-1/3.1 in m (ft)

Where beams or struts are not fitted on every frame, the edge of the stringer is to be adequately stiffened by a flange or face bar.

FIGURE 2
Web Frames



9 Deck Structures

9.1 Strength Deck Plating Outside Line of Openings

The net thickness of the strength deck plating is to be not less than that required to meet the longitudinal hull girder strength. The deck area contributing to the hull girder strength for amidships 0.4L is to be gradually reduced to the end of the vessel. Where bending moment envelope curves are used to determine the required hull girder section modulus as permitted in 5C-5-4/3.1.3, the strength deck area is to be maintained a suitable distance beyond superstructure breaks and is to be extended into the superstructure to provide adequate structural continuity. The net thickness is also to be not less than t specified below, except within deckhouse where the plating may be reduced by 1 mm (0.04 in.).

9.1.1 For Longitudinally Framed Decks

$t = 0.009s_b + 1.4$ mm for $s_b \le 760$ mm (30 in.)

$= 0.009s_b + 0.055$ in.

$t = 0.006s_b + 3.7$ mm for $s_b > 760$ mm (30 in.)

$= 0.006s_b + 0.146$ in.

9.1.2 For Transversely Framed Decks

$t = 0.01s_b + 1.3$ mm for $s_b \le 760$ mm (30 in.)

$= 0.01s_b + 0.05$ in.

$t = 0.0066s_b + 3.9$ mm for $s_b > 760$ mm (30 in.)

$= 0.0066s_b + 0.154$ in.

where

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

s_b = spacing of deck beams, in mm (in.)

The net thickness of the deck plating for longitudinally framed decks constructed of higher-strength material is to be not less than that obtained from the following equation:

$$t_{hts} = (t_{ms} - C)Q + C$$

where

t_{hts} = net thickness of higher-strength material, in mm (in.)

t_{ms} = net thickness, in mm (in.), of ordinary-strength steel as required above

C = 3.3 (0.13)

Q = material conversion factor, as specified in 5C-5-4/5

$0.92/\sqrt{Q}$ is to be used in lieu of Q for application of 5C-5-6/9.1.2 and is not to be less than 1.0.

In general, where the deck plating is constructed of higher-strength material, the critical buckling stress of the plating is to be checked in accordance with Appendix 5C-5-A2.

The net thickness of the stringer plate is to be increased 25% in way of breaks of superstructures, but this increase need not exceed 6.5 mm (0.25 in.).

9.3 Strength Deck Plating Within Line of Openings

Within deckhouses, the plating may be of the thickness obtained from the following equations:

$t = 0.009s_b - 0.2$ mm for $s_b \le 685$ mm (27 in.)

$= 0.009s_b - 0.008$ in.

$t = 0.0039s_b + 3.3$ mm for $s_b > 685$ mm (27 in.)

$= 0.0039s_b + 0.13$ in.

s_b is as defined in 5C-5-6/9.1, above.

9.5 Forecastle Decks

The net thickness of exposed forecastle decks plating is to be not less than that obtained from 5C-5-6/9.1.2 above.

9.7 Platform Decks in Enclosed Spaces

The net thickness of the platform deck plating including lower decks is to be not less than that obtained from the following equation:

$t = ks_b\sqrt{h} + a$ mm (in.)

but not less than 4.0 mm (0.16 in.).

where

k = 0.00394 (0.00218)

a = 0.5 (0.02)

h = tween deck height, in m (ft)

= p/n when a design load, p, is specified

p = specified design load, in kN/m^2 (kgf/m^2, lbf/ft^2)

n = 7.05 (715, 45)

s_b is as defined in 5C-5-6/9.1.

Where the platform decks are subjected to hull girder bending, special consideration is to be given to the structural stability of deck supporting members. Appendix 5C-5-A2 may be applied.

9.9 Watertight Flats

Watertight flats over tunnels or forming recesses or steps in bulkheads are to be of not less thickness than required for the plating of ordinary bulkhead at the same level obtained from 5C-5-6/17.1 plus 1 mm (0.04 in.).

For decks forming tops of tanks see requirements in 5C-5-6/19.1.

9.11 Deck Longitudinals and Beams

9.11.1 Deck Longitudinals Outside the Line of Openings

The net sectional area of each deck longitudinal or beam, in association with the effective deck plating, is to be not less than that required to meet the longitudinal hull girder strength, nor is the associated net section modulus to be less than that obtained in 5C-5-6/9.11.2, below.

9.11.2 Beams *(1 July 2005)*

Each beam, in association with the plating, is to have a net section modulus SM not less than that obtained from the following equation:

$$SM = kc_1c_2hs\ell^2Q \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

where

k	=	7.8 (0.0041)	
s	=	spacing of beams, in m (ft.)	
c_1	=	0.585	for beams between longitudinal deck girders for longitudinal beams of platform decks and between hatches at all decks
	=	0.90	for beams at deep-tank tops supported at one or both ends at the shell or longitudinal bulkheads
	=	0.945	for longitudinal beams of strength decks and of effective lower decks
	=	1.0	for beams at deep-tank top between longitudinal girders
c_2	=	0.85	
ℓ	=	span of beams between effective supports, as shown in 5C-5-4/Figure 6, in m (ft)	
h	=	height, in m (ft), as follows:	
	=	for bulkhead recesses and tunnel flats, is the height to the bulkhead deck at the centerline; where that height is less than 6.10 m (20 ft), the value of h is to be taken as 0.8 times the actual height plus 1.22 m (4 ft)	
	=	for deep-tank tops, is not to be less than two-thirds of the distance from the top of the tank to the top of the overflow; it is not to be less than 1.3 m (4.27 ft), the height to the load line or two-thirds of the height to the bulkhead or freeboard deck, whichever is greatest	

Elsewhere, the value of h may be taken as follows:

h	=	2.9 m (9.5 ft)	for bulkhead or freeboard deck having no deck below
	=	2.29 m (7.5 ft)	for bulkhead or freeboard deck having deck below
	=	1.98 m (6.5 ft)	for lower decks and platform deck
	=	1.68 m (5.5 ft)	for forecastle deck above bulkhead deck
Q	=	material conversion factor, as specified in 5C-5-4/5	

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

Calculations are to be submitted to show adequate provision against buckling where higher-strength materials are used for deck beams. Longitudinal beams are to be essentially of the same material as the plating they support.

9.13 Deck Girders and Transverses Clear of Tanks

9.13.1 Section Modulus

Each deck girder or transverse is to have a net section modulus SM not less than obtained from the following equation:

$$SM = kc_1c_2bh\ell^2Q \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

where

k = 4.74 (0.0025)

c_1 = 1.0

c_2 = 0.95

b = mean breadth of the area of deck supported, in m (ft)

h = height, in m (ft), normally to be the height measured at the side of the vessel, of the cargo space wherever stores or cargo may be carried. Where the cargo load differs from 715 kgf/m^3 (45 lbf/ft^3) multiplied by the tween-deck height, in m (ft), the height is to be proportionately adjusted.

Elsewhere, the value of h may be taken as follows:

h	=	2.9 m (9.5 ft)	for bulkhead or freeboard deck having no deck below
	=	2.29 m (7.5 ft)	for bulkhead or freeboard deck having deck below
	=	1.98 m (6.5 ft)	for lower decks and platform deck
	=	1.68 m (5.5 ft)	for forecastle deck above bulkhead deck

ℓ = span between centers of supporting pillars, or between pillar and bulkhead, in m (ft). Where an effective bracket is fitted at the bulkhead, the length ℓ may be modified as shown in 5C-5-4/Figure 9.

Q = material conversion factor, as specified in 5C-5-4/5

9.13.2 Proportions

The depth and net thickness of the girders and transverses are not to be less than d_w and t_w, respectively, as defined below:

$$d_w = k\ell \qquad \text{mm (in.)}$$

$$t_w = d_w/100 + a \qquad \text{mm (in.)}$$

$\geq$ 7.5 mm (0.30 in.)	for $A_F \leq$ 38 cm^2 (5.27 in^2)
$\geq$ 9.0 mm (0.35 in.)	for $A_F \leq$ 46 cm^2 (8.84 in^2)
$\geq$ 11.5 mm (0.45 in.)	for $A_F \leq$ 101 cm^2 (18.14 in^2)
$\geq$ 14.0 mm (0.55 in.)	for $A_F >$ 165 cm^2 (27.44 in^2)

where

k = 58.3 (0.7)

a = 3 (0.12)

The thickness for intermediate face area may be obtained by linear interpolation.

A_F is the net face area and ℓ is as defined in 5C-5-6/9.13.1, above.

9.15 Deck Girders and Transverses in Tanks

Deck girders and transverses in tanks are to have net section modulus *SM* not less than obtained in the same manner as given in 5C-5-6/9.13.1 above, except the values of c_1 and h are to be as modified below. The proportionality requirements are to be the same as given in 5C-5-6/9.13.2 of the above, except that k for d_w is not to be less than 83.3 (1.0).

c_1 = 1.5

h = the greatest of the following distances, in m (ft), from the middle of ℓ to:

- A point located two-thirds of the distance from the top of the tank to the top of the overflow
- 1.3 m (4.27 ft) above the top of the tank
- The load line
- A point located at two-thirds of the distance to the bulkhead or freeboard deck

11 Pillars or Struts

11.1 Permissible Load

The permissible load W_a of a pillar or strut is to be obtained from the following equation which will, in all cases, be equal to or greater than the calculated load W as determined in 5C-5-6/11.3 below.

$$W_a = c_2(k - n\ell/r)A_c \qquad \text{kN(tf, Ltf)}$$

where

c_2 = 1.05

k	=	12.09 (1.232, 7.83)	ordinary strength steel
	=	16.11 (1.643, 10.43)	HT32
	=	18.12 (1.848, 11.73)	HT36

ℓ = unsupported span, in cm (ft)

The length ℓ is to be measured from the top of the inner bottom, deck or other structure on which the pillars or struts are based to the underside of the beam or girder supported.

r = least radius of gyration, in cm (in.)

A_c = net cross sectional area of pillar or strut, in cm^2 (in^2)

n	=	0.0444 (0.00452, 0.345)	ordinary strength steel
	=	0.0747 (0.00762, 0.581)	HT32
	=	0.0900 (0.00918, 0.699)	HT36

11.3 Calculated Load

The calculated load W for a pillar or strut is to be obtained from the following equation:

$W = nbhs$ kN(tf, Ltf)

where

n = 7.04 (0.715, 0.02)

b = mean breadth of the area supported, in m (ft)

h = height above the area supported, as defined below, in m (ft)

For pillars spaced not more than two frame spaces, the height h is to be taken as the distance from the deck supported to a point 3.80 m (12.5 ft) above the freeboard deck.

For wide-spaced pillars, the height h is to be taken as the distance from the deck supported to a point 2.44 m (8 ft) above the freeboard deck, except in the case of such pillars immediately below the freeboard deck, in which case, the value of h is not to be less than 2.9 m (9.5 ft) in measuring the distance from the deck supported to the specified height above the freeboard deck.

s = mean length of the area supported, in m (ft)

11.5 Pillars under the Tops of Deep Tanks

Pillars under the tops of deep tanks are not to be less than required by the foregoing. They are to be of solid sections and to have the net cross sectional area not less than A, as specified below:

$A = c_1 c_2\, nbhs$ cm^2 (in^2)

where

c_1 = 0.1035 (1.015, 0.16) ordinary strength steel

= 0.0776 (0.761, 0.12) HT32

= 0.069 (0.677, 0.107) HT36

c_2 = 0.95

n = 10.5 (1.07, 0.03)

b = breadth of the area of the top of the tank supported by the pillar, in m (ft)

s = length of the area of the top of the tank supported by the pillar, in m (ft)

h = two-thirds of the distance from the top of the tank to the top of the overflow; it is not to be less than 1.3 m (4.27 ft), the height to the load line or two-thirds of the height to the bulkhead or freeboard deck, whichever is greatest.

13 Transition Zone

13.1 General

In the transition zone in way of the forepeak bulkhead, consideration is to be given to the proper tapering of longitudinal members such as flats, decks, longitudinal bulkheads, horizontal ring frames or side stringers forward into the fore peak.

15 Fore-peak Structure

15.1 General

The center girder continued from the midship is to extend as far forward as practicable. Forepeak frames are to be efficiently connected to deep floors. The floors are to extend as high as necessary to give lateral stiffness to the structure and are to be properly stiffened on their upper edges. Care is to be taken in arranging the framing and floors to assure no wide areas of unsupported plating adjacent to the stem. Angle ties are to be fitted as required across the tops of the floors and across all tiers of beams or struts to prevent vertical or lateral movement. Breast hooks are to be arranged at regular intervals at and between the stringers above and below the waterline.

15.3 Center Girder and Floor Plating *(2001)*

The net thickness of the plating is not to be less than that obtained from the following equation, but need not exceed 12.5 mm (0.50 in.), provided the stiffeners are not spaced more than 1.22 m (4 ft).and the buckling strength is proven adequate (see 5C-5-A2/3).

t = $0.036L + 3.2$ mm

= $0.00043L + 0.126$ in.

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

Floors and girders, where constructed of higher-strength material, are to be not less in thickness than as modified by the following equation:

$$t_{hts} = [t_{ms} - C][(Q + 2\sqrt{Q})/3] + C$$

where

t_{hts} = net thickness of higher-strength material, in mm (in.)

t_{ms} = net thickness, in mm (in.), of ordinary-strength steel, as required above.

Q = material conversion factor, as specified in 5C-5-4/5

C = 1.5 (0.06)

15.5 Peak Frames

The net section modulus of each peak frame is to be in compliance with 5C-5-6/5.11.

Peak frames in way of fore peak tank are to be in compliance with 5C-5-6/19.3.

17 Watertight Bulkheads

17.1 Plating *(2002)*

The net thickness t of the bulkhead plating forming watertight boundaries is to be not less than obtained from the following equation:

$$t = sk\sqrt{qh}/C + a \quad \text{mm (in.)}$$

but not less than $t_{\min}$ or $s/200 + c_1$, whichever is greater.

where

$t_{\min}$ = 5.5 mm (0.22 in.) within cargo spaces

5.0 mm (0.20 in.) for other than cargo spaces

c_1 = 2.0 mm (0.08 in.) within cargo spaces

1.5 mm (0.06 in.) for other than cargo spaces

s = spacing of stiffeners, in mm (in.)

k = $(3.075\sqrt{\alpha} - 2.077)/(\alpha + 0.272)$ $(1 \leq \alpha \leq 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

q = $235/Y$ (N/mm^2), $24/Y$ (kgf/mm^2) or $34{,}000/Y$ (lbf/in^2)

Y = specified minimum yield point or yield strength, in N/mm^2 (kgf/mm^2, lbf/in^2), for the higher-strength material or 72% of the specified minimum tensile strength, whichever is the lesser

h = distance from the lower edge of the plate to the deepest equilibrium waterline in the one compartment damaged condition, in m (ft)

h is to be not less than the distance to the bulkhead deck at center unless a deck lower than the uppermost continuous deck is designated as the freeboard deck, as allowed in 3-1-1/13.1. In such case, h is to be not less than the distance to the designated freeboard deck at center.

C = 290 (525)

a = 1.0 (0.04) within cargo spaces

= 0.5 (0.02) for other than cargo spaces

17.3 Stiffeners *(2002)*

The net section modulus of each stiffener, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equation:

$$SM = kc_1c_2hs\ell^2Q \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

where

k = 7.8 (0.0041)

c_1 = 0.56

c_2 = 0.85

s = spacing of the stiffeners, in m (ft)

h = distance, in m (ft), from the middle of ℓ to the deepest equilibrium waterline in the one compartment damaged condition

h is to be not less than the distance to the bulkhead deck at center unless a deck lower than the uppermost continuous deck is designated as the freeboard deck, as allowed in 3-1-1/13.1. In such case, h is to be not less than the distance to the designated freeboard deck at center.

Where the distance indicated above is less than 6.10 m (20 ft), h is to be taken as 0.8 times the distance plus 1.22 m (4 ft)

ℓ = span of stiffeners between effective supports, as shown in 5C-5-4/Figure 6, in m (ft)

Q = material conversion factor, as specified in 5C-5-4/5

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

17.5 Girders and Webs

17.5.1 Section Modulus *(2002)*

Each girder and web which supports bulkhead stiffeners is to have a net section modulus *SM* not less than obtained from the following equation:

$$SM = kc_1c_2hs\ell^2Q \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

where

k = 4.74 (0.0025)

c_1 = 1.0

c_2 = 0.95

h = vertical distance, in m (ft), to the deepest equilibrium waterlline in the one compartment damaged condition from the middle of s in the case of girders, and from the middle of ℓ in the case of webs

h is to be not less than the distance to the bulkhead deck at center unless a deck lower than the uppermost continuous deck is designated as the freeboard deck, as allowed in 3-1-1/13.1. In such case, h is to be not less than the distance to the designated freeboard deck at center.

Where the distance indicated above is less than 6.10 m (20 ft), h is to be taken as 0.8 times the distance plus 1.22 m (4 ft).

s = sum of half lengths (on each side of girder or web) of the stiffener supported, in m (ft)

ℓ = span measured between the heel of end attachments, in m (ft). Where an effective bracket is fitted at the bulkhead, the length ℓ may be modified as shown in 5C-5-4/Figure 9.

Q = material conversion factor, as specified in 5C-5-4/5

17.5.2 Proportions

The depth and net thickness of the girders and webs are not to be less than d_w and t_w, respectively, as defined below:

d_w = $83.3\ell + 0.25d_S$ mm

= $\ell + 0.25d_s$ in.

t_w = $d_w/100 + 2.0$ mm need not exceed 10.5 mm (0.41 in.)

= $d_w/100 + 0.08$ in.

d_S is the depth of the slots for the stiffeners, in mm (in.) and ℓ is as defined in 5C-5-6/17.5.1 above.

19 Deep Tank Bulkheads

This section applies to deep tank bulkheads where the requirements in this section exceed those of 5C-5-6/17.

19.1 Plating *(1 July 2005)*

The net thickness t of bulkhead plating forming tank boundaries is to be not less than obtained from the following equation:

$$t = sk\sqrt{qh}/C + a \qquad \text{mm (in.)}$$

but not less than 5.0 mm (0.2 in.) or s/150 + 1.0 mm (s/150 + 0.04 in.), whichever is greater.

where

s = spacing of stiffeners, in mm (in.)

k = $(3.075\sqrt{\alpha} - 2.077)/(\alpha + 0.272)$ $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

q = $235/Y$ (N/mm^2), $24/Y$ (kgf/mm^2) or $34{,}000/Y$ (lbf/in^2)

Y = specified minimum yield point or yield strength, in N/mm^2 (kgf/mm^2, lbf/in^2), for the higher-strength material or 72% of the specified minimum tensile strength, whichever is the lesser

h = the greatest of the following distances, in m (ft), from the lower edge of the plate to:

- A point located two-thirds of the distance from the top of the tank to the top of the overflow; where a side wing tank top extends to the underdeck passageway (second deck), this distance need not be greater than one-third of the distance from the second deck to the top of the overflow
- 1.3 m (4.27 ft) above the top of the tank
- The load line
- A point located at two-thirds of the distance to the bulkhead or freeboard deck

C = 254 (460)

a = 1.0 (0.04)

The tops of tanks are to have plating 0.5 mm (0.02 in.) thicker than would be required for vertical plating at the same level.

19.3 Stiffeners *(1 July 2005)*

The net section modulus of each stiffener, in association with the effective plating to which it is attached, is not to be less than that obtained from the following equation:

$$SM = kc_1c_2hs\ell^2Q \qquad \text{cm}^3\ (\text{in}^3)$$

where

k = 7.8 (0.0041)

c_1 = 0.90

c_2 = 0.85

s = spacing of the stiffeners, in m (ft)

h = the greatest of the following distances, in m (ft), from the middle of ℓ to:

- A point located two-thirds of the distance from the top of the tank to the top of the overflow; where a side wing tank top extends to the underdeck passageway (second deck), this distance need not be greater than one-third of the distance from the second deck to the top of the overflow
- 1.3 m (4.27 ft) above the top of the tank
- The load line
- A point located at two-thirds of the distance to the bulkhead or freeboard deck

ℓ = span of stiffeners between effective supports, as shown in 5C-5-4/Figure 6, in m (ft)

Q = material factor, as specified in 5C-5-4/5

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5

19.5 Girders and Webs

19.5.1 Section Modulus

Each girder and web which support bulkhead stiffeners are to have a net section modulus SM not less than obtained from the following equation:

$$SM = kc_1c_2sh\ell^2Q \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

where

k = 4.74 (0.0025)

c_1 = 1.5

c_2 = 0.95

h = vertical distance, in m (ft), from the middle of s in the case of girders, and from the middle of ℓ in the case of webs to the same height to which h for the stiffeners is measured. See 5C-5-6/19.3, above.

s = sum of half lengths (on each side of girder or web) of the frame or stiffener supported, in m (ft)

ℓ = span measured between the heels of the end of the attachments, in m (ft). Where effective brackets are fitted, the length ℓ may be modified as shown in 5C-5-4/Figure 9.

Q = material conversion factor, as specified in 5C-5-4/5

19.5.2 Proportions

The depth and net thickness of the girders and webs are to be not less than d_w and t_w, respectively, as defined below:

d_w	=	$145\ell + 0.25d_S$	mm	
		where no struts or ties are fitted		
	=	$1.74\ell + 0.25d_S$	in.	
	=	$83.3\ell + 0.25d_S$	mm	
		where struts are fitted		
	=	$\ell + 0.25d_S$	in.	
t_w	=	$d_w/100 + 1.5$	mm	need not exceed 10.0 mm (0.4 in.)
	=	$d_w/100 + 0.06$	in.	

d_S is the depth of the slots, in mm (in.), for the stiffeners and ℓ is as defined above. In general, the depth of the girder or web is not to be less than three (3) times the depth of the slots or the slots are to be fitted with filler plates.

21 Collision Bulkheads

21.1 Plating *(2002)*

The net thickness t of the collision bulkhead plating is to be not less than obtained from the following equation:

$t = sk\sqrt{qh}/C + \alpha$ mm (in.)

but not less than t_{min} or $s/200 + c_1$, whichever is greater.

where

t_{min}	=	5.5 mm (0.22 in.)	within cargo spaces
		5.0 mm (0.20 in.)	for other than cargo spaces
c_1	=	2.0 mm (0.08 in.)	within cargo spaces
		1.5 mm (0.06 in.)	for other than cargo spaces
s	=	spacing of stiffeners, in mm (in.)	
k	=	$(3.075\sqrt{\alpha} - 2.077)/(\alpha + 0.272)$	$(1 \leq \alpha \leq 2)$
	=	1.0	$(\alpha > 2)$
α	=	aspect ratio of the panel (longer edge/shorter edge)	
q	=	235/Y (N/mm^2), 24/Y (kgf/mm^2) or 34,000/Y (lbf/in^2)	
Y	=	specified minimum yield point or yield strength, in N/mm^2 (kgf/mm^2, lbf/in^2), for the higher-strength material or 72% of the specified minimum tensile strength, whichever is the lesser	

h = distance from the lower edge of the plate to the deepest equilibrium waterline in the one compartment damaged condition , in m (ft)

h is to be not less than the distance to the bulkhead deck at center unless a deck lower than the uppermost continuous deck is designated as the freeboard deck, as allowed in 3-1-1/13.1. In such case, *h* is to be not less than the distance to the designated freeboard deck at center.

C = 254 (460)

α = 1.0 (0.04) within cargo spaces

= 0.5 (0.02) for other than cargo spaces

Where the plating of collision bulkheads forms tank boundaries, the plating is not to be less than required for bulkhead plating obtained in 5C-5-6/19.1.

21.3 Stiffeners *(2002)*

The net section modulus of each stiffener, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equation:

$$SM = kc_1c_2hs\ell^2Q \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

where

k = 9.75 (0.0051)

c_1 = 0.56

c_2 = 0.85

s = spacing of the stiffeners, in m (ft)

h = distance, in m (ft), from the middle of ℓ to the deepest equilibrium waterline in the one compartment damaged condition

h is to be not less than the distance to the bulkhead deck at center unless a deck lower than the uppermost continuous deck is designated as the freeboard deck, as allowed in 3-1-1/13.1. In such case, *h* is to be not less than the distance to the designated freeboard deck at center.

Where the distance indicated above is less than 6.10 m (20 ft), *h* is to be taken as 0.8 times the distance plus 1.22 m (4 ft).

ℓ = span of stiffeners between effective supports, as shown in 5C-5-4/Figure 6, in m (ft)

Q = material conversion factor, as specified in 5C-5-4/5

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

For stiffeners on bulkheads forming a tank boundary, the net section modulus is not to be less than required for stiffeners obtained in 5C-5-6/19.3.

21.5 Girders and Webs

21.5.1 Section Modulus *(2002)*

Each girder and web which supports bulkhead stiffeners is to have a net section modulus *SM* not less than obtained from the following equation:

$$SM = k\,c_1c_2hs\ell^2Q \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

where

k = 5.925 (0.0031)

c_1 = 1.0

c_2 = 0.95

h = vertical distance, in m (ft), to the deepest equilibrium waterline in the one compartment damaged condition from the middle of s in the case of girders, and from the middle of ℓ in the case of webs

h is to be not less than the distance to the bulkhead deck at center unless a deck lower than the uppermost continuous deck is designated as the freeboard deck, as allowed in 3-1-1/13.1. In such case, h is to be not less than the distance to the designated freeboard deck at center.

Where the distance indicated above is less than 6.10 m (20 ft), h is to be taken as 0.8 times the distance plus 1.22 m (4 ft).

s = sum of half lengths (on each side of girder or web) of the stiffener supported, in m (ft)

ℓ = span measured between the heels of end attachments, in m (ft). Where an effective bracket is fitted at the bulkhead, the length ℓ may be modified as shown in 5C-5-4/Figure 9.

Q = material factor, as specified in 5C-5-4/5

Where the girders and webs form tank boundaries, the net section modulus is to comply with 5C-5-6/19.5.

21.5.2 Proportions

The depth and net thickness of the girders and webs are to be not less than d_w and t_w, respectively, as defined below:

$d_w = 83.3\ell + 0.25d_S$ mm

$= \ell + 0.25d_S$ in.

$t_w = d_w/100 + 2.0$ mm need not exceed 10.5 mm (0.41 in.)

$= d_w/100 + 0.08$ in.

d_S is the depth of the slots, in mm (in.), for the stiffeners and ℓ is as defined above.

Where the girders and webs form tank boundaries, the proportions are to be in compliance with 5C-5-6/19.5.

23 Structure Strengthening for Impact Loads

Where the hull structure is subject to impact loads as specified in 5C-5-3/5.3 or 5C-5-3/11, appropriate strengthening is to be required, as outlined below.

23.1 Bottom Slamming

When bottom slamming as specified in 5C-5-3/11.1 is considered, the bottom structure in the region of the flat of bottom forward of 0.25L from the FP is to be in compliance with the following requirements.

23.1.1 Bottom Plating

The net thickness of the flat of bottom plating forward of $0.25L$ from the FP is not to be less than t_1 or t_2, whichever is greater, obtained from the following equations:

$$t_1 = 0.73s(k_1 p_s/f_1)^{1/2} \quad \text{mm (in.)}$$

$$t_2 = 0.73s(k_2 p_s/f_2)^{1/2} \quad \text{mm (in.)}$$

where

s = spacing of longitudinals or transverse stiffeners, in mm (in.)

k_1 = 0.342 for longitudinally stiffened plating

= $0.5k^2$ for transversely stiffened plating

k_2 = 0.5 for longitudinally stiffened plating

= 0.342 for transversely stiffened plating

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$ $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

p_s = the maximum slamming pressure = $k_u p_{si}$

p_{si} = nominal bottom slamming pressure, as specified in 5C-5-3/11.1 at the center of the panel, in N/cm² (kgf/cm², lbf/in²)

k_u = slamming load factor = 1.1

f_1 = permissible bending stress in the longitudinal direction, in N/cm² (kgf/cm², lbf/in²)

= $0.85 S_m f_y$ forward of $0.125L$ from the FP

= $0.75 S_m f_y$ between $0.125L$ and $0.25L$, from the FP

f_2 = permissible bending stress in the transverse direction, in N/cm² (kgf/cm², lbf/in²)

= $0.85 S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

23.1.2 Bottom Longitudinals and Frames

The section modulus of the frame, including the associated effective plating on the flat of bottom plating forward of $0.25L$ from the FP, is not to be less than that obtained from the following equation:

$$SM = M/f_b \quad \text{cm}^3 \text{ (in}^3\text{)}$$

$$M = p_s s \ell^2 10^3/k \quad \text{N-cm (kgf-cm, lbf-in)}$$

where

k = 16 (16, 111.1)

p_s = the maximum slamming pressure = $k_u p_{si}$

p_{si} = nominal bottom slamming pressure, as specified in 5C-5-3/11.1, at the midpoint of the span ℓ, in N/cm² (kgf/cm², lbf/in²)

k_u = slamming load factor = 1.1

s = spacing of longitudinal or transverse frames, in mm (in.)

ℓ = the unsupported span of the frame, as shown in 5C-5-4/Figure 6, in m (ft)

f_b = $0.9\ S_m f_y$ for transverse and longitudinal frames in the region forward of 0.125L from the FP, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.8\ S_m f_y$ for longitudinal frames in the region between 0.125L and 0.25L from the FP, in N/cm^2 (kgf/cm^2, lbf/in^2)

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

Struts connecting the bottom and inner bottom longitudinals are not to be fitted.

23.3 Bowflare Slamming

When bowflare slamming as specified in 5C-5-3/11.3 is considered, the side shell structure above the waterline in the region between 0.0125L and 0.25L from the FP is to be in compliance with the following requirements in addition to 5C-5-6/5.

23.3.1 Side Shell Plating *(2007)*

The net thickness of the side shell plating between 0.0125L and 0.25L from the FP is not to be less than t_1 or t_2, whichever is greater, obtained from the following equations:

$t_1 = 0.73s(k_1\, p_s/f_1)^{1/2}$ in mm (in.)

$t_2 = 0.73s(k_2\, p_s/f_2)^{1/2}$ in mm (in.)

where

s = spacing of longitudinal or transverse frames, in mm (in.)

k_1 = 0.342 for longitudinally stiffened plating

= $0.5\ k^2$ for transversely stiffened plating

k_2 = 0.5 for longitudinally stiffened plating

= 0.342 for transversely stiffened plating

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

p_s = the design slamming pressure = $k_u p_{ij}$

p_{ij} = nominal bowflare slamming pressure, as specified in 5C-5-3/11.3.1, at the center of the supported panel under consideration, in N/ cm^2 (kgf/cm^2, lbf/in^2)

k_u = slamming load factor = 1.1

f_1 = $0.9\ S_m f_y$ for side shell plating in the region between 0.0125L and 0.125L, from the FP, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.75\ S_m f_y$ for side shell plating in the region between 0.125L and 0.25L, from the FP, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_2 = $0.9\ S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

S_m and f_y are as defined in 5C-5-4/11.3.1.

23.3.2 Side Longitudinals and Frames

The net section modulus of the frame, including the associated effective plating, is not to be less than that obtained from the following equation:

$SM = M/f_b$ in cm^3 (in^3)

$M = p_s s \ell^2 10^3/k$, in N-cm (kgf-cm, lbf-in)

where

k = 16 (16, 111.1)

ℓ = unsupported span of the frame, as shown in 5C-5-4/Figure 6, in m (ft)

p_s = the maximum slamming pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in 5C-5-6/23.3.1 above, at the midpoint of the span ℓ

s = spacing of longitudinal or transverse frames, in mm (in.)

f_b = $0.9\, S_m f_y$ for transverse and longitudinal frames in the region between $0.0125L$ and $0.125L$, from the FP

= $0.8\, S_m f_y$ for longitudinal frames in the region between $0.125L$ and $0.25L$ from the FP, in N/cm^2 (kgf/cm^2, lbf/in^2)

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

S_m and f_y are as defined in 5C-5-4/11.3.1.

23.3.3 Side Transverses and Stringers *(1 July 2008)*

Note: When the scantlings of side transverses and stringers are evaluated, the section modulus and effective shear area are to be calculated with due consideration to the inclined angle (5C-5-1/3). If the flange of such a member is constructed in a less effective way to resist bending (such as snipped close to the most critical area), the section modulus is to be calculated without considering the contribution from the flange.

23.3.3(a) Section Modulus. The net section modulus of side transverse and stringer, in association with the effective side shell plating, is not to be less than that obtained from the following equation:

$SM = M/f_b$ in cm^3 (in^3)

i) *Longitudinally Framed Side Shell*

For side stringer

$M = c_1 c_2\, p s \ell_t \ell_s 10^5/k$ in N-cm (kgf-cm, lbf-in)

For side transverse, M is not to be less than M_1 or M_2, whichever is greater

$M_1 = c_3\, p s\, \ell_t^2 (1.0 - c_4 \phi) 10^5/k$ in N-cm (kgf-cm, lbf-in)

$M_2 = p_1 s\, \ell_t^2\, 10^5/k$ in N-cm(kgf-cm, lbf-in)

where

k = 12 (12, 44.64)

c_1 = $0.125 + 0.875\phi$, but not less than 0.3

Coefficients c_2, c_3 and c_4 are given in the 5C-5-6/Tables 1, 2 and 3, respectively.

p = slamming pressure = $k_u\, p_{ij}$, in kN/m^2 (tf/m^2, Ltf/ft^2)

For side transverse; p is taken at the midspan of ℓ_t of the side transverse under consideration.

For side stringer; p is taken at the midspan of ℓ_s of the stringer under consideration.

p_1 = slamming pressure, in kN/m^2 (tf/m^2, Lft/ft^2), at the midspan of ℓ_{t1} of the side transverse under consideration.

= $k_u p_{ij}$

k_u = slamming load factor = 0.71

p_{ij} = nominal bowflare slamming pressure, in kN/m^2 (tf/m^2, Lft/ft^2), as defined in 5C-5-3/11.3.1

s = sum of half distances on each side of a transverse, in m (ft), between the side transverse under consideration and adjacent side transverses or transverse bulkhead (strength bulkhead)

= $0.45\ell_s$ for stringer

ϕ = $1/(1 + \alpha)$

α = $1.33(I_t/I_s)(\ell_s/\ell_t)^3$

I_t = moment of inertia, in cm^4 (in^4), (with effective side plating) of side transverse. I_t is to be taken as average of those at the middle of each span ℓ_{t1} between side stringers or side stringer and platform (flat), clear of the bracket

I_s = moment of inertia, in cm^4 (in^4), (with effective side plating) of side stringer at the middle of the span ℓ_s clear of the bracket

ℓ_t = spans, in m (ft), of the side transverse under consideration between platforms or flats, as shown in 5C-5-6/Figure 3b

ℓ_s = spans, in m (ft), of the side stringer under consideration between transverse bulkheads or strength bulkheads, as shown in 5C-5-6/Figure 3a

ℓ_{t1} = span, in m (ft), of side transverse under consideration between stringers, or stringer and platform (flat), as shown in 5C-5-6/Figure 3b

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.75\, S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

The bending moment for side transverse below stringer (or below the platform if no stringer is fitted) is not to be less than 80% of that for side transverse above stringer (or above platform if no stringer is fitted).

TABLE 1
Coefficient c_2 *(1 July 2008)*

Number of Side Stringers Between Platforms (flats)	*No Stringer*	*One Stringer*	*More than One Stringer*
Stringer	0.0	1.06	0.94

TABLE 2
Coefficient c_3 *(1 July 2008)*

Number of Side Stringers Between Platforms (flats)	*No Stringer*	*One Stringer*	*More than One Stringer*
Transverse	1.0	0.80	0.80

TABLE 3
Coefficient c_4

Number of Side Stringers Between Platforms (flats)	*No Stringer*	*One Stringer*	*More than One Stringer*
Transverse	0.0	0.75	0.80

ii) *Transversely Framed Side Shell*

For side transverse

$M = c_1\, ps\ell_t\ell_s 10^5/k$ in N-cm (kgf-cm, lbf-in)

For side stringer, M is not to be less than M_1 or M_2, whichever is greater

$M_1 = c_2\, ps\,\ell_s^2(1.0 - c_3\phi_1)10^5/k$ in N-cm (kgf-cm, lbf-in)

$M_2 = 1.30 p_1\, s\,\ell_{s1}^2\, 10^5/k$ in N-cm (kgf-cm, lbf-in)

where

k = 12 (12, 44.64)

c_1 = $0.12 + 0.82\phi_1$, but not to be taken less than 0.1

If no side transverses are fitted between transverse bulkheads or strength bulkheads

c_2 = 1.3

c_3 = 0

If side transverses are fitted between transverse bulkheads or strength bulkheads

c_2 = 0.94

c_3 = 0.8

p is as defined in 5C-5-6/23.3.3(a)i) above.

p_1 = slamming pressure, in kN/m^2 (tf/m^2, Lft/ft^2), at the midspan of ℓ_{s1} of the side stringer under consideration.

= $k_u\, p_{ij}$

p_{ij} = nominal bowflare slamming pressure, in kN/cm^2 (tf/m^2, Ltf/ft^2), as defined in 5C-5-3/11.3.1

k_u = slamming load factor = 0.71

s = sum of half distances, in m (ft), between side stringer under consideration and adjacent side stringers or platforms (flats), on each side of the stringer.

= for transverse; $0.45\ell_t$

ϕ_1 = $\alpha/(1+\alpha)$

ℓ_{s1} = span, in m (ft), of side stringer under consideration between side transverses, or side transverse and transverse bulkhead (strength bulkhead), as shown in 5C-5-6/Figure 3a

f_b = permissible bending stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.75\, S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

ℓ_t, ℓ_s and α are as defined in 5C-5-6/23.3.3(a)i) above.

23.3.3(b) Sectional Area of Web. The net sectional area of the web portion of the side transverse and side stringer is not to be less than that obtained from the following equation:

$A = F/f_s$ cm^2 (in^2)

i) Longitudinally Framed Side Shell

For side stringer

$F = kc_1\, p\ell s 10^3$ in N (kgf, lbf)

For side transverse, F is not to be less than F_1 or F_2, whichever is greater

$F_1 = kc_2\, p\ell s(1.0 - c_3\phi - 2h_e/\ell)10^3$ in N (kgf, lbf)

$F_2 = 2kc_2\, p_1 s(0.5\ell_1 - h_e)10^3$ in N (kgf, lbf)

where

k = 0.5 (0.5, 1.12)

c_2 = 1.0

Coefficients c_1, and c_3 are given in the 5C-5-6/Table 4 and 5C-5-6/Table 5, respectively.

ℓ = span, in m (ft), of the side transverse under consideration between platforms (flats), as shown in 5C-5-6/Figure 3b

ℓ_1 = span, in m (ft), of the side transverse under consideration between side stringers or side stringer and platforms (flats), as shown in 5C-5-6/Figure 3b

h_e = length, in m (ft), of the end bracket of the side transverse, as shown in 5C-5-6/Figure 3b

To obtain F_1, h_e is equal to the length of the end bracket at the end of span ℓ of side transverse, as shown in 5C-5-6/Figure 3b.

To obtain F_2, h_e is equal to the length of the end bracket at the end of span ℓ_1 of side transverse, as shown in 5C-5-6/Figure 3b.

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\, S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

p, p_1, ϕ and s are as defined in 5C-5-6/23.3.3(a)i).

The shear force for the side transverse below the lowest stringer (or below the platform if no stringer is fitted) is not to be less than 110% of that for the side transverse above the top stringer (or above the platform if no stringer is fitted).

TABLE 4
Coefficient c_1 *(1 July 2008)*

Number of Side Stringers Between Platforms (flats)	*No Stringer*	*One Stringer*	*More than One Stringer*
Stringers	0.0	0.61	0.72

TABLE 5
Coefficient c_3

Number of Side Stringers Between Platforms (flats)	*No Stringer*	*One Stringer*	*More than One Stringer*
Transverses	0.0	0.5	0.6

ii) Transversely Framed Side Shell

For side transverse

$F = kc_1 p\ell s 10^3$ in N (kgf, lbf)

For side stringer, F is not to be less than F_1 or F_2, whichever is greater

$F_1 = 1.18kp\ell s(1.0 - 0.6\phi_1 - 2h_e/\ell)10^3$ in N (kgf, lbf)

$F_2 = 2.4kp_1 s(0.5\ell_1 - h_e)10^3$ in N (kgf, lbf)

where

k = 0.5 (0.5, 1.12)

c_1 = $0.1 + 0.7\phi_1$, but not to be taken less than 0.2

ℓ = span, in m (ft), of the side stringer under consideration between transverse bulkheads, as shown in 5C-5-6/Figure 3a

ℓ_1 = span, in m (ft), of the side stringer under consideration between side transverses or side transverse and bulkhead, as shown in 5C-5-6/Figure 3a

h_e = length, in m (ft), of the end bracket of the side stringer under consideration, as shown in 5C-5-6/Figure 3a

To obtain F_1, h_e is equal to the length of the end bracket at the end of span ℓ of side stringer, as shown in 5C-5-6/Figure 3a.

To obtain F_2, h_e is equal to the length of the end bracket at the end of span ℓ_1 of side stringer, as shown in 5C-5-6/Figure 3a.

f_s = permissible shear stress, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $0.45\, S_m f_y$

S_m and f_y are as defined in 5C-5-4/11.3.1.

p, p_1, ϕ and s are as defined in 5C-5-6/23.3.3(a)ii) above.

23.3.3(c) Depths of Side Transverses and Stringers. The depths of side transverses and stringers d_w are neither to be less than that obtained from the following equations nor be less than 2.5 times the depth of the slots, respectively.

i) Longitudinally Framed Side Shell

For side transverse

If side stringer is fitted between platforms (flats)

$d_w = (0.08 + 0.80\alpha)\ell_t$ for $\alpha \le 0.05$

$= (0.116 + 0.084\alpha)\ell_t$ for $\alpha > 0.05$ and need not be greater than $0.2\ell_t$

If no side stringer is fitted between platforms (flats):

$d_w \ge 0.2\ell_t$

For side stringer

$d_w = (0.42 - 0.9\alpha)\ell_s$ for $\alpha \le 0.2$

$= (0.244 - 0.0207\alpha)\ell_s$ for $\alpha > 0.2$

α is not to be taken greater than 8.0 to determine the depth of the side stringer.

ℓ_t, ℓ_s and α are as defined in 5C-5-6/23.3.3(a)i), above.

ii) Transversely Framed Side Shell

For side stringer

If side transverse is fitted between transverse bulkheads

$d_w = (0.08 + 0.80\alpha_1)\ell_s$ for $\alpha_1 \le 0.05$

$= (0.116 + 0.084\alpha_1)\ell_s$ for $\alpha_1 > 0.05$ and need not be greater than $0.2\ell_s$

If no side transverse is fitted between transverse bulkheads

$d_w = 0.2\ell_s$

For side transverse

$d_w = (0.277 - 0.385\alpha_1)\ell_t$ for $\alpha_1 \le 0.2$

$= (0.204 - 0.0205\alpha_1)\ell_t$ for $\alpha_1 > 0.2$

α is not to be taken greater than 7.5 to determine the depth of the side transverse.

where

$\alpha_1 = 1/\alpha$

ℓ_t, ℓ_s and α are as defined in 5C-5-6/23.3.3(a)i), above.

23.5 Bow Strengthening

When impact loads on bow, as specified in 5C-5-3/5.3.4, is considered, the side shell structure above the waterline in the region forward of collision bulkhead is to be in compliance with the following requirements in addition to 5C-5-6/5.

23.5.1 Side Shell Plating *(1999)*

The net thickness of the side shell plating is not to be less than t_3, obtained from the following equations:

$$t_3 = 0.73sk(k_3\, p_b/f_3)^{1/2} \quad \text{in mm (in.)}$$

where

s = spacing of longitudinal or transverse frames, in mm (in.)

k_3 = 0.5

k = $(3.075(\alpha)^{1/2} - 2.077)/(\alpha + 0.272)$, $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

p_b = the design bow pressure = $k_u\, p_{bij}$

p_{bij} = nominal bow pressure, as specified in 5C-5-3/5.3.4(a), at the center of the supported panel under consideration, in N/cm^2 (kgf/cm^2, lbf/in^2)

k_u = impact load factor = 1.1

f_3 = $0.85\, S_m f_y$, in N/cm^2 (kgf/cm^2, lbf/in^2)

S_m and f_y are as defined in 5C-5-4/11.3.1.

23.5.2 Side Longitudinals and Frames

The net section modulus of the frame, including the effective plating, is not to be less than that obtained from the following equation:

$$SM = M/f_{bi} \quad \text{in cm}^3 \text{ (in}^3\text{)}$$

$$M = p_b s \ell^2 10^3/k \quad \text{in N-cm (kgf-cm, lbf-in)}$$

where

k = 16 (16, 111.1)

ℓ = unsupported span of the frame, as shown in 5C-5-4/Figure 6, in m (ft)

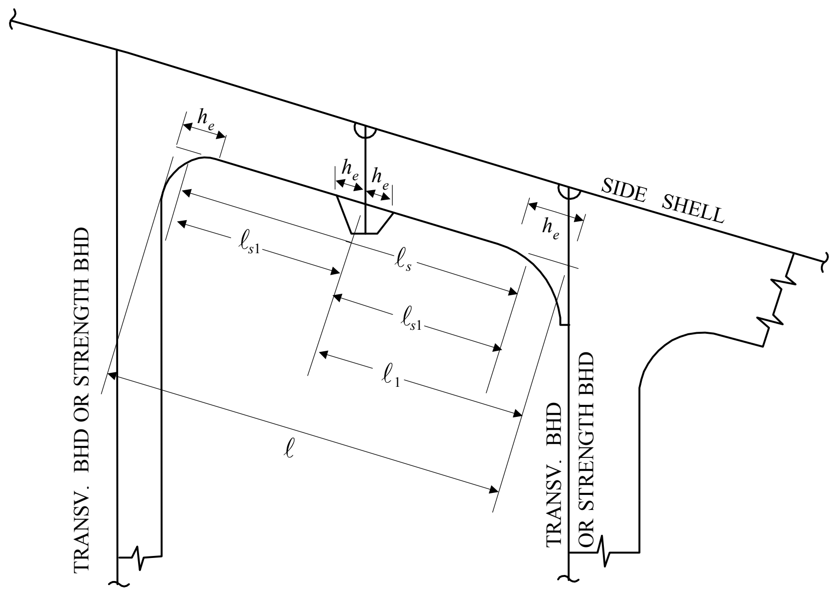
p_b = the maximum bow pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), as defined in 5C-5-6/23.5.1 above, at the midpoint of the span ℓ

s = spacing of longitudinal or transverse frames, in mm (in.)

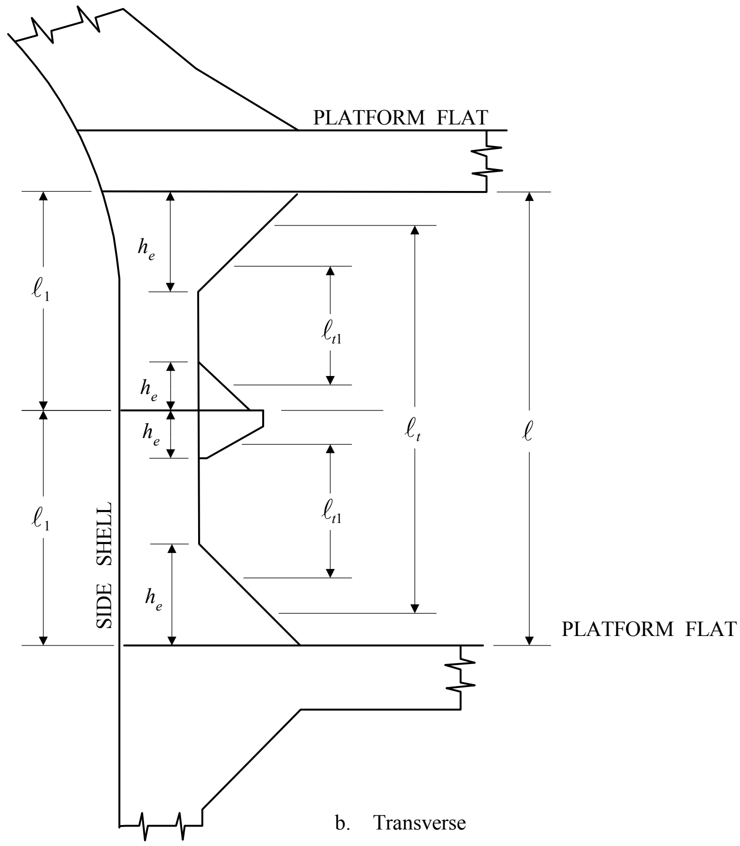
f_{bi} = $0.9\, S_m f_y$ for transverse and longitudinal frames

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

FIGURE 3
Definition of Spans



a. Stringer



b. Transverse

25 Aftbody and Machinery Space Structure

25.1 Bottom Structure

25.1.1 Bottom Shell Plating

The minimum net thickness of the bottom shell plating is not to be less than t, obtained from the following equations and is not to extend for more than 0.1L from the aft end.

Between the midship 0.4L and 0.1L from the aft end, the thickness of the plating may be gradually tapered.

$t = 0.03(L + 29) + 0.009s$ mm for $L \leq 305$ m

$t = (10.70 + 0.009s)\sqrt{D/35}$ mm for $L > 305$ m

$t = 0.00036(L + 95) + 0.009s$ in. for $L \leq 1000$ ft

$t = (0.402 + 0.009s)\sqrt{D/114.8}$ in. for $L > 1000$ ft

where

s = after peak frame spacing, in mm (in.)

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

D = molded depth, as defined in 3-1-1/7.1, in m (ft), or 35 m (114.8 ft), whichever is greater

The net bottom-shell plating where constructed of higher-strength material is not to be less in thickness than that obtained from the following equation:

$$t_{hts} = [t_{ms} - C]\,[(Q + 2\sqrt{Q}\,)/3] + C$$

where

t_{hts} = net thickness of higher-strength material, in mm (in.)

t_{ms} = net thickness, in mm (in.), of ordinary-strength steel, as required above

Q = material conversion factor, as specified in 5C-5-4/5

C = 3.3 (0.13)

In determining the thickness of bottom shell plating constructed of higher-strength material and transversely framed, the critical buckling stress of the plating is to be checked in accordance with Appendix 5C-5-A2.

Shell plating is also not to be less in thickness than required by 5C-5-6/25.17 for deep tanks.

25.1.2 Bottom Longitudinals and Transverse Frames

Frames are not to have less strength than is required in 5C-5-6/25.1.2(a) and 5C-5-6/25.1.2(b) below, respectively. In way of deep tanks, they are not to have less strength than is required in 5C-5-6/25.17 for stiffeners on deep-tank bulkheads.

25.1.2(a) Bottom Longitudinals. The net section modulus of the bottom longitudinal, required by 5C-5-4/11.5 for 0.4L amidship may be gradually reduced to the values required by 5C-5-6/25.5.4(a) toward 0.1L from the end, provided that the hull girder section modulus at the location under consideration is in compliance with the requirements given in 5C-5-4/3.1.1. In no case is the net section modulus of each bottom shell longitudinal, in association with the effective plating to which it is attached, to be less than obtained from the equations 5C-5-6/25.5.4(a).

25.1.2(b) Bottom Transverse Frames. The bottom shell transverse frame, in association with the effective plating, is to be not less than that obtained from the following equation:

$SM = kc_1c_2hs\ell^2Q$ $\quad$ cm^3 (in^3)

where

k = 7.8 (0.0041)

s = spacing of the frames, in m (ft)

c_1 = 1.0

c_2 = 0.85

h = the vertical distance, in m (ft), from the middle of ℓ to the load line, or two-thirds of the distance to the bulkhead deck or freeboard deck, whichever is greater

ℓ = span of frames between effective supports, in m (ft), as shown in 5C-5-4/Figure 6

Q = material conversion factor, as specified in 5C-5-4/5

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

25.3 Double Bottom in Engine Space

25.3.1 Depth

The depth of the double bottom in the engine space, d_{DB}, is not to be less than that obtained from the following equation:

$d_{DB} = 32B + 190\sqrt{d}$ $\quad$ mm

$d_{DB} = 0.384B + 4.13\sqrt{d}$ $\quad$ in.

where

B = breadth of vessel, as defined in 3-1-1/5, in m (ft)

d = molded draft of vessel, as defined in 3-1-1/9, in m (ft)

25.3.2 Center Girder

The net thickness of center-girder plates is not to be less than that obtained from the following equation:

$t = 0.056L + 4.0$ $\quad$ mm

$t = 0.00067L + 0.157$ $\quad$ in.

25.3.3 Solid Floors and Side Girders *(2001)*

The net thickness of solid floors and side girders is not to be less than that obtained from the following equation:

$t = 0.036L + 3.2$ $\quad$ mm

$t = 0.00043L + 0.126$ $\quad$ in.

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

Solid floors are to be fitted on every frame under machinery and transverse boiler bearers. In this arrangement, the net thickness of floors needs not exceed 12.5 mm (0.5 in.), provided the buckling strength is proven adequate (see 5C-5-A2/3).

Where boilers are mounted on the tank top, the thickness of the floors in way of the boilers is to be increased by 1.5 mm (0.06 in.).

Floors and side girders where constructed of higher-strength material are to be not less in thickness than obtained from the following equation:

$$t_{hts} = [t_{ms} - C][(Q + 2\sqrt{Q})/3] + C$$

where

t_{hts}	=	net thickness of higher-strength material, in mm (in.)
t_{ms}	=	net thickness, in mm (in.), of ordinary-strength steel, as required above.
Q	=	material conversion factor, as specified in 5C-5-4/5.
C	=	1.5 (0.06)

25.3.4 Floor Stiffeners

Stiffeners spaced not more than 1.53 m (5 ft) apart are to be fitted on solid floors. Stiffeners may be omitted on non-tight floors with transverse framing, provided the thickness of the floor plate is increased 10% above the thickness obtained from 5C-5-6/25.3.3, above.

25.3.5 Inner-bottom Plating Thickness

The net thickness of inner-bottom plating is not to be less than that obtained from the following equation:

$$t = 0.037L + 0.009s \quad \text{mm}$$

$$t = 0.00044L + 0.009s \quad \text{in.}$$

where

L	=	length of vessel, as defined in 3-1-1/3.1, in m (ft)
s	=	frame spacing, in mm (in.)

For vessels with longitudinally-framed inner bottoms, the thickness of inner-bottom plating, as obtained above, may be reduced by 1.0 mm (0.04 in.).

The net inner-bottom plating, where constructed of higher-strength material, is to be not less in thickness than that obtained by the following equation:

$$t_{hts} = [t_{ms} - C][(Q + 2\sqrt{Q})/3] + C$$

where

t_{hts}	=	net thickness of higher-strength material, in mm (in.)
t_{ms}	=	net thickness, in mm (in.), of ordinary-strength steel, as required above.
Q	=	material conversion factor, as specified in 5C-5-4/5
C	=	1.5 (0.06)

In way of engine bed plates or thrust blocks which are bolted directly to the inner bottom, the net plating thickness is to be at least 17.5 mm (0.7 in.); the thickness is to be increased according to the size and power of the engines. Holding down bolts are to pass through angle flanges of sufficient breadth to take the nuts.

Also see 3-2-12/1.

Where the inner-bottom forms tank boundaries, plating is to be in compliance with 5C-5-6/25.17.1.

25.5 Side Shell Structures

25.5.1 Side Shell Plating

The minimum net thickness of the side shell plating at ends, including transom plating, is to be not less than t, obtained from the following equations and is not to extend for more than $0.1L$ from the aft end. Between the midship $0.4L$ and the end $0.1L$, the thickness of the plating may be gradually tapered.

$t = 0.029(L + 29) + 0.009s$ mm for $L \le 305$ m

$t = (10.20 + 0.009s)\sqrt{D/35}$ mm for $L > 305$ m

$t = 0.00036(L + 95) + 0.009s$ in. for $L \le 1000$ ft

$t = (0.402 + 0.009s)\sqrt{D/114.8}$ in. for $L > 1000$ ft

where

s = after peak frame spacing, in mm (in.)

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

D = molded depth, in m (ft), as defined in 3-1-1/7.1 or 35 m (114.8 ft), whichever is greater

Where the strength deck at the ends is above the freeboard deck, the net thickness of the side shell plating above the freeboard deck may be reduced to the thickness as given in 5C-5-6/25.5.2 below.

The required net thickness of the side shell plating is also to meet the hull girder shear strength at the location considered.

The net thickness of side-shell plating where constructed of higher-strength material is to be not less in thickness than that obtained from the following equation:

$$t_{hts} = [t_{ms} - C][(Q + 2\sqrt{Q})/3] + C$$

where

t_{hts} = net thickness of higher-strength material, in mm (in.)

t_{ms} = net thickness, in mm (in.), of ordinary-strength steel, as required above.

Q = material conversion factor, as specified in 5C-5-4/5

C = 2.8 (0.11)

In determining the thickness of side-shell plating constructed of higher-strength material and transversely framed, the critical buckling stress of the plating is to be checked in accordance with Appendix 5C-5-A2.

Shell plating is also not to be less in thickness than required by 5C-5-6/25.17 for deep tanks.

Shell plating thickness is to be increased 25% in way of breaks of superstructures, but this increase need not exceed 6.5 mm (0.25 in.).

25.5.2 Poop Side Plating

The net thickness, t, of the plating is not to be less than that obtained from the following equation:

$t = 0.028(L + 150) + 0.006(s - S)$ mm

$t = 0.00034(L + 492) + 0.006(s - S)$ in.

where

s	=	frame spacing. in mm (in.)		
S	=	standard frame spacing		
	=	$2.08L + 438$	mm	for $L \leq 270$ m
	=	$0.025L + 17.25$	in.	for $L \leq 886$ ft
	=	1000 (39.4)	mm (in.)	for $L > 270$ m (886 ft)
	=	610 (24)	mm (in.)	in way of the aft peak
L	=	length of vessel, as defined in 3-1-1/3.1, in m (ft), but need not be taken more than 305 m (1000 ft)		

Where constructed of higher-strength material, the plating is to be not less in thickness than that obtained from the following equation:

$t_{hts} = [t_{ms} - C][(Q + 2\sqrt{Q})/3] + C$

where

t_{hts} = net thickness of higher-strength material, in mm (in.)

t_{ms} = net thickness, in mm (in.), of ordinary-strength steel, as required above

Q = material conversion factor, as specified in 5C-5-4/5

C = 2.8 (0.11)

25.5.3 Stern Thruster Tunnels

The net thickness of the tunnel plating is to be not less than required by 5C-5-6/25.5.1, where s is to be taken as the standard frame spacing S given by the equation in 5C-5-6/25.5.2, nor is the thickness to be less than that obtained from the following equation:

$t = 0.008d + 1.8$ mm

$t = 0.008d + 0.07$ in.

d = inside diameter of the tunnel, in mm (in.), but is to be taken not less than 968 mm (38 in.)

Where the outboard ends of the tunnel are provided with bars or grids, the bars or grids are to be effectively secured.

25.5.4 Side Longitudinals and Transverse Frames

Frames are not to have less strength than is required in 5C-5-6/25.15.2 for bulkhead stiffeners in the same location in conjunction with the heads to the bulkhead deck. In way of deep tanks, they are not to have less strength than is required in 5C-5-6/25.17.2 for stiffeners on deep-tank bulkheads. Framing sections are to have sufficient thickness and depth in relation to the spans between supports. See also 5C-5-A2/11.9.

25.5.4(a) Side Longitudinals. The net section modulus of each side longitudinal, in association with the effective plating to which it is attached, is not to be less than that obtained from the following equation:

$$SM = kc_1c_2hs\ell^2Q \qquad \text{cm}^2\ (\text{in}^2)$$

where

k = 7.8 (0.0041)

s = spacing of side longitudinals, in m (ft)

c_1 = 0.95

c_2 = 0.85

above 0.5D from the keel:

h = the vertical distance, in m (ft), from the side longitudinal to the bulkhead deck, but is not to be taken less than 2.13 m (7.0 ft)

at and below 0.5D from the keel:

h = 0.75 times the vertical distance, in m (ft), from the longitudinal frame to the bulkhead deck, but is not to be less than 0.5D

D = depth of vessel, in m (ft), as defined in 3-1-1/7.

ℓ = span of longitudinal between effective supports, as shown in 5C-5-4/Figure 6, in m (ft)

Q = material conversion factor, as specified in 5C-5-4/5

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

25.5.4(b) Transverse Frames. The net section modulus SM of each transverse frame, in association with the effective plating to which it is attached, is to be obtained from the following equation:

$$SM = c_2s\ell^2\,(h + bh_1/33)(7 + 45/\ell^3)Q \qquad \text{cm}^3$$

$$SM = c_2s\ell^2\,(h + bh_1/100)(0.0037 + 0.84/\ell^3)Q \qquad \text{in}^3$$

where

s = spacing of side frames, in m (ft)

c_2 = 0.85

ℓ = the span of frames between effective supports, as defined in 5C-5-6/Figure 1, in m (ft). The value of ℓ for use with the equation is not to be less than 2.10 m (7 ft).

h = vertical distance, in m (ft), from the middle of ℓ to the load line or 0.4ℓ, whichever is the greater, as shown in 5C-5-6/Figure 1.

b = horizontal distance, in m (ft), from the outside of the frames to the first row of deck supports, as shown in 5C-5-6/Figure 1

h_1 = vertical distance, in m (ft), from the deck at the top of the frame to the bulkhead or freeboard deck plus the height of all cargo tween-deck spaces and one half the height of all passenger spaces above the bulkhead or freeboard deck, or plus 2.44 m (8 ft) if that be greater. Where the cargo load differs from 715 kgf/m^3 (45 lbf/ft^3) multiplied by the tween-deck height in m (ft), the height of that tween-deck is to be proportionately adjusted in calculating h_1.

Q = material conversion factor, as specified in 5C-5-4/5

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

25.5.4(c) Transverse tween-deck Frames. The net section modulus *SM* of each transverse tween-deck frame, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equation:

$SM = c_2(7 + 45/\ell^3)s\ell^2KQ$ cm^3

$SM = c_2(0.0037 + 0.84/\ell^3)s\ell^2KQ$ in^3

where

s = spacing of side frames, in m (ft)

c_2 = 0.85

ℓ = tween deck height or unsupported span along the frame length, as shown in 5C-5-4/Figure 6, whichever is greater, in m (ft)

K = factor appropriate to the length of vessel and type of tween decks, as shown in 5C-5-6/Figure 1, defined as follows:

For L in m:

K_A = $0.022L - 0.47$

K_B = $0.034L - 0.56$

K_C = $0.036L - 0.09$ for $L \leq 180$ m

K_C = $0.031L + 0.83$ for $L > 180$ m

K_D = $0.029L + 1.78$

For L in ft:

K_A = $0.022L - 1.54$

K_B = $0.034L - 1.84$

K_C = $0.036L - 0.29$ for $L \leq 590$ ft

K_C = $0.031L + 2.8$ for $L > 590$ ft

K_D = $0.029L + 5.84$

L = length of vessel, as defined in 3-1-1/3.1, in m (ft), but need not be taken as greater than 305 m (1000 ft)

Q = material conversion factor, as specified in 5C-5-4/5

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

25.7 Side Transverse Web Frames and Stringers

25.7.1 Transverse Web Frames

The net section modulus of each web frame, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equation:

$$SM = kc_1c_2s\ell^2(h + bh_1/45K)Q \quad \text{cm}^3$$

$$SM = kc_1c_2s\ell^2(h + bh_1/150K)Q \quad \text{in}^3$$

where

k = 4.74 (0.0025)

c_1 = 1.5

c_2 = 0.95

s = spacing of the web frames, in m (ft)

ℓ = span, in m (ft), measured from the line of the inner bottom (extended to the side of the vessel) to the deck at the top of the web frames. Where effective brackets are fitted, the length ℓ may be modified as shown in 5C-5-4/Figure 9.

h = vertical distance, in m (ft), from the middle of ℓ to the load line, the value of h is not to be less than 0.5ℓ

h_1 = vertical distance, in m (ft), from the deck at the top of the frame to the bulkhead or freeboard deck plus the height of all cargo tween-deck spaces and one half the height of all passenger spaces above the bulkhead or freeboard deck, or plus 2.44 m (8 ft) if that be greater. Where the cargo load differs from 715 kgf/m^3 (45 lb/ft^3) multiplied by the tween-deck height in m (ft), the height of that tween-deck is to be proportionately adjusted in calculating h_1.

b = horizontal distance, in m (ft), from the outside of the frame to the first row of deck supports, as shown in 5C-5-6/Figure 2

K = 1.0, where the deck is longitudinally framed and a deck transverse is fitted in way of each web frame

= number of transverse frame spaces between web frames where the deck is transversely framed

Q = material conversion factor, as specified in 5C-5-4/5

The depth and net thickness of the web are not to be less than d_w and t_w, respectively, as defined below:

$d_w = 125\ell$ mm

$= 1.5\ell$ in.

$t_w = d_w/100 + 2.5$ mm need not be greater than 13.0 mm (0.51 in.)

$= d_w/100 + 0.1$ in.

ℓ is as defined above.

Where the webs are in close proximity to boilers, the thickness of the webs, face bars, flanges, etc., are to be increased 1.5 mm (0.06 in.) above the normal requirements.

Web frames in way of deep-tank are to comply with 5C-5-6/25.17

25.7.2 Stringers

The net section modulus of each side stringer, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equation:

$SM = kc_1c_2hs\ell^2Q$ cm^3 (in^3)

where

k = 4.74 (0.0025)

c_1 = 1.5

c_2 = 0.95

Q = material conversion factor, as specified in 5C-5-4/5

h = vertical distance, in m (ft), from the middle of s to the load line, or to two-thirds of the distance from the keel to the bulkhead deck, or 1.8 m (6 ft), whichever is greatest

s = sum of the half lengths, in m (ft), (on each side of the stringer) of the frame supported

ℓ = span, in m (ft), between web frames, or between web frame and bulkhead; where brackets are fitted, the length ℓ may be modified as shown in 5C-5-4/Figure 9

The depth and net thickness of the stringer are not to be less than d_w and t_w, respectively, as defined below:

$d_w = 125\ell + 0.25d_s$ mm

$= 1.5\ell + 0.25d_s$ in.

but need not exceed depth of the web frames to which they are connected

$t_w = 0.014L + 6.2$ mm for $L \leq 200$ m

$= 0.007L + 7.6$ mm for $L > 200$ m

$t_w = 0.00017L + 0.24$ in. for $L \leq 656$ ft

$= 0.00008L + 0.3$ in. for $L > 656$ ft

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

d_S is the depth of the slot, in mm (in.), for the transverse frames and ℓ is as defined above. In general, the depth of the stringers is not to be less than three (3) times the depth of the slots or the slots are to be fitted with filler plates.

Where the stringers are in close proximity to boilers, the thickness of the stringer plates, face bars, flanges, etc. are to be increased 1.5 mm (0.06 in.) above the normal requirements.

Stringers in way of deep-tanks are also to comply with 5C-5-6/25.17.

25.7.3 After-peak Stringers

The after peak stringer plate net thickness t and breadth b are not to be less than that obtained from the following equations:

$t = 0.014L + 5.7$ mm for $L \le 200$ m

$t = 0.007L + 7.1$ mm for $L > 200$ m

$t = 0.00017L + 0.22$ in. for $L \le 656$ ft

$= 0.0008L + 0.28$ in. for $L > 656$ ft

$b = 2.22L + 600$ mm

$= 0.0266L + 23.62$ in.

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

Where beams or struts are not fitted on every frame, the edge of the stringer is to be adequately stiffened by a flange or face bar.

25.9 Decks

25.9.1 Strength Deck Plating Outside Line of Openings

The net thickness of the strength deck plating is to be not less than that required to meet the longitudinal hull girder strength. The deck area contributing to the hull girder strength for amidship 0.4L is gradually reduced to the end of the vessel. Where bending moment envelope curves are used to determine the required hull girder section modulus as permitted in 5C-5-4/3.1.1, the strength deck area is to be maintained a suitable distance beyond superstructure breaks and is to be extended into the superstructure to provide adequate structural continuity. The thickness is also to be not less than t, specified below, except within deckhouse where the plating may be reduced by 1 mm (0.04 in.).

25.9.1(a) for longitudinally framed decks

$t = 0.009s_b + 1.4$ mm

$= 0.009s_b + 0.055$ in. for $s_b \le 760$ mm (30 in.)

$t = 0.006s_b + 3.7$ mm

$= 0.006s_b + 0.146$ in. for $s_b > 760$ mm (30 in.)

25.9.1(b) for transversely framed decks

$t = 0.01s_b + 1.3$ mm

$= 0.01s_b + 0.05$ in. for $s_b \le 760$ mm (30 in.)

$t = 0.0066s_b + 3.9$ mm

$= 0.0066s_b + 0.154$ in. for $s_b > 760$ mm (30 in.)

where

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

s_b = spacing of deck beams, in mm (in.)

The net thickness of deck plating, for longitudinally framed decks, constructed of higher-strength material, is to be not less than that obtained from the following equation:

$$t_{hts} = (t_{ms} - C)\,Q + C$$

where

c = 3.3 (0.13)

t_{hts} = net thickness of higher-strength material, in mm (in.)

t_{ms} = net thickness, in mm (in.), of ordinary-strength steel, as required above

Q = material conversion factor $0.92/\sqrt{Q}$ is to be used in lieu of Q, as specified in 5C-5-4/5 and is not to be less than 1.0.

In general, where the deck plating is constructed of higher-strength material, the critical buckling stress of the plating of the higher-strength material is to be checked in accordance with Appendix 5C-5-A2.

The net thickness of the stringer plate is to be increased 25% in way of breaks of superstructures, but this increase need not exceed 6.5 mm (0.25 in.).

25.9.2 Strength Deck Plating within Line of Openings

Within deckhouses, the plating may be of the thickness obtained from the following equations:

$t = 0.009s_b - 0.2$	mm	for $s_b \le 685$ mm
$t = 0.0039s_b + 3.3$	mm	for $s_b > 685$ mm
$t = 0.009s_b - 0.008$	in.	for $s_b \le 27$ in.
$t = 0.0039s_b - 0.13$	in.	for $s_b > 27$ in.

s_b is as defined in 5C-5-6/25.9.1 above.

25.9.3 Poop Decks

The net thickness of exposed poop deck plating is to be not less than that obtained from 5C-5-6/25.9.2, above.

25.9.4 Platform Decks in Enclosed Spaces

The net thickness of platform deck plating, including lower decks in machinery space, is to be not less than that obtained from the following equation:

$$t = ks_b\sqrt{h} + a \qquad \text{mm (in.)}$$

but not less than 4.0 mm (0.2 in.).

where

k = 0.00394 (0.00218)

a = 0.5 (0.02)

h = tween deck height, in m (ft)

= p/n, when a design load, p, is specified

p = specified design load, in kN/m^2 (kgf/m^2, lbf/ft^2)

n = 7.05 (715, 45)

s_b is as defined in 5C-5-6/25.9.1 above.

Where the platform decks are subjected to hull girder bending, special consideration is to be given to the structural stability of deck supporting members. Appendix 5C-5-A2 may be used.

25.9.5 Watertight Flats *(1 July 2005)*

Watertight flats over tunnels or forming recesses or steps in bulkheads are to be of not less thickness than required for the plating of ordinary bulkhead at the same level obtained from 5C-5-6/25.15.1 plus 1 mm (0.04 in.).

For decks forming tops of tanks, see requirements in 5C-5-6/25.17.

25.9.6 Deck Longitudinals and Beams *(1 July 2005)*

25.9.6(a) Deck Longitudinals Outside the Line of Openings. The net sectional area of each deck longitudinal or beam, in association with the effective deck plating to which it is attached, is to be not less than that required to meet the longitudinal hull girder strength nor is the associated net section modulus to be less than that obtained in 5C-5-6/25.9.6(b), below.

25.9.6(b) Beams. The net section modulus of each deck longitudinal or beams in association with the effective plating is not to be less than that obtained from the following equation:

$$SM = kc_1c_2hs\ell^2Q \qquad \text{cm}^3\ (\text{in}^3)$$

where

k = 7.8 (0.0041)

s = spacing of longitudinals or beams, in m (ft)

c_1 = 0.585 for beams between longitudinal deck girders.
for longitudinal beams of platform decks and between hatches at all decks

= 0.90 for beams at deep-tank tops supported at one or both ends at the shell or on longitudinal bulkheads

= 0.945 for longitudinals of strength decks and of effective lower decks

= 1.0 for beams at deep-tank top

c_2 = 0.85

ℓ = span of longitudinals or beams between effective supports, as shown in 5C-5-4/Figure 6, in m (ft).

h = height, in m (ft), as follows

= for bulkhead recesses and tunnel flats, is the height to the bulkhead deck at the centerline; where that height is less than 6.10 m (20 ft), the value of h is to be taken as 0.8 times the actual height plus 1.22 m (4 ft).

= for deep-tank tops, is not to be less than two-thirds of the distance from the top of the tank to the top of the overflow; it is not to be less than 1.3 m (4.27 ft), the height to the load line or two-thirds of the height to the bulkhead or freeboard deck, whichever is greatest.

Elsewhere, the value of h may be taken as follows.

h = 2.9 m (9.5 ft) for bulkhead or freeboard deck having no deck below

= 2.29 m (7.5 ft) for bulkhead or freeboard deck having deck below

= 1.98 m (6.5 ft) for lower decks and platform deck

= 1.68 m (5.5 ft) for poop deck above bulkhead deck

Q = material conversion factor, as specified in 5C-5-4/5

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5. Calculations are to be submitted to show adequate provision against buckling where higher-strength materials is used for deck beams. Longitudinal members are to be essentially of the same material as the plating they support.

25.9.7 Deck Girders and Transverses Clear of Tanks

25.9.7(a) Section Modulus. The net section modulus of each deck girder or transverse with the effective plating is not to be less than that obtained from the following equation:

$$SM = kc_1c_2bh\ell^2Q \qquad \text{cm}^3\ (\text{in}^3)$$

where

k = 4.74 (0.0025)

c_1 = 1.0

c_2 = 0.95

b = mean breadth of the area of deck supported, in m (ft)

h = the height, in m (ft), measured at the side of the vessel, of the cargo space wherever stores or cargo may be carried. Where the cargo load differs from 715 kgf/m^3 (45 lbf/ft^3) multiplied by the tween-deck height, in m (ft), the height is to be proportionately adjusted.

Elsewhere, the value of h may be taken as follows.

h	=	2.9 m (9.5 ft)	for bulkhead or freeboard deck having no deck below
	=	2.29 m (7.5 ft)	for bulkhead or freeboard deck having deck below
	=	1.98 m (6.5 ft)	for lower decks and platform deck
	=	1.68 m (5.5 ft)	for poop deck above bulkhead deck

ℓ = span between centers of supporting pillars, or between pillar and bulkhead, in m (ft). Where an effective bracket is fitted at the bulkhead, the ℓ may be modified, as shown in 5C-5-4/Figure 9.

Q = material conversion factor, as specified in 5C-5-4/5

25.9.7(b) Proportions. The depth and net thickness of the girders and transverses are not to be less than d_w and t_w, respectively, as defined below:

d_w	=	$k\ell$	mm (in.)
t_w	=	$d_w/100 + a$	mm (in.)
	≥	7.5 mm (0.30 in.)	for $A_F \le 38$ cm^2 (5.27 in^2)
	≥	9.0 mm (0.35 in.)	for $A_F \le 46$ cm^2 (8.84 in^2)
	≥	11.5 mm (0.45 in.)	for $A_F \le 101$ cm^2 (18.14 in^2)
	≥	14.0 mm (0.55 in.)	for $A_F > 165$ cm^2 (27.44 in^2)
k	=	58.3 (0.7)	
a	=	3.0 (0.12)	

The thickness for intermediate face area may be obtained by interpolation.

A_F is the net face area and ℓ is as defined in 5C-5-6/25.9.7(a), above.

25.9.8 Deck Girders and Transverses in Tanks

The net section modulus *SM* of deck girders and transverses in tanks are to be obtained in the same manner as given in 5C-5-6/25.9.7 above, except the values of c_1 and h are to be as modified below. The proportionality requirements are to be the same as given in 5C-5-6/25.9.7 above, except that k for d_w is not to be less than 83.3 (1.0).

c_1 = 1.5

h = the greatest of the following distances, in m (ft), from the middle of ℓ to;

- A point located two-thirds of the distance from the top of the tank to the top of the overflow
- 1.3 m (4.27 ft) above the top of the tank
- The load line
- A point located at two-thirds of the distance to the bulkhead or freeboard deck

25.11 Pillars

25.11.1 Permissible Load

The permissible load W_a of a pillar or strut is to be obtained from the following equation which will, in all cases, be equal to or greater than the calculated load W as in 5C-5-6/25.11.2, below.

$$W_a = c_2(k - n\ell/r)A_c \quad \text{kN(tf, Ltf)}$$

where

c_2 = 1.05

k = 12.09 (1.232, 7.83) ordinary strength steel
= 16.11 (1.643, 10.43) HT32
= 18.12 (1.848, 11.73) HT36

ℓ = unsupported span, in cm (ft)

The length ℓ is to be measured from the top of the inner bottom, deck or other structure on which the pillars or struts are based to the underside of the beam or girder supported.

r = least radius of gyration, in cm (in.)

A_c = net cross sectional area of pillar or strut, in cm^2 (in^2)

n = 0.0444 (0.00452, 0.345) ordinary strength steel
= 0.0747 (0.00762, 0.581) HT32
= 0.0900 (0.00918, 0.699) HT36

25.11.2 Calculated Load

The calculated load W for a specific pillar is to be obtained from the following equation:

$$W = nbhs \quad \text{kN (tf, Ltf)}$$

where

n = 7.04 (0.715, 0.02)

b = mean breadth of the area supported, in m (ft)

h = height above the area supported, as defined below, in m (ft)

For pillars spaced not more than two frame spaces, the height h is to be taken as the distance from the deck supported to a point 3.80 m (12.5 ft) above the freeboard deck.

For wide-spaced pillars, the height h is to be taken as the distance from the deck supported to a point 2.44 m (8 ft) above the freeboard deck, except in the case of such pillars immediately below the freeboard deck, in which case, the value of h is not to be less than 2.9 m (9.5 ft) in measuring the distance from the deck supported to the specified height above the freeboard deck, the height for any tween decks devoted to crew accommodation may be taken as 1.98 m (6.5 ft).

s = mean length of the area supported, in m (ft)

25.11.3 Pillars under the Tops of Deep Tanks

Pillars under the tops of deep tanks are not to be less than required by the foregoing. They are to be of solid sections and to have the net cross sectional area not less than A, specified below.

$A = c_1 c_2\, nbhs$ kN (tf, Ltf)

where

c_1	=	0.1035 (1.015, 0.16)	ordinary strength steel
	=	0.0776 (0.761, 0.12)	HT32
	=	0.069 (0.677, 0.107)	HT36
c_2	=	0.95	
n	=	10.5 (1.07, 0.03)	
b	=	breadth of the area of the top of the tank supported by the pillar, in m (ft)	
s	=	length of the area of the top of the tank supported by the pillar, in m (ft)	
h	=	two-thirds of the distance from the top of the tank to the top of the overflow; it is not to be less than 1.3 m (4.27 ft), the height to the load line or two-thirds of the height to the bulkhead or freeboard deck, whichever is greatest.	

25.13 After-peak

25.13.1 Center Girder and Floor Plating

The center girder continued from the midship is to extend as far aft as practicable and to be attached to the stern frame. The net thickness of plating is not to be less than that obtained from the following equation, but need not exceed 12.5 mm (0.5 in.), provided that it is suitably stiffened.

$t = 0.036L + 3.2$ mm

$t = 0.00043L + 0.126$ in.

L = length of vessel, as defined in 3-1-1/3.1, in m (ft)

The floors are to extend as high as necessary to give lateral stiffness to the structure and are to be properly stiffened with flanges. If applicable, means are to be provided to prevent lateral movement of floors.

25.13.2 Peak Frame

The net section modulus of each peak frame is to comply with 5C-5-6/25.5.4.

Peak frames in way of aft peak tank are to be in compliance with 5C-5-6/25.17.2.

25.15 Watertight Bulkheads

25.15.1 Plating *(2002)*

The net thickness t of bulkhead plating forming watertight boundaries is to be obtained from the following equation:

$$t = sk\sqrt{qh}/C + a \qquad \text{mm (in.)}$$

but not less than t_{min} or $s/200 + c_1$, whichever is greater.

where

t_{min}	=	5.5 mm (0.22 in.)	within cargo spaces
		5.0 mm (0.20 in.)	for other than cargo spaces
c_1	=	2.0 mm (0.08 in.)	within cargo spaces
		1.5 mm (0.06 in.)	for other than cargo spaces
C	=	290 (525)	
a	=	1.0 (0.04) within cargo spaces	
	=	0.5 (0.02) for other than cargo spaces	
s	=	spacing of stiffeners, in mm (in.)	
k	=	$(3.075\sqrt{\alpha} - 2.077)/(\alpha + 0.272)$	$(1 \le \alpha \le 2)$
	=	1.0	$(\alpha > 2)$
α	=	aspect ratio of the panel (longer edge/shorter edge)	
q	=	$235/Y$ (N/mm^2), $24/Y$ (kgf/mm^2) or $34{,}000/Y$ (lbf/in^2)	
Y	=	minimum specified yield point or yield strength, in N/mm^2 (kgf/mm^2, lbf/in^2), for the higher-strength material or 72% of the specified minimum tensile strength, whichever is the lesser	
h	=	distance from the lower edge of the plate to the deepest equilibrium waterline in the one compartment damaged condition, in m (ft) h is to be not less than the distance to the bulkhead deck at center unless a deck lower than the uppermost continuous deck is designated as the freeboard deck, as allowed in 3-1-1/13.1. In such case, h is to be not less than the distance to the designated freeboard deck at center.	

The net plating thickness of afterpeak bulkheads below the lowest flat is not to be less than required for solid floors obtained by 5C-5-6/25.13.1.

25.15.2 Stiffeners *(2002)*

The net section modulus of each stiffener, in association with the effective plating to which it is attached, is to be not less than that obtained from the following equation:

$$SM = kc_1c_2hs\ell^2Q \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

where

k	=	7.8 (0.0041)
c_1	=	0.56

c_2 = 0.85

s = spacing of the stiffeners, in m (ft)

h = distance, in m (ft), from the middle of ℓ to the deepest equilibrium waterline in the one compartment damaged condition

h is to be not less than the distance to the bulkhead deck at center unless a deck lower than the uppermost continuous deck is designated as the freeboard deck, as allowed in 3-1-1/13.1. In such case, *h* is to be not less than the distance to the designated freeboard deck at center.

Where the distance indicated above is less than 6.10 m (20 ft), *h* is to be taken as 0.8 times the distance plus 1.22 m (4 ft).

ℓ = span of stiffeners between effective supports, as shown in 5C-5-4/Figure 6, in m (ft)

Q = material conversion factor, as specified in 5C-5-4/5

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

25.15.3 Girders and Webs (Watertight Bulkhead) *(2002)*

25.15.3(a) Section Modulus. The net section modulus *SM* of each girder and web with effective plating which support bulkhead stiffeners is not to be less than as obtained from the following equation:

$$SM = kc_1c_2hs\ell^2Q \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

where

k = 4.74 (0.0025)

c_1 = 1.0

c_2 = 0.95

h = vertical distance, in m (ft), to the deepest equilibrium waterline in the one compartment damaged condition from the middle of s in the case of girders, and from the middle of ℓ in the case of webs

h is to be not less than the distance to the bulkhead deck at center unless a deck lower than the uppermost continuous deck is designated as the freeboard deck, as allowed in 3-1-1/13.1. In such case, *h* is to be not less than the distance to the designated freeboard deck at center.

Where the distance indicated above is less than 6.10 m (20 ft), *h* is to be taken as 0.8 times the distance plus 1.22 m (4 ft).

s = sum of half lengths ℓ on each side of girder or web of the stiffeners supported, in m (ft)

ℓ = span measured between the heels of end attachments, in m (ft). Where an effective bracket is fitted at the bulkhead, the length ℓ may be modified as shown in 5C-5-4/Figure 9.

Q = material conversion factor, as specified in 5C-5-4/5

25.15.3(b) Proportions. The depth and net thickness of the girders and web are not to be less than d_w and t_w, respectively, as defined below:

$d_w = 83.3\ell + 0.25d_S$ mm

$d_w = 1.0\ell + 0.25d_S$ in.

$t_w = d_w/100 + 2.0$ mm need not exceed 10.5 mm (0.41 in.)

$t_w = d_w/100 + 0.08$ in.

d_S is the depth of the slots in mm (in.) for the stiffeners and ℓ is as defined above.

25.17 Deep Tank Bulkheads

This section applies to deep tank bulkheads where the requirements in this section exceed those of 5C-5-6/25.15.

25.17.1 Plating *(1 July 2005)*

The net thickness t of bulkhead plating forming tank boundary is to be obtained from the following equation:

$t = sk\sqrt{qh}/C + a$ mm (in.)

but not less than 5.0 mm (0.2 in.) or s/150 + a mm (in.), whichever is greater.

where

C = 254 (460)

a = 1.0 (0.04)

s = spacing of stiffeners, in mm (in.)

k = $(3.075\sqrt{\alpha} - 2.077)/(\alpha + 0.272)$ $(1 \le \alpha \le 2)$

= 1.0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

q = $235/Y$ (N/mm^2), $24/Y$ (kgf/mm^2) or $34{,}000/Y$ (lbf/in^2)

Y = minimum specified yield point or yield strength, in N/ mm^2 (kgf/mm^2, lbf/in^2), for the higher-strength material or 72% of the specified minimum tensile strength, whichever is the lesser

h = the greatest of the following distances, in m (ft), from the lower edge of the plate to:

- A point located two-thirds of the distance from the top of the tank to the top of the overflow; where a side wing tank top extends to the underdeck passageway (second deck), this distance need not be greater than one-third of the distance from the second deck to the top of the overflow
- 1.3 m (4.27 ft) above the top of the tank
- The load line
- A point located at two-thirds of the distance to the bulkhead or freeboard deck

The tops of tanks are to have plating 0.5 mm (0.02 in.) thicker than would be required for vertical plating at the same level.

25.17.2 Stiffeners *(1 July 2005)*

The net section modulus of each stiffener, in association with the effective plating to which it is attached, is not to be less than that obtained from the following equation:

$$SM = kc_1c_2hs\ell^2Q \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

where

k = 7.8 (0.0041)

c_1 = 0.90

c_2 = 0.85

s = spacing of the stiffeners, in m (ft)

h = the greatest of the following distances, in m (ft), from the middle of ℓ to:

- A point located two-thirds of the distance from the top of the tank to the top of the overflow; where a side wing tank top extends to the underdeck passageway (second deck), this distance need not be greater than one-third of the distance from the second deck to the top of the overflow
- 1.3 m (4.27 ft) above the top of the tank
- The load line
- A point located at two-thirds of the distance to the bulkhead or freeboard deck

ℓ = span of stiffeners between effective supports, as shown in 5C-5-4/Figure 6, in m (ft)

Q = material conversion factor, as specified in 5C-5-4/5

The effective breadth of plating, b_e, is as defined in 5C-5-4/11.5.

25.17.3 Girders and Webs (Deep Tank Bulkhead)

25.17.3(a) Section Modulus. The net section modulus of each girder and web with effective plating which supports bulkhead stiffeners is not to be less than that obtained from the following equation:

$$SM = kc_1c_2sh\ell^2Q \qquad \text{cm}^3 \text{ (in}^3\text{)}$$

where

k = 4.74 (0.0025)

c_1 = 1.5

c_2 = 0.95

h = vertical distance, in m (ft), from the middle of s in the case of girders, and from the middle of ℓ in the case of webs to the same height to which h for the stiffeners is measured (See 5C-5-6/25.17.2, above).

s = sum of half lengths ℓ on each side of girder or web of the frame or stiffener supported, in m (ft)

ℓ = span measured between the heels of the end of the attachments, in m (ft). Where effective brackets are fitted, the length ℓ may be modified as defined in 5C-5-4/Figure 9.

Q = material conversion factor, as specified in 5C-5-4/5

25.17.3(b) Proportions. The depth and net thickness of the girders and web are not to be less than d_w and t_w, respectively, as defined below:

d_w = $145\ell + 0.25d_S$ mm

= $1.74\ell + 0.25d_S$ in.

where no struts or ties are fitted

d_w = $83.3\ell + 0.25d_S$ mm

= $1.0\ell + 0.25d_S$ in.

where struts are fitted

t_w = $d_w/100 + 1.5$ mm need not exceed 10.0 mm (0.4 in.)

= $d_w/100 + 0.06$ in.

d_S is the depth of the slots, in mm (in.), for the stiffeners and ℓ is as defined above. In general, the depth is not to be less than three (3) times the depth of the slots or the slots are to be fitted with filler plates.

25.19 Machinery Space

Care is to be taken to provide sufficient transverse strength and stiffness in the machinery space by means of webs, plated through beams, and heavy pillars in way of deck openings and casings.

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PART

5C

CHAPTER 5 Vessels Intended to Carry Containers (130 meters (427 feet) to 450 meters (1476 feet) in Length)

SECTION 7 Cargo Safety

1 Application

The provisions of Part 5C, Chapter 5, Section 7 (referred to as Section 5C-5-7) apply to vessels intended to carry containers in respect of hazards posed by some cargoes. They form a part of the necessary condition for assigning the class notation **Container Carrier**. The provisions of Part 4, specifying conditions for assigning the machinery class notation **AMS** (see 4-1-1/1.5), are applicable to container carriers in addition to the provisions of this Section.

3 Container Cargo Spaces

3.1 General Fire Protection

Except for cargo spaces covered in 5C-5-7/3.3, cargo spaces of vessels of 2,000 gross tonnage and upwards are to be protected by a fixed gas fire extinguishing system complying with the provisions of 4-7-3/3 or by a fire extinguishing system which gives equivalent protection.

3.3 Vessels Intended to Carry Dangerous Goods

Container holds intended for the carriage of dangerous goods are to comply with the following tabulated requirements, except when carrying dangerous goods in limited quantities (as defined in section 18 of the General Introduction of *IMDG Code*):

- 5C-5-7/Table 1 provides a description of the list of dangerous goods as defined in *IMDG Code*.
- 5C-5-7/Table 2 provides the application of the requirements described in 4-7-2/7.3 to container cargo spaces.
- 5C-5-7/Table 3 provides the application of the requirements described in 4-7-2/7.3 to the different classes of dangerous goods except dangerous goods in bulk.

5 Refrigerated Containers *(2000)*

Where independent refrigerated containers are carried, requirements specified in 4-8-2/3.1.1 are to be complied with, taking into consideration electrical loads of the containers with any one generator in reserve.

TABLE 1
Dangerous Goods Classes

Class	*Substance*
1 (1.1 through 1.6)	Explosives
2.1	Flammable gases (compressed, liquefied or dissolved under pressure)
2.2	Non flammable gases (compressed, liquefied or dissolved under pressure)
2.3	Toxic gases
3 (3.1 through 3.3)	Flammable liquids
4.1	Flammable solids
4.2	Substances liable to spontaneous combustion
4.3	Substances which, in contact with water, emit flammable gases
5.1	Oxidizing substances
5.2	Organic peroxides
6.1	Toxic substances
6.2	Infectious substances
7	Radioactive materials
8	Corrosives
9	Miscellaneous dangerous substances and articles, that is any substance which experience has shown, or may show, to be of such a dangerous character that the provisions for dangerous substance transportation are to be applied.

TABLE 2
Application of Requirements to Container Cargo Spaces

4-7-2/...	*Requirements*	*Container cargo spaces*	*Weather deck*
7.3.1(a)	Availability of water	x	x
7.3.1(b)	Quantity of water	x	x
7.3.1(c)	Underdeck cargo space cooling	x	-
7.3.1(d)	Alternative to cooling by water	x	-
7.3.2	Sources of ignition	x	-
7.3.3	Detection system	x	-
7.3.4	Ventilation	x (1)	-
7.3.5	Bilge pumping	x	-
7.3.6	Personnel protection	x	x
7.3.7	Portable fire extinguisher	-	x
7.3.8	Insulation of machinery space boundary	x (2)	x
7.3.9	Water-spray system	-	-

Notes

1 For classes 4 and 5.1 dangerous goods not applicable to closed freight containers. For classes 2, 3, 6.1 and 8 when carried in closed freight containers, the ventilation rate may be reduced to not less than two air changes. For the purpose of this requirement, a portable tank is a closed freight container.

2 Applicable to decks only.

TABLE 3
Application of the Requirements in 4-7-2/7.3 to Different Classes of Dangerous Goods, Except Solid Dangerous Goods in Bulk

Dangerous goods class	*4-7-2/ paragraph:*												
	7.3.1				*7.3.2*	*7.3.3*	*7.3.4*		*7.3.5*	*7.3.6*	*7.3.7*	*7.3.8*	*7.3.9*
	(a)	*(b)*	*(c)*	*(d)*			*(a)*	*(b)*					
1.1 – 1.6	x	x	x	x	x	x						x [2]	x
1.4S	x	x				x							x
2.1	x	x			x	x	x	x		x		x	x
2.2	x	x				x				x		x	x
2.3	x	x				x	x			x		x	x
3.1, 3.2	x	x			x	x	x	x	x	x	x	x	x
3.3	x	x				x				x	x	x	x
4.1	x	x				x	x [1]			x	x	x	x
4.2	x	x				x	x [1]			x	x	x	x
4.3	x	x				x	x			x	x	x	x
5.1	x	x				x	x [1]			x	x	x [3]	x
5.2	x	x								x			x
6.1 liquids	x	x				x			x	x			x
6.1 liquids ≤ 23°C	x	x			x	x	x	x	x	x	x	x	x
6.1 liquids > 23°C ≤ 61°C	x	x				x	x	x	x	x	x	x	x
6.1 solids	x	x				x	x [1]			x			x
8 liquids	x	x				x				x			x
8 liquids ≤ 23°C	x	x			x	x	x	x	x	x	x	x	x
8 liquids > 23°C ≤ 61°C	x	x				x	x	x		x	x	x	x
8 solids	x	x				x				x			x
9	x						x [1]			x [4]			x

Notes

1 When "mechanically ventilated spaces" are required by the *IMDG Code*, as amended.

2 Stow 3 m (10 ft) horizontally away from the machinery space boundaries in all cases.

3 Refer to the *IMDG Code*.

4 As appropriate to the goods being carried.

PART

5C

CHAPTER **5** **Vessels Intended to Carry Containers (130 meters (427 feet) to 450 meters (1476 feet) in Length)**

APPENDIX **1** **Guide for Fatigue Strength Assessment of Container Carriers**

1 General

1.1 Note

This Guide provides a designer oriented approach to fatigue strength assessment which may be used, for certain structural details, in lieu of more elaborate methods such as spectral fatigue analysis. The term assessment is used here to distinguish this approach from the more elaborate analysis.

The criteria in this Guide are developed from various sources including the Palmgren-Miner linear damage model, S-N curve methodologies, long-term environment data of the North-Atlantic Ocean (Walden's Data), etc., and assume workmanship of commercial marine quality acceptable to the Surveyor. The capacity of structures to resist fatigue is given in terms of permissible stress range to allow designers the maximum flexibility possible.

While this is a simplified approach, a good amount of effort is still required in applying these criteria to the actual design. For this reason, PC-based software has been developed and is available to the clients. Interested parties are kindly requested to contact the nearest ABS plan approval office for more information.

1.3 Applicability *(1998)*

The criteria in this Guide are specifically written for container carriers to which Part 5C, Chapter 5 is applicable.

1.5 Loadings *(1998)*

The criteria have been written for ordinary wave-induced motions and loads. Other cyclic loadings, which may result in significant levels of stress ranges over the expected lifetime of the vessel, are also to be considered by the designer.

Where it is known that a vessel will be engaged in long-term service on a route with more severe environment, the fatigue strength assessment criteria in this Guide are to be modified, accordingly.

1.7 Effects of Corrosion *(1998)*

To account for the mean wastage throughout the service life, the total stress range calculated using the net scantlings (i.e., deducting nominal design corrosion values, see 5C-5-2/Table 1) is modified by a factor c_f. See 5C-5-A1/7.5.1.

1.9 Format of the Criteria *(1998)*

The criteria in this Guide are presented as a comparison of fatigue strength of the structure (capacity) and fatigue inducing loads (demands) as represented by the respective stress ranges. In other words, the permissible stress range is to be not less than the total stress range acting on the structure.

5C-5-A1/5 provides the basis to establish the permissible stress range for the combination of the fatigue classification and typical structural joints of container carriers. 5C-5-A1/7 presents the procedures to be used to establish the applied total stress range. 5C-5-A1/9 provides typical stress concentration factors (SCFs) and guidelines for direct calculation of the required SCFs. 5C-5-A1/11 provides the guidance for assessment of stress concentration factors and the selection of compatible S-N data where a fine mesh finite element approach is used.

3 Connections to be Considered for the Fatigue Strength Assessment

3.1 General *(1998)*

These criteria have been developed to allow consideration of a broad variation of structural details and arrangements so that most of the important structural details anywhere in the vessel can be subjected to an explicit (numerical) fatigue assessment using these criteria. However, where justified by comparison with details proven satisfactory under equal or more severe conditions, an explicit assessment can be exempted.

3.3 Guidance on Locations *(1998)*

As a general guidance for assessing fatigue strength for a container carrier, the following connections and locations are to be considered:

3.3.1 Connections of Longitudinal Stiffeners to Transverse Web/Floor and to Transverse Bulkhead

3.3.1(a) Two (2) to three (3) selected side longitudinals in the region from 1.1 draft (d) to about $^1/_3$ draft (d) in the midship region and also in the region between 0.15L and 0.25L from the FP

3.3.1(b) One (1) to two (2) selected longitudinals from each of the following groups:

Deck longitudinals, bottom longitudinals, inner bottom longitudinals and longitudinals on the longitudinal bulkheads.

For these structural details, the fatigue assessment is to be first focused on the flange of the longitudinal at the rounded toe welds of attached flat bar stiffeners and brackets, as illustrated for Class F item 2) and Class F_2 item 1) and at the connection of the strut for Class G item 4) in 5C-5-A1/Table 1.

Then, the critical spots on the web plate cut-out, on the lower end of the flat bar stiffener as well as the weld throat are also to be checked for the selected structural detail. For illustration, see 5C-5-A1/9.3.1 and 5C-5-A1/9.3.2(a), 5C-5-A1/9.3.2(b) and 5C-5-A1/9.3.2(c).

Where the longitudinal stiffener end bracket arrangements are different on opposing sides of a transverse web or transverse bulkhead, both configurations are to be checked.

3.3.2 End Connections of Side Frame and Vertical Stiffener on Longitudinal Bulkhead

End connections of side frame and vertical stiffener on longitudinal bulkhead.

3.3.3 Connections of Transverse Web or Floor to Side Shell, Bottom, Inner Bottom or Bulkhead Plating (for Fatigue Strength of Plating)

3.3.3(a) One (1) to two (2) selected locations of side shell plating near the summer *LWL* amidships and between 0.15*L* and 0.25*L* from the FP, respectively.

3.3.3(b) One (1) to two (2) selected locations in way of bottom, inner bottom and also lower strakes of the longitudinal bulkhead amidships, respectively.

3.3.4 Hatch Corners

The following locations (stations) of hatch corners, as shown in 5C-5-4/Figure 5:

3.3.4(a) Typical hatch corners within 0.4*L* amidships, one each at water-tight and mid-hold strength bulkheads, station D and D′.

3.3.4(b) Hatch corners immediately forward and aft of the engine room, stations C and B.

3.3.4(c) One of the forward hatch corners subject to significant warping constraint from the adjacent structures, station E, F or G, whichever has the greatest warping constraint.

3.3.5 Connection of Longitudinal Hatch Girders and Cross Deck Box Beams to Other Supporting Structures

Two or more representative locations of each hatch girder and cross deck box beam connections.

3.3.6 End Bracket Connections for Transverses and Girders

One (1) to two (2) selected locations in the midship region for each type of bracket configuration.

3.3.7 End Bracket Connections for Hatch Side and Hatch End Coamings

One (1) to two (2) selected locations in the midship region for each type of bracket configuration.

3.3.8 Representative Cut-outs

Representative cut-outs in the longitudinal bulkheads, longitudinal deck girder, hatch side coamings and cross deck box beams.

3.3.9 Other Regions and Locations

Highly stressed by fluctuating loads, as identified from structural analysis

For these structural details of items 5C-5-A1/3.3.4, 5C-5-A1/3.3.5 and 5C-5-A1/3.3.7, the value of the total stress range, f_R, as specified in 5C-5-A1/7.5.1, may be determined from fine mesh F.E.M. analyses for the combined load cases, as specified in 5C-5-A1/7.5.2(d). Alternatively, the value of f_R may be calculated by the approximate equations given in this Guide.

3.5 Fatigue Classification

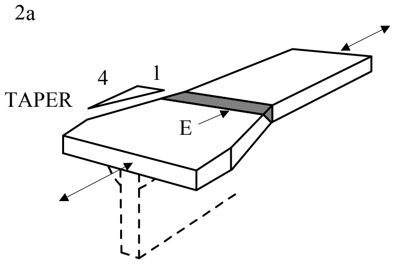
3.5.1 Welded Connections with One Load Carrying Member

Fatigue classification for structural details is shown in 5C-5-A1/Table 1.

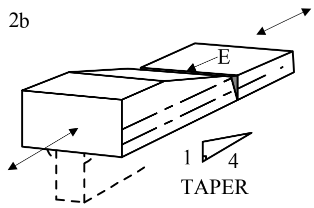
TABLE 1
Fatigue Classification for Structural Details *(1998)*

Class Designation		*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* kgf/mm^2
B		Parent material, plates or shapes as rolled or draw, with no flame-cut edges	0.7	92.2*
			0.8	75.9
			0.9	64.2
			1.0	55.6
C	1)	Parent material with automatic flame-cut edges	0.7	79.2
	2)	Full penetration seam welds or longitudinal fillet welds made by an automatic submerged or open are process, and with no stop-start positions within the length.	0.8	63.9
			0.9	53.3
			1.0	45.7
D	1)	Full penetration butt welds made either manually or by an automatic process other than submerged arc, from both sides, in downhand position.	0.7	59.9
			0.8	47.3
			0.9	38.9
	2)	Weld in C-2) with stop-start positions within the length	1.0	32.9
E	1)	Full penetration butt welds made by other processes than those specified under D-1)	0.7	52.8
			0.8	41.7
	2)	Full penetration butt welds made form both sides between plates of unequal widths or thicknesses	0.9	34.2
			1.0	29.0

2a



2b



3) Welds of brackets and stiffeners to web plat of girders

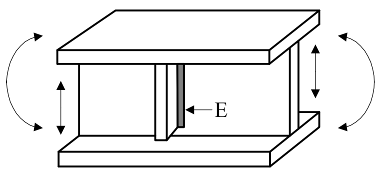
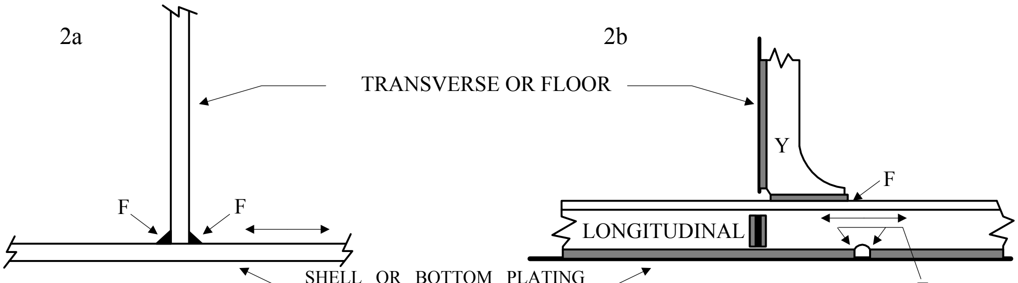


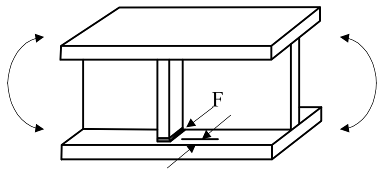
TABLE 1 (continued)
Fatigue Classification for Structural Details *(1998)*

Class Designation		*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* *kgf/mm²*
F	1)	Full penetration butt weld made on a permanent backing strip	0.7	44.7
			0.8	35.3
	2)	Rounded fillet welds as shown below	0.9	29.0
			1.0	24.5

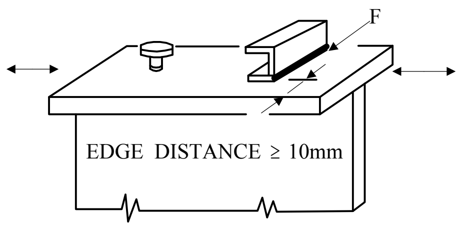


"Y" IS REGARDED AS A NON-LOAD CARRYING MEMBER

3) Welds of brackets and stiffeners to flanges



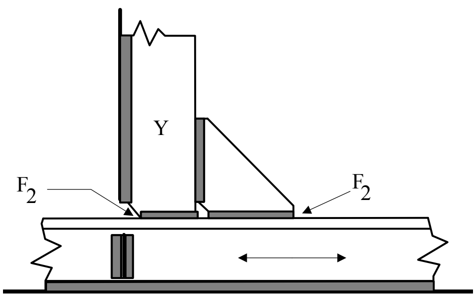
4) Attachments on plate or face plate



(Class G for edge distance < 10 mm)

Class Designation		*Description*	γ	*kgf/mm²*
F_2	1)	Fillet welds as shown below with rounded welds and no undercutting	0.7	39.3
			0.8	31.1
			0.9	25.5

1a



"Y" is a non-load carrying member

1b

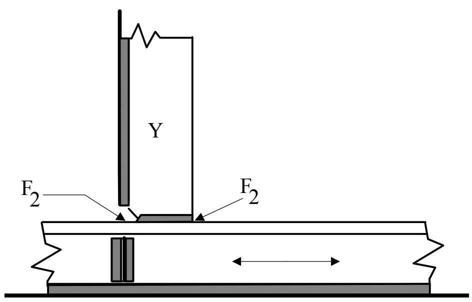
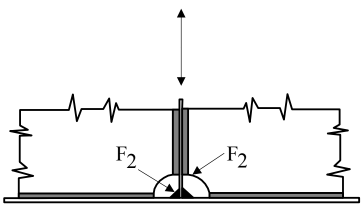


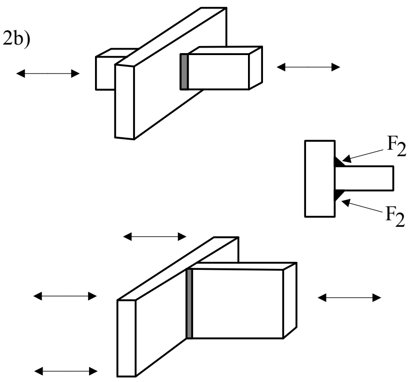
TABLE 1 (continued)
Fatigue Classification for Structural Details *(1998)*

Class Designation		*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* kgf/mm^2
	2)	Fillet welds with any undercutting at the corners dressed out by local grinding	1.0	21.6

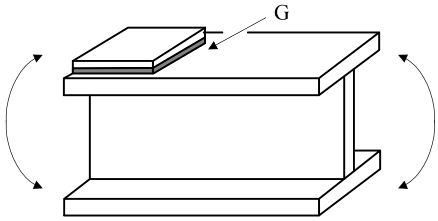
2a)



2b)



Class Designation		*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* kgf/mm^2
G	1)	Fillet welds in F_2 – 1) without rounded tow welds or with limited minor undercutting at corners or bracket toes	0.7 0.8	32.8 25.9
	2)	Fillet welds in F_2 – 2) with minor undercutting	0.9	21.3
	3)	Doubler on face plate or flange, small deck openings	1.0	18.0
	4)	Overlapped joints as shown below		



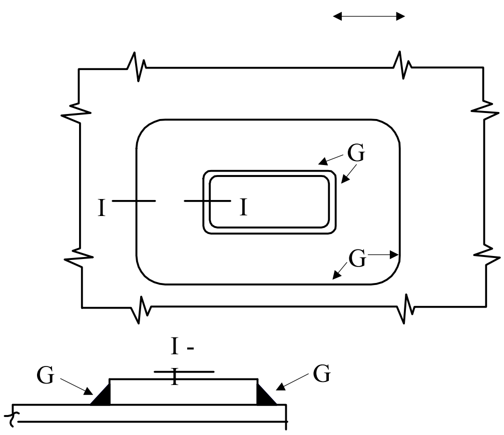
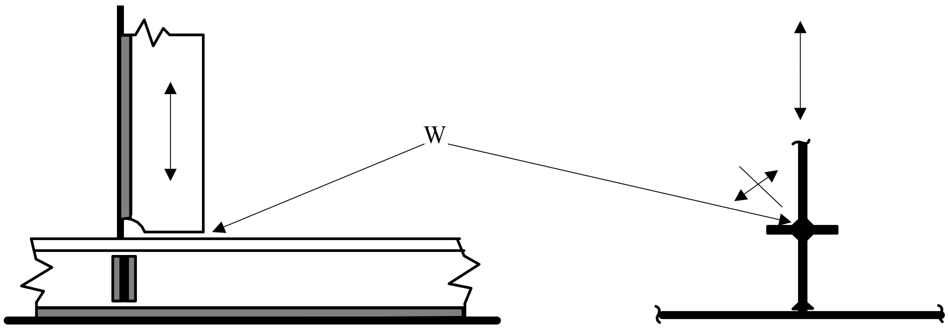


TABLE 1 (continued)
Fatigue Classification for Structural Details *(1998)*

Class Designation		*Description*	*Long-term Distribution Parameter* γ	*Permissible Stress Range* *kgf/mm²*
W	1)	Fillet welds in G - 3) with any undercutting at the toes	0.7	28.3
			0.8	22.3
	2)	Fillet welds - weld throat	0.9	18.4
			1.0	15.5



1) The permissible stress range can not be taken greater that two times the specified minimum tensile strength of the material.

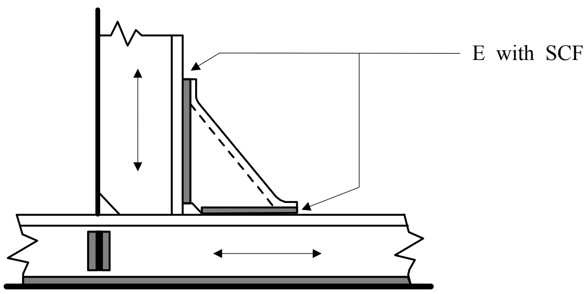
2) To obtain the permissible stress range in SI and U.S. Units, the conversion factors of 9.807 (N/mm^2) and 1422 (lb/in^2) can be used, respectively.

3.5.2 Welded Joint with Two or More Load Carrying Members

For brackets connecting two or more load carrying members, an appropriate stress concentration factor (SCF) determined from fine mesh 3D or 2D finite element analysis is to used. In this connection, the fatigue class at bracket toes may be upgraded to class E. Sample connections are illustrated below with/without SCF.

TABLE 2
Welded Joint with Two or More Load Carrying Members

a Connections of Longitudinal and Stiffener



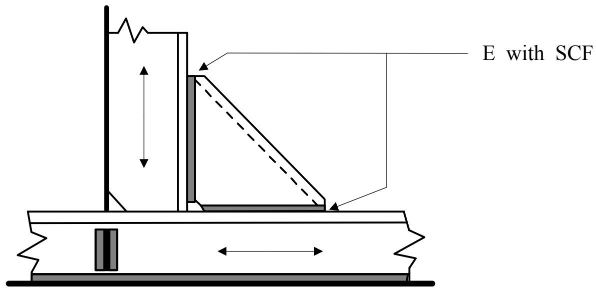
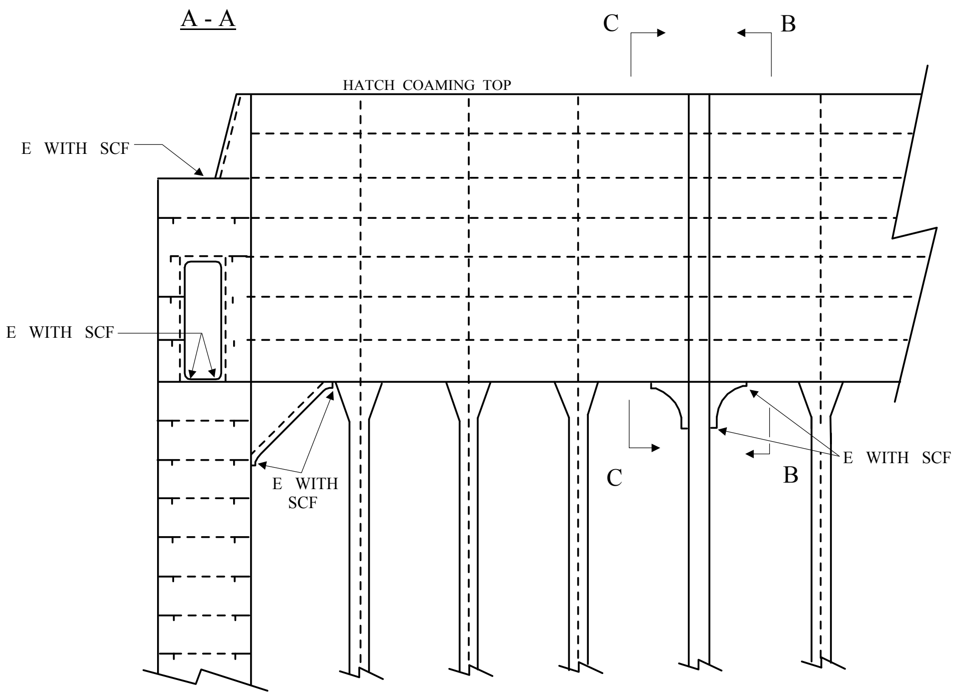


TABLE 2 (continued)
Welded Joint with Two or More Load Carrying Members

b Connections of Longitudinal Deck Girders and Cross Deck Box Beams to Other Supporting Structures



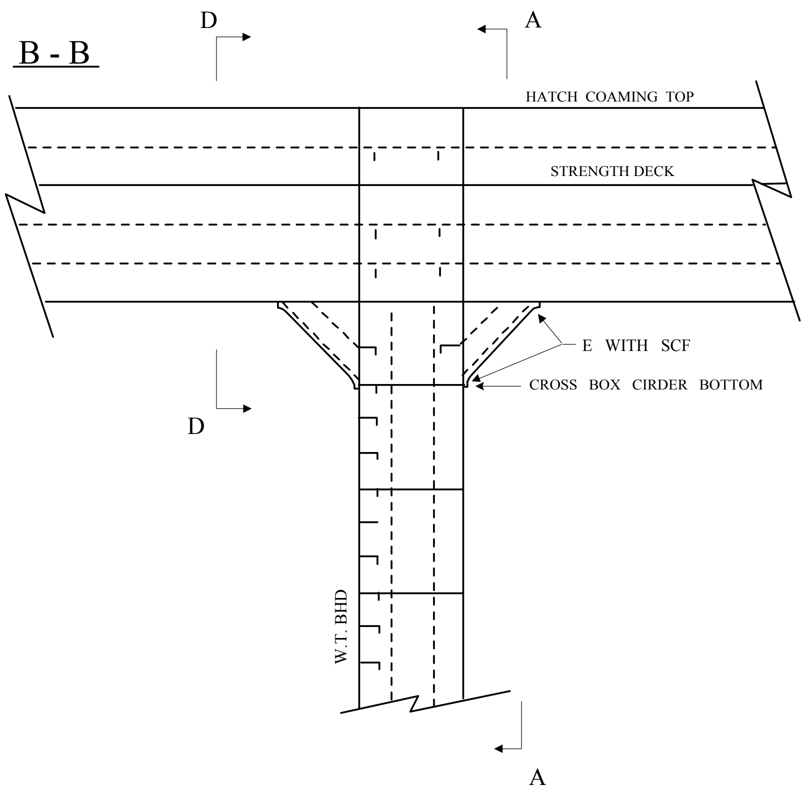
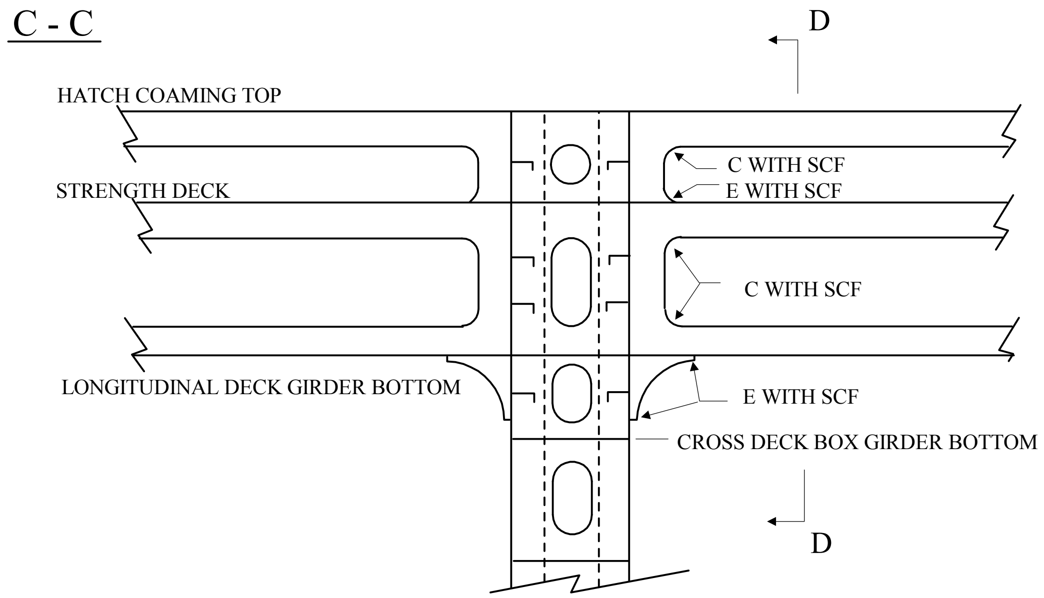


TABLE 2 (continued)
Welded Joint with Two or More Load Carrying Members



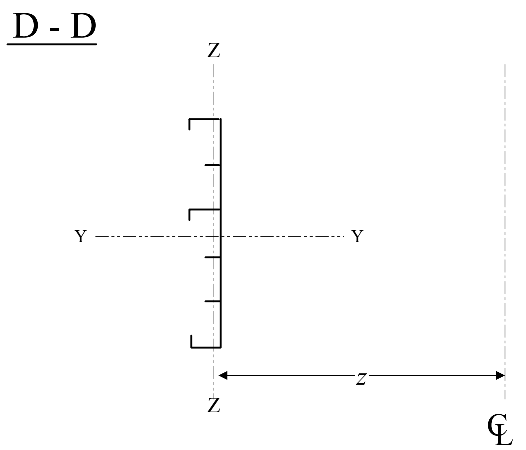
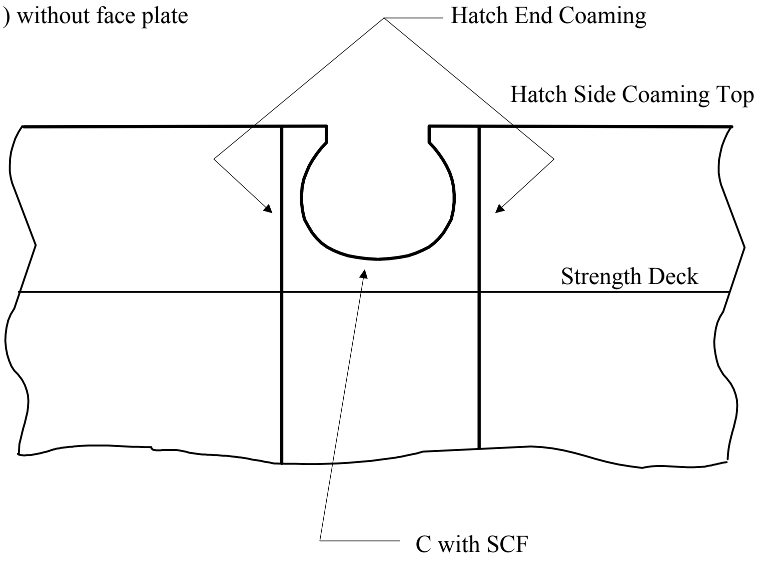


TABLE 2 (continued)
Welded Joint with Two or More Load Carrying Members

c Discontinuous Hatch Side Coaming

1) without face plate



2) with face plate

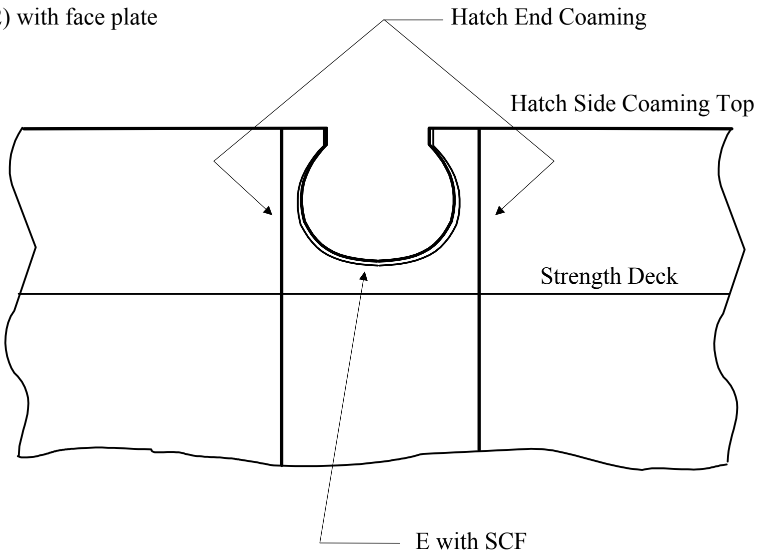
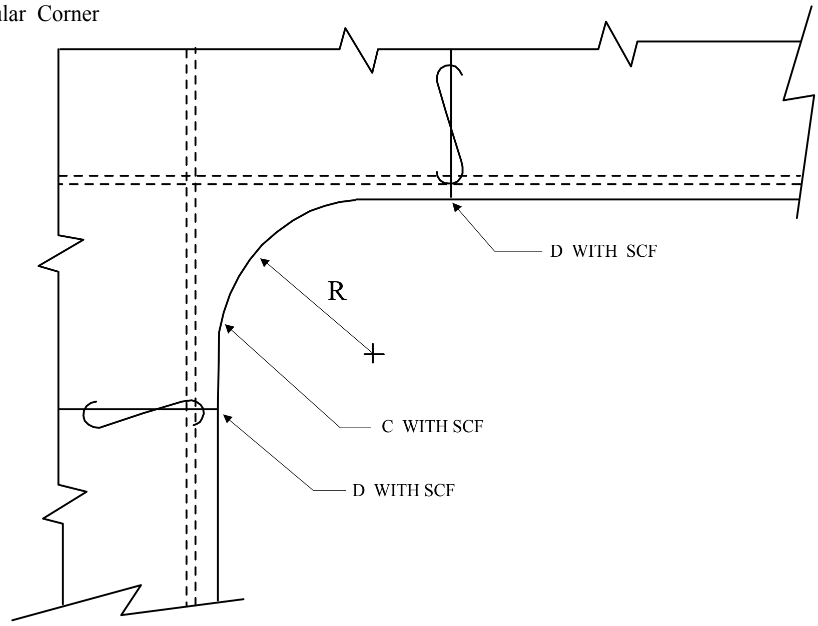


TABLE 2 (continued)
Welded Joint with Two or More Load Carrying Members

d Hatch Corners

Circular Corner



Double Curvature

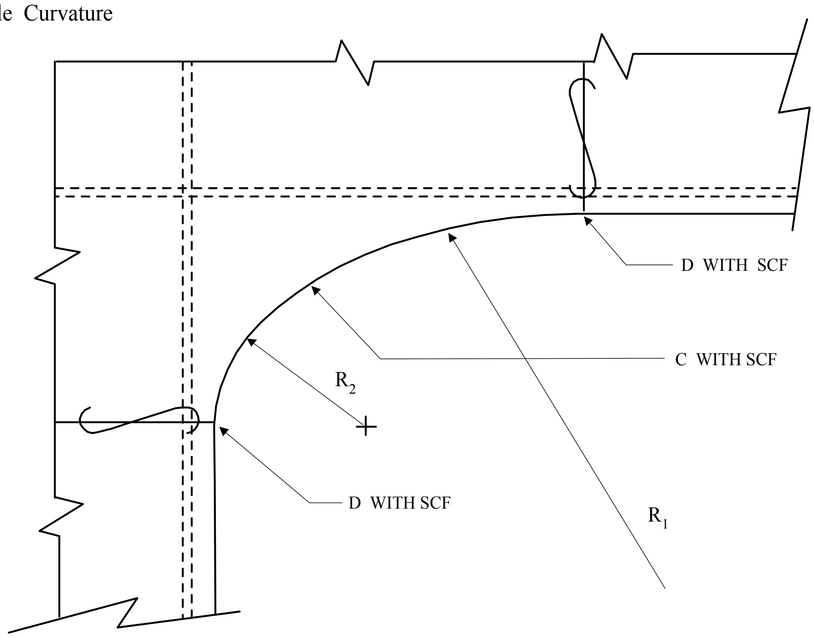


TABLE 2 (continued)
Welded Joint with Two or More Load Carrying Members

Cut-out Radius

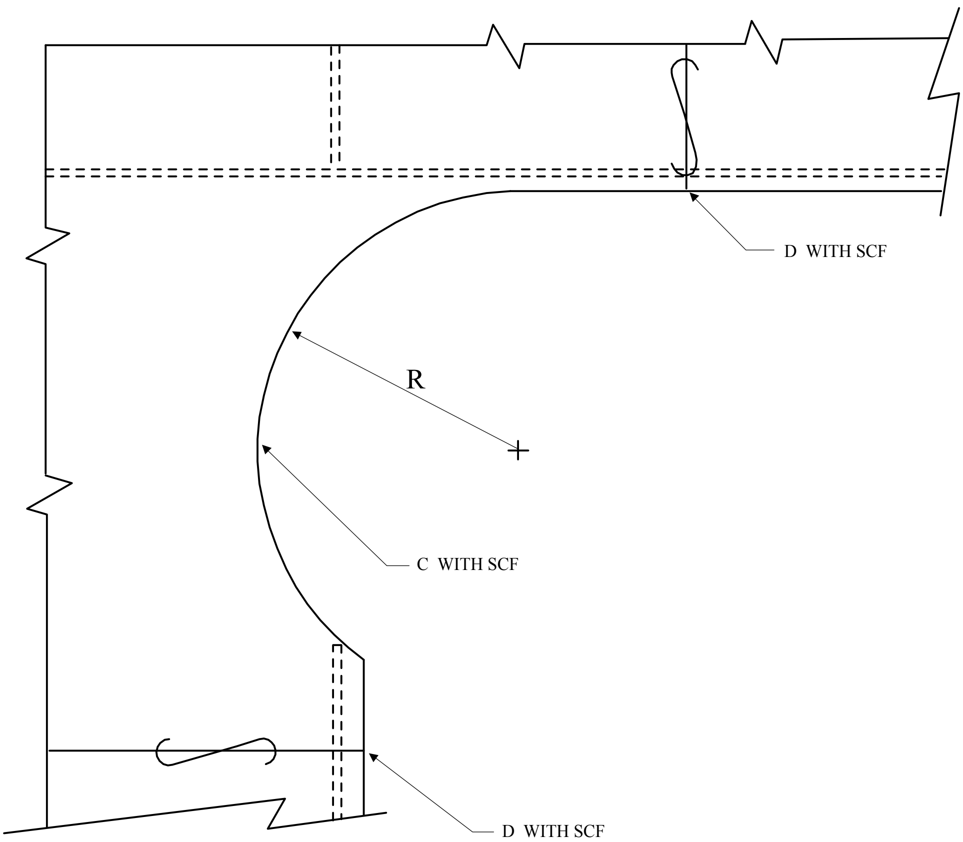
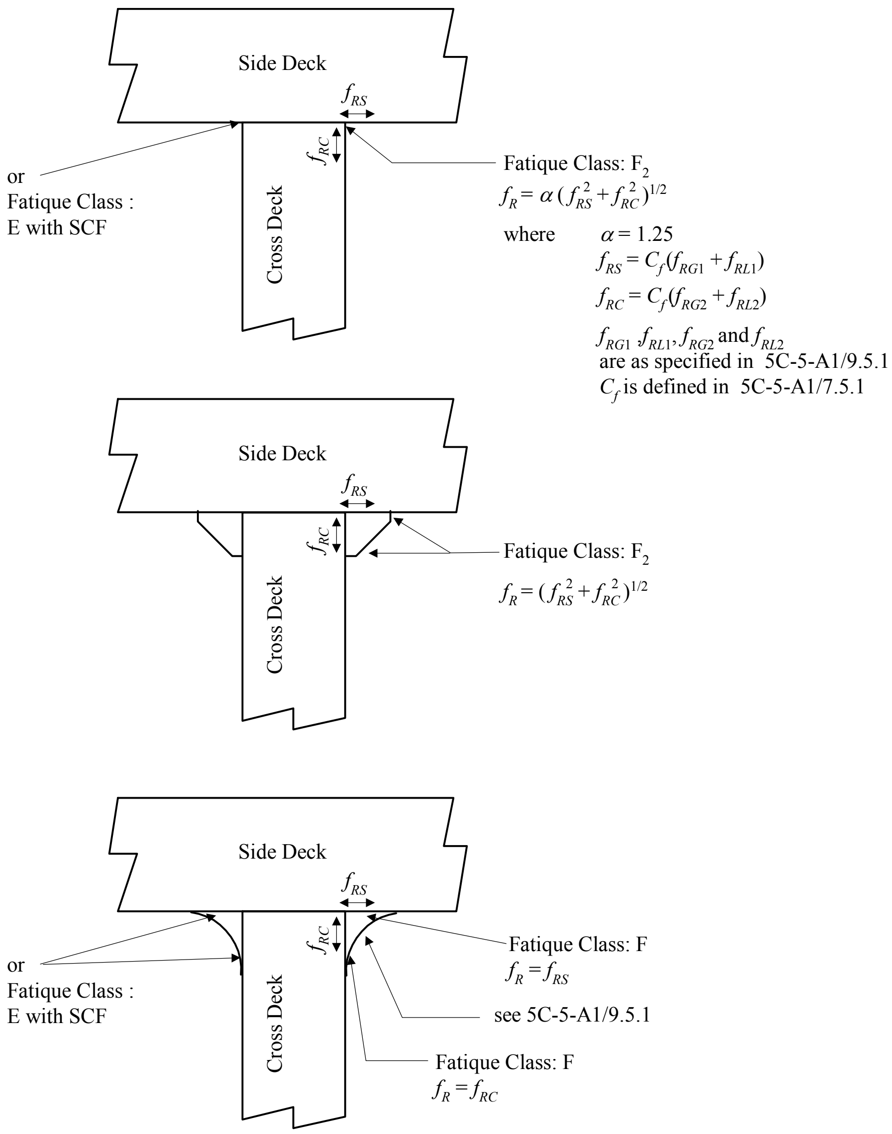


TABLE 2 (continued)
Welded Joint with Two or More Load Carrying Members

End Connections at Lower Deck



Note: Thickness of brackets is to be not less than that of cross deck plating in the same location (level).

For fitting of cell guide, no cut nor welding to the brackets is allowed.

5 Permissible Stress Range

5.1 Assumption *(1998)*

The fatigue strength of a structural detail under the loads specified here in terms of a long term, permissible stress range is to be evaluated using the criteria contained in this section. The key assumptions employed are listed below for guidance.

- A linear cumulative damage model (i.e., Palmgren-Miner's Rule) has been used in connection with the S-N data in 5C-5-A1/Figure 1 (extracted from Ref. 1*).

  * Ref. 1: "Offshore Installations: Guidance on Design, Construction and Certification", Department of Energy, U.K., Fourth Edition - 1990, London: HMSO

- Cyclic stresses due to the loads in 5C-5-A1/7 have been used and the effects of mean stress have been ignored.
- The target design life of the vessel is taken to be 20 years.
- The long-term stress ranges on a detail can be characterized by using a modified Weibull probability distribution parameter (γ).
- Structural details are classified and described in 5C-5-A1/Table 1, "Fatigue Classification of Structural Details".
- Simple nominal stress (e.g., determined by P/A and M/SM) is the basis of fatigue assessment rather than more localized peak stress in way of weld.

The structural detail classification in 5C-5-A1/Table 1 is based on joint geometry and direction of the dominant load. Where the loading or geometry is too complex for a simple classification, a finite element analysis of the details is to be carried out to determine the stress concentration factors. 5C-5-A1/11 contains guidance on finite element analysis modeling to determine stress concentration factors for weld toe locations that are typically found at longitudinal stiffener end connections.

5.3 Criteria *(1998)*

The permissible stress range obtained using the criteria in 5C-5-A1/5 is to be not less than the fatigue inducing stress range obtained from 5C-5-A1/7.

5.5 Long Term Stress Distribution Parameter, γ *(1998)*

In 5C-5-A1/Table 1, the permissible stress range is given as a function of the long-term distribution parameter, γ, as defined below.

$$\gamma = m_s \gamma_o$$

where

m_s = 1.05 for deck and bottom structures of vessels with a forebody parameter, $A_r d_k$ = 155 m^2 (1667.5 ft^2), as defined in 5C-5-3/11.3.

= 1.02 for deck and bottom structures of vessels with a forebody parameter, $A_r d_k$ = 112 m^2 (1205 ft^2)

= 1.0 for structures elsewhere, and all structures of vessels without bowflare slamming [$A_r d_k \leq$ 70 m^2 (753 ft^2)]

For intermediate values of $A_r d_k$, m_s may be obtained by linear interpolation. For $A_r d_k >$ 155 m^2 (1667.5 ft^2), m_s is to be determined by direct calculations.

γ_o = $1.40 - 0.2\ \alpha L^{0.2}$ for $130 < L \leq 305$ m

= $1.54 - 0.245\ \alpha^{0.8} L^{0.2}$ for $L > 305$ m

γ_o = $1.40 - 0.16\ \alpha L^{0.2}$ for $427 < L \leq 1001$ ft

= $1.54 - 0.19\ \alpha^{0.8} L^{0.2}$ for $L > 1001$ ft

where

α = 1.0 for deck structures, including side shell and longitudinal bulkhead structures within 0.1D from the deck

= 0.93 for bottom structures, including inner bottom, and side shell and longitudinal bulkhead structures within 0.1D from the bottom

= 0.86 for side shell and longitudinal bulkhead structures within the region of 0.25D upward and 0.3D downward from the mid-depth

= 0.80 for side frames, vertical stiffeners on longitudinal bulkhead and transverse bulkhead structures

α may be linearly interpolated for side shell and longitudinal bulkhead structures between 0.1D and 0.25D from the deck and between 0.1D and 0.2D from the bottom.

In the calculation of γ for fatigue assessment of hatch corners, m_s, given in the above equation in association with $A_r\ d_k$, is to be used in L.C.1 through L.C.4 and m_s may be taken as 1.0 in other loading conditions. α may be also taken as 1.0.

L and D are the vessel's length and depth, as defined in 3-1-1/3.1 and 3-1-1/7.

5.7 Permissible Stress Range *(1998)*

5C-5-A1/Table 1 contains a listing of permissible stress ranges for various categories of structural details. The permissible stress range is determined for the combination of the types of connections/ details, the direction of the dominant loading and the parameter, γ, as defined in 5C-5-A1/5.5. Linear interpolation may be used to determine the values of permissible stress range for γ between those given.

(2003) For vessels designed for a fatigue life in excess of the minimum design fatigue life of 20 years (see 5C-5-1/1.2), the permissible stress ranges (PS) calculated above are to be modified by the following equation:

$PS[Y_r]$ = $C(20/Y_r)^{1/m}\ PS$

where

$PS[Y_r]$ = permissible stress ranges for the design fatigue life for the Y_r

Y_r = target value of "design fatigue life" set by the applicant in 5 year increment

m = 3 for Class D through W of S-N curve, 3.5 for Class C or 4 for Class B curves

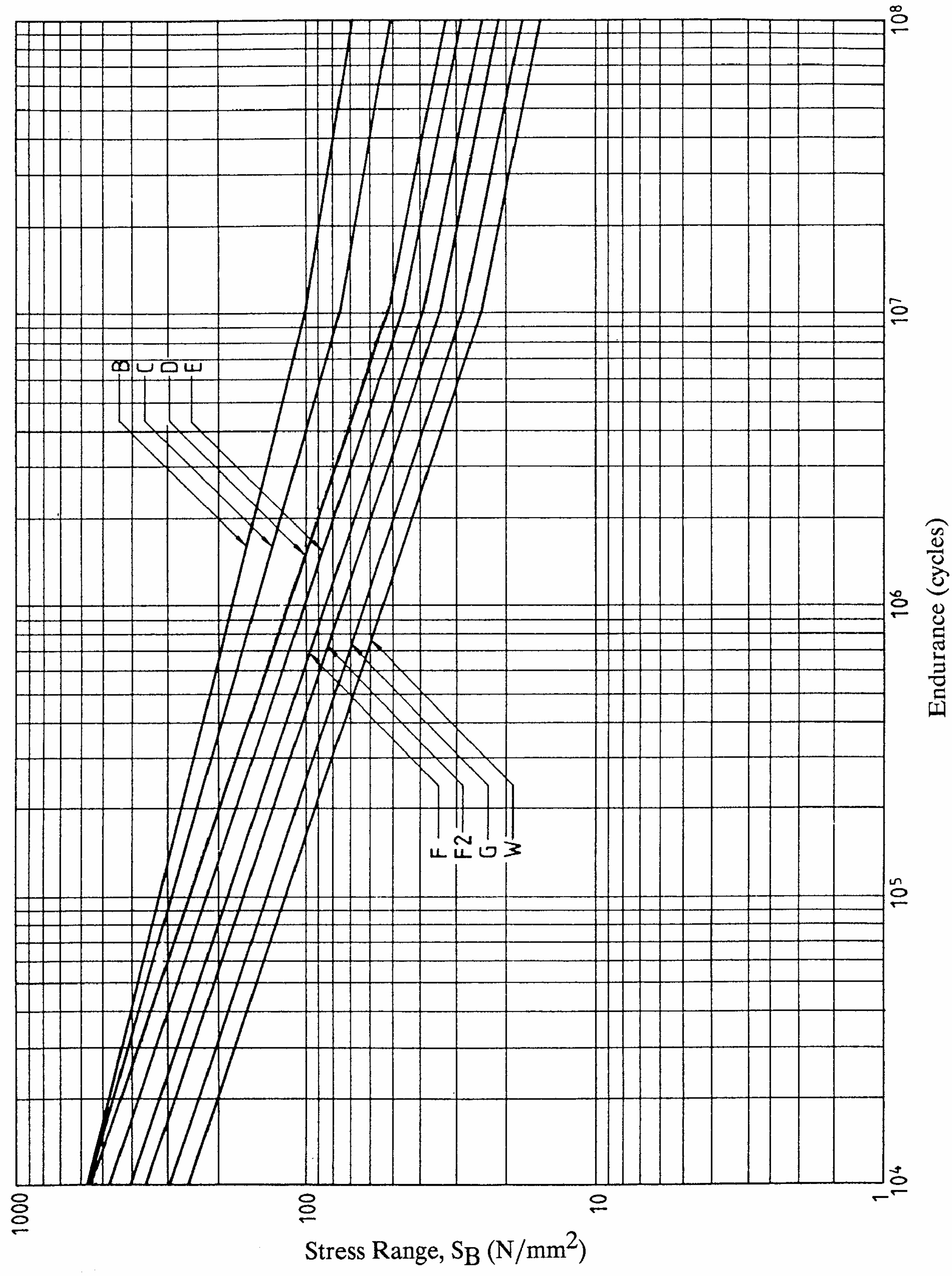
C = correction factor related to target design fatigue life considering the two-segment S-N curves (see 5C-5-A1/Table 2A).

TABLE 2A
Coefficient, C

Long-term stress distribution parameter γ	*Target Design Fatigue Life, years* Y_r	*S-N Curve Classes*		
		B	*C*	*D through W*
0.7	20	1.000	1.000	1.000
	30	1.004	1.006	1.011
	40	1.007	1.012	1.020
	50	1.010	1.016	1.028
0.8	20	1.000	1.000	1.000
	30	1.005	1.008	1.014
	40	1.009	1.015	1.025
	50	1.013	1.021	1.035
0.9	20	1.000	1.000	1.000
	30	1.006	1.010	1.016
	40	1.012	1.019	1.030
	50	1.017	1.026	1.042
1.0	20	1.000	1.000	1.000
	30	1.008	1.012	1.019
	40	1.015	1.022	1.035
	50	1.020	1.031	1.049

Note: Linear interpolations may be used to determine the values of C where Y_r = 25, 35 and 45

FIGURE 1
Basic Design S-N Curves *(1998)*



Notes (For 5C-5-A1/Figure 1)

a) Basic design S-N curves

The basic design curves consist of linear relationships between $\log(S_B)$ and $\log(N)$. They are based upon a statistical analysis of appropriate experimental data and may be taken to represent two standard deviations below the mean line.

Thus the basic S-N curves are of the form:

$$\log(N) = \log(K_2) - m \log(S_B)$$

where

$$\log(K_2) = \log(K_1) - 2\sigma$$

N is the predicted number of cycles to failure under stress range S_B;

K_1 is a constant relating to the mean S-N curve;

σ is the standard deviation of log N;

m is the inverse slope of the S-N curve.

The relevant values of these terms are shown in the table below.

The S-N curves have a change of inverse slope from m to $m + 2$ at $N = 10^7$ cycles.

Details of basic S-N curves

Class	K_1	K_1		m	*Standard Deviation*		K_2
		$\log_{10}$	$\log_e$		$\log_{10}$	$\log_e$	
B	2.343×10^{15}	15.3697	35.3900	4.0	0.1821	0.4194	1.01×10^{15}
C	1.082×10^{14}	14.0342	32.3153	3.5	0.2041	0.4700	4.23×10^{13}
D	3.988×10^{12}	12.6007	29.0144	3.0	0.2095	0.4824	1.52×10^{12}
E	3.289×10^{12}	12.5169	28.8216	3.0	0.2509	0.5777	1.04×10^{12}
F	1.726×10^{12}	12.2370	28.1770	3.0	0.2183	0.5027	0.63×10^{12}
F_2	1.231×10^{12}	12.0900	27.8387	3.0	0.2279	0.5248	0.43×10^{12}
G	0.566×10^{12}	11.7525	27.0614	3.0	0.1793	0.4129	0.25×10^{12}
W	0.368×10^{12}	11.5662	26.6324	3.0	0.1846	0.4251	0.16×10^{12}

7 Calculation of Fluctuating Loads and Determination of Total Stress Ranges

7.1 General *(1998)*

This section provides: 1) the criteria to define the individual load components considered to cause fatigue damage (see 5C-5-A1/7.3.1); 2) the load combination cases to be considered for different regions of the hull containing the structural detail being evaluated (see 5C-5-A1/7.5.2); and 3) procedures to idealize the structural components to obtain the total stress ranges acting on the structure.

7.3 Wave-induced Loads

7.3.1 Load Components *(1998)*

The fluctuating load components to be considered are those induced by the seaway. They are divided into the following three groups:

- Hull girder wave-induced moments (vertical, horizontal, and torsion), see 5C-5-3/5 and 5C-5-3/7.
- External hydrodynamic pressures, see 5C-5-3/5.3.
- Internal fluid loads (including inertial loads and added static head due to ship's motion), see 5C-5-3/5.5.

7.5 Resulting Stress Ranges

7.5.1 Definitions *(2007)*

The total stress range, f_R, is computed as the sum of the two stress ranges, as follows:

$$f_R = c_f c_m (f_{RG} + f_{RL}) \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

f_{RG} = global dynamic stress range, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $|(f_{d1vi} - f_{d1vj}) + (f_{d1hi} - f_{d1hj}) + (f_{d1wi} - f_{d1wj})|$

f_{RL} = local dynamic stress range, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $c_w\,|(f_{d2i} + f^*_{d2i} + f_{d3i}) - (f_{d2j} + f^*_{d2j} + f_{d3j})|$

c_f = adjustment factor to reflect a mean wasted condition

= 0.95

c_m = 0.85 for connections of longitudinals to transverse web/floor and transverse bulkhead in bottom part of Zone A, as specified in 5C-5-A1/7.5.2(a)

c_m = 0.85 for connection of floor to plates in bottom part of Zone A

= 1.0 for all other locations

c_w = coefficient for the weighted effects of the two paired loading patterns

= 0.75 for local dynamic stress range, as specified in 5C-5-A1/7.9.1, 5C-5-A1/7.9.2 and 5C-5-A1/7.11

= 1.0 otherwise

f_{d1vi}, f_{d1vj} = wave-induced component of the primary stresses produced by hull girder vertical bending, in N/cm^2 (kgf/cm^2, lbf/in^2), for load case i and j of the selected pairs of combined load cases, respectively. For this purpose, k_w is to be taken as $k_0^{1/2}$ in calculating M_w (sagging and hogging) in 5C-5-3/5.1.1

f_{d1hi}, f_{d1hj} = wave-induced component of the primary stresses produced by hull girder horizontal bending, in N/cm^2 (kgf/cm^2, lbf/in^2), for load case i and j of the selected pairs of combined load cases, respectively

f_{d1wi}, f_{d1wj} = wave-induced component of the primary stresses produced by hull girder torsion (warping stress) moment, in N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively. These components are applicable to the structural details in 5C-5-A1/3.3.4 and 5C-5-A1/3.3.5

f_{d2i}, f_{d2j} = wave-induced component of the secondary bending stresses produced by the bending of cross stiffened panels between transverse bulkheads, in N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively

f^*_{d2i}, f^*_{d2j} = wave-induced component of the additional secondary bending stresses produced by the local bending of the longitudinal stiffener between supporting structures (e.g., transverse bulkheads and web frames), in N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively

f_{d3i}, f_{d3j} = wave-induced component of the tertiary bending stresses produced by the local bending of plated elements between the longitudinal stiffeners, in N/cm^2 (kgf/cm^2, lbf/in^2), for load case *i* and *j* of the selected pairs of combined load cases, respectively

For calculating the wave induced stresses, sign convention is to be observed for the respective directions of wave-induced loads, as specified in 5C-5-3/Table 1. The wave-induced load components are to be calculated with the sign convention for the external and internal loads and the wave-induced local net pressure is to be taken positive toward inboard and positive upwards; however, the total of the external static and dynamic components or the total of the internal static and dynamic components need not be taken less than zero.

These wave-induced stresses are to be determined based on the net ship scantlings (see 5C-5-A1/1.7) and in accordance with 5C-5-A1/7.5.2 through 5C-5-A1/7.11. The results of direct calculation, where carried out, may also be considered.

7.5.2 Fatigue Assessment Zones and Controlling Load Combination *(1998)*

Depending on the location of the structural detail undergoing the fatigue assessment, different combinations of load cases are to be used to find the appropriate stress range as indicated below for indicated respective zones.

7.5.2(a) Zone A. Zone A consists of deck and bottom structures, side shell and all longitudinal bulkhead structures within 0.10*D* (*D* is vessel's molded depth) from deck or bottom, respectively, except for members and locations specified in 5C-5-A1/3.3.6 through 5C-5-A1/3.3.9 (see 5C-5-A1/7.5.2(d) below). For Zone A, stresses are to be calculated based on the wave-induced loads specified in 5C-5-3/Table 1, as follows, except for the members and locations specified in 5C-5-A1/3.3.4, 5C-5-A1/3.3.5, 5C-5-A1/3.3.7 and 5C-5-A1/3.3.8 (see 5C-5-A1/7.5.2(d) below).

1 Calculate dynamic component of stresses for load cases L.C.1 through L.C.4, respectively.

2 Calculate two sets of stress ranges, one each for the following two pairs of combined loading cases.

- L.C.1 and L.C.2, and
- L.C.3 and L.C.4

3 Use the greater of the stress ranges obtained by 2.

7.5.2(b) Zone B. Zone B consists of side shell and all longitudinal bulkhead structures within the region between 0.25*D* upward and 0.30*D* downward from the mid-depth and all transverse bulkhead structures. The total stress ranges for Zone B may be calculated based on the wave-induced loads specified in 5C-5-A1/Table 3 and 5C-5-3/Table 1, as follows, except for the members and locations specified in 5C-5-A1/3.3.4, 5C-5-A1/3.3.5, 5C-5-A1/3.3.7 and 5C-5-A1/3.3.8 (see 5C-5-A1/7.5.2(d) below).

1 Calculate dynamic component of stresses for load cases L.C.5 through L.C.10, L.C.F1 and L.C.F2, respectively.

2 Calculate four sets of stress ranges, one each for the following four pairs of combined loading cases.

- L.C.5 and L.C.6,
- L.C.7 and L.C.8,
- L.C.9 and L.C.10, and
- L.C.F1 and L.C.F2

3 Use the greater of the stress ranges obtained by 2.

7.5.2(c) Transitional Zone. Transitional zone between A and B consists of side shell and all longitudinal bulkhead structures between 0.1*D* and 0.25*D* (0.2*D*) from deck (bottom).

$$f_R = f_{R(B)} - [f_{R(B)} - f_{R(A)}]\, y_u / 0.15D$$

for upper transitional zone

$$f_R = f_{R(B)} - [f_{R(B)} - f_{R(A)}]\, y_\ell / 0.10D$$

for lower transitional zone

where

$f_{R(A)}, f_{R(B)}$	=	the total stress ranges based on the combined load cases defined for Zone A and Zone B, respectively
y_u	=	vertical distance from 0.25*D* upward from the mid-depth upward to the location considered
y_ℓ	=	vertical distance from 0.3*D* downward from the mid-depth downward to the location considered

7.5.2(d) Hatch Related Members For members and locations specified in 5C-5-A1/3.3.4, 5C-5-A1/3.3.5 and 5C-5-A1/3.3.7, the total stress ranges are to be obtained in the same manner as in 5C-5-A1/7.5.2(a) and 5C-5-A1/7.5.2 (b) for Zones A and B for the following six pairs of combined loading cases:

- L.C.1 and L.C.2,
- L.C.3 and L.C.4,
- L.C.5 and L.C.6,
- L.C.7 and L.C.8,
- L.C.9 and L.C.10, and
- L.C.F1 and L.C.F2

7.5.2(e) Vessels with either Special Loading Patterns or Special Structural Configuration. For vessels with either special loading patterns or special structural configurations/features, additional load cases may be required for determining the stress range.

7.7 Primary Stress f_{d1} (2002)

f_{d1v} and f_{d1h} may be calculated by a simple beam approach. For assessing fatigue strength of side shell and longitudinal bulkhead plating at welded connections, the value of wave-induced primary stress is to be taken as that of maximum principal stresses at the location considered to account for the combined load effects of the normal stresses and shear stresses. For calculating the value of f_{d1v} for longitudinal deck members, normal camber may be disregarded.

f_{d1w} in way of hatch corners at strength deck, top of continuous hatch side coaming and lower deck, which is effective for the hull girder strength and is located in line with the bottom of cross deck box beam, within 0.22D below the strength deck at side, may be approximated by the following equation:

$$f_{d1w} = k_c f_{LWW} \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

f_{LWW} is defined in 5C-5-4/9.3 as specified for cargo space forward of engine room and for cargo space abaft engine room. ω is to be used as a warping function at the location under consideration.

In a calculation of f_{LWW}, C_w for the lower deck is to be used as 80% of that given for the strength deck in 5C-5-4/9.3.

k_c is specified in 5C-5-A1/Table 3 and 5C-5-3/Table 1 for torsional moment with α_s = 1.0.

7.9 Secondary Stress f_{d2i} (1998)

When a 3D structural analysis is not available, the secondary bending stress ranges may be obtained from an analytic calculation or experimental data with appropriate boundary conditions. Otherwise, the secondary bending stresses may be calculated using the approximate equations given below. For the connections specified in 5C-5-A1/3.3.1, the secondary bending stresses are low and may be ignored.

7.9.1 Double Bottom

The secondary longitudinal bending stress in double bottom panels may be obtained from the following equation:

$$f_{d2bi} = k_{1b} k_{2b} k_{3b}\, p_{bei}\, \ell_s^2 r_b / i_G\,, \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

f_{d2bi} = secondary longitudinal bending stress in the double bottom panel at the intersection with the transverse bulkhead for the load case "i" considered. For other intersections with transverse web/floor, f_{d2bi} may be taken as zero.

k_{1b} = 100 (100, 0.173)
for bottom or inner bottom plating

= 91 (91, 0.157)
for face plates, flanges and web plates of bottom and inner bottom longitudinals

k_{2b} = coefficient depending on apparent aspect ratio "ρ_b", as given in 5C-5-A1/Table 4

ρ_b = $2.1(b/\ell_s)(i_G/i_F)^{1/4}$

k_{3b} = $1 - 3.9(z/b)^2$

z = the distance from vessel's centerline to the double bottom longitudinal member under consideration, in m (ft)

p_{bei} = wave-induced external pressure on the bottom shell at the centerline and at midpoint between watertight and mid-hold strength bulkheads of the hold under consideration, for the load case "*i*" considered, as specified in 5C-5-3/9, in N/cm^2 (kgf/cm^2, lbf/in^2)

b = width of the double bottom panel (see 5C-5-A1/Figure 2), in m (ft)

ℓ_s = length between watertight bulkheads of the cargo hold being considered (see 5C-5-4/Figure 8), in m (ft)

i_G and i_F = unit moments of inertia of the double bottom girders and floors, respectively

$i_G = I_G / S_G$

$i_F = I_F / S_F$

I_G and I_F = moments of inertia of an average girder and an average floor (see 5C-5-A1/Figure 2), respectively, including the effective width of plating and stiffeners attached to the effective plating, in cm^4 (in^4)

S_G and S_F = average spacing of bottom girders and floors, respectively, in m (ft)

r_b = distance between the horizontal neutral axis of the double bottom cross section and the location of the structural element being considered (bending lever arm – see 5C-5-A1/Figure 2), in cm (in.)

7.9.2 Double Sides

For double side structural members, the secondary longitudinal bending stress at the intersection with the transverse strength bulkheads and web frames may be obtained from the following equation:

$$f_{d2si} = k_{1s} k_{2s}\, p_{sei}\, h^2 r_s / (i_S\, i_W)^{1/2}, \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

f_{d2si} = secondary longitudinal bending stress in the double side panel for the load case "*i*" considered. f_{d2si} at other intersections with transverse web/web frame may be taken as zero.

k_{1s} = 7.5 (7.5, 0.013)
for side shell or longitudinal bulkhead plating

= 6.8 (6.8, 0.012)
for face plates, flanges and web plates of side longitudinals and longitudinal bulkhead stiffeners

k_{2s} = $[4a_i(1 - y/h) - b_i(1 - 2y/h)](y/h)$

a_i and b_i = coefficients depending on apparent aspect ratio "ρ_s", as given in 5C-5-A1/Table 5,

y = vertical distance from the lower end of "*h*" to the longitudinal member under consideration, as shown in 5C-5-A1/Figure 2, in m (ft)

ρ_s = $0.48\,(\ell_s/h)(i_W/i_S)^{1/4}$

p_{sei} = wave-induced external pressure on the double side at the lower end of "h" (but need not be lower than the upper turn of bilge) at the midpoint between watertight and mid-hold strength bulkheads of hold under consideration, for the load case "i" considered, as specified in 5C-5-3/9 in N/cm^2 (kgf/cm^2, lbf/in^2)

h = height of the double side panel (see 5C-5-A1/Figure 2), in m (ft)

ℓ_s = length between watertight bulkheads of the cargo hold being considered (see 5C-5-4/Figure 8), in m (ft)

i_S and i_W = unit moments of inertia of the double side panel in the longitudinal and vertical directions, respectively

$i_S = I_S / S_S$

$i_W = I_W / S_W$

I_S and I_W = moments of inertia of an average longitudinal stringer and an average web frame, respectively, including the effective width of plating and stiffeners attached to the effective plating, in cm^4 (in^4); where no stringers are fitted within the double side height "h", I_S is to be calculated for a unit including an average single longitudinal stiffener, as shown in 5C-5-A1/Figure 2

S_S and S_W = average spacing of longitudinal stringers and web plates, respectively, in m (ft); where no stringers are fitted within the double side height "h", S_S is to be taken as an average spacing between longitudinal stiffeners, as shown in 5C-5-A1/Figure 2

r_s = distance between the vertical neutral axis of the double side cross section and the location of structural element being considered (bending lever arm – see 5C-5-A1/Figure 2), in cm (in.)

7.11 Additional Secondary Stresses f^*_{d2i} and Tertiary Stresses f_{d3i} *(1998)*

7.11.1 Calculation of f^*_{d2i}

Where required, the additional secondary stresses acting at the flange of a longitudinal stiffener, f^*_{d2i} may be approximated by

$$f^*_{d2i} = C_t C_y M_i / SM \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

M_i = $p_i s \ell^2/12$ N-cm (kgf-cm, lbf-in)
at the supported ends of longitudinal without strut

= $(cp_i + c_o p_{oi}) s \ell^2/12$ N-cm (kgf-cm, lbf-in)
at the supported ends and at the strut connection of a longitudinal with strut

Where flat bar stiffeners or brackets are fitted, the bending moment, M_i, given above, may be adjusted to the location of the brackets toe, i.e., M_x in 5C-5-4/Figure 7.

Where a longitudinal has remarkably different support stiffness at its two ends (e.g., a longitudinal connected to a transverse bulkhead on one end), consideration is to be given to the increase of bending moment at the joint.

p_i	=	wave-induced local net pressure, N/cm^2 (kgf/cm^2, lbf/in^2), for specified location for the load case "*i*" at the midspan of the longitudinal considered	
p_{oi}	=	wave-induced local net pressure, N/cm^2 (kgf/cm^2, lbf/in^2), for specified location for the load case "*i*" considered at the midspan of the longitudinal connected to the other end of the strut	
c	=	0.650	at the supported ends
	=	-0.15	at the strut connection
c_o	=	0.375	at the supported ends
	=	-0.375	at the strut connection
s	=	spacing of longitudinals/stiffeners, in cm (in.)	
ℓ	=	unsupported span of longitudinal/stiffener, in cm (in.), as shown in 5C-5-4/Figure 6	
SM	=	net section modulus of the longitudinal with the associated effective plating, in cm^3 (in^3), at the flange or point considered. The effective breadth, b_e, in cm (in.), may be determined as shown in 5C-5-4/Figure 7.	
C_t	=	correction factor for the combined bending and torsional stress induced by lateral loads at the welded connection of the flat bar stiffener or bracket to the flange of longitudinal, as shown in 5C-5-4/Figure/6.	
	=	$1.0 + a_r$	for unsymmetrical sections, fabricated or rolled
	=	1.0	for tee and flat bars
C_y	=	$0.656(d/y)^4 \geq 0.30$	for side longitudinals, for $y/d \geq 0.9$
	=	1.0	for all other locations
d	=	draft, as defined in 3-1-1/9, in m (ft)	
y	=	vertical distance from the base line to the side longitudinal under consideration, in m (ft)	
a_r	=	$C_n C_p SM/K$	
C_p	=	$31.2 d_w (e/\ell)^2$	
e	=	horizontal distance between web centerline and shear center of the cross section, including longitudinal and the effective plating	
		$\approx d_w b_f^2 t_f u/(2SM)$	cm (in.)
K	=	St. Venant torsion constant for the longitudinal's cross section, excluding the associated plating	
	=	$[b_f t_f^3 + d_w t_w^3]/3$	cm^4 (in^4)
C_n	=	coefficient given in 5C-5-A1/Figure 3, as a function of ψ, for point (1) shown in 5C-5-A2/Figure 1.	
u	=	$1 - 2b_1/b_f$	
ψ	=	$0.31\ell(K/\Gamma)^{1/2}$	

Γ = Warping constant

= $mI_{yf}\, d_w^2 + d_w^3\, t_w^3/36$ cm^6 (in^6)

I_{yf} = $t_f\, b_f^3(1.0 + 3.0u^2A_w/A_s)/12$ cm^4 (in^4)

A_w = $d_w\, t_w$ cm^2 (in^2)

A_s = net sectional area of the longitudinals, excluding the associated plating, in cm^2 (in^2)

m = $1.0 - u(0.7 - 0.1d_w/b_f)$

d_w, t_w, b_1, b_f, t_f, all in cm (in.), are as defined in 5C-5-A2/Figure 1.

For general applications, a_r need not be taken greater than 0.65 for a fabricated angle bar and 0.50 for a rolled section.

For connection as specified in 5C-5-A1/3.3.3, the wave-induced additional secondary stress f^*_{d2i} may be ignored.

7.11.2 Calculation of f_{d3i}

For welded joints of a stiffened plate panel, f_{d3i} may be determined based on the wave-induced local loads as specified in 5C-5-A1/7.11.1 above, using the approximate equations given below. For direct calculation, non-linear effect and membrane stresses in the plate may be considered.

For plating subjected to lateral load, f_{d3i} in the longitudinal direction is determined as:

$$f_{d3i} = 0.182p_i(s/t_n)^2 \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

p_i = wave-induced local net pressure for the load case "i" considered, in N/cm^2 (kgf/cm^2, lbf/in^2)

s = spacing of longitudinal stiffeners, in mm (in.)

t_n = net thickness of plate, in mm (in.)

7.13 Calculation of Stress Range for Side Frame and Vertical Stiffener on Longitudinal Bulkhead *(1998)*

For fatigue strength assessment, the stress range acting at the flange of a side frame and vertical stiffener on longitudinal bulkhead may be obtained from the following equation:

$$f_R = c_f\, c_w(\,|\,f^*_{d2i}\,| + |\,f^*_{d2j}\,|\,) \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

The values of f^*_{d2i} and f^*_{d2j} may both be approximated by

$$f^*_{d2i} = C_t M_i/SM \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

M_i = $p_i s\ell^2/12$ N-cm (kgf-cm, lbf-in)

at the supported ends of frame without strut

= $(cp_i + c_o p_{oi})s\ell^2/12$ N-cm (kgf-cm, lbf-in)

at the supported ends and at the strut connection of a frame with strut

Where flat bar stiffeners or brackets are fitted, the bending moment, M_i, given above, may be adjusted to the location of the bracket toe, i.e., M_x in 5C-5-4/Figure 7.

p_i = wave-induced local net pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), for specified location for load case "*i*" at the midspan of the frame considered. The local net pressure is to be taken as an average value of that calculated at lower and upper ends of the span.

p_{oi} = wave-induced local net pressure, in N/cm^2 (kgf/cm^2, lbf/in^2), for specified location for load case "*i*" at the midspan of the stiffener connected to the other end of the strut

c = 0.650 at the supported ends

= -0.125 at the strut connection

c_o = 0.375 at the supported ends

= -0.375 at the strut connection

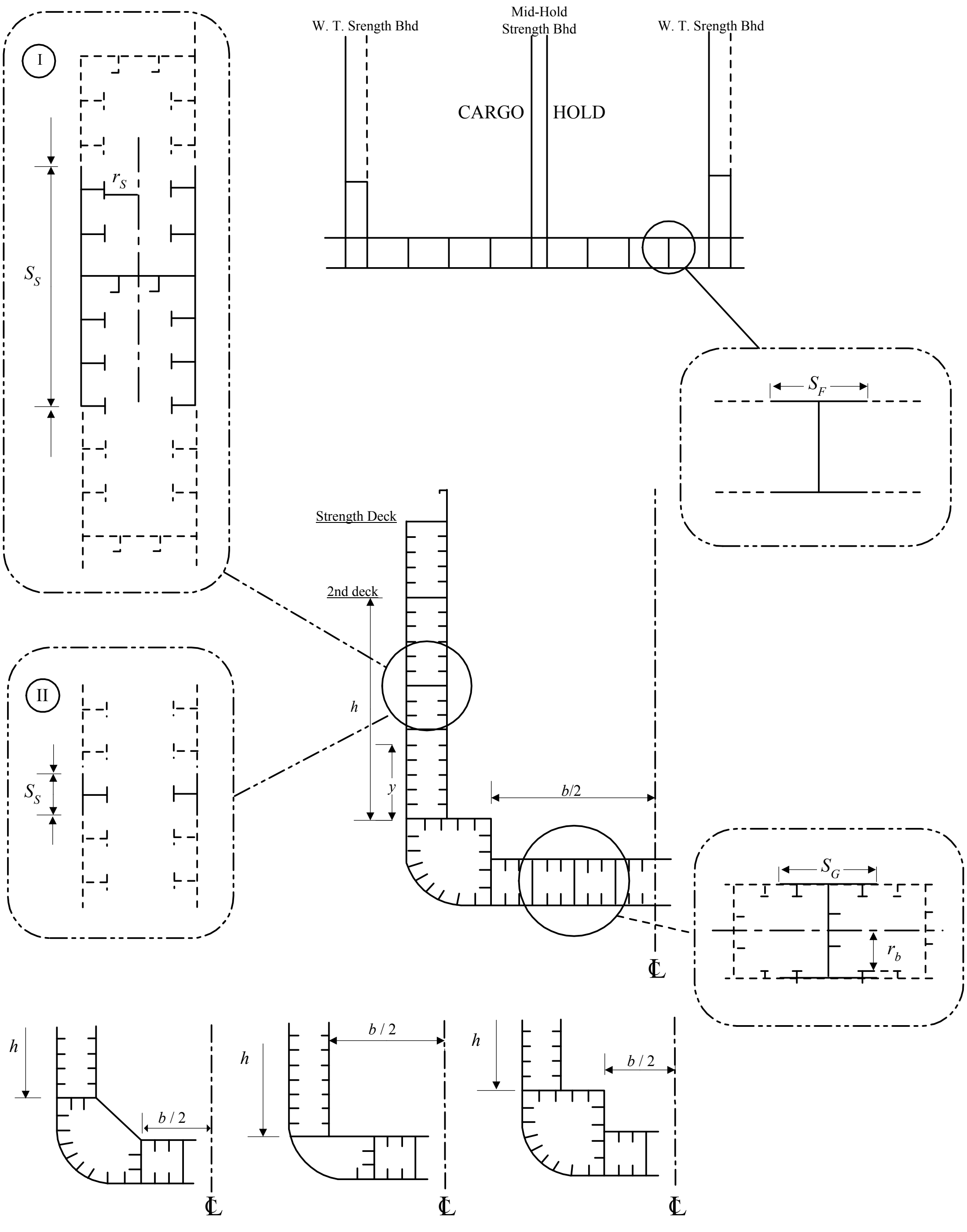
s = spacing of frame/stiffener, in cm (in.)

ℓ = unsupported span of frame/stiffener, in cm (in.)

SM = net section modulus of the frame with the associated effective plating, in cm^3 (in^3), at the flange or point considered. The effective breadth, b_e, in cm (in.), may be determined as shown in 5C-5-4/Figure 7.

c_f and c_w are as defined in 5C-5-A1/7.5.1 and C_t is as defined in 5C-5-A1/7.11.1.

FIGURE 2
Dimensions of Double Bottom and Double Side *(1998)*



Type I when one or more longitudinal stringers (decks) are fitted in double-side structure

Type II when no longitudinal stringers are fitted in double-side structure

FIGURE 3
$C_n = C_n(\psi)$ *(1998)*

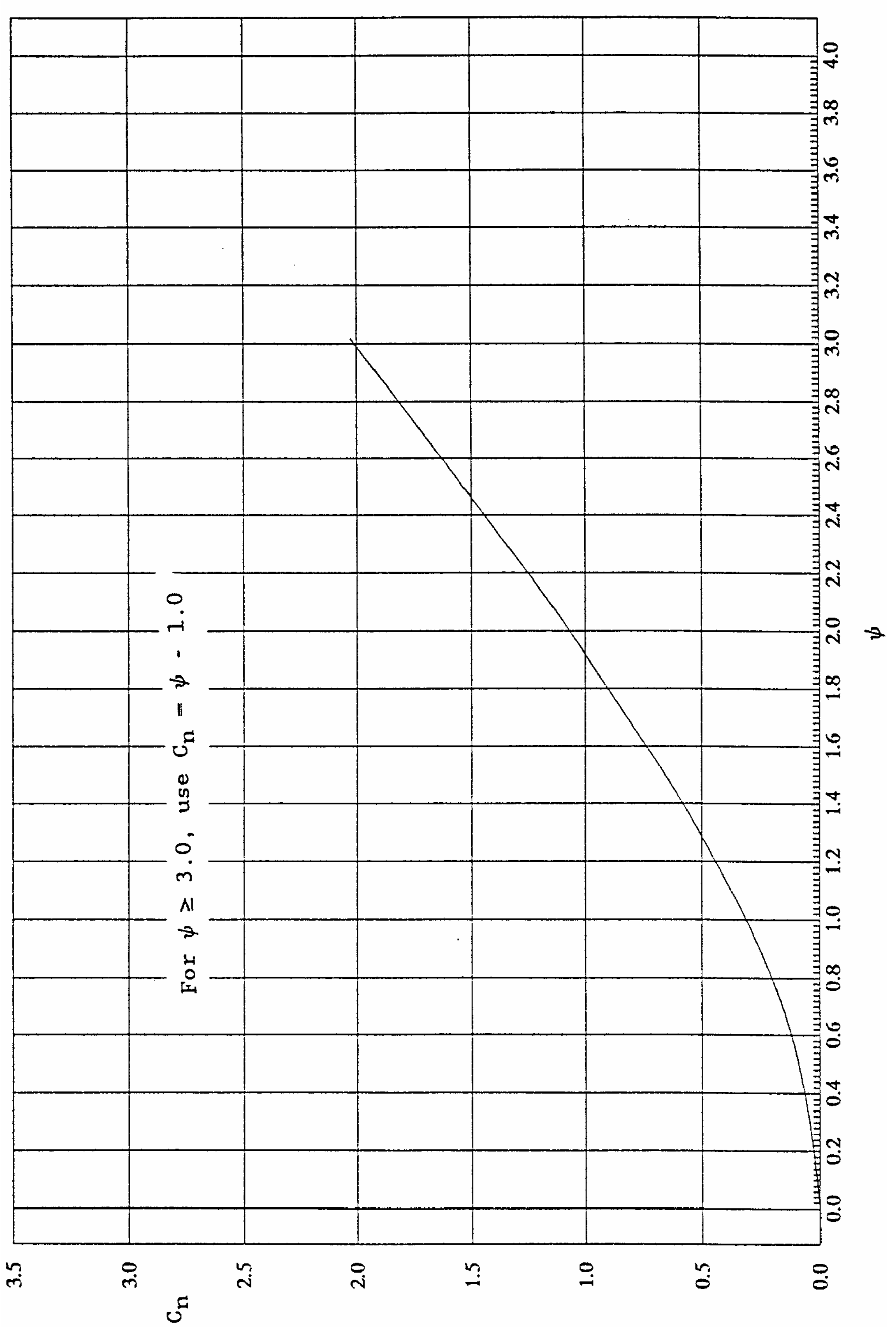
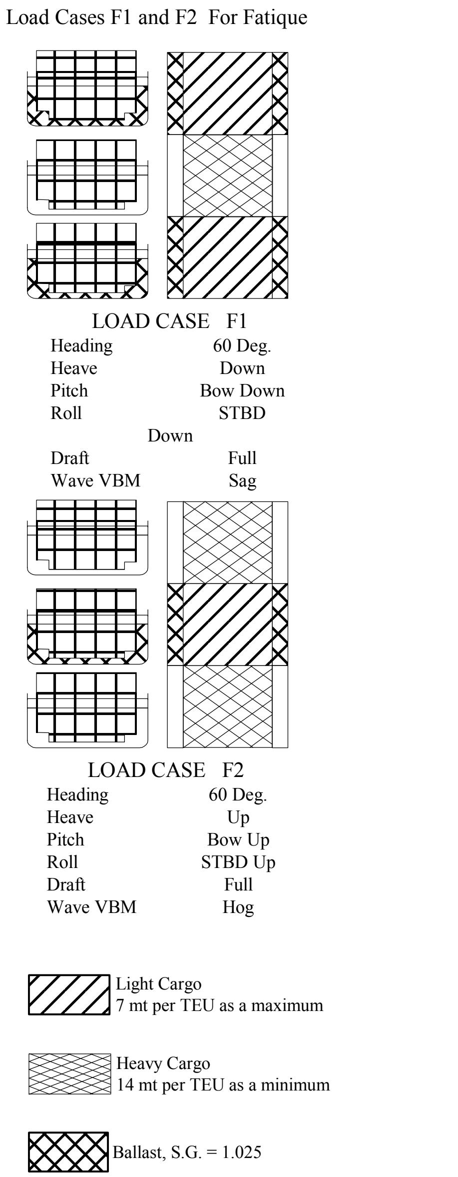


TABLE 3
Combined Load Cases for Container Carriers *(1998)*

Fatigue Assement (1)

		L.C. F1	L.C. F2
A	HULL GIRDER LOADS (2)		
	Vertical B.M. (3) k_c	Sag (–) 0.4	Hog (+) 0.4
	Vertical S.F. k_c	(+) 0.4	(–) 0.4
	Horizontal B.M. k_c	Stbd Tens (-) 1.0	Port Tens (+) 1.0
	Horizontal S.F. k_c	(+) 1.0	(–) 1.0
	Torsional Mt. (4) k_c	(–) 0.55 α_s	(+) 0.55 α_s
B	EXTERNAL PRESSURE		
	k_c	0.5	1.0
	k_{f0}	–1.0	1.0
C	CONTAINER CARGO LOAD		
	k_c	1.0	0.5
	c_V	0.7	–0.7
	c_L	Fwd Bhd 0.7 Aft Bhd 0.0	Fwd Bhd 0.0 Aft Bhd –0.7
	c_T	Port Wall 0.0 Stbd Wall 0.7	Port Wall –0.7 Stbd Wall 0.0
	C_ϕ, Pitch	–0.7	0.7
	C_θ, Roll	0.7	–0.7
D	INTERNAL BALLAST TANK PRESSURE		
	k_c	1.0	0.5
	w_v	0.4	–0.4
	w_l	Fwd Bhd 0.2 Aft Bhd –0.2	Fwd Bhd –0.2 Aft Bhd 0.2
	w_t	Port Wall –0.4 Stbd Wall 0.4	Port Wall 0.4 Stbd Wall –0.4
	C_ϕ, Pitch	–0.7	0.7
	C_θ, Roll	0.7	–0.7
E	REFERENCE WAVE HEADING AND POSITION		
	Heading Angle	60	60
	Heave	Down	Up
	Pitch	Bow Down	Bow Up
	Roll	Stbd Down	Stbd Up
	Draft	1	1

Load Cases F1 and F2 for Fatigue



1 k_u = 1.0 for all load components.

2 Boundary forces are to be applied to produce the above specified hull girder bending moment at the middle of the structural model, and specified hull girder shear force at one end of the middle hold of the model. The sign convention for the shear force corresponds to the forward end of middle hold. The specified torsional moment is to be produced at the aft bulkhead of the middle hold.

3 The following still water bending moment (SWBM) is to be used for structural analysis.
L.C. F1: Maximum sagging SWBM.
L.C. F2: Maximum hogging SWBM.

4 *(1999)* α_s is to be obtained by the following equation:

$$\alpha_s = (T_m + T_s)/T_m$$

where

T_m = nominal wave-induced torsional moment amidships, in kN-m (tf-m, Ltf-ft), as defined in 5C-5-3/5.1.5(a)
T_s = still-water torsionl moment amidships, in kN-m (tf-m, Ltf-ft), as defined in 5C-5-3/3.1

TABLE 4
Coefficient k_{3b} for Double Bottom Panels

ρ_b	1.0	1.2	1.4	1.6	1.8	2.0	≥ 2.2
k_{2b}	700	791	844	876	896	908	915

TABLE 5
Coefficient a_i and b_i for Double Bottom Panels

	ρ_s	0.7	0.8	0.9	1.0	1.2	1.5	≥ 2.0
At W/T Strength Bhd	a_i	566	464	389	333	254	183	120
	b_i	166	150	136	123	101	74	45
At Mid-hold Strength Bhd	a_i	508	417	350	299	228	164	108
	b_i	150	136	123	111	91	67	40

9 Determination of Stress Concentration Factors (SCFs) *(1998)*

9.1 General

This section contains information on stress concentration factors (SCFs) to be considered in the fatigue assessment.

Where, for a particular example shown, no specific value of SCF is given when one is called for, it indicates that a finite element analysis is needed. When the fine mesh finite element approach is used, additional information on calculations of stress concentration factors and the selection of compatible S-N data is given in 5C-5-A1/11.

9.3 Sample Stress Concentration Factors (SCFs) *(1 July 2001)*

9.3.1 Cut-outs (Slots) for Longitudinal *(1998)*

SCFs, fatigue classifications and peak stress ranges may be determined in accordance with 5C-5-A1/Table 6 and 5C-5-A1/Figure 4.

TABLE 6
K_s (SCF) Values

	K_s *(SCF)*					
Configuration	*Unsymmetrical Flange*			*Symmetrical Flange*		
Location	[1]	[2]	[3]	[1]	[2]	[3]
Single-sided Support	2.0	2.1	—	1.8	1.9	—
Single-sided Support with F.B. Stiffener	1.9	2.0	—	1.7	1.8	—
Double-sided Support	2.4	2.6	1.9	2.4	2.4	1.8
Double-sided Support with F.B. Stiffener	2.3	2.5	1.8	2.3	2.3	1.7

Notes:

a The value of K_s is given based on nominal shear stresses near the locations under consideration.

b Fatigue classification

Locations [1] and [2]: Class C or B as indicated in 5C-5-A1/Table 1

Location [3]: Class F

c The peak stress range is to be obtained from the following equations:

1 **For locations [1] and [2]** *(1999)*

$$f_{RI} = c_f\,[K_s f_{si} + f_{ni}]$$

where

c_f = 0.95

f_{si} = $f_{sc} + \alpha_i f_{swi}$, $f_{si} \geq f_{sc}$

α_i = 1.8 for single-sided support

= 1.0 for double-sided support

f_{ni} = normal stress range in the web plate

f_{swi} = shear stress range in the web plate

= F_i/A_w

F_i is the calculated web shear force range at the location considered. A_w is the area of web.

f_{sc} = shear stress range in the support (lug or collar plate)

= $C_y P/(A_c + A_s)$

C_y is as defined in 5C-5-A1/7.11.1.

P = $s\, \ell\, p_o$

p_o = fluctuating lateral pressure

A_c = sectional area of the support or of both supports for double-sided support

A_s = sectional area of the flat bar stiffener, if any

K_{si} = SCFs given above

s = spacing of longitudinal/stiffener

ℓ = spacing of transverses

2 For location [3]

$$f_{R3} = c_f[f_{n3}^2 + (K_s f_{s2})^2]^{1/2}$$

where

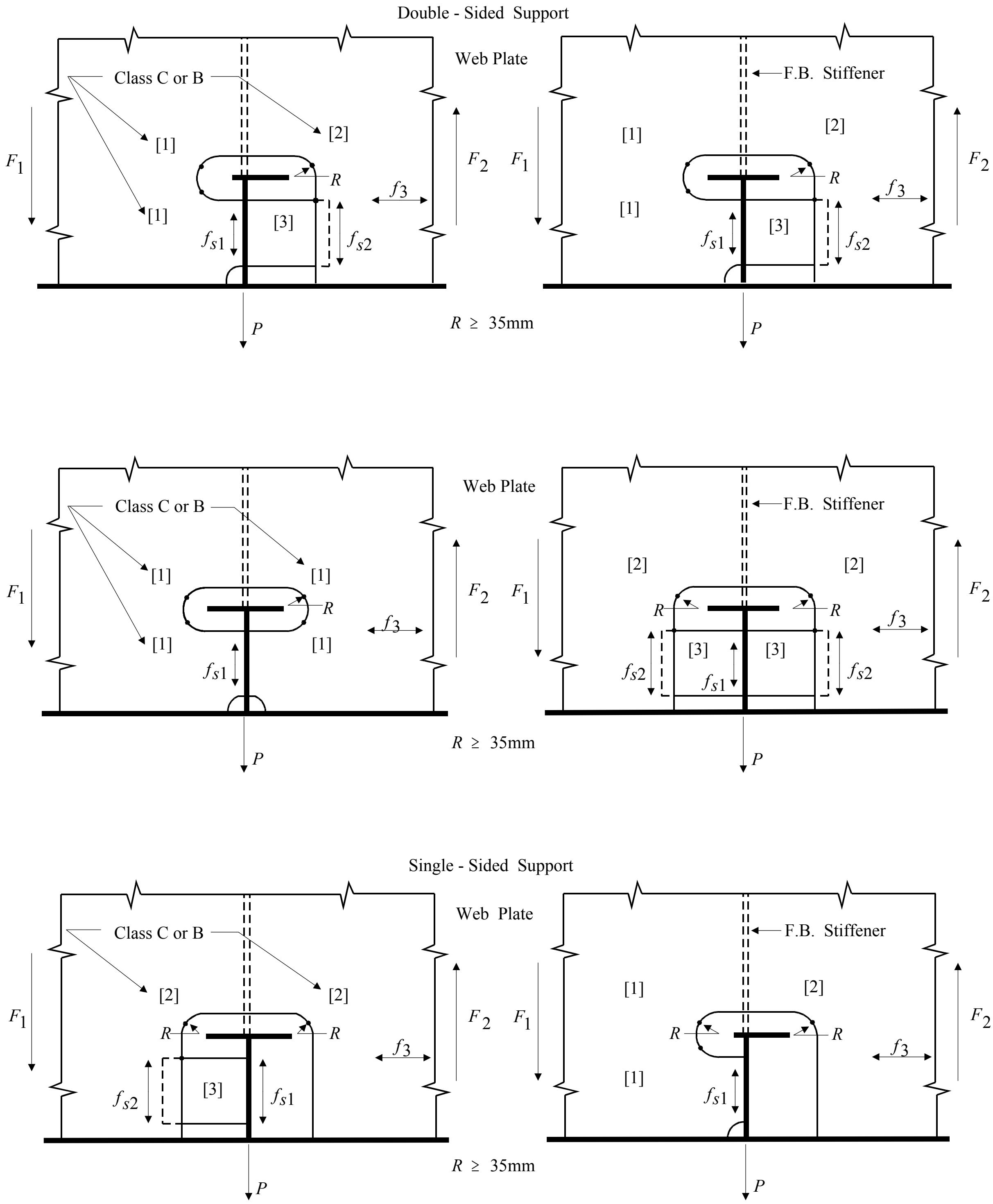
c_f = 0.95

f_{n3} = normal stress range at location [3]

f_{s2} = shear stress range as defined in 1 above near location [3].

K_s = SCFs given above

FIGURE 4
Cut-outs (Slots) For Longitudinal *(1998)*



9.3.2 Flat Bar Stiffeners for Longitudinals *(1999)*

9.3.2(a) For assessing fatigue life of a flat bar stiffener at location [1] or [2] as shown in 5C-5-A1/Figure 5, the peak stress range is to be obtained from the following equations:

$$f_{Ri} = [(\alpha_i f_s)^2 + f_L{}^2\,]^{1/2} \qquad (i = 1 \text{ or } 2)$$

where

f_s = nominal stress range in the flat bar stiffener.

= $c_f C_y P/(A_s + A_c)$

P, A_s, A_c, c_f as defined in 5C-5-A1/9.3.1 and C_y in 5-3-A1/7.11.1. For flat bar stiffeners with soft-toed brackets, the brackets may be included in the calculation of A_s.

f_{Li} = stress range in the longitudinal at location i (i = 1 or 2), as specified in 5C-5-A1/7.5

α_i = stress concentration factor at location i (i = 1 or 2) accounting for misalignment and local distortion.

At location [1]

For flat bar stiffener without brackets

α_1 = 1.50 for double-sided support connection

= 2.00 for single-sided support connection

For flat bar stiffener with brackets

α_1 = 1.00 for double-sided support connection

= 1.25 for single-sided support connection

At location [2]

For flat bar stiffener without brackets

α_2 = 1.25 for single or double-sided support connection

For flat bar stiffener with brackets

α_2 = 1.00 for single or double-sided support connection

9.3.2(b) For assessing the fatigue life of the weld throat as shown in 5C-5-A1/Table 1, Class W, the peak stress range f_R at the weld may be obtained from the following equation:

$$f_R = 1.25 f_s A_s / A_{sw}$$

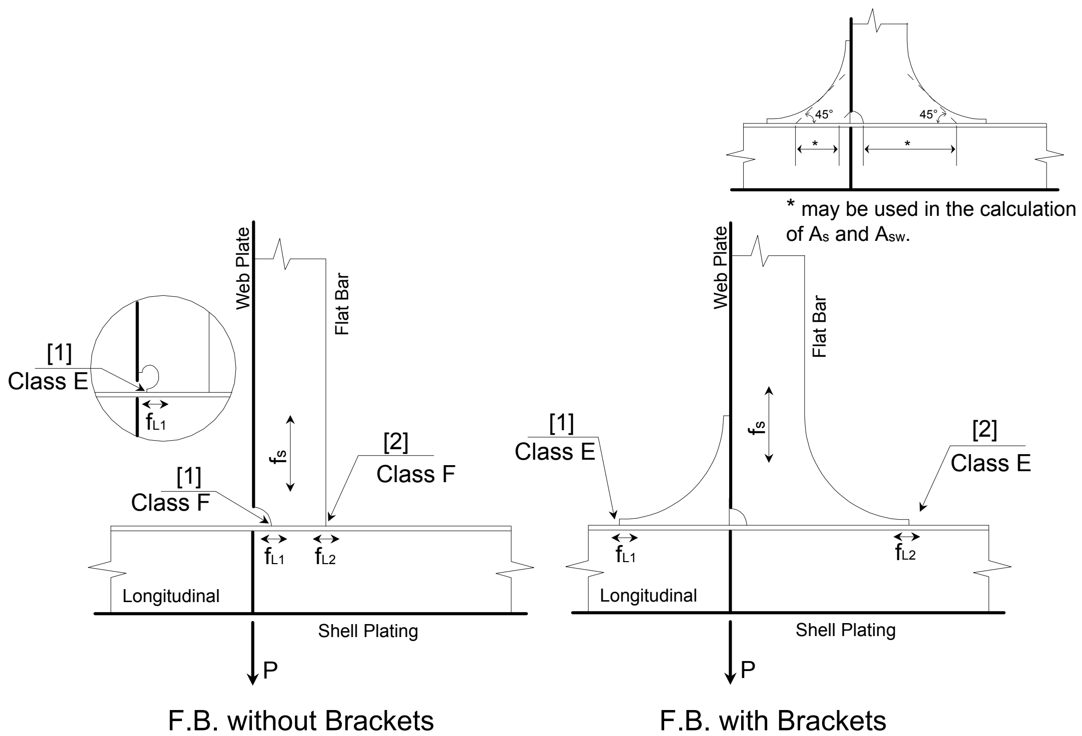
where

A_{sw} = sectional area of the weld throat. Brackets may be included in the calculation of A_{sw}

f_s and A_s are as defined in 5C-5-A1/9.3.2(a) above.

9.3.2(c) To assess the fatigue life of the longitudinal, the fatigue classification given in 5C-5-A1/Table 1 for the longitudinal as the only load carrying member is to be considered. Alternatively, the fatigue classification shown in 5C-5-A1/Figure 5 in conjunction with the combined stress effects, f_R, may be used. In calculation of f_R, the α_i may be taken as 1.25 for both locations [1] and [2].

FIGURE 5
Fatigue Classification for Longitudinals in way of Flat Bar Stiffener



9.5 Hatch Corner *(1998)*

9.5.1 Side Hatch Corners

The peak stress range, f_R, for hatch corners at the strength deck, the top of the continuous hatch side coaming and the lower deck which is effective for the hull girder strength and is located in line with the bottom of cross deck box beam, within 0.22*D* below the strength deck at side may be approximated by the following equation:

$$f_R = c_f\,[K_{s1}c_{L1}(f_{RG1} + f_{RL1}) + K_{s2}c_{L2}(f_{RG2} + f_{RL2})] \quad \text{N/cm}^2\ (\text{kgf/cm}^2,\ \text{lbf/in}^2)$$

where

f_{RG1} = global dynamic longitudinal stress range at the inboard edge of the strength deck plating of hull girder section under consideration clear of hatch corner, in N/cm^2 (kgf/cm^2, lbf/in^2)

$= |(f_{d1vi} - f_{d1vj}) + (f_{d1hi} - f_{d1hj}) + (f_{d1wi} - f_{d1wj})|$

f_{RG2} = bending stress range in connection with hull girder twist induced by torsion in cross deck structure in transverse direction, in N/cm^2 (kgf/cm^2, lbf/in^2). f_{RG2} may be taken as zero in Stations A, B, C, F′ and G in 5C-5-4/Figure 5.

$= |f_{d1ci} - f_{d1cj}|$

f_{RL1} = secondary dynamic longitudinal stress range induced by external pressure at the inboard edge of the strength deck plating of hull girder section under consideration clear of hatch corner, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $c_w\,(|f_{d2si} - f_{d2sj}|)$

f_{RL2} = secondary stress range on the cross deck structure in transverse direction due to dynamic container load in longitudinal direction, in N/cm^2 (kgf/cm^2, lbf/in^2). f_{RL2} may be taken as zero in Stations A, B, C, F′ and G in 5C-5-4/Figure 5.

= $c_w(|f_{d2ci} - f_{d2cj}|)$

c_w = 0.75

c_f, c_w, f_{d1vi}, f_{d1vj}, f_{d1hi}, f_{d1hj}, f_{d1wi} and f_{d1wj} are as defined in 5C-5-A1/7.5.1 and 5C-5-A1/7.7.

K_{s1} and K_{s2} are stress concentration factors for the hatch corners considered and can be obtained by a direct finite element analysis. When a direct analysis is not available, these may be obtained from the following equations, but not to be taken less than 1.0:

$$K_{s1} = \alpha_{\ell 1} c_t \alpha_{t1} \alpha_c \alpha_s k_{s1}$$

$$K_{s2} = \alpha_{\ell 2} \alpha_g \alpha_{ct} \alpha_{t2} k_{s2}$$

where

k_{s1} = nominal stress concentration factor in longitudinal direction, as given in a table below

k_{s2} = nominal stress concentration factor in transverse direction, as given in a table below

c_t = 0.8 for locations where coaming top terminated

= 1.0 for other locations

$\alpha_{\ell 1}$ = location adjustment factor

= 1.0 for typical hatch corners of the strength deck and the lower deck in the midship region, e.g., Stations D and D′ as in 5C-5-4/Figure 5

= 1.2 for hatch corners of the strength deck and the lower deck at Stations E and F as in 5C-5-4/Figure 5 where there is a change in width of the hatch opening

= 1.55 for hatch corners of the strength deck and the lower deck at Stations A, B, C, F′ and G, as in 5C-5-4/Figure 5

= 0.9 for a hatch corner at the top of a continuous hatch side coaming

$\alpha_{\ell 2}$ = 1.0 for a hatch corner at the strength deck and the lower deck

= 0.9 for a hatch corner at the top of a continuous hatch side coaming

α_c = adjustment factor for cutout at hatch corners

= 1.0 for shapes without cutout

= $1 - 0.04(c/R)^{3/2}$ for circular shapes with a cutout

= $[1 - 0.04(c/r_d)^{3/2}]$ for double curvature shapes with a cutout

= $[1 - 0.04(c/R_1)^{3/2}]$ for elliptical shapes with a cutout

α_s = adjustment factor for contour curvature

= 1.0 for circular shapes

= $0.33\ [1 + 2(r_{s1}/r_d) + 0.1(r_d/r_{s1})^2]$ for double curvature shapes

= $0.33\ [1 + 2(R_2/R_1) + 0.1(R_1/R_2)^2]$ for elliptical shapes

α_g = 0.9 for hatch corners at Station E and F where there is a change in width of the hatch opening by an offset of one container row.

= 0.8 for hatch corners at Station E and F where there is a change in width of the hatch opening by an offset of two container rows or more

= 1.0 for other hatch corners

α_{ct} = 1.0 for shapes without cutout

= 0.5 for shapes with cutout

α_{t1} = $(t_s/t_i)^{1/2}$

α_{t2} = $6.0/[5.0 + (t_i/t_c)]$, but not less than 0.85

α_{t1} or α_{t2} is to be taken as 1.0 where longitudinal or transverse extent of the reinforced plate thickness in way of the hatch corner is less than that required in 5C-5-A1/9.5.3 below, as shown in 5C-5-A1/Figure 6.

r_{s1} = R for circular shapes in 5C-5-A1/Figure 7, in mm (in.)

= $[3R_1/(R_1 - R_2) + \cos\theta]r_{e2}/[3.816 + 2.879R_2/(R_1 - R_2)]$

for double curvature shapes in 5C-5-A1/Figure 8, in mm (in.)

= R_2 for elliptical shapes in 5C-5-A1/Figure 9, in mm (in.)

r_{s2} = R for circular shapes in 5C-5-A1/Figure 7, in mm (in.)

= R_2 for double curvature shapes in 5C-5-A1/Figure 8, in mm (in.)

= R_2^2/R_1 for elliptical shapes in 5C-5-A1/Figure 9, in mm (in.)

r_d = $(0.753 - 0.72R_2/R_1)[R_1/(R_1 - R_2) + \cos\theta]r_{e1}$

t_s = net plate thickness of the strength deck, hatch side coaming top or lower deck clear of the hatch corner under consideration, in mm (in.)

t_c = net plate thickness of the cross deck, hatch end coaming top or bottom of cross box beam clear of the hatch corner under consideration, in mm (in.)

t_i = net plate thickness of the strength deck, hatch coaming top or lower deck in way of the hatch corner under consideration, in mm (in.).

R, R_1 and R_2 for each shape are as shown in 5C-5-A1/Figures 7, 8 and 9.

θ for double curvature shapes is defined in 5C-5-A1/Figure 8.

r_{e1} and r_{e2} are also defined for double curvature shapes in 5C-5-A1/9.5.3 below.

k_{s1}

r_{s1} / w_1	0.1	0.2	0.3	0.4	0.5
k_{s1}	1.945	1.89	1.835	1.78	1.725

k_{s2}

r_{s2} / w_2	0.1	0.2	0.3	0.4	0.5
k_{s2}	2.35	2.20	2.05	1.90	1.75

Note: k_{s1} and k_{s2} may be obtained by interpolation for intermediate values of r_{s1} / w_1 or r_{s2} / w_2.

where

w_1 = width of the cross deck under consideration, in mm (in.), for hatch corners of the strength deck and lower deck at Stations D, D′, E and F

= $100b_1$ for SI or MKS Units, ($1.2b_1$ for U.S. Units) for hatch corners of the strength deck and lower deck at Stations A, B, C, F′ and G

= width of the coaming top for the continuous hatch side coaming, in mm (in.)

w_2 = width of the cross deck under consideration, in mm (in.), for strength deck and lower deck

= width of the coaming top for the hatch end coaming, in mm (in.)

b_1 = width of the hatch opening under consideration, in m (ft)

K_{s1} and K_{s2} for hatch corners with configurations other than that specified in this section are to be determined from fine mesh 3D and 2D finite element analysis.

The angle ϕ in degrees along the hatch corner contour is defined as shown in 5C-5-A1/Figures 7, 8 and 9 and c_{L1} and c_{L2} at a given ϕ may be obtained by the following equations. For determining the maximum f_R, c_{L1} and c_{L2} are to be calculated at least for 5 locations, i.e., at $\phi = \phi_1$, ϕ_2 and three intermediate angles for each pair of the combined load cases considered. Alternatively, the maximum f_R may be searched by a computer program provided in the SafeHull software package.

for circular shapes, $25 \le \phi \le 55$

c_{L1} = $1 - 0.00045(\phi - 25)^2$

c_{L2} = $0.8 - 0.0004(\phi - 55)^2$

for double curvature shapes, $\phi_1 \le \phi \le \phi_2$

c_{L1} = $[1.0 - 0.02(\phi - \phi_1)]/[1 - 0.015(\phi - \phi_1) + 0.00014(\phi - \phi_1)^2]$ for $\theta < 55$

= $[1.0 - 0.026(\phi - \phi_1)]/[1 - 0.03(\phi - \phi_1) + 0.0012(\phi - \phi_1)^2]$ for $\theta \ge 55$

c_{L2} = $0.8/[1.1 + 0.035(\phi - \phi_2) + 0.003(\phi - \phi_2)^2]$

where

ϕ_1 = $\mu(95 - 70r_{s1}/r_d)$

ϕ_2 = $95/(0.6 + r_{s1}/r_d)$

μ = $0.165(\theta - 25)^{1/2}$ for $\theta < 55$

= 1.0 for $\theta \ge 55$

for elliptical shapes, $\phi_1 \le \phi \le \phi_2$

c_{L1} = $1 - 0.00004(\phi - \phi_1)^{-3}$

c_{L2} = $0.8/[1 + 0.0036(\phi - \phi_2)^2]$

where

ϕ_1 = $95 - 70R_2/R_1$

ϕ_2 = $88/(0.6 + R_2/R_1)$

The peak stress range, f_R, is to be obtained through calculations of c_{L1} and c_{L2} at each ϕ along a hatch corner.

The formulas for double curvature shapes and elliptical shapes may be applicable to the following range:

$0.3 \le R_2/R_1 \le 0.6$ and $45° \le \theta \le 70°$ for double curvature shapes

At Stations A, B, C, F′ and G, the upper limit of θ may be increased to 80°.

For hatch coaming top and longitudinal deck girders, R_2/R_1 may be reduced to 0.15.

$0.3 \le R_2/R_1 \le 0.9$ for elliptical shapes

f_{d1ci}, f_{d2si} and f_{d2ci} for the load case i may be obtained from the following equations:

9.5.1(a) Calculation of f_{d1ci} (2002)

$f_{d1ci} = ck_cM_1/SM_c$ N/cm² (kgf/cm², lbf/in²)

where

SM_c = net section modulus of the cross deck box beam clear of the hatch corner under consideration with respect to the vertical axis z (5C-5-4/Figure 4), in cm³ (in³)

c = 1.0 for strength deck and hatch coaming top

= 0.8 for lower deck

M_1 is as defined in 5C-5-4/17.7.4. In calculation of M_1, T_s is to be taken as zero and z is to be taken as a distance from the vessel's centerline to a section clear of hatch corner but need not be more than $b_0/2$ at each station, as shown in 5C-5-4/Figure 5.

f_{d1ci} may be taken as zero at Stations A, B, C, F′ and G in 5C-5-4/Figure 5.

k_c is specified in 5C-5-A1/Table 3 and 5C-5-3/Table 1 for torsional moment with α_s = 1.0..

9.5.1(b) Calculation of f_{d2si}

$f_{d2si} = M_s/SM$ N/cm² (kgf/cm², lbf/in²)

where

M_s = secondary bending moment due to external water pressure at watertight or mid-hold strength bulkhead, in N-m (kgf-cm, lbf-in)

= $kp_{si}\ell_o^2h$

k = 1000 (1000, 269)

p_{si} = wave-induced external pressure, kN/m^2 (tf/m^2, Ltf/ft^2), at the lower end of h (but need not be lower than the upper turn of bilge) at the midpoint of the hatch opening under consideration.

ℓ_o = length of the hatch opening under consideration, in m (ft)

h is as defined in 5C-5-A1/7.9.2.

SM is as defined in 5C-5-4/17.5.2.

9.5.1(c) Calculation of f_{d2ci}

$f_{d2ci} = M/SM_c$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

M = secondary bending moment on the cross deck structure due to dynamic container load in longitudinal direction, in N-cm (kgf-cm, lbf-in)

= $KC_2[0.5Q_{d1} + 0.25Q_{d2}\ n/(n+1)]b_1 10^5$

K = 0.17 (0.17, 0.046)

Q_{d1} = total dynamic container load in longitudinal direction on cross deck box beam (above the bottom of cross deck box beam), in kN (tf, Ltf)

= $m_1 m_2(1 - h_5/h_4)\,F_{d\ell 1}$

Q_{d2} = total dynamic container load in longitudinal direction on transverse bulkhead, (below the bottom of cross deck box beam), in kN (tf, Ltf)

= $m_1 m_2(h_5/h_4)\,F_{d\ell 2}$

m_1 = tier number of container stacks in the cargo hold under consideration

m_2 = row number of container stacks in the cargo hold under consideration

h_4 = $m_1 h_C$

h_5 = vertical distance between the bottom of the cargo hold under consideration and the bottom of cross deck box beam at center line, in m (ft)

$F_{d\ell 1}$ = dynamic longitudinal container force $F_{d\ell}$, as specified in 5C-5-3/5.5.2(b), with W of the maximum design container weight at a vertical height $0.5(h_4 + h_5)$, measured from inner bottom

$F_{d\ell 2}$ = dynamic longitudinal container force $F_{d\ell}$, as specified in 5C-5-3/5.5.2(b), with W of the maximum design container weight at a vertical height $0.5h_5$, measured from inner bottom

W, C_2, n and h_C are as defined in 5C-5-4/17.5.3.

b_1 is as defined in 5C-5-4/17.7.4, but need not be taken as greater than b_0 at each station in 5C-5-4/Figure 5.

f_{d2ci} may be taken as zero at Stations A, B, C, F′ and G in 5C-5-4/Figure 5.

SM_c is as defined in 5C-5-A1/9.5.1(a) above.

9.5.2 Hatch Corners at the End Connections of Longitudinal Deck Girder

The total stress range, f_R, for hatch corners at the connection of longitudinal deck girder with cross deck box beam may be approximated by the following equation:

$$f_R = c_f[(\alpha_i K_{d1}(f_{RG1} + f_{RL1}) + K_{d2} f_{RG2}] \quad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

f_{RG1} = wave-induced stress range by hull girder vertical and horizontal bending moments at the longitudinal deck girder of hull girder section, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $|(f_{d1vi} - f_{d1vj}) + (f_{d1hi} - f_{d1hj})|$

f_{RG2} = wave-induced stress range by hull girder torsional moment at the connection of the longitudinal deck girder with the cross deck box beam, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $|f_{d1di} - f_{d1dj}|$

f_{RL1} = secondary dynamic stress range on the longitudinal deck girder due to on-deck container load in vertical direction, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $c_w(\,|f_{d2di} - f_{d2dj}|\,)$

c_w = 0.75

α_i = 1.0 for symmetrical section of the longitudinal deck girder about its vertical neutral axis

= 1.25 for unsymmetrical section of the longitudinal deck girder about its vertical neutral axis

c_f is as defined in 5C-5-A1/7.5.1.

K_{d1} and K_{d2} may be obtained from the following equations, but not to be taken less than 1.0:

$$K_{d1} = 1.0$$

$$K_{d2} = \alpha_1 \alpha_s k_d$$

where

k_d = nominal stress concentration factor as given in a table below

α_s = 1.0 for circular shapes

= $0.33[1 + 2(r_{s1}/r_d) + 0.1(r_d/r_{s1})^2]$ for double curvature shapes

= $0.33[1 + 2(R_2/R_1) + 0.1(R_1/R_2)^2]$ for elliptical shapes

α_t = $(t_d/t_i)^{1/2}$

α_t is to be taken as 1.0 where longitudinal or transverse extent of the reinforced plate thickness in way of the hatch corner is less than that in 5C-5-A1/9.5.3 below, as shown in 5C-5-A1/Figure 10.

t_d = flange net plate thickness of the longitudinal deck girder clear of the hatch corner under consideration, in mm (in.)

t_i = net plate thickness at the end connection of the longitudinal deck girder under consideration, in mm (in.).

R, R_1 and R_2 for each shape are as shown in 5C-5-A1/Figures 7, 8 and 9.

θ for double curvature shapes is defined in 5C-5-A1/Figure 8.

r_{s1} and r_d are as defined for double curvature shapes in 5C-5-A1/9.5.1, above.

r_{e1} and r_{e2} are as defined for double curvature shapes in 5C-5-A1/9.5.3, below.

k_d

r_{s1} / w_d	0.1	0.2	0.3	0.4	0.5
k_d	2.35	2.20	2.05	1.90	1.75

Note: k_d may be obtained by interpolation for intermediate values of r_{s1} / w_d.

where

w_d = width of the longitudinal deck girder, in mm (in.)

f_{d1vi}, f_{d1hi}, f_{d1di} and f_{d2di} for the load case i may be obtained from the following equations:

9.5.2(a) Calculation of f_{d1vi}

$f_{d1vi} = cH_oM_{wE}/SM$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

c = 1000 (1000, 2240)

H_o = effectiveness of longitudinal deck structure, as specified in 3-2-1/17.3

M_{wE} = wave-induced bending moment at the section under consideration, in a condition as specified in 5C-5-3/Table 1 and 5C-5-A1/Table 3, in kN-m (tf-m, Ltf-ft)

= $k_u k_c f_{MV} M_w$

SM = net hull girder vertical section modulus at the section under consideration, cm^2-m (in^2-ft)

= I/y

I = moment of inertia of hull girder section under consideration about the horizontal neutral axis, in cm^2-m^2 (in^2-ft^2)

y = vertical distance from the horizontal neutral axis of the hull girder section to the point under consideration, m (ft)

M_w = the nominal wave-induced vertical bending moment, as defined in 5C-5-3/5.1.1, with $k_w = k_0^{1/2}$ for either hogging or sagging condition, as specified in 5C-5-3/Table 1 and 5C-5-A1/Table 3, in kN-m (tf-m, Ltf-m)

k_u and k_c are specified in 5C-5-A1/Table 3 and 5C-5-3/Table 1 for hull girder vertical bending moment.

f_{MV} is as shown in 5C-5-3/Figure 2.

9.5.2(b) Calculation of f_{d1hi}

$f_{d1hi} = cH_o M_{HE}/SM_H$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

c = 1000 (1000, 2240)

H_o = effectiveness of longitudinal deck structure, as specified in 3-2-1/17.3

M_{HE} = effective wave-induced horizontal bending moment at the section under consideration, in a condition as specified in 5C-5-3/Table 1 and 5C-5-A1/Table 3, in kN-m (tf-m, Ltf-ft)

= $k_u k_c m_h M_H$

SM_H = net hull girder horizontal section modulus at the section under consideration, in cm^2-m (in^2-ft)

= I_H/z

I_H = moment of inertia of hull girder section under consideration about the vessel's centerline, in cm^2-m^2 (in^2-ft^2)

z = horizontal distance from the vessel's centerline to the vertical neutral axis (z axis of section D-D in item b of 5C-5-A1/Table 2) of the longitudinal side deck girder, in m (ft)

f_{d1hi} for the centerline deck girder may be taken zero.

k_u and k_c are specified in 5C-5-A1/Table 3 and 5C-5-3/Table 1 for hull girder horizontal bending moment.

M_H is as defined in 5C-5-3/5.1.3 and m_h is as shown in 5C-5-3/Figure 4.

9.5.2(c) Calculation of f_{d1di} *(2002)*

$f_{d1di} = M_D/SM_h$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

M_D = $kc_1 k_c C_1 T_M L_0^2\, \omega_M 10^5/(c_2 b_0 \alpha_M \Gamma_M)$ N-cm (kgf-cm, lbf-in)

k = 1.0 (1.0, 0.269)

SM_h = net section modulus of the longitudinal deck girder under consideration about its vertical neutral axis (z axis of section D-D in item b of 5C-5-A1/Table 2), in cm^3 (in^3)

c_s = 0.53 for centerline deck girder

= 0.42 for two side deck girders

c_2 = $c_3 b_0/I^*_{CB} + \ell_0/I_g$

c_3 = 0.75 for centerline deck girder

= 0.425 for two side deck girders

ℓ_0 = length of the hatch opening amidships, in m (ft)

I^*_{CB} = average net moment of inertia of the cross deck box beam at the vessel's centerline, in m^4 (ft^4), fore and aft of the hatch opening amidships with respect to vertical axis, z.

I_g = net moment of inertia of the longitudinal deck girder amidships about its vertical neutral axis (z axis of section D-D in 5C-5-A1/Table 2b), in cm^4 (in^4)

T_M, L_0, ω_M, α_M, Γ_M and b_0 are as defined in 5C-5-4/7 and C_1 is as defined in 5C-5-4/17.7.2. k_c is specified in 5C-5-3/Table 1 and 5C-5-A1/Table 3 for torsional moment with α_s = 1.0.

For the longitudinal deck girders abaft the engine room, L_0 may be taken as L_0' defined in 5C-5-4/9.3.2.

9.5.2(d) Calculation of f_{d2di}

$f_{d2di} = M/SM_V$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

M = secondary bending moment on the longitudinal deck girder due to dynamic container load on deck in vertical direction, in N-cm (kgf-cm, lbf-in)

= $k\,c\,m_{d1}m_{d2}F_{dv}\ell \cdot 10^5$

k = 1.0 (1.0, 0.269)

c = 0.042 for centerline deck girder

= 0.028 for two side deck girders

m_{d1} = tier number of 20 ft container stacks on deck

m_{d2} = row number of 20 ft container stacks on deck

F_{dv} = dynamic vertical container force as specified in 5C-5-3/5.5.2 with W of the maximum design 20 ft container weight on deck and W not to be taken less than 137.3 kN (14 tf, 13.8 Ltf)

SM_v = net section modulus of the longitudinal deck girder under consideration about its horizontal axis (y axis of section D-D in 5C-5-A1/Table 2b), in cm^3 (in^3)

ℓ is as defined in 5C-5-A1/7.9.2.

For calculation of C_v in 5C-5-3/5.5.1(c), z, defined in 5C-5-A1/9.5.2(b) above, may be used.

9.5.3 Extent of Reinforced Plate Thickness at Hatch Corners

Where plating of increased thickness is inserted at hatch corners, the extent of the inserted plate, as shown in 5C-5-A1/Figure 6 and 5C-5-A1/Figure 10, is to be generally not less than that obtained from the following:

$\ell_i = 1.75 r_{e1}$ mm (in.)

$b_i = 1.75 r_{e2}$ mm (in.)

$b_d = 1.1 r_{e2}$ mm (in.)

for a cut-out radius type,

$\ell_{i1} = 1.75 r_{e1}$ mm (in.)

$\ell_{i2} = 1.0 r_{e1}$ mm (in.)

$b_i = 2.5 r_{e2}$ mm (in.)

$b_d = 1.25 r_{e2}$ mm (in.)

where

r_{e1}	=	R	for circular shapes in 5C-5-A1/Figure 7, in mm (in.)
	=	$R_2 + (R_1 - R_2)\cos\theta$	for double curvature shapes in 5C-5-A1/Figure 8, in mm (in.)
	=	$(R_1 + R_2)/2$	for elliptical shapes in 5C-5-A1/Figure 9, in mm (in.)
r_{e2}	=	R	for circular shapes in 5C-5-A1/Figure 7, in mm (in.)
	=	$R_1 - (R_1 - R_2)\sin\theta$	for double curvature shapes in 5C-5-A1/Figure 8, in mm (in.)
	=	R_2	for elliptical shapes in 5C-5-A1/Figure 9, in mm (in.)

At welding joints of the inserted plates to the adjacent plates, a suitable transition taper is to be provided and the fatigue assessment at these joints may be approximated by the following:

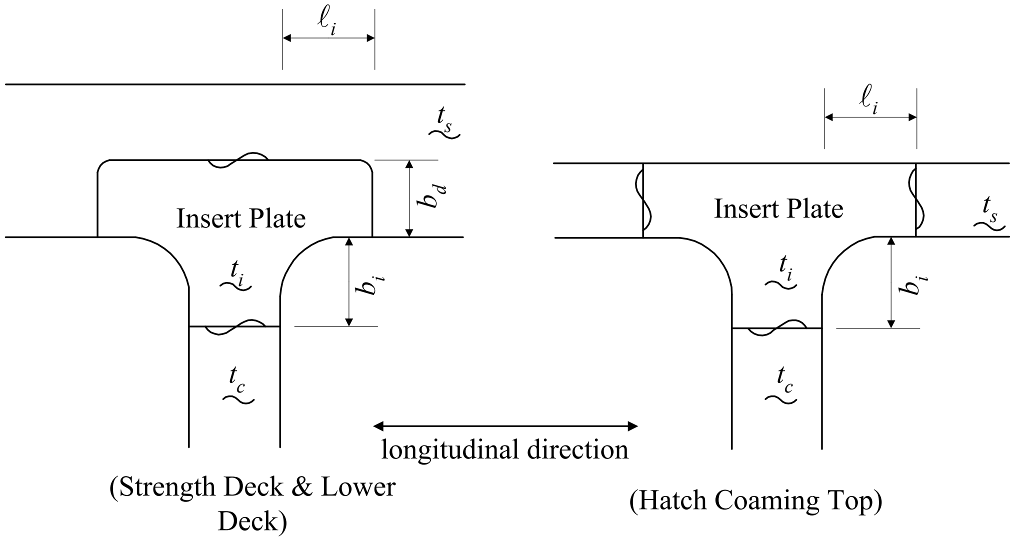
$f_R = c_f K_t f_s$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

f_s	=	nominal stress range at the joint under consideration	
	=	$f_{RG1} + f_{RL1}$	for side longitudinal deck box, as specified in 5C-5-A1/9.5.1, in N/ cm^2 (kgf/cm^2, lbf/in^2)
	=	$f_{RG2} + f_{RL2}$	for cross deck box beam, as specified in 5C-5-A1/9.5.1, in N/cm^2 (kgf/cm^2, lbf/in^2)
	=	$f_{RG1} + f_{RG2} + f_{RL1}$	for longitudinal deck girder, as specified in 5C-5-A1/9.5.2, in N/cm^2 (kgf/cm^2, lbf/in^2)
K_t	=	$0.25(1 + 3t_i/t_a)$	≤ 1.25
t_i	=	net plate thickness of inserted plate, in mm (in.)	
t_a	=	net plate thickness of plate adjacent to the inserted plate, in mm (in.)	

c_f is as defined in 5C-5-A1/7.5.1.

FIGURE 6
Side Hatch Corners *(1998)*



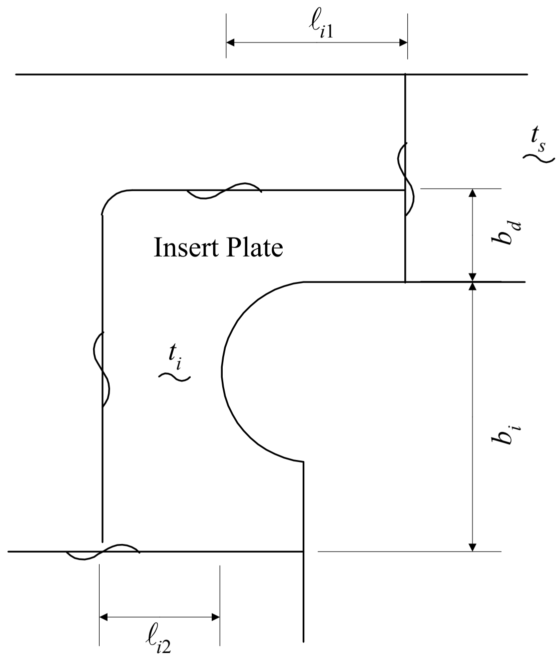


FIGURE 7
Circular Shape

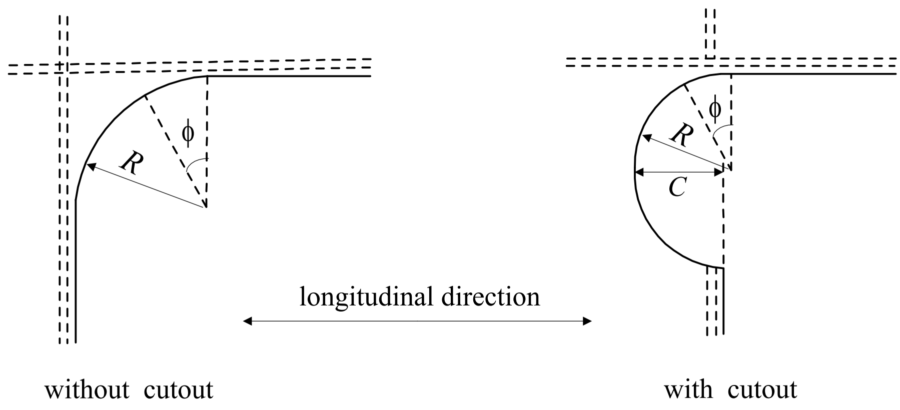


FIGURE 8
Double Curvature Shape

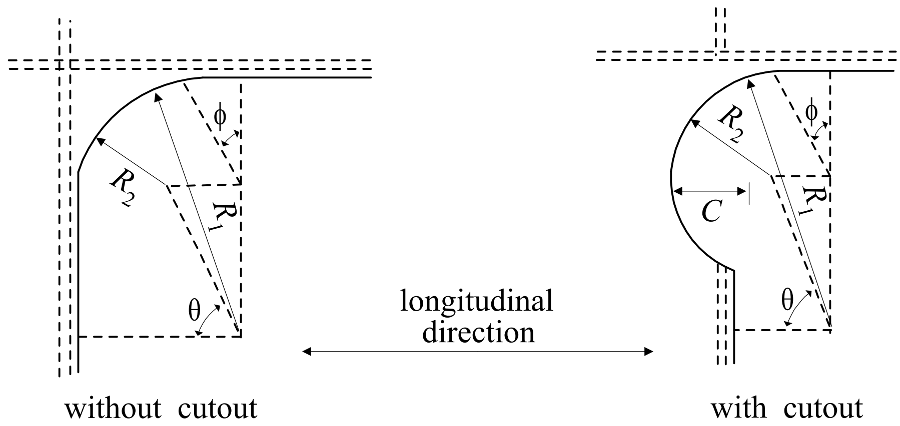


FIGURE 9
Elliptical Shape

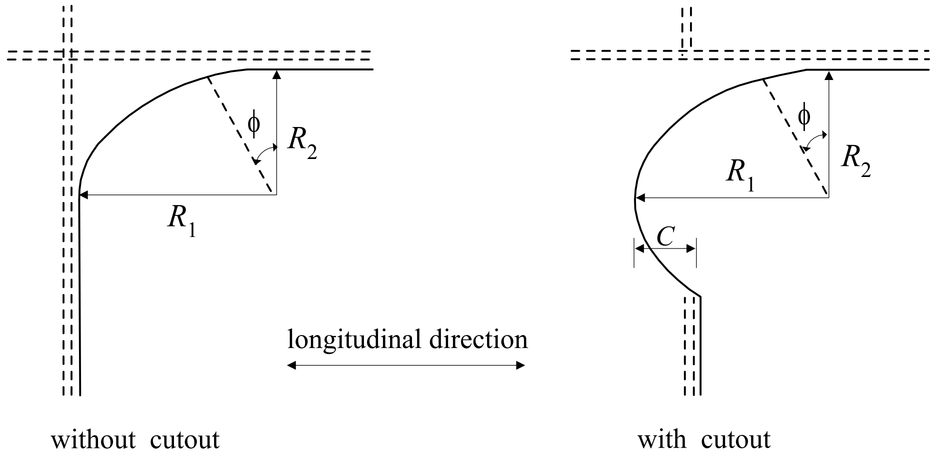
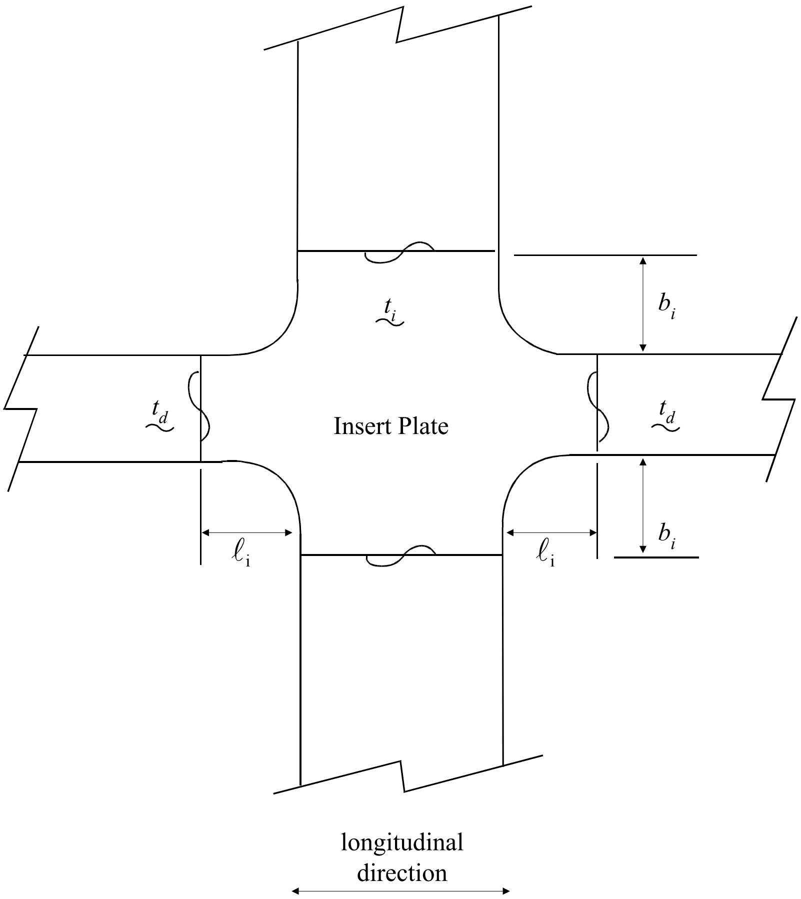


FIGURE 10
Hatch Corner for Longitudinal Deck Girder *(1998)*



11 Stress Concentration Factors Determined from Finite Element Analysis

11.1 General *(1998)*

S-N data and stress concentration factors (SCFs) are related to each other and therefore should be considered together so that there is a consistent basis for the fatigue assessment.

The following guidance is intended to help make correct decisions.

11.3 S-N Data *(1998)*

S-N data are presented as a series of straight-lines plotted on log-log scale. The data reflect the results of numerous tests which often display considerable scatter. The recommended design curves for different types of structural details and welded connections recognize the scatter in test results in that the design curves have been based on the selection of the lower bound, 95% confidence limit. In other words, about 2.5% of the test failure results fall below this curve. Treating the design curve in this manner introduces a high, yet reasonable degree of conservatism in the design and fatigue evaluation processes.

Individual S-N curves are presented to reflect certain generic structural geometries or arrangements. 5C-5-A1/Table 1 and 5C-5-A1/9.3 contain sketches of typical weld connections and other details in ship structure, giving a list of the S-N classification. This information is needed to assess the fatigue strength of a detail. Also needed is a consistent way to establish the demands or load effects placed on the detail so that a compatible assessment can be made of the available strength versus the demand. Here is where interpretation and judgment enter the fatigue assessment.

S-N curves are obtained from laboratory sample testing. The applied reference stress on the sample which is used to establish the S-N data is referred to as the nominal stress. The nominal stress is established in a simple manner, such as force divided by area and bending moment divided by section modulus (P/A & M/SM). The structural properties used to establish the nominal stress are taken from locations away from any discontinuities to exclude local stress concentration effects arising from the presence of a weld or other local discontinuity. In an actual structure, it is rare that a match will be found between the tested sample geometry and loadings. One is then faced with the problem of making the appropriate interpretation.

11.5 S-N Data and SCFs *(2003)*

Selection of appropriate S-N data is straight-forward with respect to “standard details” offered in 5C-5-A1/Table 1 or other similar reference. However, in the case of welded connections in complex structures, it is required that SCFs be used to modify the nominal stress range. An example of the need to modify the nominal stress for fatigue assessment purposes is shown in 5C-5-A1/Figure 11 below, relating to a hole drilled in the middle of a flat plate traversed by a butt weld.

In this example, the nominal stress S_N is P/Area, but the stress to be used to assess the fatigue strength at point A is S_A or $S_N \cdot$SCF. This example is deceptively simple because it does not tell the entire story. The prerequisite of the example is that one needs to have a definitive and consistent basis to obtain the SCF. There are reference books which indicate that based on the theory of elasticity, the SCF to be applied in this case is 3.0. However, when the SCF is computed using the finite element analysis techniques, the SCF obtained can be quite variable depending on the mesh size. The example does not indicate which S-N curve should be applied, nor does the example show how the selection of the design S-N data could be affected by the mentioned finite element analysis issues. Therefore, if such interpretation questions exist for a simple example, the higher difficulty of appropriately treating more complex structures should be evident.

Referring to the S-N curves to be applied to welded connections (for example, S-N curves, D-W in 5C-5-A1/Figure 1) the SCFs resulting from the presence of the weld itself are already accounted for in these curves. If one were to have the correct stress distribution in the region – from the weld to a location sufficiently away from the weld toe (where the stress is suitably established by the nominal stress obtained from *P*/*A* and *M*/*SM*) – the stress distribution may be generically separated into three distinct segments, as shown in the 5C-5-A1/Figure 12, below.

- Region III is a segment where the stress gradient is controlled by the nominal stress gradient.
- Region II is a segment where the nominal stress gradient is being modified due to the presence of other structure such as the bracket end shown in the figure. This must be accounted for to obtain an appropriate stress at the weld toe to be used in the fatigue analysis.
- Region I is a segment where the stress gradient is being modified due to the presence of the weld metal itself. The stress concentration due to the weld is already accounted for in the S-N design curve and need not be discussed further. Since the typical way to determine the stress distribution is via planar/linear elements which ignore the weld, this is consistent with the method of analysis.

This general description of the stress distribution is again inconclusive because one does not know in advance and with certainty the distances from the weld toe where the indicated changes of slope for the stress gradient occur. For this reason, definite rules need to be established to determine the slopes, then criteria can be established and used to find the stress at the weld toe which is to be used in the fatigue assessment.

In this regard, two approaches can be used to find the stress at the weld toe, which reflect two methods of structural idealization. One of these arises from the use of a conventional beam element idealization of the structure including the end bracket connection, and the other arises from the use of a fine mesh finite element idealization. Using a beam element idealization, the nominal stress at any location (i.e. P/A and M/SM) can be obtained (see 5C-5-4/Figure 7 for a sample beam element model). In the beam element idealization there will be difficulty in accounting for the geometric stress concentration due to the presence of other structure; this is the "Segment II" stress gradient previously described. In the beam modeling approach shown in the figure, the influence on stresses arising from the "carry over" of forces and bending moments from adjacent structural elements has been approximately accounted for. At the same time, the strengthening effect of the brackets has been ignored. Hence for engineering purposes, this approach is considered to be sufficient in conjunction with the nominal stress obtained at the location of interest and the nominal S-N curve, i.e., the F or F2 Class S-N data, as appropriate.

In the fine mesh finite element analysis approach, one needs to define the element size to be used. This is an area of uncertainty because the calculated stress distribution can be unduly affected by both the employed mesh size and the uniformity of the mesh adjacent to the weld toe. Therefore, it is necessary to establish "rules", as given below, to be followed in producing the fine mesh model adjacent to the weld toe. Further, since the area adjacent to the weld toe (or other discontinuity of interest) may be experiencing a large and rapid change of stress (i.e., a high stress gradient) it is also necessary to provide a rule which can be used to establish the stress at the location where the fatigue assessment is to be made.

5C-5-A1/Figure 13 shows an acceptable method which can be used to extract and interpret the "near weld toe" element stresses and to obtain a (linearly) extrapolated stress at the weld toe. When plate or shell elements are used in the modeling, it is recommended that each element size is to be equal to the plate thickness. When stresses are obtained in this manner, the use of the E Class S-N data is considered acceptable.

Weld hot spot stress can be determined from linear extrapolation of surface component stresses at $t/2$ and $3t/2$ from weld toe. The principal stresses at hot spot are then calculated based on the extrapolated stresses and used for fatigue evaluation. Description of the numerical procedure is given in 5C-5-A1/13.7, below.

FIGURE 11
(1998)

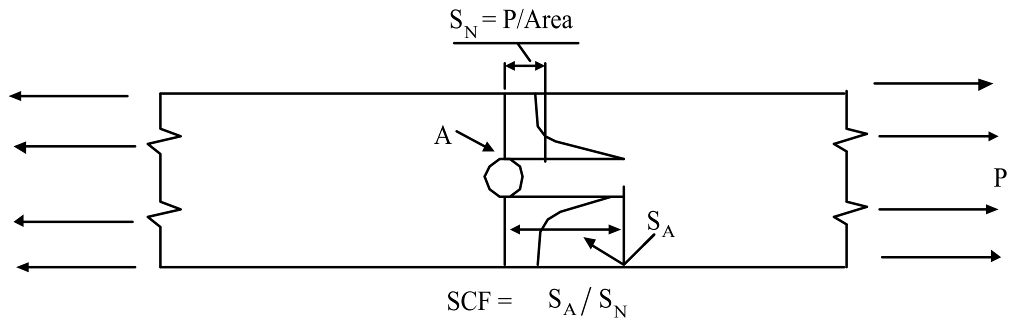


FIGURE 12
(1998)

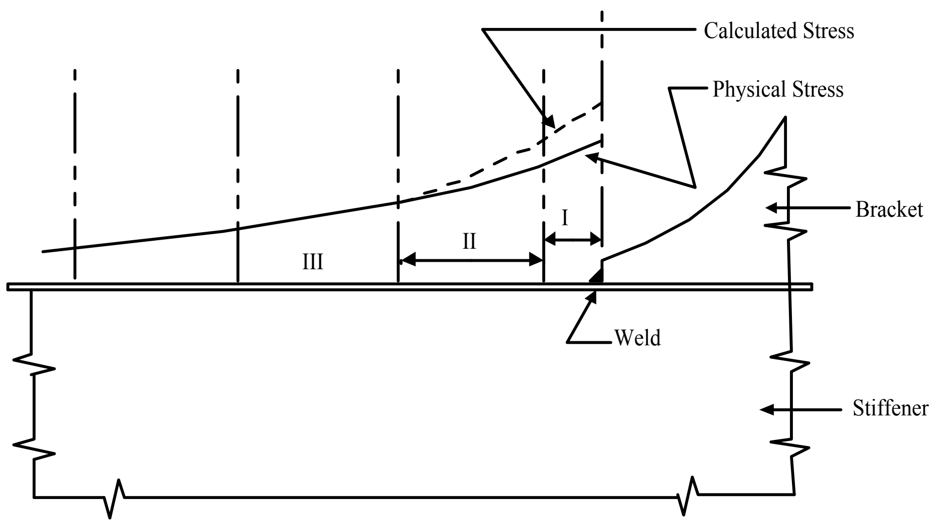
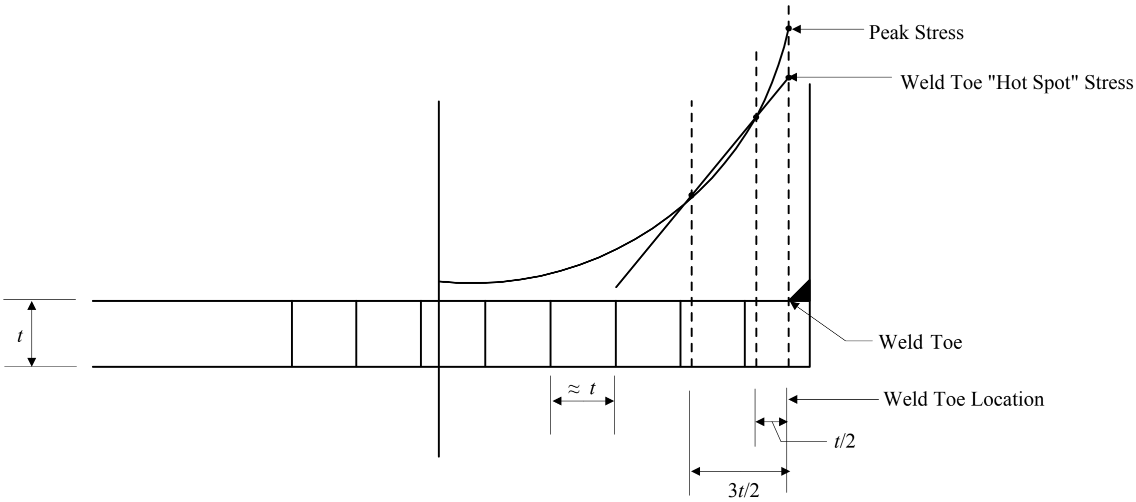


FIGURE 13
(2003)



11.7 Calculation of Hot Spot Stress for Fatigue Analysis of Ship Structures *(2003)*

The algorithm described in the following is applicable to obtain the hot spot stress for the point at the toe of a weld. The weld typically connects either a flat bar member or a bracket to the flange of a longitudinal stiffener, as shown below in 5C-5-A1/Figure 14.

Consider the four points, P_1 to P_4, measured by the distances X_1 to X_4 from the weld toe, designated as the origin of the coordinate system. These points are the centroids of four neighboring finite elements, the first of which is adjacent to the weld toe. Assuming that the applicable surface component stresses, S_i, at P_i have been determined from FEM analysis, the corresponding stresses at "hot spot", i.e., the stress at the weld toe can be determined by the following procedure:

11.7.1

Select two points, L and R, such that points L and R are situated at distances $t/2$ and $3t/2$ from the weld toe; i.e.,

$$X_L = t/2, \quad X_R = 3t/2$$

where t denotes the thickness of the member to which elements 1 to 4 belong (e.g., the flange of a longitudinal stiffener).

11.7.2

Let $X = X_L$ and compute the values of four coefficients as follows:

$$C_1 = [(X - X_2)(X - X_3)(X - X_4)] / [(X_1 - X_2)(X_1 - X_3)(X_1 - X_4)]$$

$$C_2 = [(X - X_1)(X - X_3)(X - X_4)] / [(X_2 - X_1)(X_2 - X_3)(X_2 - X_4)]$$

$$C_3 = [(X - X_1)(X - X_2)(X - X_4)] / [(X_3 - X_1)(X_3 - X_2)(X_3 - X_4)]$$

$$C_4 = [(X - X_1)(X - X_2)(X - X_3)] / [(X_4 - X_1)(X_4 - X_2)(X_4 - X_3)]$$

The corresponding stress at Point L can be obtained as:

$$S_L = C_1 S_1 + C_2 S_2 + C_3 S_3 + C_4 S_4$$

11.7.3

Let $X = X_R$ and repeat Step in 5C-5-A1/11.7.2 to determine four new coefficients, the stress at Point R can be obtained likewise, i.e.,

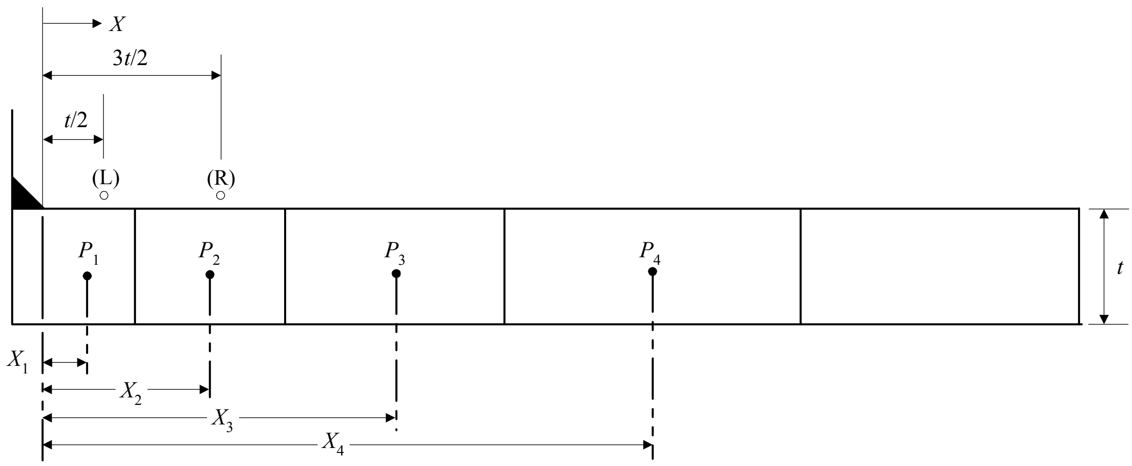
$$S_R = C_1S_1 + C_2\,S_2 + C_3\,S_3 + C_4\,S_4$$

11.7.4 *(2003)*

The corresponding stress at hot spot, S_0, is given by:

$$S_0 = (3S_L - S_R)/2$$

FIGURE 14
(1998)



Footnotes:

The algorithm presented in the foregoing involves two types of operations. The first is to utilize the stress values at the centroid of the four elements considered to obtain the estimates of the stress at Points L and R by way of an interpolation algorithm known as Lagrange interpolation. The second operation is to make use of the stress estimates S_L and S_R to obtain the hot spot stress via linear extrapolation.

While the Lagrange interpolation is applicable to any order of polynomial, it is not advisable to go beyond the 3rd order (cubic). Also, the even order polynomials are biased; so that leaves the choice between a linear scheme and a cubic scheme. Therefore, the cubic interpolation as described in 5C-5-A1/11.7.2 should be used. It can be observed that the coefficients, C_1 to C_4 are all cubic polynomials. It is also evident that, when $X = X_j$ which is not equal to X_i all of the C's vanish, except C_i; and if $X = X_i$, $C_i = 1$.

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PART

5C

CHAPTER 5 Vessels Intended to Carry Containers (130 meters (427 feet) to 450 meters (1476 feet) in Length)

APPENDIX 2 Calculation of Critical Buckling Stresses

1 General

The critical buckling stresses for various structural elements and members may be determined in accordance with this Appendix or other recognized design practices. Critical buckling stresses derived from experimental data or analytical studies may be considered, provided well documented supporting data are submitted for review.

3 Rectangular Plates *(1998)*

The critical buckling stresses for rectangular plate elements, such as plate panels between stiffeners; web plates of longitudinals, girders, floors and transverses; flanges and face plates, may be obtained from the following equations with respect to uniaxial compression, bending and edge shear, respectively.

$$f_{ci} = f_{Ei}, \qquad \text{for } f_{Ei} \le P_r f_{yi}$$

$$f_{ci} = f_{yi}[1 - P_r(1 - P_r) f_{yi}/f_{Ei}], \qquad \text{for } f_{Ei} > P_r f_{yi}$$

where

f_{ci} = critical buckling stress with respect to uniaxial compression, bending or edge shear, separately, in N/cm^2 (kgf/cm^2, lbf/in^2)

f_{Ei} = $K_i[\pi^2 E/12(1 - \nu^2)](t_n/s)^2$, N/cm^2 (kgf/cm^2, lbf/in^2)

K_i = buckling coefficient, as given in 5C-5-A2/Table 1

E = modulus of elasticity of the material, may be taken as 2.06×10^7 N/cm^2 (2.1×10^6 kgf/cm^2, 30×10^6 lbf/in^2) for steel

ν = Poisson's ratio, may be taken as 0.3 for steel.

t_n = net thickness of the plate, in cm (in.)

s = spacing of longitudinals/stiffeners, in cm (in.)

P_r = proportional linear elastic limit of the structure, may be taken as 0.6 for steel

f_{yi} = f_y, for uniaxial compression and bending

= $f_y/\sqrt{3}$ for edge shear

f_y = specified minimum yield point of the material, in N/cm^2 (kgf/cm^2, lbf/in^2)

TABLE 1
Buckling Coefficient, K_i *(1995)*

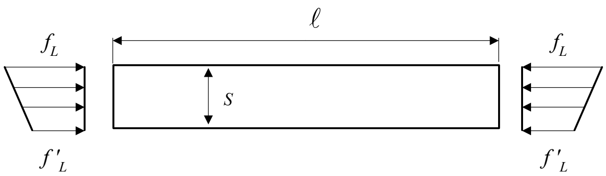
For Critical Buckling Stress Corresponding to f_L, f_T, f_b or f_{LT}

I. Plate panel between stiffeners — K_i

A Uniaxial compression

1. Long plate

$\ell \geq s$



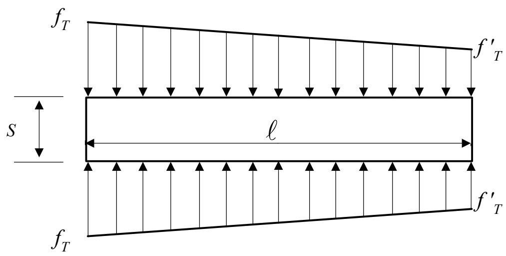
a. For f'_L, $= f_L$: $4C_1$,

b. For f'_L, $= f_L/3$: $5.8C_1$,

(see note)

2. Wide plate

$\ell \geq s$



a. For f'_T, $= f_T$: $[1 + (s/\ell)^2]^2 C_2$

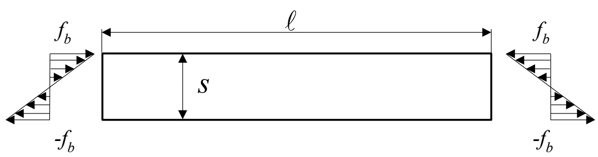
b. For f'_T, $= f_T/3$: $1.45[1 + (s/\ell)^2]^2 C_2$

(see note)

B Ideal Bending

1. Long plate

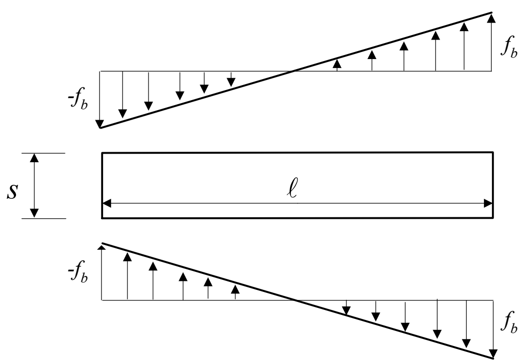
$\ell \geq s$



$24C_1$

2. Wide plate

$\ell \geq s$

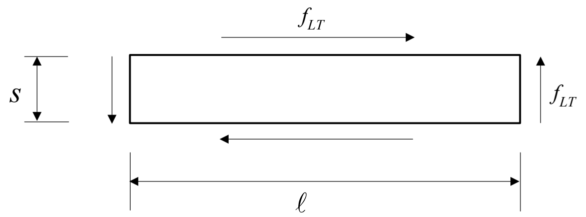


a. For $1.0 \leq \ell/s \leq 2.0$: $24(s/\ell)^2 C_2$

b. For $2.0 < \ell/s$: $12(s/\ell) C_2$

TABLE 1 (continued)
Buckling Coefficient, K_i (1995)

C Edge Shear — K_i



$[5.34 + 4\,(s/\ell)^2]C_1$

D Values of C_1 and C_2

1. For plate panels between angles or tee stiffeners

C_1 = 1.1

C_2 = 1.3 within the double bottom or double side*

C_2 = 1.2 elsewhere

2. For plate panels between flat bars or bulb plates

C_1 = 1.0

C_2 = 1.2 within the double bottom or double side*

C_2 = 1.1 elsewhere

* applicable where shorter edges of a panel are supported by rigid structural members, such as bottom, inner bottom, side shell, inner skin bulkhead, double bottom floor/girder and double side web stringer.

II. Web of Longitudinal or Stiffener — K_i

A Axial compression

Same as I.A.1 by replacing s with depth of the web and ℓ with unsupported span

a. For $f'_L = f_L$: — $4C$

b. For $f'_L = f_L/2$: — $5.2C$

(see note)

where

C = 1.0 for angle or tee stiffeners

C = 0.33 for bulb plates

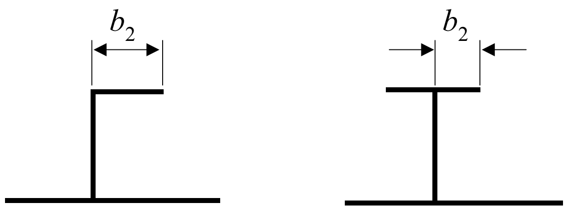
C = 0.11 for flat bars

B Ideal Bending

Same as I.B.1 by replacing s with depth of the web and ℓ with unsupported span — $24C$

TABLE 1 (continued)
Buckling Coefficient, K_i *(1995)*

III. Flange and Face Plate	K_i
Axial Compression	0.44



$s = b_2$

ℓ = unsupported span

Note:

In I.A. (II.A), K_i for intermediate values of f'_L / f_l (f'_T / f_T) may be obtained by interpolation between a and b.

5 Longitudinal Deck Girders, Cross Deck Box Beams, Vertical Webs, Longitudinals and Stiffeners

5.1 Axial Compression *(2002)*

The critical buckling stress f_{ca}, of a beam-column, i.e., the longitudinal and the associated effective plating, with respect to axial compression, may be obtained from the following equations:

$f_{ca} = f_E$, for $f_E \le P_r f_y$

$f_{ca} = f_y[1 - P_r(1 - P_r)f_y/f_E]$, for $f_E > P_r f_y$

where

f_E = $\pi^2 E/(\ell/r)^2$, in N/cm^2 (kgf/cm^2, lbf/in^2)

ℓ = unsupported span of the longitudinal or stiffener, in cm (in.), as defined in 5C-5-4/Figure 6.

r = radius of gyration of area, A_e, in cm (in.)

A_e = $A_s + b_{wL}t_n$

A_s = net sectional area of the longitudinals or stiffeners, excluding the associated plating, in cm^2 (in^2)

b_{wL} = effective width of the plating, as given in 5C-5-5/5.3.2, in cm (in.)

t_n = net thickness of the plating, in cm (in.)

f_y = minimum specified yield point of the longitudinal or stiffener under consideration, N/cm^2 (kgf/cm^2, lbf/in^2)

P_r and E are as defined in 5C-5-A2/3.

5.3 Bending

5.3.1 Longitudinals, Stiffeners and Frames *(1998)*

The allowable ultimate stress with respect to bending moment induced by lateral loads, f_{ub}, for a longitudinal may be taken as f_y. In this regard, the corresponding bending stress, f_b, specified in 5C-5-5/5.5, is to be determined from the following equation:

$f_b = M/SM_e$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

M = maximum total bending moment induced by lateral loads and the end structures connected

= $c_m ps\ell^2/12$ N-cm (kgf-cm, lbf-in)

c_m = moment adjustment coefficient, and may be taken as 0.75

p = lateral pressure for the region considered, in N/cm^2 (kgf/cm^2, lbf/in^2)

SM_e = net section modulus of the longitudinals, in cm^3 (in^3), including the effective breadth of the plating, b_e, at midspan. b_e may be taken as that given in 5C-5-4/Figure 7.

s is as defined in 5C-5-A2/3.

ℓ is as defined in 5C-5-A2/5.1.

5.3.2 Longitudinal Deck Girders, Cross Deck Box Beams and Vertical Webs *(1998)*

The allowable ultimate stress with respect to bending moment, f_{ub}, for these structural members may be taken as f_y. In this regard, the corresponding bending stress, f_b, specified in 5C-5-5/5.11, is to be determined from the following equations:

5.3.2(a) Longitudinal Deck Girders inboard of Lines of Hatch Openings

$f_b = M/SM$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

M = $kc_1 K_C C_1 T_M L_o^2 \omega_M 10^5/(c_2 b_o \alpha_M \Gamma_M)$ N-cm (kgf-cm, lbf-in)

k = 1.0 (1.0, 0.269)

SM = net section modulus of the longitudinal deck girder about its vertical neutral axis (z axis of section C-C in 5C-5-4/Figure 4), in cm^3 (in^3)

c_1 = 0.53 for centerline deck girders

= 0.42 for two side deck girders

K_c = $0.9k_c$

k_c is specified in 5C-5-3/Table 1 for torsional moment.

c_2 = $c_3 b_o / I^*_{CB} + \ell_o / I_g$

c_3 = 0.75 for centerline deck girder

= 0.425 for two side deck girders

T_M, L_o, ω_M, ℓ_M, b_o, ℓ_o, α_M and Γ_M are as defined in 5C-5-4/9.3 and C_1 and I^*_{CB} are as defined in 5C-5-4/17.7.2.

5.3.2(b) Cross Deck Box Beams where no Longitudinal Deck Girders are installed

$f_b = (K_c M_1 + M_2)/SM$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

M_1 is defined in 5C-5-4/17.7.4. In calculation of M_1, z is to be taken as 0.5 b_1 where b_1 is as defined in 5C-5-4/17.7.4

K_c = $0.9\, k_c$

k_c is specified in 5C-5-3/Table 1 for torsional moment.

M_2 = $kC_2[0.5Q_{d1} + 0.25Q_{d2}\, n/(n + 1)]b_1 10^5$

k = 0.17 (0.17, 0.046)

Q_{d1} = total dynamic container load in longitudinal direction on cross deck box beam (above the bottom of the cross deck box beam), in kN (tf, Ltf)

= $m_1 m_2(1 - h_5/h_4)\, F_{d\ell 1}$

Q_{d2} = total dynamic container load in longitudinal direction on transverse bulkhead, (below the bottom of cross deck box beam), in kN (tf, Ltf)

= $m_1 m_2(h_5/h_4)\, F_{d\ell 2}$

m_1 = tier number of container stacks in the cargo hold under consideration

m_2 = row number of container stacks in the cargo hold under consideration

h_4 = $m_1 h_C$

h_5 = vertical distance between inner bottom and the bottom of cross deck box beam at center line, in m (ft)

$F_{d\ell 1}$ = longitudinal dynamic container load $F_{d\ell}$,as specified in 5C-5-3/5.5.2(b), with W of the maximum design container weight at a vertical height $0.5(h_4 + h_5)$, measured from inner bottom

$F_{d\ell 2}$ = longitudinal dynamic container load $F_{d\ell}$, as specified in 5C-5-3/5.5.2(b), with W of the maximum design container weight at a vertical height $0.5h_5$, measured from inner bottom

SM = net section modulus of the cross deck box beam clear of the hatch corner under consideration about vertical axis (z axis of section A-A in 5C-5-4/Figure 4), in cm^3 (in^3)

W, C_2, n and h_C are as defined in 5C-5-4/17.5.3 and b_1 is as defined in 5C-5-4/17.7.4.

5.3.2(c) Vertical Webs of Mid-hold Strength Bulkhead where no Horizontal Girder is Installed

$f_b = M/SM$ N/cm^2 (kgf/cm^2, lbf/in^2)

where

M = $kcF_{dt}\ell_v$

k = 1.0 (1.0, 0.269)

c = $8330(m_1 - 1)$

m_1 is as defined in 5C-5-A2/5.3.2(b)

F_{dt} = transverse dynamic container load, as specified in 5C-5-3/5.5.2(b), with W of the maximum design container weight at the mid-span of vertical web of span ℓ_v, in kN (tf, Ltf)

SM = net section modulus of the vertical web under consideration about the neutral axis parallel to the longitudinal centerline plane of vessel, in cm^3 (in^3)

W and ℓ_v are as defined in 5C-5-4/17.5.3 and 5C-5-4/25.1, respectively.

5.5 Torsional/Flexural Buckling *(1998)*

The critical torsional/flexural buckling (ultimate) stress with respect to axial compression, e.g., of a longitudinal or stiffener including its associated plating (effective width, b_{wL}) may be obtained from the following equations:

$f_{ct} = f_{ET}$, for $f_{ET} \le P_r f_y$

$f_{ct} = f_y[1 - P_r(1 - P_r)f_y/f_{ET}]$, for $f_{ET} > P_r f_y$

where f_{ET} may be determined as follows.

5.5.1 Longitudinals, Stiffeners and Frames *(2002)*

$$f_{ET} = E[K/2.6 + (n\pi/\ell)^2\Gamma + C_o(\ell/n\pi)^2/E]/I_o[1 + C_o(\ell/n\pi)^2/I_o f_{cL}],$$

in N/cm^2 (kgf/cm^2, lbf/in^2)

where

f_{ct} = critical torsional/flexural buckling (ultimate) stress with respect to axial compression, N/cm^2 (kgf/cm^2, lbf/in^2).

K = St. Venant torsion constant for the stiffener's cross section, excluding the associated plating, in cm^4 (in^4)

= $1/3[b_f t_f^3 + d_w t_w^3]$

I_o = polar moment of inertia of the stiffener's cross section, excluding the associated plating, about the toe (intersection of web and plating), in cm^4 (in^4)

= $I_x + mI_y + A_s(x_o^2 + y_o^2)$

I_x, I_y = moment of inertia of the longitudinal about the x- and y-axis, respectively, through the centroid of the longitudinal, excluding the plating (x-axis perpendicular to the web), in cm^4 (in^4)

m = $1.0 - u(0.7 - 0.1d_w/b_f)$

u = unsymmetry factor

= $1 - 2b_1/b_f$

x_o = horizontal distance between centroid of stiffiner A_s and centerline of the web plate, in cm (in.)

y_o = vertical distance between the centroid of the longitudinal's cross section A_s and its toe, in cm (in.)

d_w = depth of the web, in cm (in.)

t_w = net thickness of the web, in cm (in.)

b_f = total width of the flange/face plate, in cm (in.)

b_1 = smaller outstanding dimension of flange with respect to web's centerline (see 5C-5-A2/Figure 1), in cm (in.)

t_f = net thickness of the flange/face plate, in cm (in.)

C_o = $E\,t_n^3/3s$

Γ = warping constant, in cm^6 (in^6)

≅ $mI_{yf}\,d_w^2 + d_w^3\,t_w^3/36$

I_{yf} = $t_f\,b_f^3\,(1.0 + 3.0u^2d_wt_w/A_s)/12$, cm^4 (in^4)

f_{cL} = critical buckling stress for the associated plating corresponding to n-half waves, in N/cm^2 (kgf/cm^2, lbf/in^2)

= $\pi^2E(n/\alpha + \alpha/n)^2(t_n/s)^2/12(1 - \nu^2)$

α = ℓ/s

n = number of half-waves which yield smallest f_{ET}

f_y = minimum specified yield point of the longitudinal or stiffener under consideration, N/cm^2 (kgf/cm^2, lbf/in^2)

P_r, E, s and ν are as defined in 5C-5-A2/3.

A_s, t_n and ℓ are as defined in 5C-5-A2/5.1.

5.5.2 Longitudinal Deck Girders, Cross Deck Box Beams, and Vertical Webs

$$f_{ET} = E[K/2.6 + (\pi/\ell)^2\Gamma]/I_o$$

f_{ct} = critical torsional/flexural buckling (ultimate) stress with respect to axial compression, in N/cm^2 (kgf/cm^2, lbf/in^2).

K = St. Venant torsion constant for the member's cross section, in cm^4 (in^4)

Γ = warping constant, in cm^6 (in^6)

I_o = polar moment of inertia of the member's cross section with respect to shear center, in cm^4 (in^4)

= $I_x + I_y + A(y_o^2 + x_o^2)$

I_x, I_y = moment of inertia of the member's cross section about the x- and y-plane, through its neutral axis (x-plane perpendicular to the web), in cm^4 (in^4)

y_o = vertical distance between the centroid of the member's cross section A and its shear center, in cm (in.)

x_o = horizontal distance between the centroid of member's cross section A and its shear center, in cm (in.)

A = total net sectional area of the structural members, in cm^2 (in^2)

ℓ is as defined in 5C-5-A2/5.1

For illustration purposes, the torsional properties are shown in 5C-5-A2/Figure 2 for I section with two planes of symmetry and channel section with one plane of symmetry.

FIGURE 1
Net Dimensions and Properties of Stiffeners *(1998)*

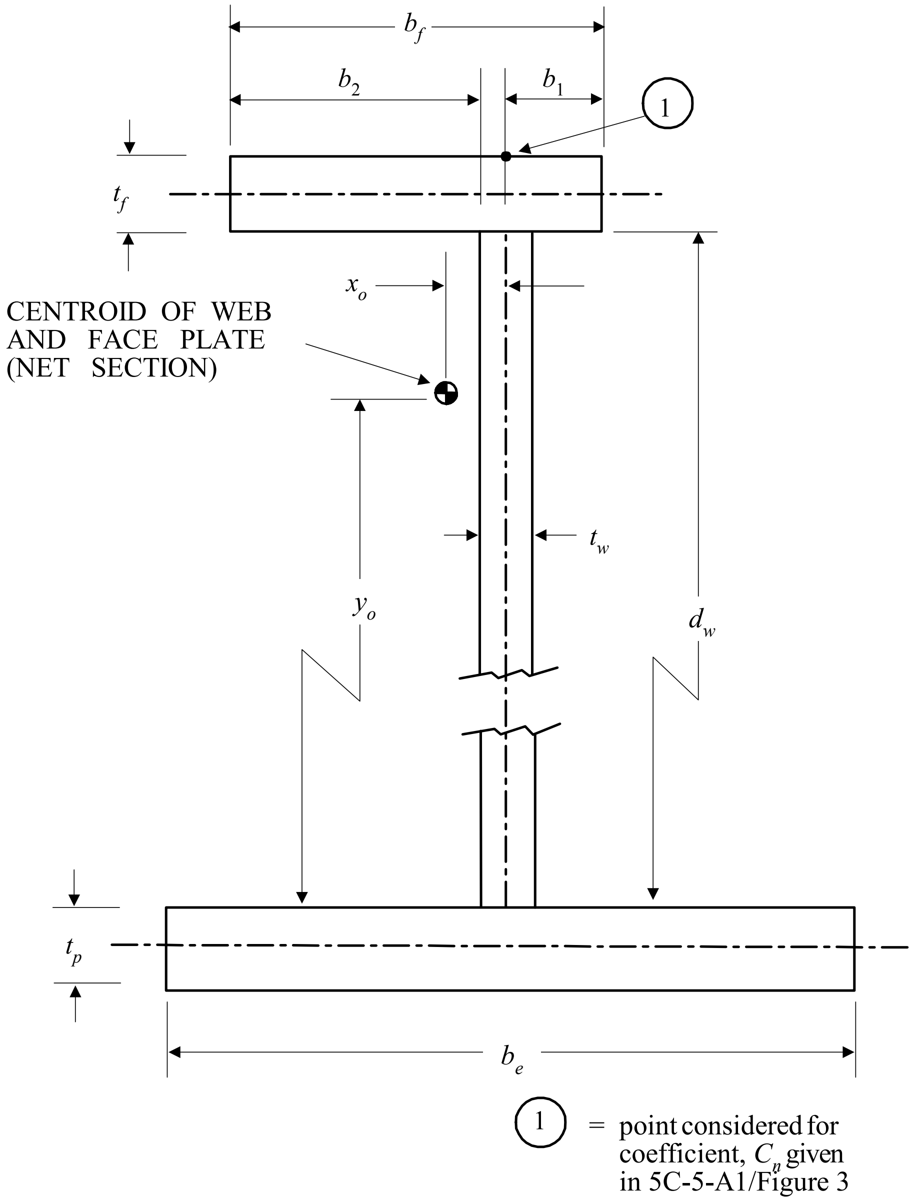
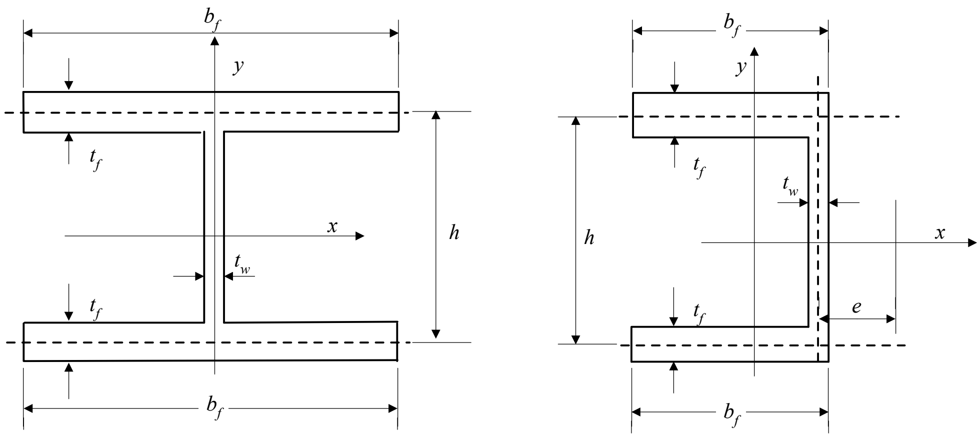


FIGURE 2
Torsional Properties



For I section with two axes of symmetry:

$$e = 0$$

$$K = \frac{2\,b_f t_f{}^3 + h\,t_w{}^3}{3}$$

$$\Gamma = \frac{t_f h^2 b_f{}^3}{24}$$

For channel section with one axis of symmetry:

$$e = \frac{3\,b_f{}^2\,t_f}{6\,b_f\,t_f + h\,t_w}$$

$$K = \frac{2\,b_f t_f{}^3 + h\,t_w{}^3}{3}$$

$$\Gamma = \frac{t_f h^2\,b_f{}^3\,(3\,b_f t_f + 2\,h\,t_w)}{12\,(6\,b_f\,t_f + h\,t_w)}$$

7 Stiffened Panels *(1998)*

For large stiffened panels between bulkheads or panels stiffened in one direction between transverses and girders, the critical buckling stresses with respect to uniaxial compression may be determined from the following equations:

$f_{ci} = f_{Ei}$ for $f_{Ei} \le P_r f_y$

$f_{ci} = f_y[1 - P_r(1 - P_r) f_y / f_{Ei}]$, for $f_{Ei} > P_r f_y$

where

$f_{Ei} = k_L \pi^2 (D_L D_T)^{1/2} / t_L b^2$ in the longitudinal direction, N/cm^2 (kgf/cm^2, lbf/in^2)

$f_{Ei} = k_T \pi^2 (D_L D_T)^{1/2} / t_T \ell^2$ in the transverse direction, N/cm^2 (kgf/cm^2, lbf/in^2)

k_L = 4 for $\ell/b \geq 1$

= $[1/\phi_L^2 + 2\eta + \phi_L^2]$ for $\ell/b < 1$

k_T = 4 for $b/\ell \geq 1$

= $[1/\phi_T^2 + 2\eta + \phi_T^2]$ for $b/\ell < 1$

D_L = $EI_L/s_L(1 - \nu^2)$

D_L = $Et_n^3/12(1 - \nu^2)$ if no stiffener in the longitudinal direction

D_T = $EI_T/s_T(1 - \nu^2)$

D_T = $Et_n^3/12(1 - \nu^2)$ if no stiffener in the transverse direction

ℓ, b = length and width between transverse bulkheads and side shell/longitudinal bulkheads, respectively, cm (in.) (See 5C-5-A2/Figure 2.)

t_L, t_T = equivalent net thickness of the plating and smeared stiffener in the longitudinal and transverse direction, respectively, cm (in.)

= $(s_L t_n + A_{sL})/s_L$ or $(s_T t_n + A_{sT})/s_T$

s_L, s_T = spacing of longitudinals and transverses, respectively, cm (in.) (See 5C-5-A2/Figure 2.)

ϕ_L = $(\ell/b)(D_T/D_L)^{1/4}$

ϕ_T = $(b/\ell)(D_L/D_T)^{1/4}$

η = $[(I_{pL}I_{pT})/(I_L I_T)]^{1/2}$

A_{sL}, A_{sT} = net sectional area of the longitudinal and transverse, excluding the associated plating, respectively, cm^2 (in^2)

I_{pL}, I_{pT} = moment of inertia of the effective plating (effective breadth due to shear lag) alone about the neutral axis of the combined cross section, including stiffener and plating, in the longitudinal and transverse direction, respectively, cm^4 (in^4)

I_L, I_T = moment of inertia of the stiffener (one) with effective plating in the longitudinal and transverse direction, respectively, cm^4 (in^4)

If no stiffener, the moment of inertia is calculated for the plating only.

P_r, f_y, E and ν are as defined in 5C-5-A2/3. t_n is as defined in 5C-5-A2/5.1.

Except for deck panels, when the lateral load parameter, q_o, defined below is greater than 5, reduction of the critical buckling stresses given above is to be considered.

$q_o = p_n\ell^4/(\pi^4 t_L D_L)$ if no stiffener in the transverse direction

$q_o = p_n b^4/(\pi^4 t_T D_T)$ for all other cases

where

p_n = average net lateral pressure, N/cm^2 (kgf/cm^2, lbf/in^2)

D_L, D_T, b, ℓ, t_T, and t_L are as defined above.

In this regard, the critical buckling stress may be approximated by:

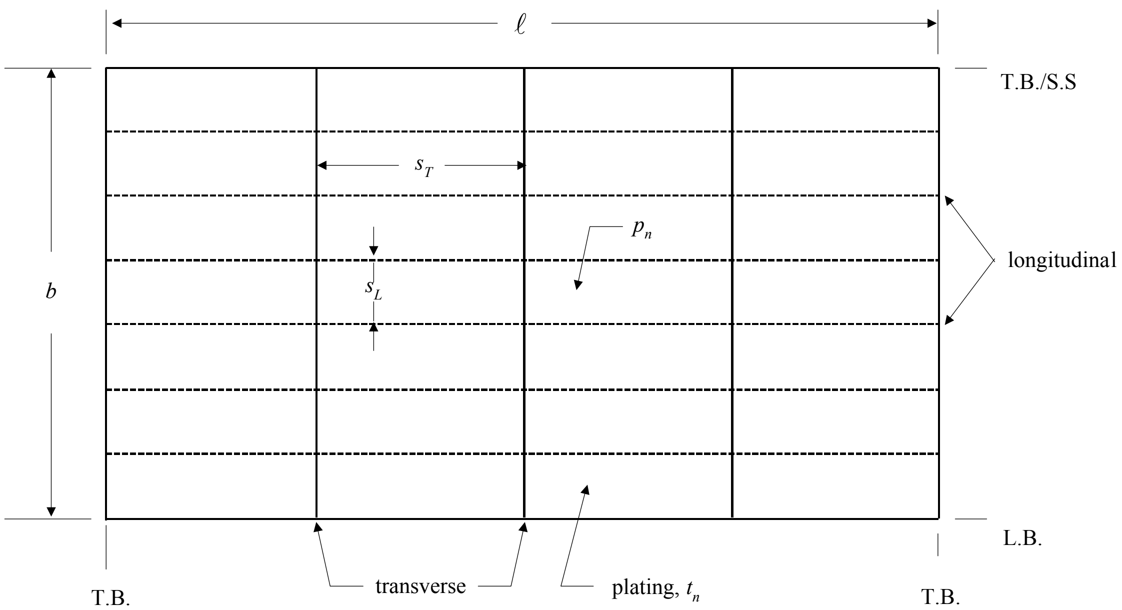
$$f'_{ci} = R_o f_{ci} \qquad \text{N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

where

$$R_o = 1 - 0.045(q_o - 5) \quad \text{for } q_o \geq 5$$

For deck panels, $R_o = 1.0$ and $f'_{ci} = f_{ci}$

FIGURE 3



9 Deep Girders, Webs and Stiffened Brackets

9.1 Critical Buckling Stresses of Web Plates and Large Brackets *(1998)*

The critical buckling stresses of web plates and large brackets between stiffeners may be obtained from the equations given in 5C-5-A2/3 for uniaxial compression, bending and edge shear.

9.3 Effects of Cut-outs *(1998)*

The depth of cut-outs, in general, is to be not greater than $d_w/3$, where d_w is the depth of the web, and the stresses in the area calculated are to account for the local increase due to the cut-out.

When cut-outs are present in the web plate, the effects of the cut-outs on reduction of the critical buckling stresses are to be considered as outlined below:

9.3.1 Reinforced by Stiffeners Around Boundaries of Cut-outs

When reinforcement is made by installing straight stiffeners along the boundaries of the cut-outs, the critical buckling stresses of web plate between stiffeners with respect to compression and shear may be obtained from equations given in 5C-5-A2/3

9.3.2 Reinforced by Face Plates Around Contour of Cut-outs

When reinforcement is made by adding face plates around the contours of the cut-outs, the critical buckling stresses with respect to compression, bending and shear may be obtained from equations given in 5C-5-A2/3, without reduction, provided the net sectional area of the face plate is not less than $8\,t_w^2$, where t_w is the net thickness of the web plate and the depth of the cut-outs is not greater than $d_w/3$, where d_w is the depth of the web.

9.3.3 No Reinforcement Provided

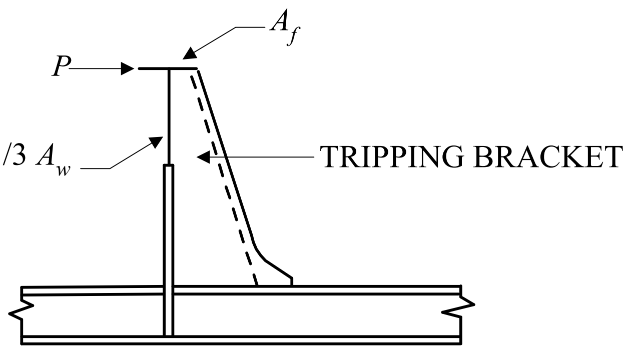
When reinforcement is not provided, the buckling strength of web plate surrounding the cut-out may be treated as a strip of plate with one edge free and the other edge simply supported.

9.5 Tripping *(1998)*

To prevent tripping of deep girders and webs with wide flanges, tripping brackets are to be installed with a spacing generally not greater than 3 meters (9.84 feet).

Design of tripping brackets may be based on the force, P, acting on the flange, as given by the following equation:

$$P = 0.02 f_{c\ell}\,(A_f + A_w/3)$$



where

$f_{c\ell}$	=	critical lateral buckling stress with respect to axial compression between tripping brackets, N/cm^2 (kgf/ cm^2, lbf/in^2)	
$f_{c\ell}$	=	f_{ce}	for $f_{ce} \le P_r f_y$
	=	$f_y[1 - P_r(1 - P_r) f_y / f_{ce}]$	for $f_{ce} > P_r f_y$
f_{ce}	=	$0.6E[(b_f / t_f)\,(t_w / d_w)^3]$	N/cm^2 (kgf/cm^2, lbf/in^2)
A_f	=	net cross sectional area of the flange/face plate, in cm^2 (in^2)	
A_w	=	net cross sectional area of the web, in cm^2 (in^2)	

b_f, t_f, d_w, t_w are as defined in 5C-5-A2/5.5.1.

E, P_r and f_y are as defined in 5C-5-A2/3.

11 Stiffness and Proportions

To fully develop the intended buckling strength of the assemblies of structural members and panels, supporting elements of plate panels and longitudinals are to satisfy the following requirements for stiffness and proportion in highly stressed regions.

11.1 Stiffness of Longitudinals *(1998)*

The net moment of inertia of the longitudinals, i_o, with effective plating is to be not less than that given by the following equation:

$$i_o = \frac{s\,t_n^3}{12(1-\nu^2)}\gamma_o \qquad \text{cm}^4\ (\text{in}^4)$$

where

γ_o = $(2.6 + 4.0\delta)\alpha_2 + 12.4\alpha - 13.2\alpha^{1/2}$

δ = $A/(st_n)$

α = ℓ/s

s = spacing of longitudinals/stiffeners, in cm (in.)

t_n = net thickness of plating supported by the longitudinal, in cm (in.)

ν = Poisson's ratio

= 0.3 for steel

A = net sectional area of the longitudinal section (excluding effective plating), in cm^2 (in^2)

ℓ = unsupported span of the longitudinal, in cm (in.)

11.3 Stiffness of Web Stiffeners *(1998)*

The net moment of inertia, i, of the web stiffener with the effective breadth of net plating not exceeding s or b_e, as specified in 5C-5-4/11.5, whichever is less, is not to be less than that obtained from the following equations:

$$i = 0.17\ell t^3(\ell/s)^3 \qquad \text{cm}^4\ (\text{in}^4) \qquad \text{for } \ell/s \le 2.0$$

$$i = 0.34\ell t^3(\ell/s)^2 \qquad \text{cm}^4\ (\text{in}^4) \qquad \text{for } \ell/s > 2.0$$

where

ℓ = length of stiffener between effective supports, in cm (in.)

t = required net thickness of web plating, in cm (in.)

s = spacing of stiffeners, in cm (in.)

11.5 Stiffness of Supporting Members *(1998)*

The net moment of inertia of the supporting members such as transverses, girders and webs is to be not less than that obtained from the following equation:

$$I_s/i_o \geq 0.2(B_s/\ell)^3(B_s/s)$$

where

I_s = moment of inertia of the supporting member, including the effective plating, in cm^4 (in^4)

i_o = moment of inertia of the longitudinals/stiffeners, including the effective plating, in cm^4 (in^4)

B_s = unsupported span of the supporting member, in cm (in.)

ℓ and s are as defined in 5C-5-A2/11.1.

11.7 Proportions of Flanges and Face Plates *(1998)*

The breadth-thickness ratio of flanges and face plates of longitudinals and girders is to satisfy the limits given below:

$$b_2/t_f \leq 0.4(E/f_y)^{1/2}$$

where

b_2 = breadth of flange, as given in 5C-5-A2/Figure 1, in cm (in.)

t_f = net thickness of flange/face plate, in cm (in.)

E and f_y are as defined in 5C-5-A2/3.

11.9 Proportions of Webs of Longitudinals and Stiffeners *(1998)*

The depth-thickness ratio of webs of longitudinals and stiffeners is to satisfy the limits given below:

$d_w/t_w \leq 1.5(E/f_y)^{1/2}$ for angles and tee-bars

$d_w/t_w \leq 0.85(E/f_y)^{1/2}$ for bulb plates

$d_w/t_w \leq 0.5(E/f_y)^{1/2}$ for flat bars

where

d_w and t_w are as defined in 5C-5-A2/5.5 and E and f_y are as defined in 5C-5-A2/3.

When these limits are complied with, the assumption on buckling control stated in 5C-5-5/5.1.2(e) is considered satisfied. If not, the buckling strength of the web is to be further investigated, as per 5C-5-A2/3.

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PART

5C

CHAPTER 5 Vessels Intended to Carry Containers (130 meters (427 feet) to 450 meters (1476 feet) in Length)

APPENDIX 3 Definition of Hull Girder Torsional Properties

1 General *(1998)*

The hull girder torsional properties may be calculated based on the thin walled beam theory. The hull girder section of a typical container carrier is usually modeled as an assemblage of segments (plates) connected to nodal points, consisting of open zones and closed cells. The following sections define the torsional properties used in the Rules. The torsional properties for each design will be calculated with SafeHull software.

3 Warping Function, ω *(1998)*

The warping function for node "N", $\omega(s)_N$, may be obtained from the following equation:

$$\omega(s)_N = \omega(s)^*_N + e\,x_N$$

$$\omega(s)^*_N = \int_o^{"N"} \left(r_s - \frac{q_s}{t_s} \right) ds$$

where

r_s = distance from the origin to the axis of each segment

The origin is taken as the intersection of the centerline and baseline of the vessel.

q_s = specific stress flow of cell to which each segment belongs

t_s = plate thickness of each segment with the area of longitudinal stiffeners smeared

e = distance of shear center of the hull girder section, measured from the baseline, positive upward

x_N = horizontal distance from the centerline of the vessel to node "N"

s = length along girth

The specific stress flow, q, of each cell may be obtained from the following set of equations; the number of the equations is equal to the number of cells in hull girder section.

$$q_i \oint_i \frac{ds}{t} - q_{i-1} \int_{Div} \frac{ds}{t} - q_{i+1} \int_{Div} \frac{ds}{t} = 2A_i, (i = 1, 2, ---k)$$

where

q_i = specific flow for cell "i"

$q_i - 1$ = specific flow for adjacent cell "$i - 1$"

$q_i + 1$ = specific flow for adjacent cell "$i + 1$"

k = number of the cells in hull girder section

A_i = enclosed area of cell "i"

t = plate thickness of segment with the area of longitudinal stiffeners smeared

5 Location of Shear Center, *e* (1998)

The location of the shear center, e, of the hull girder, measured from the baseline may be obtained from the following equation:

$$e = -(I_{\omega y}/I_y)$$

where

$I_{\omega y}$ = sectorial moment

= $\int_c \omega(s)_N^* x_N t_s ds$

I_y = hull girder moment of inertia about the centerline of the vessel

C = total girth length

$\omega(s)_N^*$, x_N, t_s are as defined in 5C-5-A3/3.

7 Warping Constant, *Γ* (1998)

The warping constant, Γ, for the hull girder section may be obtained from the following equation:

$$\Gamma = \sum_{n-1}^{p} t_n \int_0^{\ell_n} \omega^2(s) ds$$

where

p = number of segments in hull girder section

ℓ_n = length of segment "n"

t_n = plate thickness of segment "n" with the area of longitudinal stiffeners smeared

$\omega(s)$ = warping function

9 St. Venant Torsional Constant, *J (1998)*

The St. Venant torsional constant, *J*, may be obtained from the following equation:

$$J = 4\sum_{i=1}^{k} \frac{A_i^2}{\oint ds/t}$$

where

A_i = enclosed area of cell "*i*"

t = plate thickness of segment in cell "*i*" without smearing longitudinal stiffeners

k is as defined in 5C-5-A3/3.

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PART

5C

CHAPTER **6 Vessels Intended to Carry Containers (Under 130 meters (427 feet) in Length)**

CONTENTS

PART

5C

CHAPTER 6 Vessels Intended to Carry Containers (Under 130 meters (427 feet) in Length)

SECTION 1 Introduction

1 General

1.1 Classification

In accordance with 1-1-3/3, the classification ✠ **A1 Container Carrier** is to be assigned to vessels built to the requirements of this Chapter and other relevant Sections of the Rules.

1.3 Application

The requirements in this Chapter are applicable to vessels designed primarily for the carriage of containers in holds or on deck, or both, with structures for that purpose, such as cell guides, pedestals, etc.

1.5 Arrangement

Strength bulkheads or combined deep webs and substantial partial bulkheads are to be provided in accordance with 3-2-9/1.7. Upper wing torsional boxes or double hull side construction are to be provided in way of container holds having wide deck openings.

1.7 Submission of Plans

In addition to the plans listed elsewhere in the Rules, the following plans are to be submitted. See Section 1-1-7.

Stowage arrangement of containers including stacking loads. Location of container supports and their connection to hull.

3 Definitions

3.1 Freeboard Deck

For the purpose of this Part, freeboard deck may be taken as the lowest actual deck from which the draft can be obtained under the International Load Line Regulations.

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PART

5C

CHAPTER 6 Vessels Intended to Carry Containers (Under 130 meters (427 feet) in Length)

SECTION 2 Hull Structure

1 Hull Girder Strength

1.1 Normal-strength Standard

The longitudinal hull girder strength is to be required by the equations given in Section 3-2-1.

1.3 Hull Girder Shear and Bending Moment

For shear and bending-moment calculation requirements, see Section 3-2-1.

1.5 Torsion and Horizontal Bending

The hull girder strength calculations under combined vertical and horizontal bending moment and torsion are to be submitted. ABS *Guide for Strength Assessment of Container Carriers* (Appendix 5C-6-A1) provides guidance in performing this calculation. A more comprehensive analysis will also be acceptable.

1.7 Loading Guidance

Loading guidance is to be as required by 3-2-1/7.

1.9 Continuous Longitudinal Deck Structures Between Hatch Openings

The degree of effectiveness of continuous longitudinal deck structures between hatch openings is to be determined in accordance with 3-2-1/17.3.

3 Local Strength

3.1 Double Bottom

Structures under base sockets are to be reinforced to withstand the anticipated load. An engineering analysis for the double bottom structure may be required.

In determining the scantlings of inner bottom longitudinals and bottom longitudinals with struts, reduced length permitted for uniformly loaded inner bottom is not to be used.

3.3 Container Loading

Deck and hatch cover structures supporting containers are to have scantlings, as required by 3-2-7/5, 3-2-8/1.3 and 3-2-15/9.9. See also 3-2-15/5.5 for chocks and pads on hatch coaming.

3.5 Securing Arrangement

When requested, the container securing system may be certified in accordance with the ABS *Guide for Certification of Container Securing Systems*. Additional plans and calculations as required in that Guide are to be submitted.

3.7 Hatchway Closures

For gasketless hatch covers, see 3-2-15/11.1. Vessels without hatch covers will be specially considered.

PART

5C

CHAPTER 6 Vessels Intended to Carry Containers (Under 130 meters (427 feet) in Length)

SECTION 3 Cargo Safety

See Section 5C-5-7.

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PART

5C

CHAPTER 6 Vessels Intended to Carry Containers (Under 130 meters (427 feet) in Length)

APPENDIX 1 Guide for Strength Assessment of Container Carriers – Vessels Under 130 meters (427 feet) in Length

1 Note

The requirements given herein contain equation for warping stress developed from the theory of thin-walled beams. Equations for horizontal bending stress are also included together with that for combined stress which is being used as the parameter. The combined stresses, calculated for four designs, were used in arriving at the acceptance criteria.

3 Application

These criteria are applicable to steel vessels of up to 130 m (427 ft) in length, designed for the carriage of containers and intended for unrestricted ocean service. The basic structural arrangement consists of a double bottom with a double skin side structure or a single skin side structure with upper torsion boxes.

In addition to complying with the ABS *Rules for Building and Classing Steel Vessels*, the strength of the vessel is to be evaluated using the criteria presented in this Guide.

If the stresses, determined in accordance with this Guide, exceed the permissible value given herein, a direct calculation stress analysis can be carried out to evaluate the adequacy of the vessel's structural design in a more sophisticated manner. On request, this analysis may be carried out by the Bureau.

5 Hull Girder Longitudinal Strength

5.1 Check Points

The combined longitudinal hull girder stress σ is to be calculated at the inboard edge of the strength (upper) deck plating at the transverse sections shown on 5C-6-A1/Figure 1:

1 The aft end of the hatch opening immediately forward of the machinery room, (Section No. 1).

2 The forward end of the foremost hatch where there is a change in the width of the hatch, (Section No. 2).

3 The forward end of the next hatch aft of the section No. 2, (Section No. 3).

5.3 Hull Girder Stress

5.3.1 Combined Longitudinal Hull Girder Stress

The combined longitudinal hull girder stress σ at the inboard edge of the strength deck plating is to be obtained from the following equation:

$$\sigma = \sigma_s + \sigma_v + \sigma_H + \sigma_T$$

where

σ_s = still-water bending component, see 5C-6-A1/5.3.2

σ_v = vertical wave-induced bending component, see 5C-6-A1/5.3.3

σ_H = horizontal wave-induced bending component, see 5C-6-A1/5.3.4

σ_T = warping component, see 5C-6-A1/5.3.5

The calculated longitudinal hull girder stress σ is not to exceed 60% of the minimum specified yield point or yield strength of the material.

5.3.2 Still-water Bending Component

The still-water bending component is to be obtained from the following equation:

$$\sigma_s = M_s/SM \qquad \text{kN/cm}^2 \text{ (tf/cm}^2\text{, Lft/in}^2\text{)}$$

where

M_s = still-water bending at the section under consideration for design loading conditions, in kN-m (ft-m, Ltf-ft).

SM = hull girder section modulus about the horizontal neutral axis at the section under consideration, in cm^2-m (in^2-ft).

5.3.3 Vertical Wave-induced Bending Component

The vertical wave-induced bending component is to be obtained from the following equation:

$$\sigma_v = 0.47M \cdot M_{wh}/SM \qquad \text{kN/cm}^2 \text{ (ft/cm}^2\text{, Ltf/in}^2\text{)}$$

where

M_{wh} = wave-induced bending moment amidships, as given in 3-2-1/3.5.1 of the Rules, in kN-m (tf-m, Ltf-ft)

SM = hull girder section modulus, defined in 5C-6-A1/5.3.2, in cm^2-m (in^2-ft)

M = distribution factor given by 3-2-1/Figure 2 of the Rules

5.3.4 Horizontal Wave-induced Bending Component

The horizontal wave-induced bending component is to be obtained from the following equation:

$$\sigma_H = \frac{0.175 M_{wh} b_o (1 - 2x/L)}{I_z} \qquad \text{kN/cm}^2 \text{ (ft/cm}^2\text{, Ltf/in}^2\text{)}$$

where

M_{wh} = wave-induced bending moment amidships, as given by 3-2-1/3.5.1 of the Rules, in kN-m (tf-m, Ltf-ft)

L = length of the vessel, as defined in 3-1-1/3.1 of the Rules, in m (ft)

x = distance from amidships to the section under consideration, in m (ft)

b_o = width of the strength deck's hatch opening of the section under consideration, measured between the inboard edges of the strength deck, (5C-6-A1/Figure 3), in m (ft)

I_z = hull girder moment of inertia of the section under consideration about the vertical axis through the centerline of the vessel, in cm^2-m^2 (in^2-ft^2)

5.3.5 Warping Component

The warping component is to be obtained from the following equation:

$$\sigma_T = \frac{KK_1^3 N\alpha h L_o^3 B_o(1-0.7b_o/B_o)(1-0.062K_1\sqrt{C})}{Dt(0.45-0.4b/B)} \text{ kN/cm}^2 \text{ (tf/cm}^2\text{, Ltf/in}^2\text{)}$$

where

K = 9.81 if σ_T in kN/cm^2

= 1.0 if σ_T in tf/cm^2

= 21.58×10^{-4} if σ_T in Ltf/in^2

B = breadth of the vessel amidships, as defined in 3-1-1/5 of the Rules, in m (ft)

B_o = breadth of the vessel at the section under consideration, (5C-6-A1/Figure 3), in m (ft)

D = depth of the vessel amidships, as defined in 3-1-1/7 of the Rules, in m (ft)

h = $0.0124L_o + 4.37L_o/L$ SI/MKS units ($0.124\,L_o + 14.34\,L_o/L$ US units)

L_o = length, as shown on 5C-6-A1/Figure 1, measured from the forward engine room's bulkhead and the first section of the forward part of the hatch opening that has hatch width greater than the hatch forward, in m (ft)

K_1 = 1.0 for sections Nos. 1 and 2, as defined in 5C-6-A1/5.1

= ℓ/L_o for section No. 3, as defined in 5C-6-A1/5.1

K_1 is not to be less than 0.85.

ℓ = distance from the forward engine room bulkhead to the section No. 3, in m (ft)

N for section No. 1

= 2.8×10^{-7}, ($C_b \le 0.65$)

= $8(1 - C_b) \times 10^{-7}$, ($C_b > 0.65$)

N for sections Nos. 2 and 3

= 5.6×10^{-7}, ($C_b \le 0.65$)

= $16(1 - C_b) \times 10^{-7}$, ($C_b > 0.65$)

C_b = block coefficient at summer load waterline

b = width of the strength deck's hatch opening amidships, measured between the inboard edges of the strength deck, (5C-6-A1/Figure 2), in m (ft)

b_o = width of the strength deck's hatch opening of the section under consideration, measured between the inboard edges of the strength deck, (5C-6-A1/Figure 3), in m (ft)

t = apparent thickness of the side and bottom structures amidships, in mm (in.)

The apparent thickness is the total area of the side and bottom structures (plating and longitudinals) divided by the combined girth of the side and bottom.

where

$$C = \frac{\left[Bd_{DB} + 2Dd_D\right]^2 L_0^2}{B^3 D^2 t\left(1.67d_D / t_D + 1.11D / t_s + 0.56B / t_B\right)\left(0.45 - 0.4b / B\right)}$$

d_{DB} = depth of double bottom amidships, (5C-6-A1/Figure 2), in m (ft)

d_D = width of the strength deck plating amidships, (5C-6-A1/Figure 2), in m (ft)

t_D, t_s, t_B = mean thickness of the strength deck, side shell, and bottom plating amidships (inner bottom and longitudinal bulkhead plating are not to be included), (5C-6-A1/Figure 2), in mm (in.)

α = $a\, B_1/B_o + c$

B_1 = width of the section under consideration at a height of $D/2$, as shown on 5C-6-A1/Figure 3, in m (ft)

a and *c* are coefficients, as given in the following table:

Section Number per 5C-6-A1/5.1	*Coefficient a*	*Coefficient c*
1	2	-1.45
2	0.53	-0.02
3	0.33	0.05

FIGURE 1
Strength (Upper) Deck

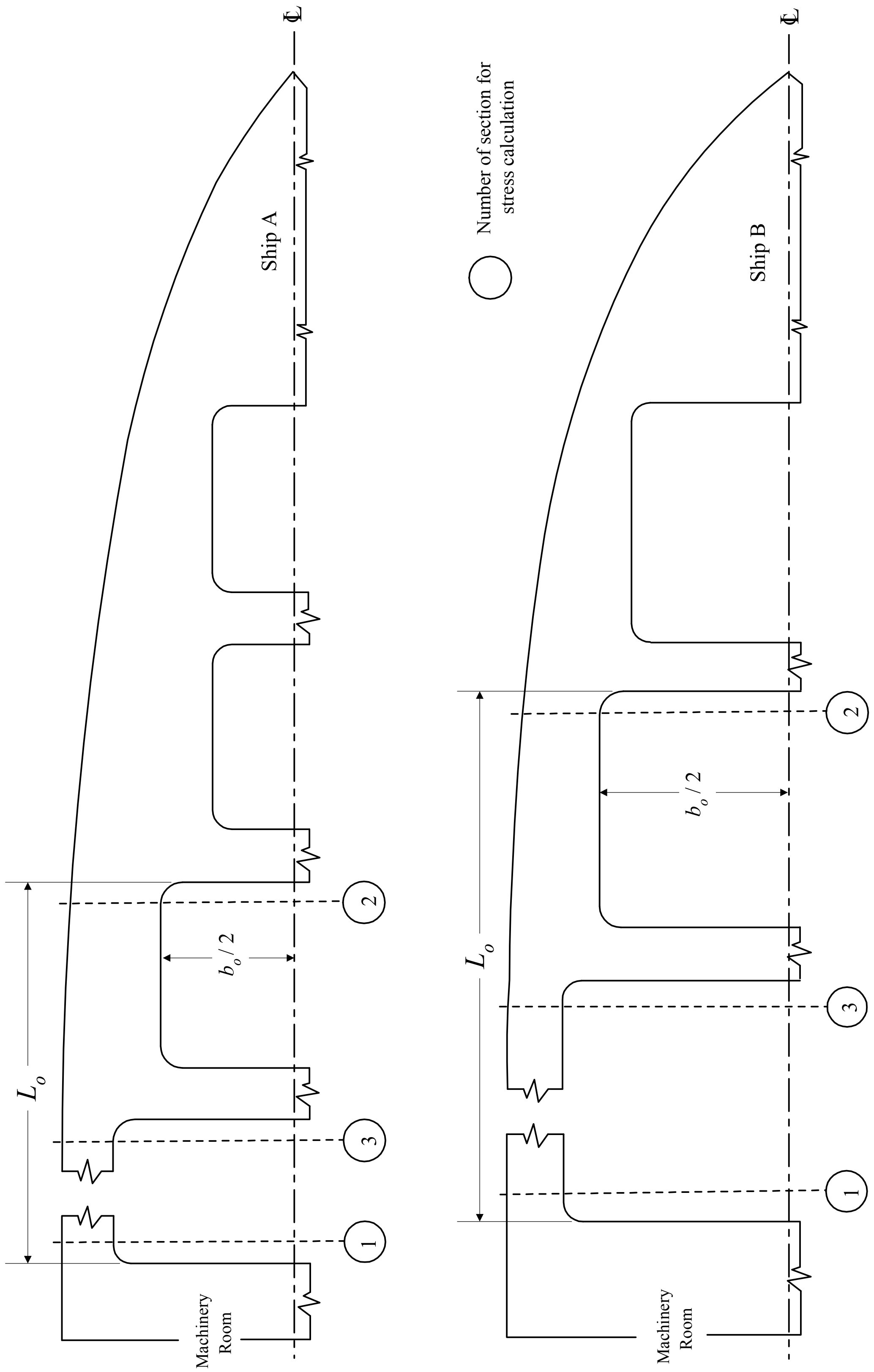


FIGURE 2
Midship Section

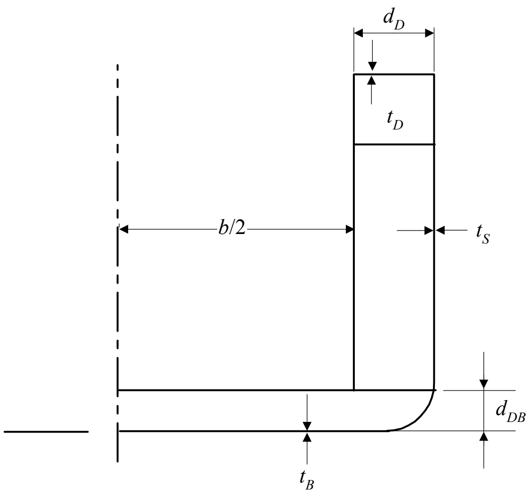
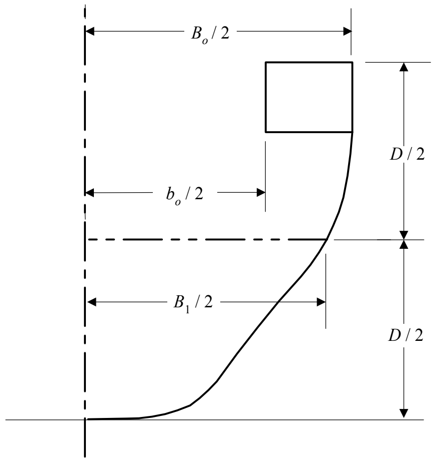


FIGURE 3
Section Under Consideration



PART

5C

APPENDIX 1 **Guide for SafeHull Construction Monitoring Program** *(1 July 2001)*

1 Introduction

The structural strength criteria specified in the ABS Rules are used by designers to establish acceptable scantlings in order that a vessel constructed to such standards and properly maintained will have adequate durability and capability to resist the failure modes of yielding, buckling and fatigue.

The application of SafeHull and other review techniques to assess a design for compliance with Rule criteria also gives the designer and ABS the ability to identify areas that are considered critical to satisfactory in-service performance.

Knowing that the actual structural performance is also a function of construction methods and standards, it is prudent to identify 'critical' areas, particularly those approaching design limits, and use appropriate specified construction quality standards and associated construction monitoring and reporting methods to limit the risk of unsatisfactory in-service performance.

Accordingly, this Guide defines what is meant by critical areas, describes how they are to be identified and recorded, delineates what information the shipyard is to include in the construction monitoring plan and lays out the certification regime to be followed.

3 Application

Vessels designed and reviewed to Part 5C, Chapters 1, 3 and 5 of the ABS Rules are to comply with the requirements of this Guide and have the notation **SH, SHCM**. Other vessel types may be considered on a case by case basis.

5 Critical Area

The term *critical area*, as used in this Guide, is defined as an area within the structure that may have a higher probability of failure during the life of the vessel compared to the surrounding areas, even though they may have been modified in the interest of reducing such probability. The higher probability of failure can be a result of stress concentrations, high stress levels and high stress ranges due to loading patterns, structural discontinuities or a combination of these factors.

In order to provide an even greater probability of satisfactory in-service performance, the areas that are approaching the acceptance criteria can be identified so that additional attention may be paid during fabrication.

The objective of heightened scrutiny of building tolerance and monitoring in way of the critical areas is to minimize the effect of stress increases incurred as a result of the construction process. Improper alignment and fabrication tolerances may be potentially influential in creating construction-related stress.

7 Determination of Critical Areas

Critical areas can be determined in a number of ways, including but not limited to:

i) The results of engineering strength and fatigue analyses, such as specified in the ABS Rules Section 5C-1-5, 5C-3-5 or 5C-5-5 (SafeHull), Finite Element Analysis or a Dynamic Loading Approach analysis, particularly for areas approaching the allowable criteria.

ii) The application of ABS Rules, such as 3-1-2/15.3.

iii) Details where fabrication is difficult, such as blind alignment, complexity of structural details and shape, limited access, etc.

iv) Input from owners, designers and/or shipyards based on previous in-service experience from similar vessels, such as corrosion, wear and tear, etc.

9 Construction Monitoring Plan

A Construction Monitoring Plan for critical areas is to be prepared by the shipyard and submitted for approval prior to the start of fabrication. The plan is to include:

i) Structural drawings indicating the location of critical areas as identified by the ABS review (see 5C-A1/7).

ii) Construction standards and control procedures to be applied.

iii) Verification and recording procedures at each stage of construction, including any proposed nondestructive testing.

iv) Procedures for defect correction.

An approved copy of the Construction Monitoring plan is to be placed onboard the vessel.

11 Surveys After Construction

To monitor critical areas during service, an approved copy of the Construction Monitoring Plan should be available for all subsequent surveys.

13 Notation

Vessels having been found in compliance with the requirements of this Guide may be distinguished in the *Record* with the notation **SH, SHCM**.

PART

5C

APPENDIX 2 Guide for SafeShip Construction Monitoring Program *(1 April 2006)*

(This Appendix applies to Part 5A and Part 5B of the *Rules for Building and Classing Steel Vessels* for the class notation, CSR, SafeShip-CM.)

1 Introduction

The structural strength criteria specified in the ABS Rules are used by designers to establish acceptable scantlings in order that a vessel constructed to such standards and properly maintained will have adequate durability and capability to resist the failure modes of yielding, buckling and fatigue.

The application of Part 5A "Common Structural Rules for Double Hull Oil Tankers", Part 5B "Common Structural Rules for Bulk Carriers" and other review techniques to assess a design for compliance with Rule criteria also gives the designer and ABS the ability to identify areas that are considered critical to satisfactory in-service performance.

Knowing that the actual structural performance is also a function of construction methods and standards, it is prudent to identify 'critical' areas, particularly those approaching design limits, and use appropriate specified construction quality standards and associated construction monitoring and reporting methods to limit the risk of unsatisfactory in-service performance.

Accordingly, this Guide defines what is meant by critical areas, describes how they are to be identified and recorded, delineates what information the shipyard is to include in the construction monitoring plan and lays out the certification regime to be followed.

3 Application

Vessels designed and reviewed to Part 5A and Part 5B of the ABS Rules are to comply with the requirements of this Guide and have the notation **CSR, SafeShip-CM**.

5 Critical Area

The term *critical area*, as used in this Guide, is defined as an area within the structure that may have a higher probability of failure during the life of the vessel compared to the surrounding areas, even though they may have been modified in the interest of reducing such probability. The higher probability of failure can be a result of stress concentrations, high stress levels and high stress ranges due to loading patterns, structural discontinuities or a combination of these factors.

In order to provide an even greater probability of satisfactory in-service performance, the areas that are approaching the acceptance criteria can be identified so that additional attention may be paid during fabrication.

The objective of heightened scrutiny of building tolerance and monitoring in way of the critical areas is to minimize the effect of stress increases incurred as a result of the construction process. Improper alignment and fabrication tolerances may be potentially influential in creating construction-related stress.

7 Determination of Critical Areas

Critical areas can be determined in a number of ways, including but not limited to:

v) The results of engineering strength and fatigue analyses, such as specified in the ABS Rules Section 5A-9 or Chapters 5B-7 and 5B-8, particularly for areas approaching the allowable criteria.

vi) The application of ABS Rules, such as 3-1-2/15.3 and Section 5A-4-3/2.

vii) Details where fabrication is difficult, such as blind alignment, complexity of structural details and shape, limited access, etc.

viii) Input from owners, designers and/or shipyards based on previous in-service experience from similar vessels, such as corrosion, wear and tear, etc.

9 Construction Monitoring Plan

A Construction Monitoring Plan for critical areas is to be prepared by the shipyard and submitted for approval prior to the start of fabrication. The plan is to include:

i) Structural drawings indicating the location of critical areas as identified by the ABS review (see 5A/5B-A1/7).

ii) Construction standards and control procedures to be applied.

iii) Verification and recording procedures at each stage of construction, including any proposed nondestructive testing.

iv) Procedures for defect correction.

An approved copy of the Construction Monitoring plan is to be placed onboard the vessel.

11 Surveys After Construction

To monitor critical areas during service, an approved copy of the Construction Monitoring Plan should be available for all subsequent surveys.

13 Notation

Vessels having been found in compliance with the requirements of this Guide may be distinguished in the *Record* with the notation **CSR, SafeShip-CM**.