

GUIDE FOR BUILDING AND CLASSING

LIQUEFIED GAS CARRIERS WITH INDEPENDENT TANKS

JANUARY 2010

Guide to Color Coding Used in Online Version of the Guide

The following summarizes the colors corresponding to Rule Changes, Corrigenda items and editorial changes in the Guide files which are available for download.

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GUIDE FOR BUILDING AND CLASSING

LIQUEFIED GAS CARRIERS WITH INDEPENDENT TANKS

HULL STRUCTURAL DESIGN AND ANALYSIS

JANUARY 2010 (Updated January 2015 – see next page)

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Foreword (1 June 2011)

The industry and ABS share a large and successful body of experience with liquefied gas carriers with independent tanks. Owners and designers familiar with the benefits of the ABS SafeHull Rule approach in the design and analysis of other vessel types requested that ABS adapt the SafeHull criteria so that it can be used in the Classification of liquefied gas carriers with independent tanks. This Guide is developed and issued in response to the request.

This Guide provides criteria that can be applied in the Classification of the hull structure of a liquefied gas carrier with independent tanks.

The strength criteria contained herein are to be used to verify compliance with the structural analysis requirements in the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) as a condition of classification. These strength criteria are to be considered supplementary to those for corresponding aspects of Classification as given in Part 5C, Chapter 8 of the *Steel Vessel Rules*. The Owner may select to use either this Guide or Part 5C, Chapter 8 of the *Steel Vessel Rules*, however the Classification symbol, **SH**, (signifying compliance with the SafeHull based criteria in this Guide) will only be granted when the design is based on the criteria of this Guide.

After a certain period for trial use, the criteria contained in this Guide will be incorporated and published in the *Steel Vessel Rules*. ABS encourages and welcomes at any time the submission of comments on this Guide.

The ABS *Guide for Liquefied Petroleum Gas Carriers with Type-A Independent Tanks* became effective 1 JANUARY 2006. In May 2009, the criteria was extended to cover liquefied gas carriers with Type B and Type C independent tanks. This revision adds guidelines for hull girder ultimate strength assessment and has an effective date of 1 January 2010. **The June 2011 revision includes fatigue, fracture, and thermal analysis for type-B independent tanks which is required by IGC code. Paragraph 6/9.7 and Appendix 5 are added to the Guide.**

Reference Note

Reference to a paragraph in the *Steel Vessel Rules* is made in the format “P-C-S/ss.p.sp.i” where “P” is the Part, “C” is the Chapter, “S” is the Section, “ss” is the subsection, “p” is the paragraph, “sp” is the subparagraph and “i” is the item.

Reference to a paragraph in this Guide is made in the format “S/ss.p.sp.i”, where “S” is the Section, “ss” is the subsection, “p” is the paragraph and “sp” is the subparagraph and “i” is the item.

Reference to a Figure or Table in this Guide is made, respectively, in the format “S, Figure #”, or “S, Table #” where “S” is the Section in which the figure or table is located.

GUIDE FOR BUILDING AND CLASSING

LIQUEFIED GAS CARRIERS WITH INDEPENDENT TANKS

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SECTION 1 Introduction

1 General

1.1 Classification (1 May 2009)

In accordance with 1-1-3/3 of the *ABS Rules for Conditions of Classification* and 5C-8-1/1 of the *ABS Rules for Building and Classing Steel Vessels* (the Rules), the classification notation **A1 Liquefied Gas Carrier with Independent Tanks, SH, SHCM** is to be assigned to vessels designed for the carriage of liquefied gases, and built to the requirements of this Guide and other relevant sections of the Rules.

1.3 Optional Class Notation for Design Fatigue Life (1 May 2009)

Vessels designed and built to the requirements in this Guide 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 3, "Rule-based Fatigue Strength Assessment" of this Guide. 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 3, "Rule-based Fatigue Strength Assessment" of this Guide 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.

1.5 Application

1.5.1 General

In view of the similarity of structural arrangements, this Guide has many cross-references to the general requirements for hull construction in Part 3 of the Rules and the particular requirements in Part 5C, Chapter 8 of the Rules for vessels intended to carry liquefied gases in bulk. These cross-references are presented in a simple format throughout the Guide in order to provide quick reference to the users, (i.e., 1-2-3/4.5.6 of the Rules denotes Part 1, Chapter 2, Section 3/Subparagraph 4.5.6 of the Rules).

1.5.2 Size and Proportion (1 May 2009)

The requirements contained in this Guide are applicable to liquefied gas carriers with independent tanks intended for unrestricted service, having lengths of 90 meters or more, and having parameters within the range as specified in 3-2-1/1 of the Rules.

1.5.3 Vessel Types (1 May 2009)

These requirements are intended to apply to steel vessels with machinery aft, engaged in the carriage of liquefied gases in independent tanks (Type A, Type B, and Type C) as defined in 5C-8-4/2.4.2 of the Rules. The technical requirements of the *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)* are also to be followed.

For Type A independent tanks, the scantling requirements and strength criteria in the Guide are considered equivalent to those in 5C-8-4/4.4 of the Rules.

For Type B independent tanks, the requirements in 5C-8-4/4.5 of the Rules with respect to crack propagation and fatigue failure are to be additionally verified. The scantling requirements and strength criteria in the Guide are considered equivalent to the remaining requirements in 5C-8-4/4.5 of the Rules.

For Type C independent tanks (pressure vessels), the scantling requirements and strength criteria in 5C-8-4/4.6 of the Rules are to be verified. The strength criteria in the Guide are considered equivalent to the remaining requirements in 5C-8-4/4.6 of the Rules.

1.5.4 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.

1.5.5 SafeHull Construction Monitoring Program

A Construction Monitoring Plan for critical areas, prepared in accordance with the requirements of 5C-A1 of the Rules, is to be submitted for approval prior to commencement of fabrication. See Part 5C, Appendix 1, “[SafeHull Construction Monitoring Program](#)” of the Rules.

1.7 Internal Members

1.7.1 Section Properties of Structural Members (1 May 2009)

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 of the Rules or Section 5, Figure 3, as applicable). For structural members with angle θ (see Section 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” ($\theta = 90$ 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 Section 1, Figure 1).

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

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

where

$$\alpha_{\theta} = 1.45 - 40.5/\theta$$

$$SM_{90} = \text{the section modulus at } \theta = 90 \text{ degrees}$$

Effective section area may be obtained by the following equation:

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

where

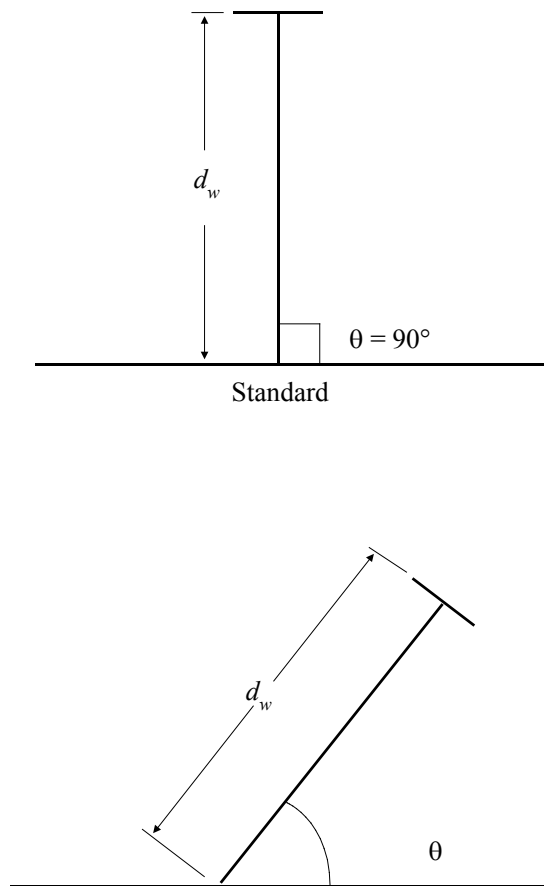
$$A_{90} = \text{effective shear area at } \theta = 90 \text{ degrees}$$

1.7.2 Detailed Design (1 May 2009)

The detailed design of internals is to follow the guidance given in 3-1-2/15 of the Rules and in 5/1.3 of this Guide.

See also Appendix 3, “Rule-based Fatigue Strength Assessment”.

FIGURE 1



1.9 Breaks

Special care is to be taken to provide structural reinforcements against local stresses at the ends of the cargo tank spaces, superstructures, etc., and throughout the structure in general. The main longitudinal bulkheads are to be suitably tapered at their ends. Where effective longitudinal bulkheads are provided in the poop or deckhouse, they are to be located such as to provide effective continuity between the structure in way of and beyond the main cargo spaces.

1.11 Variations (1 May 2009)

Liquefied gas carriers with independent tanks of a special type or design, differing from those described in this Guide, will be specially considered on the basis of equivalent strength.

1.13 Loading Guidance

Loading guidance is to be as required by 3-2-1/7 of the Rules.

1.15 Design Vapor Pressure

The design vapor pressure p_o as defined in 5C-8-4/2.6 of the Rules should not exceed 0.7 bar (0.714 kgf/cm²).

1.17 Protection of Structure

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

1.19 Aluminum Paint

Paint containing aluminum is not to be used in cargo tanks, 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.

1.21 Containment System

Secondary barrier, insulation, materials, construction and testing of the cargo containment system are to comply with the applicable requirements in Section 5C-8-4 of the Rules.

1.23 Determination of Temperature Distribution for Material Selection (1 May 2009)

The temperature distribution in the hull and cargo tank structures is to be determined based on the design ambient and cargo temperatures. Section 1, Table 1 summarizes the design ambient temperatures that are to be commonly used in the temperature distribution calculation. For vessels trading in other cold regions, the design ambient temperatures are to be specially considered.

TABLE 1
Design Ambient Temperatures (1 May 2009)

	<i>Air</i>	<i>Still Sea Water</i>
IMO IGC World-wide Services (5C-8-4/8.1)	5°C at 0 knots	0°C
USCG Requirements for US Waters except Alaskan Waters (Appendix 5C-8-A2)	–18°C at 5 knots	0°C
USCG Requirements for Alaskan Waters (Appendix 5C-8-A2)	–29°C at 5 knots	–2°C

The design temperature for cargo tanks is the minimum temperature at which cargo may be loaded or transported. The boiling temperatures and corresponding densities are listed in Section 1, Table 2 for some common liquefied gas cargoes.

TABLE 2
Cargo Properties of Common Liquefied Gas Cargoes (1 May 2009)

<i>Cargo</i>	<i>Chemical Formula</i>	<i>Vapor Detection</i>	<i>Boiling Temperature (°C)</i>	<i>Density (kg/m³)</i>
Acetaldehyde	CH ₃ CHO	F + T	+20.8	780
Ammonia, Anhydrous	NH ₃	T	-33.4	680
Butadiene 1.3 (inhibited)	CH ₂ CHCHCH ₂	F + T	-4.5	650
Butane, also called N-Butane	C ₄ H ₁₀	F	-0.5	600
Butane/Propane mixtures		F		630
Butylenes		F	-6.3	630
Chlorine	Cl ₂	T	-34	1560
Diethyl Ether	C ₂ H ₅ O C ₂ H ₅	F + T	34.6	640
Dimethylamine	(CH ₃) ₂ NH	F + T	6.9	670
Ethane	C ₂ H ₆	F + T	-88	550
Ethyl Chloride	CH ₃ CH ₂ Cl	F + T	12.4	920
Ethylene	C ₂ H ₄	F	-104	560
Ethylene Oxide	(CH ₂) ₂ O	F + T	11	870
Ethylene Oxide/Propylene Oxide Mixture With Ethylene Oxide content of not more than 30% by weight	(CH ₂) ₂ O ₂ + CH ₃ CHOCH ₂	F + T	27	830
Isoprene (inhibited)	CH ₂ C(CH ₃)CHCH ₂	F	34.0	680
Isopropylamine	(CH ₃) ₂ CH N H ₂	F + T	33.0	670
Methane (LNG)	CH ₄	F	-163	420
Methyl Acetylene – Propadiene mixture		F		620
Methyl Bromide	CH ₃ Br	F + T	4	1730
Methyl Chloride	CH ₃ Cl	F + T	-24.0	970
Monoethylamine	C ₂ H ₃ NH ₂	F + T	16.6	690
Nitrogen	N ₂	O	-196	808
Pentanes (all Isomers)	CH ₃ (CH ₂) ₃ CH ₃	F	29 to 36	626
Pentene (all Isomers)	CH ₃ CH ₂ CH ₂ CH=CH ₂	F	30 to 37	656
Propane	C ₃ H ₈	F	-42.3	590
Propylene	C ₃ H ₆	F	-47.7	610
Propylene Oxide	CH ₃ CHOCH ₂	F + T	+33.9	822
Refrigerant gases			3.6 to -81.4	1410 to 1526
Sulphur Dioxide	SO ₂	T	-10	1460
Vinyl Chloride Monomer (VCM)	CH ₂ CHCl	F + T	-13.9	970
Vinyl Ethyl Ether	CH ₂ -CHOC ₂ H ₅	F + T	35.5	750
Vinylidene Chloride	C ₂ H ₂ -CCl ₂	F + T	31.7	1250

Note: F – flammable vapor detection

T – toxic vapor detection

The design temperature for cargo piping, cargo process pressure vessels and all associated equipment is the minimum temperature in the systems and components during the cargo operations.

The design temperature for a complete or partial secondary barrier is to be assumed to be the cargo temperature at atmospheric pressure.

For the purpose of determining the temperatures of the internal hull structural members beyond the cargo block, the ambient air temperature in the forebody and engine room spaces may be assumed to be 5°C.

The minimum temperature of the hull structure, tank supports and chocks is to be determined by direct temperature calculations, taking into account the efficiency of any insulation and means of heating if accepted according to 5C-8-4/8.

In absence of direct temperature calculations and for the purposes of material grade selection, the typical internal structural members (excluding tank supports and chocks) in liquefied gas carriers with Type A independent tanks may be determined with the following assumptions:

- The design temperature for the stiffeners is to be the same as that of the attached plating.
- The design temperature for the main supporting members without or away from large openings is to be taken as the average design temperature of the two adjoining plates.
- The design temperature for the main supporting members within large openings is to be the same as that of the attached plating.
- The extent of the low temperature steel for deck plating between the two upper wing tanks is to be based on the 30-degree static heel condition.
- The low temperature steel for the longitudinally continuous plating such as deck, inner bottom, and inner longitudinal bulkheads is to be extended 400 mm beyond the required position of the secondary barrier. The plating adjoining the low temperature steel is to be of E or DH Grade. The extent of such material grade need not be more than 400 mm.

SECTION 2 Design Considerations and General Requirements

1 General Requirements

1.1 General

The proposed scantlings are to comply with the requirements specified in this Guide. Owner's extra scantlings (i.e., Owner's specified additional thickness), as included in the vessel's design specifications, are not to be used in the evaluation. The requirements in this Guide are based on the gross scantling approach.

The requirements related to Type A independent cargo tanks apply only to where non-corrosive cargoes are carried. If corrosive cargoes are carried in these tanks, the scantlings are to be suitably increased or an effective method of corrosion control is to be adopted.

1.3 Initial Scantling Requirements

The initial thickness of plating, the section modulus of longitudinals/stiffeners, and the scantlings of main supporting structures are to be determined in accordance with Section 5. The scantlings that comply with the requirements in Section 5 are to be used for further assessment as required in the following paragraph.

1.5 Strength Assessment – Failure Modes

A total strength assessment of the structures, determined on the basis of the initial strength criteria in Section 5 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 Subsection 6/5 for the applicable load cases specified in Subsection 4/3.

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 Subsection 6/7 for the applicable load cases specified in Subsection 4/3.

1.5.3 Fatigue

The fatigue strength of structural details and welded joints in highly stressed regions, is to be analyzed in accordance with Subsection 6/9 for the applicable load cases specified in Subsection 4/5.

1.7 Structural Redundancy and Residual Strength (1 May 2009)

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

The hull structure is to be in compliance with the hull girder ultimate strength requirements specified in 6/7.7.

SECTION 3 Dynamic Load Criteria

1 General

For strength assessment against the yielding and buckling failure modes, the dynamic load criteria represent the long-term extreme values for the North Atlantic, corresponding to a probability of exceedance of 10^{-8} . For vessels serving in more severe seas, the dynamic load criteria are to be modified. These dynamic load criteria have an implied ship speed of zero knots in extreme sea conditions with exception of the impact load criteria. The ship speed used to calculate bow wave impact, bow flare slamming, flat bottom slamming, green water and cargo sloshing is to be taken as 75% of the design speed (MCR).

For strength assessment against the fatigue failure mode, the dynamic load criteria represent the characteristic values for the North Atlantic, corresponding to a probability of exceedance of 10^{-4} . These dynamic load criteria have an implied ship speed equal to 75% of the design speed (MCR).

The following dynamic load components are to be considered in the structural evaluation of the hull, cargo tanks, tank supports and chocks:

- Vertical and horizontal wave-induced bending moments
- Vertical and horizontal wave-induced shear forces
- External pressure
- Internal pressure
- Bow wave impact
- Bow flare slamming for forebody structures
- Bottom slamming for forebody structures
- Green water
- Sloshing loads
- Thermal loads
- Loads corresponding to ship deflection

The load combination factors for the dynamic load components and dominant parameters are included in the load formulae in this Section, but their actual values are specified in Section 4.

3 Definitions

3.1 Symbols

B	molded breadth, in m
C_b	block coefficient at the scantling draft
D	molded depth, in m
d_f	scantling draft, in m
GM	metacentric height, in m
L	scantling length, in m

L_{BP}	length between perpendiculars, in m
V	service speed, in knots
V_d	design speed (MCR), in knots

3.3 Coordinate Systems

Two sets of Cartesian coordinate systems are used to describe dynamic load criteria. When alternative coordinate systems are used, attention is to be paid to the default coordinate systems used in the dynamic load formulae.

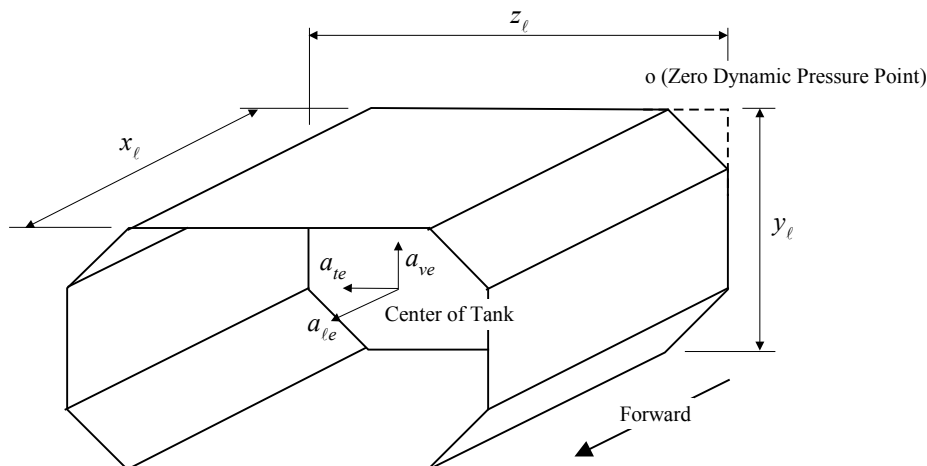
3.3.1 Ship Coordinate System for Ship Motion and External Pressure

Origin	Intersection of the AP section, waterline and centerline planes.
x_T	Longitudinal distance from the AP to the center of the tank, in m, positive toward the bow.
y_T	Vertical distance from the waterline to the center of the tank, in m, positive above and negative below the waterline.
z_T	Transverse distance from the centerline to the center of the tank, in m, positive toward starboard.
x	Longitudinal distance from the AP to the external pressure point considered, in m.
x_o	Longitudinal distance from the AP to the reference station, in m. The reference station is the point along the vessel's length where the wave trough or crest is located and may be taken at the mid-length of the considered tank.

3.3.2 Tank Coordinate System for Internal Pressure

Origin	Intersection of the vertical, horizontal, and transverse planes that are tangential to the envelope of the tank. This origin is also referred to as the zero dynamic pressure point. For example, the zero dynamic pressure point in Section 3, Figure 1 is located at the upper corner of the aft transverse bulkhead on the port side, and the forward portion of the tank on the starboard side is under high dynamic pressure and is targeted for strength assessment.
x_ℓ	Longitudinal distance from the zero dynamic pressure point of the tank to the pressure point, in m, positive toward bow for a fore cargo tank structure.
y_ℓ	Vertical distance from the zero dynamic pressure point of the tank to the pressure point, in m, positive downward.
z_ℓ	Transverse distance from the zero dynamic pressure point of the tank to the pressure point, in m, positive toward starboard.
a_{le}	Dimensionless longitudinal acceleration, positive forward
a_{te}	Dimensionless transverse acceleration, positive starboard
a_{ve}	Dimensionless vertical acceleration, positive upward

FIGURE 1
Tank Coordinate System for Internal Pressure



5 Vertical Wave-induced Bending Moment

The vertical wave-induced bending moment, in tf-m, may be obtained from the following equations:

$$M_{ws} = -11.22 k_p k_{cmv} k_s m_v C_1 L^2 B (C_b + 0.7) \times 10^{-3} \quad \text{Sagging Moment}$$

$$M_{wh} = +19.37 k_p k_{cmv} k_s m_v C_1 L^2 B C_b \times 10^{-3} \quad \text{Hogging Moment}$$

where

$$\begin{aligned} C_1 &= 10.75 - \left(\frac{300 - L}{100} \right)^{1.5} & 90 \leq L < 300 \\ &= 10.75 & 300 \leq L < 350 \\ &= 10.75 - \left(\frac{L - 350}{150} \right)^{1.5} & 350 \leq L < 500 \end{aligned}$$

k_{cmv} = load combination factor for design vertical wave-induced bending moment

k_p = load factor for adjusting the probability of exceedance

= 1.0 for yielding and buckling strength assessment

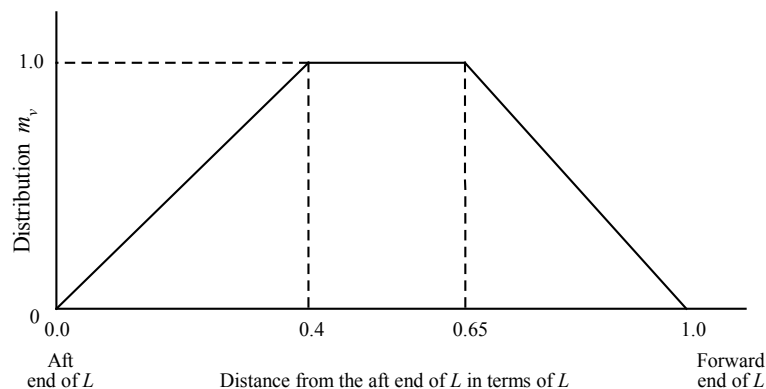
= 0.5 for fatigue strength assessment

k_s = 1.0 for yielding and buckling strength assessment

= $(1.09 + 0.029V - 0.47C_b)^{0.5}$ for fatigue strength assessment

m_v = distribution factor for vertical wave-induced bending moment (see Section 3, Figure 2)

FIGURE 2
Distribution Factor for Vertical Wave-induced Bending Moment m_v



7 Horizontal Wave-induced Bending Moment

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

$$M_h = \pm 85.656 k_p k_s k_{cmh} m_h C_1 L^2 D(C_b + 0.7) \times 10^{-4}$$

where

k_{cmh} = load combination factor for design horizontal wave-induced bending moment

k_p = load factor for adjusting the probability of exceedance

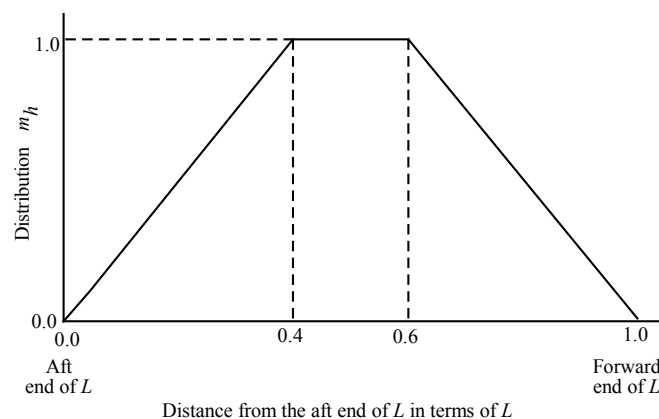
= 1.0 for yielding and buckling strength assessment

= 0.5 for fatigue strength assessment

m_h = distribution factor for horizontal wave-induced bending moment (see Section 3, Figure 3)

C_1 and k_s are as given in Subsection 3/5.

FIGURE 3
Distribution Factor for Horizontal Wave-induced Bending Moment m_h



9 External Pressure

The external pressure, p_e , positive toward inboard, in kgf/cm^2 , with waves approaching the hull from the starboard side can be expressed by the following equation at a given cross section:

$$p_e = \rho(h_s + 1.36 k_p k_s k_{ce} k_d \alpha C_1) \times 10^{-4} \geq 0$$

where

$$\begin{aligned} \alpha &= 0.75 - 1.25 \sin \mu && \text{waterline, port} \\ &= 0.2 - 0.4 \sin \mu + 0.1 \cos \mu && \text{bilge, port} \\ &= 0.3 - 0.2 \sin \mu && \text{centerline, bottom} \\ &= 0.4 - 0.1 \cos \mu && \text{bilge, starboard} \\ &= 1.0 - 0.25 \cos \mu && \text{waterline, starboard} \end{aligned}$$

$$k_d = \left\{ 1 - \left[1 - \cos \frac{2\pi(x - x_o)}{L} \right] \cos \mu \right\} [1 + (k_{\ell o} - 1) \cos \mu]$$

$$\mu = \text{wave heading angle, to be taken from } 0^\circ \text{ to } 90^\circ \text{ (} 0^\circ \text{ for head sea, } 90^\circ \text{ for beam sea, waves approaching the hull from the starboard side)}$$

$$h_s = \text{hydrostatic pressure head in still water, in m}$$

$$k_{ce} = \text{load combination factor for external pressure}$$

$$k_p = \text{load factor for adjusting the probability of exceedance}$$

$$= 1.0 \quad \text{for yielding and buckling strength assessment}$$

$$= 0.5 \quad \text{for fatigue strength assessment}$$

$$\rho = \text{specific weight of sea water in kgf/m}^3$$

C_1 and k_s are as given in Subsection 3/5 and the pressure distribution factor, $k_{\ell o}$, may be taken from Section 3, Table 1 or Section 3, Figure 4. A negative combination factor, k_{ce} , signifies that the wave trough is on the starboard side.

FIGURE 4
Pressure Distribution Function $k_{\ell o}$

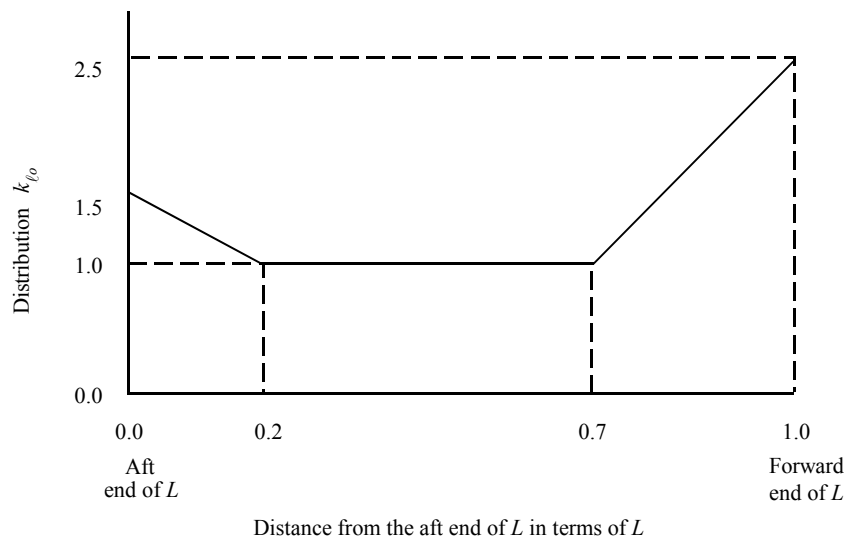


TABLE 1
 $k_{\ell o}$ Coefficient

$[x_o - (L_{BP} - L)]/L$	$k_{\ell o}$	$[x_o - (L_{BP} - L)]/L$	$k_{\ell o}$	$[x_o - (L_{BP} - L)]/L$	$k_{\ell o}$
0.000	1.500	0.175	1.063	0.850	1.750
0.025	1.438	0.200 ~ 0.700	1.000	0.875	1.875
0.050	1.375	0.725	1.125	0.900	2.000
0.075	1.313	0.750	1.250	0.925	2.125
0.100	1.250	0.775	1.375	0.950	2.250
0.125	1.188	0.800	1.500	0.975	2.375
0.150	1.125	0.825	1.625	1.000	2.500

The external pressure may be calculated for the reference section at x_o and the pressure variation over the length of the global finite element model may be ignored. The reference section may be taken at the mid-length of the targeted cargo tank. However, the pressure variation along the girth of the reference section is to be accounted for and can be represented by the pressure values at the following five points, as shown in Section 3, Figure 5:-

- E1 waterline, port
- E2 bilge, port
- E3 centerline, bottom
- E4 bilge, starboard
- E5 waterline, starboard

A positive dynamic pressure may be assumed to vary linearly above the waterline at E1 on the port side, as illustrated in Section 3, Figure 5. The zero pressure point is defined by h_1 , which is equal to the dynamic pressure head or freeboard, whichever is less.

When a negative dynamic pressure is found, for example, at the waterline at E5 on the starboard side in Section 3, Figure 5, the zero pressure point can be defined by h_2 , which can be calculated as follows:

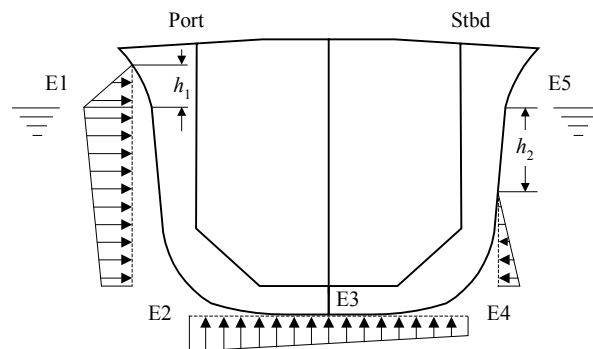
$$h_2 = d_m \frac{p_{E5}}{p_{E5} - p_{E4}}$$

The negative pressure above the zero pressure point is ignored.

The external pressure on the bottom shell plating linearly varies from pressure, p_{E2} (bilge, port), to pressure, p_{E4} (bilge, starboard). d_m is the draft the mid-length of the targeted cargo tank for a specific loading condition, in m.

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.

FIGURE 5
External Pressure Calculation Points



11 Internal Pressure

11.1 Accelerations

The accelerations acting on tanks are estimated at their center of gravity. a_{le} , a_{te} and a_{ve} are the maximum dimensionless accelerations (i.e., relative to the acceleration of gravity) in the longitudinal, transverse and vertical directions, respectively and they are considered as acting separately for calculation purposes. a_{ve} does not include the component due to the static weight, a_{te} includes the component due to the static weight in the transverse direction due to rolling and a_{le} includes the component due to the static weight in the longitudinal direction due to pitching. The following formulae are given as guidance for the components of acceleration due to ship's motions in the North Atlantic.

Vertical acceleration:

$$a_{ve} = \pm a_o \sqrt{1 + \left(5.3 - \frac{45}{L}\right)^2 \left(\frac{x'_T}{L} - 0.45\right)^2 \left(\frac{0.6}{C_b}\right)^{1.5}}$$

Transverse acceleration:

$$a_{te} = \pm a_o \sqrt{0.6 + 2.5 \left(\frac{x'_T}{L} - 0.45\right)^2 + K \left(1 + 0.6K \frac{y_T}{B}\right)^2}$$

Longitudinal acceleration:

$$a_{le} = \pm a_o \sqrt{0.06 + A^2 - 0.25A}$$

with

$$A = \left(0.7 - \frac{L}{1200} + 5 \frac{y_T}{L}\right) \left(\frac{0.6}{C_b}\right)$$

where

$$a_o = k_p \left[0.2 \left(\frac{V}{\sqrt{L}} \right) + \frac{(34 - 600/L)}{L} \right]$$

- k_p = load factor for adjusting the probability of exceedance
- = 1.0 for yielding and buckling strength assessment
- = 0.5 for fatigue strength assessment

$$x'_T = x_T - (L_{BP} - L)$$

K = 1.0 in general. For particular loading conditions and hull forms, determination of K according to the formula below may be necessary:

$$= 13GM/B, \text{ where } K \geq 1.0.$$

GM = metacentric height, in m

V = 10 knots for yielding and buckling strength assessment

Note: The accelerations calculated from the recommended formula in IGC Code at 10 knots are considered representative of the ship's actual accelerations in extreme sea conditions.

$$= 75\% \text{ of the design speed for fatigue strength assessment}$$

11.3 Internal Pressure for Initial Scantling Evaluation

To determine the inertial forces and added pressure heads for a completely filled cargo tank, the dominating ship motion parameters induced by waves are to be calculated. The internal pressure p_{eq} resulting from the design vapor pressure p_o and the liquid pressure p_{gd} , but not including effects of liquid sloshing, is to be calculated as follows:

$$p_{eq} = p_o + p_{gd}$$

The internal liquid pressures are those created by the resulting acceleration of the center of gravity of the cargo due to the motions of the ship. The value of internal liquid pressure p_{gd} resulting from combined effects of gravity and dynamic accelerations is to be calculated as follows:

$$p_{gd} = \rho a_{\beta} Z_{\beta} 10^{-4}$$

Note: For initial scantling evaluation, the cargo tank pressure is to be determined based on the full load condition corresponding to the scantling draft.

where

ρ = specific weight of ballast or cargo in kgf/m³

a_{β} = dimensionless acceleration (i.e., relative to the acceleration of gravity), resulting from gravitational and dynamic loads, in an arbitrary direction β (see Section 3, Figure 6)

Z_{β} = largest liquid height (m) above the point where the pressure is to be determined, measured from the tank shell in the β direction (see Section 3, Figure 7)

Tank domes considered to be part of the accepted total tank volume should be taken into account when determining Z_{β} unless the total volume of tank domes V_{dom} does not exceed the following value:

$$V_{dom} = V_{tank} \left(\frac{100 - FL}{FL} \right)$$

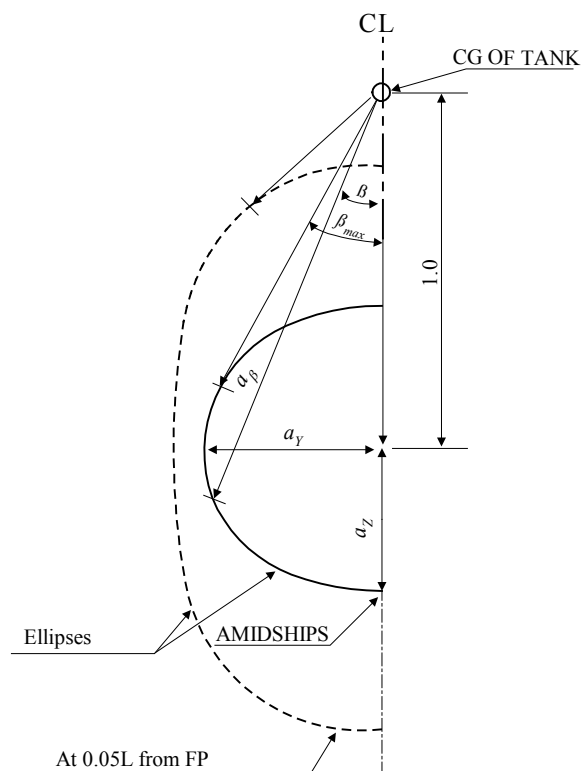
where

V_{tank} = tank volume without any domes

FL = filling limit according to Section 5C-8-15 of the Rules

The direction which gives the maximum value $(p_{gd})_{max}$ of p_{gd} is to be considered for the scantling requirements of plating and stiffeners of cargo tank boundaries. Where acceleration components in three directions need to be considered, an ellipsoid is to be used instead of the ellipse in Section 3, Figure 6. The above formula applies only to full tanks.

FIGURE 6
Acceleration Ellipse

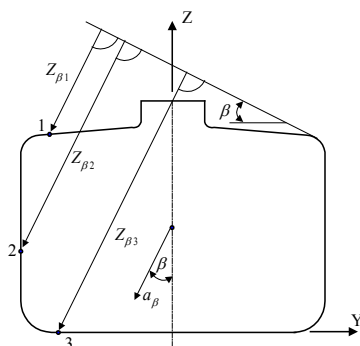


a_{β} = resulting acceleration (static and dynamic) in arbitrary direction β

a_y = transverse component of acceleration

a_z = vertical component of acceleration

FIGURE 7
Determination of Internal Pressure Heads



Note: Small tank domes not considered to be part of the accepted total volume of the cargo tank need not be considered when determining Z_{β} .

11.5 Internal Pressure Formula for Strength Assessment

For finite element strength assessment, the internal pressure acting on cargo and ballast tanks corresponds to the instantaneous value when one dominant load parameter attains its maximum value. The internal pressure, p_i , positive toward outboard, for a completely filled tank, in kgf/cm^2 , may be obtained from the following formula:

$$p_i = \rho[(k_{cl}a_{le}x_\ell + k_{ct}a_{te}z_\ell + k_{cv}a_{ve}y_\ell) + y_\ell] \times 10^{-4} + p_o$$

where

- k_{cl} = load combination factor for effective longitudinal acceleration
- k_{ct} = load combination factor for effective transverse acceleration
- k_{cv} = load combination factor for effective vertical acceleration
- ρ = specific weight of ballast or cargo in kgf/m^3 ; for ballast water, 1025 kgf/m^3 is to be used.

For a ballast tank, the design vapor pressure p_o is to be taken as the static pressure head corresponding to two thirds of the distance from the top of the tank to the top of the overflow.

13 Impact Loads

13.1 Impact Loads on Bow

When experimental data or direct calculations are not available, the nominal wave-induced bow pressure in kgf/cm^2 above the water line (*LWL*) in the region from the forward end to the collision bulkhead may be obtained from the following equation:

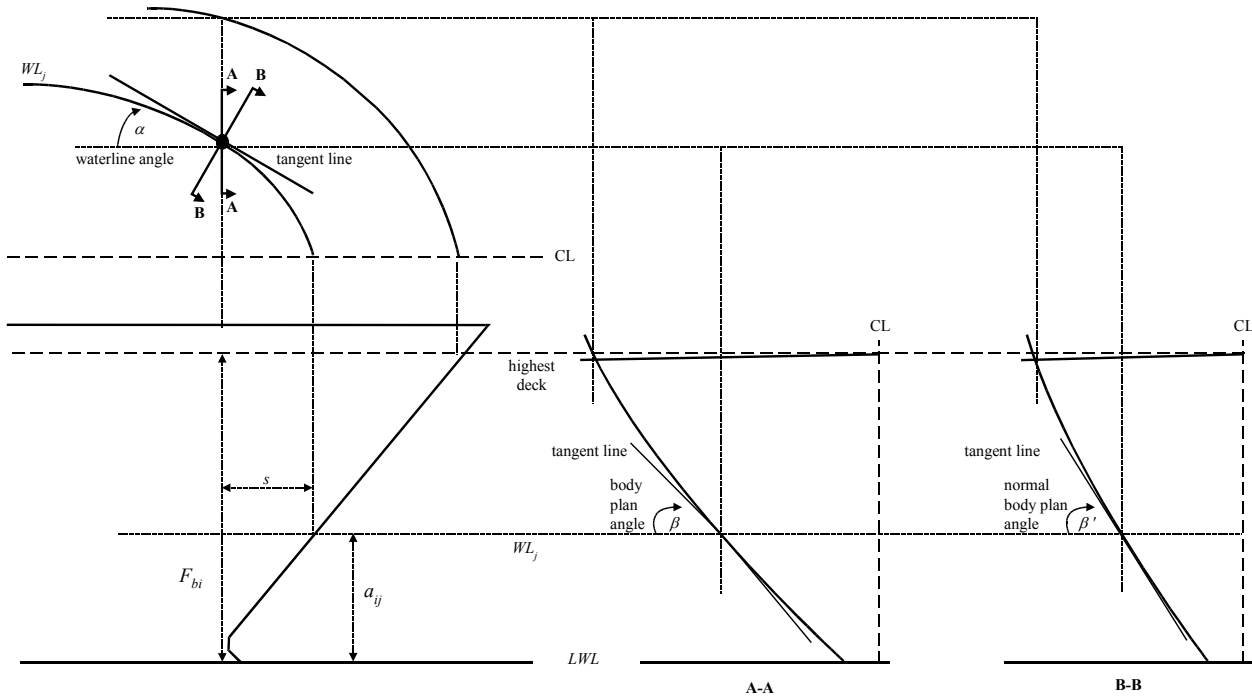
$$P_{bij} = 0.01045 C_k \left\{ 1 + \cos^2 \left[\frac{\pi}{2} \left(\frac{F_{bi} - 2a_{ij}}{F_{bi}} \right) \right] \right\}^{1/2} (0.515 V \sin \alpha_{ij} + L^{1/2})^2 \sin \gamma_{ij}$$

where

- V = 75% of the design speed, V_d , in knots. V is not to be 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 measured from the centerline, see Section 3, Figure 8, not to be taken less than 35°
- β_{ij} = local body plan angle measure from the horizontal, see Section 3, Figure 8, not to be taken less than 35°
- F_{bi} = freeboard from the highest deck at side to the *LWL* at station i , see Section 3, Figure 8
- a_{ij} = vertical distance from the *LWL* to *WL_p*, see Section 3, Figure 8
- 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 at the pressure calculation point.

To assess the strength of the plating and stiffeners, a load factor of 1.1 is to be applied to the nominal pressure given above. To assess the strength of the main supporting members, a load factor of 0.71 is to be applied to the nominal pressure given above.

FIGURE 8
Definition of Bow Geometry (1 May 2009)



13.3 Bottom Slamming Pressure (1 May 2009)

For a liquefied gas carrier with the heavy weather ballast draft forward less than $0.04L$, bottom slamming is to be considered in the strength assessment of the flat of bottom plating forward and the associated stiffening system in the forebody region. The equivalent bottom slamming pressure for the i -th section, in kgf/cm^2 , may be determined by the following equations:

$$p_{si} = 0.418k_i\omega L^{1/2} (0.0841L + B_i M_{Ri} E_{ni}) \times 10^{-4}$$

where

$$k_i = 2.2b_i^*/d_{oi} + \alpha \leq 40$$

$$\omega = \text{natural angular frequency of hull girder 2-node vertical vibration in the wet mode and the heavy weather ballast draft condition, in rad/second}$$

$$= 7475 \left\{ \frac{BD^3}{\Delta_b C_b^3 L^3 [1.2 + B/(3d_b)]} \right\}^{1/2} + 1.0 \geq 3.7$$

$$M_{Ri} = 0.44A_i(VL/C_b)^{1/2}$$

$$E_{ni} = 8.653 + 0.5 \ln B_i - (0.0841L/B_i + d_i^2)/M_{Ri} \quad \text{if } E_{ni} < 0, p_{si} = 0$$

$$V = 75\% \text{ of the design speed, } V_d, \text{ in knots. } V \text{ is not to be taken less than 10 knots.}$$

$$\Delta_b = \text{vessel's displacement in the heavy ballast condition, in tf}$$

$$b_i = \text{half breadth at the } 1/10 \text{ draft of the } i\text{-th section in the heavy ballast condition, in m}$$

$$b_i^* = \text{half width of flat of bottom at the } i\text{-th section, in m}$$

$$d_b = \text{draft amidships in the heavy ballast condition, in m}$$

d_i = draft at the i -th section in the heavy ballast condition, in m

d_{oi} = $1/10$ of the section draft of the i -th section in the heavy ballast condition, in m

α , A_i and B_i are as given in Section 3, Tables 2 and 3.

To assess the strength of the plating and stiffeners, a load factor of 1.1 is to be applied to the nominal pressure given above.

To assess the strength of the double bottom floors and girders, the nominal pressure uniformly distributed over the flat bottom of the foremost cargo tank may be taken as:

$$p_{nslam} = (1.185 \times 10^{-3} L + 0.485) \frac{\sum_{i=1}^N b_i^* s_i p_{si}}{\sum_{i=1}^N b_i^* s_i}$$

where

N = number of floors in the double bottom of the fore cargo tank

p_{si} = bottom slamming pressure at the i -th section, in kgf/cm²

p_{nslam} = nominal slamming pressure for double bottom structure, in kgf/cm²

s_i = sum of one half of floor spacings on both sides of the i -th floor, in m

To assess the strength of the main supporting members, a load factor of 1.0 is to be applied to the nominal pressure given above.

TABLE 2
 α Coefficient

b_i/d_{oi}	α
1.00	0.00
1.50	9.00
2.00	11.75
2.50	14.25
3.00	16.50
3.50	18.50
4.00	20.25
5.00	22.00
6.00	23.75
7.00	24.50
7.50	24.75
25.0	24.75
Linear interpolation may be used for intermediate values.	

TABLE 3
 A_i and B_i Coefficients

Section Location	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.		

13.5 Bowflare Slamming (1 May 2009)

For vessels possessing bowflare and having a shape parameter A_r greater than 21 m, 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 = 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. Bowflare shape parameter A_{ri} is to be calculated for five stations

$$= \left(\frac{\sum_{j=1}^n b_j}{\sum_{j=1}^n s_j} \right)^2 \sum_{j=1}^n b_j \left[1 + \left(\frac{s_j}{b_j} \right)^2 \right]^{1/2}, j = 1 \dots n, n \geq 4$$

where

n = number of segments

b_j = local change (increase) in beam for the j -th segment at station i (see Section 3, Figure 9)

s_j = local change (increase) in freeboard up to the highest deck for the j -th segment at station i forward (see Section 3, Figure 9)

When experimental data or direct calculation is not available, the nominal bowflare slamming pressure in kgf/cm² may be determined by the following equations:

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

$$P_{oij} = 0.1(9M_{Ri} - h_{ij}^2)^{2/3}$$

$$P_{bij} = 0.01045k_3[39.2 + K_{ij}B_iM_{Ri}(1 + E_{ni})]$$

where

$$k_3 = 1 \quad \text{for } h_{ij} \leq h_b^*$$

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

$$= 2 \quad \text{for } h_{ij} \geq 2h_b^*$$

$$E_{ni} = 8.653 + 0.5 \ln B_i - h_{ij}^2/M_{Ri}, \quad \text{if } E_{ni} < 0, P_{bij} = 0$$

- $M_{Ri} = 0.44A_i(VL/C_b)^{1/2}$
 $V = 75\%$ of the design speed, V_d , in knots. V is not to be taken less than 10 knots.
 $C_b =$ as defined in 3/3.1 and not to be less than 0.6.
 $h_{ij} =$ vertical distance measured from the LWL at station i to the waterline 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
 $= 7.143 \times 10^{-3}(L - 230) + 3.5$ (m) for $230 \text{ m} \leq L < 300$ m
 $= 4.0$ (m) for $L \geq 300$ m
 $p_{bij}^* = p_{bi}^* \sqrt{\beta_i^* / \beta_{ij}^*}$
 $p_{bi}^* = P_{bij}$ 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
 $b_{ij} =$ local half beam of WL_j at station i
 $b_{i0} =$ load waterline half beam at station i
 $\ell_{ij} =$ longitudinal distance of WL_j at station i measured from amidships
 $f_{ij} = [90 / \beta_{ij}' - 1]^2 [\tan^2(\beta_{ij}') / 9.86] \cos \gamma$
 $\beta_{ij}' =$ normal local body plan angle, See Section 3, Figure 8
 $= \tan^{-1}[\tan(\beta_{ij}) / \cos(\alpha_{ij})]$
 $\alpha_{ij} =$ waterline angle as in Section 3, Figure 8
 $\beta_{ij} =$ local body plan angle measured from the horizontal, in degrees, as in Section 3, Figure 9
 $\beta_{ij}^* = \beta_{ij}'$ at h_b^* above LWL
 $\gamma =$ ship stem angle at the centerline measured from the horizontal, Section 3, Figure 10, in degrees, not to be taken greater than 75 degrees

A_i and B_i are as given in Section 3, Table 3.

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.

FIGURE 9
Definition of Bowflare Geometry for Bowflare Shape Parameter

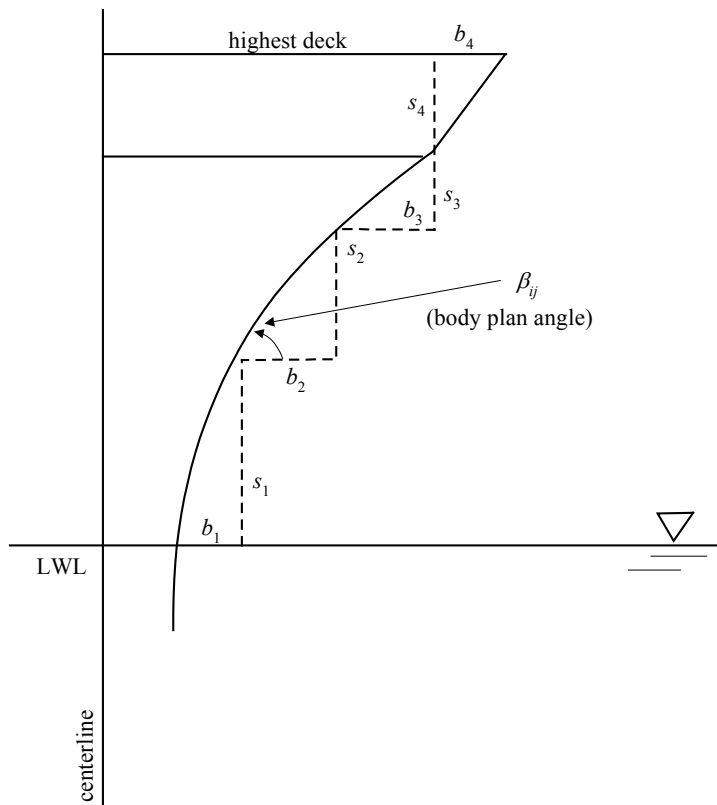
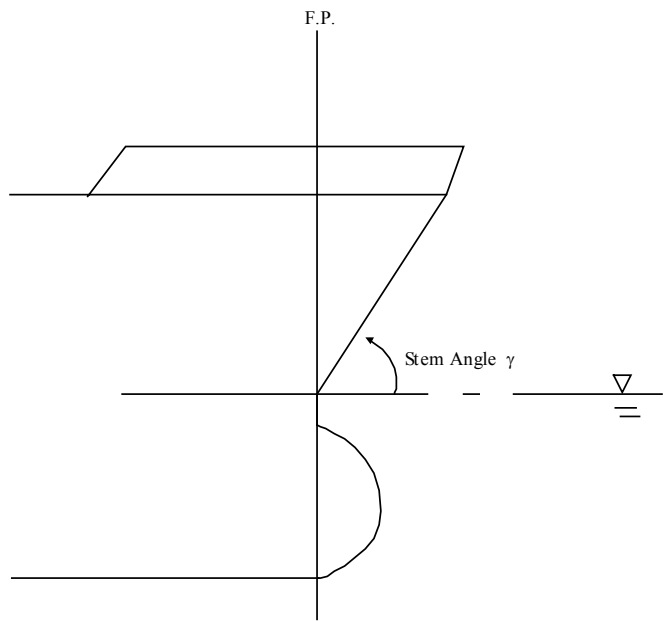


FIGURE 10
Ship Stem Angle, γ



13.7 Green Water

The nominal green water pressure imposed on the deck in the region from the FP to $0.25L$ aft, including the extension beyond the FP, may be calculated at the reference section:

$$p_{gi} = 0.2 \left[0.44 A_i \left(\frac{VL}{C_b} \right)^{1/2} - F_{bi} \right]^{1/2}, \text{ not to be less than } 0.21 \text{ kgf/cm}^2$$

where

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

F_{bi} = freeboard from the highest deck at side to the load waterline (LWL) at station i , see Section 3, Figure 8

A_i is given in Section 3, Table 3.

13.9 Sloshing Loads

Except for tanks that are situated wholly within the double side or double bottom, the natural periods of liquid motions are to be examined to assess the possibility of excessive liquid sloshing against boundary structures for all cargo tanks which will be partially filled between $0.5h_\ell$ (or $0.1h$, if lesser) and $0.9h$ (h_ℓ and h are as defined in Section 3, Figure 11). For each of the anticipated loading conditions, the “critical” filling levels of the tank are to 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. The natural periods of the fluid motions in the tank, for each of the anticipated filling levels, are to be at least 20% greater or smaller than that of the relevant ship’s motion.

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

$$T_x = (\ell)^{1/2}/k \text{ seconds in the longitudinal direction}$$

$$T_y = (b_f)^{1/2}/k \text{ seconds in the transverse direction}$$

where

ℓ = length of the tank, as defined in Section 3, Figure 11, in m

b_f = breadth of the liquid surface at d_o , as defined in Section 3, Figure 11, in m

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

$$H_1 = \pi d_o/\ell \text{ or } \pi d_o/b_f$$

d_o = filling depth, as defined in Section 3, Figure 11, in m

g = acceleration of gravity = 9.8 m/sec^2

The natural periods given below for pitch and roll of the vessel, T_p and T_r , using the actual draft and GM, if available, may be used for this purpose. In absence of these data, the vessel’s draft may be taken as $2/3d_f$.

The pitch natural period:

$$T_p = 3.5 \sqrt{C_b d_i} \text{ seconds}$$

where

d_i = draft amidships for the relevant loading conditions

The roll natural motion period:

$$T_r = 2 k_r / GM^{0.5} \text{ seconds}$$

where

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

GM = metacentric height, in m, to be taken as:

= GM (full) for full draft

= $1.5 GM$ (full) for $3/4 d_f$

= $2.0 GM$ (full) for $2/3 d_f$

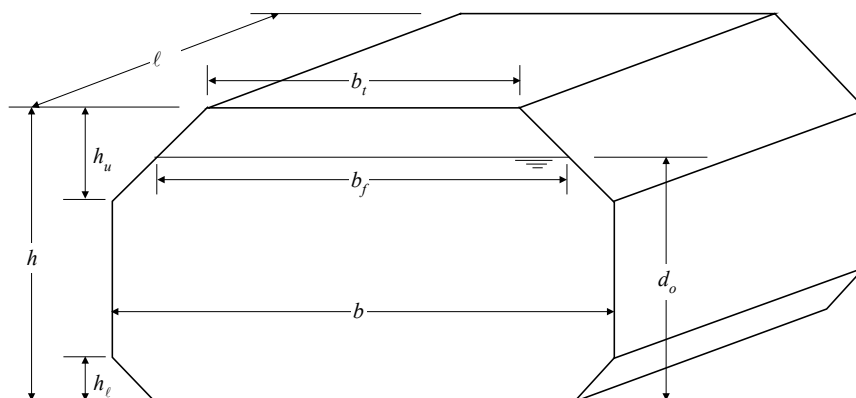
GM (full) = metacentric height for fully loaded condition

= $0.12B$ in case GM (full) is not available.

If the “critical” filling levels of the tank cannot be avoided, the tank is to have a non-tight bulkhead (i.e., swash bulkhead) to eliminate the possibility of resonance. The 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.

Alternatively, the tank boundary structures can also be designed to withstand liquid sloshing. The design sloshing pressures are to be explicitly considered in the scantling requirements of cargo tank plating and stiffeners. In addition, additional sloshing load cases are to be included in the structural analysis of the main supporting members of cargo tanks. Sloshing loads may also be determined by model experiments. Methodology and procedures of tests and measurements are to be fully documented and referenced. They are to be submitted for review by the Bureau.

FIGURE 11
Definition of Tank Geometry



15 Thermal Loads

Transient thermal loads during cooling down periods are to be considered for cargo tanks intended for cargo temperatures below -55°C .

Stationary thermal loads are to be considered for tanks where design supporting arrangement and operating temperature may give rise to significant thermal stresses.

SECTION 4 Standard Design Load Cases

1 Symbols

d_f	scantling draft, in m
d_{flood}	draft at the mid-tank for the flooded condition
d_b	ballast draft at the middle of foremost cargo tank, in m
D_f	imaginary freeboard depth, in m
k_{ce}	load combination factor for external pressure
k_{cl}	load combination factor for effective longitudinal acceleration
k_{cmh}	load combination factor for horizontal wave-induced bending moment
k_{cmv}	load combination factor for vertical wave-induced bending moment
k_{ct}	load combination factor for effective transverse acceleration
k_{cv}	load combination factor for effective vertical acceleration
μ	wave heading angle, to be taken from 0° to 90° (0° for head sea, 90° for beam sea, waves approaching the hull from the starboard side)

3 Standard Design Load Cases for Yielding and Buckling Strength Assessment (1 May 2009)

To assess the yielding and buckling strength of hull and cargo tank structures, the standard design load cases described in this Section are to be analyzed. These load cases can be categorized into the following groups:

- Dynamic sea load cases (LC1 ~ LC9 in Section 4, Table 1)
- Port condition load case (LC10 in Section 4, Table 2)
- Flooded load case for transverse bulkhead (LC11 in Section 4, Table 2)
- Accidental load cases for supports and chocks (LC12 ~ LC15 in Section 4, Table 2)

For forebody hull and cargo tank structures, a design load case for bottom slamming is also to be considered. Additional load cases may be required, as warranted.

Section 4, Figure 1 shows the direction of the inertia load due to acceleration. The loading patterns are shown in Section 4, Figure 2. For each dynamic sea load case (LC1 to LC9), the load combination factors are specified for individual dynamic load components and motion parameters in Section 4, Table 1. The waves approach the vessel from the starboard side. If the hull structure is unsymmetrical with respect to the vessel's centerline, additional load cases mirroring those of the unsymmetrical load cases in Section 4, Table 1 are to be analyzed. The dominant load parameter for each dynamic sea load case corresponds to a probability of exceedance of 10^{-8} , while the load combination factors for other load parameters represent phasing between all the load parameters.

The standard load cases in Section 4, Tables 1 and 2 are specified for the midship finite element model. The cargo tank within $0.4L$ amidships that experiences higher ship motion is to be targeted for the strength evaluation. For the forebody finite element model, tanks forward of the collision bulkhead may be assumed empty in the standard load cases. Likewise, for the aftbody finite element model, tanks aft the hull transverse bulkhead bordering the aftmost cargo tank may be assumed empty in the standard load cases.

5 Standard Design Load Cases for Fatigue Strength Assessment

To assess the critical details of the hull, cargo tanks and supporting structures, the accumulative fatigue damage may be calculated from the vessel operating in full cargo and ballast loading conditions. For each loading condition, eight dynamic sea load cases are to be analyzed to determine the stresses at critical details. These load cases are specified in Section 4, Tables 3 and 4. The stress ranges to be used for the accumulative fatigue damage are to be calculated from the following four pairs of the load cases:-

- Load Cases 1 and 2 for maximum vertical bending moment range
- Load Cases 3 and 4 for maximum local pressure range
- Load Cases 5 and 6 for maximum transverse acceleration range
- Load Cases 7 and 8 for maximum horizontal bending moment range.

The dominant load parameter for each dynamic sea load case corresponds to a probability of exceedance of 10^{-4} , while the load combination factors for other load parameters represent phasing between all the load parameters.

The standard load cases in Section 4, Tables 3 and 4 are specified for the midship finite element model. For the forebody finite element model, tanks forward of the collision bulkhead may be assumed empty in the standard load cases. Likewise, for the aftbody finite element model, tanks aft the hull transverse bulkhead bordering the aftmost cargo tank may be assumed empty in the standard load cases.

TABLE 1
Standard Design Load Cases for Yielding and Buckling Strength Assessment (1 May 2009)
 (Load Combination Factors for Dynamic Load Components)

	<i>LC1</i>	<i>LC2</i>	<i>LC3</i>	<i>LC4</i>	<i>LC5</i>	<i>LC6</i>	<i>LC7</i>	<i>LC8</i>	<i>LC9</i>
<i>Dominant Load Parameter</i>	maximum sagging BM	maximum hogging BM	maximum internal pressure	maximum external pressure	maximum internal pressure	maximum horizontal BM	maximum horizontal BM	maximum internal pressure	flat bottom slamming
<i>Wave Heading (μ)</i>	0° head	0° head	0° head	0° head	90° beam	60° oblique	60° oblique	0° head	0° head
<i>Draft (d_m)</i>	d_f	d_f	d_f	d_f	$3/4d_f$	$3/4d_f$	d_f	d_b	d_b
<i>External Pressure k_{ce}</i>	−0.50	0.50	−0.50	1.00	1.00	−0.50	1.00	−0.50	N/A
<i>Longitudinal Acceleration k_{cl}</i>	0.00	0.00	0.00	0.60	0.00	−0.40	0.40	0.00	0.00
<i>Vertical Acceleration k_{cv}</i>	0.50	−0.50	1.00	−0.80	−0.60	0.60	−0.60	1.00	−0.50
<i>Transverse Acceleration k_{ct}</i>	N/A	N/A	N/A	N/A	0.80	−0.70	0.70	N/A	N/A
<i>Vertical BM k_{cmv}</i>	1.00 sagging	1.00 hogging	0.70 sagging	0.70 hogging	0.30 hogging	0.30 sagging	0.30 hogging	0.70 sagging	N/A
<i>Horizontal BM k_{cmh}</i>	N/A	N/A	N/A	N/A	0.225 port (+)	0.75 port (−)	1.00 port (+)	N/A	N/A
<i>Frictional Coefficient</i>	N/A	N/A	N/A	N/A	0.10	0.10	N/A	N/A	N/A

Notes

- 1 LC 9 is the bottom slamming load case and only applicable to forebody hull and cargo tank structures.
- 2 port (+) and port (−) represents the port side of the hull structure is in tension and compression, respectively.
- 3 The frictional coefficient in Section 4, Table 1 for LC5 and LC6 is the representative value for the global finite element model. For the fine mesh finite element models representing individual supports or chocks, the frictional coefficient is to be taken as 0.3. Alternatively, the frictional coefficient may be determined from the measurement. The details of the support bearing materials, measurement procedure and measurement data are to be submitted for ABS review.
- 4 (1 May 2009) In LC5 and LC6, the load combination factor for horizontal bending moment is adjusted for the lower draft.
- 5 (1 May 2009) Liquefied gas carriers in cargo loaded conditions are typically subject to hogging still water bending moments. The minimum hogging still water bending moment of all the cargo loaded conditions is to be applied to LC 1, 3 and 6. However, the total bending moment used for these load cases are not to be less than 80% of the design sagging wave bending moment.

TABLE 2
Standard Design Load Cases for Yielding and Buckling Strength Assessment (1 May 2009)
 (Load Combination Factors for Port and Accidental Load Cases)

	<i>LC10</i>	<i>LC11</i>	<i>LC12</i>	<i>LC13</i>	<i>LC14</i>	<i>LC15</i>
<i>Dominant Load Parameter</i>	port condition one side loaded	flooded condition (transverse bulkhead)	flooded condition (anti-float chocks)	collision condition (forward)	collision condition (aftward)	30° static heel
<i>Draft (d_m)</i>	$1/2 d_f$	d_{flood} or $0.8D_f$	d_f	N/A	N/A	d_f
<i>Friction Coefficient</i>	N/A	N/A	0.10	0.10	0.10	0.10
<i>Longitudinal Inertia Load</i>	N/A	N/A	N/A	0.50g	−0.25g	N/A
<i>Vertical Inertia Load</i>	1.00g	N/A	1.00g	1.00g	1.00g	0.87g
<i>Transverse Inertia Load</i>	N/A	N/A	N/A	N/A	N/A	0.50g
<i>Vertical Still Water BM</i>	N/A	N/A	N/A	N/A	N/A	N/A

Notes

- 1 The frictional coefficient in Section 4, Table 2 for LC12 and LC15 is the representative value for the global finite element model. For the fine mesh finite element models representing individual supports or chocks, the frictional coefficient is to be taken as 0.3. Alternatively, the frictional coefficient may be determined from the measurement. The details of the support bearing materials, measurement procedure and measurement data are to be submitted for ABS review.
- 2 For LC10, account is to be taken of an increase of vapor pressure in port condition. This load case may be omitted, if the piping systems are designed to ensure that the cargoes on both sides of the centerline bulkhead can be loaded or discharged at the same rate.

TABLE 3
Standard Design Load Cases for Fatigue Strength Assessment (1 May 2009)
 (Load Combination Factors for Dynamic Load Components for Full Cargo Loading Condition)

Load Case Pair	LC1 & LC2		LC3 & LC4		LC5 & LC6		LC7 & LC8	
Wave Heading (μ)	0° head		0° head		90° beam		60° oblique	
Local Pressure Load Case	LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8
Draft (d_m)	d_f	d_f	d_f	d_f	d_f	d_f	d_f	d_f
External Pressure k_{ce}	-0.50	0.50	-1.00	1.00	-1.00	1.00	-1.00	1.00
Longitudinal Acceleration k_{cl}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vertical Acceleration k_{cv}	0.50	-0.50	1.00	-1.00	0.40	-0.40	0.20	-0.20
Transverse Acceleration k_{ct}	N/A	N/A	N/A	N/A	-0.70	0.70	-0.40	0.40
Vertical BM Load Case	100% Rule Vertical BM Range		50% Rule Vertical BM Range		20% Rule Vertical BM Range		30% Rule Vertical BM Range	
Horizontal BM Load Case	N/A		N/A		30% Rule Horizontal BM Range		50% Rule Horizontal BM Range	

Notes

- 1 Rule vertical bending moment range = $|M_{ws} - M_{wh}|$ (see Subsection 3/5 for M_{ws} and M_{wh})
- 2 Rule horizontal bending moment range = $2 \times M_h$ (see Subsection 3/7 for M_h)
- 3 For each load case pair, the stress range due to local pressure is the difference between the stress values for Local Pressure Load Cases. For example, for Load Case Pair LC1 & LC2, the stress range due to local pressure is the difference between the stress values for LC1 and LC2.
- 4 For each load case pair, the stress range is the sum of the absolute stress range values due to Vertical BM, Horizontal BM and Local Pressure Load Cases.
- 5 To account for the mean stress effect on the fatigue damage, the mean stress level can be determined using the static loads for the loading condition.
- 6 For the global finite element model, the frictional coefficient need not be considered. For the fine mesh finite element models representing supports or chocks, the frictional coefficient is to be taken as 0.3. Alternatively, the frictional coefficient may be taken from the measurement. The details of the support bearing materials, measurement procedure and measurement data are to be submitted for ABS review.

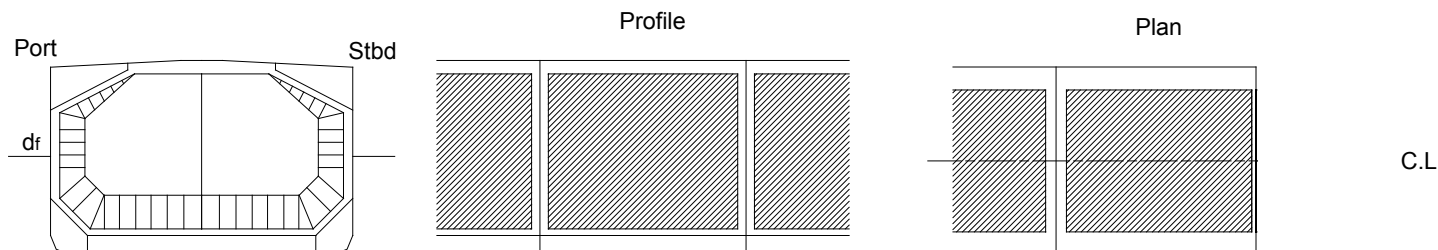


TABLE 4
Standard Design Load Cases for Fatigue Strength Assessment (1 May 2009)
 (Load Combination Factors for Dynamic Load Components for Ballast Loading Condition)

Load Case Pair	LC1 & LC2		LC3 & LC4		LC5 & LC6		LC7 & LC8	
Wave Heading (μ)	0° head		0° head		90° beam		60° oblique	
Local Pressure Load Case	LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8
Draft (d_m)	d_b	d_b	d_b	d_b	d_b	d_b	d_b	d_b
External Pressure k_{ce}	-0.50	0.50	-1.00	1.00	-1.00	1.00	-1.00	1.00
Longitudinal Acceleration k_{cl}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vertical Acceleration k_{cv}	0.50	-0.50	1.00	-1.00	0.40	-0.40	0.20	-0.20
Transverse Acceleration k_{ct}	N/A	N/A	N/A	N/A	-0.70	0.70	-0.40	0.40
Vertical BM Load Case	100% Rule Vertical BM Range		50% Rule Vertical BM Range		20% Rule Vertical BM Range		30% Rule Vertical BM Range	
Horizontal BM Load Case	N/A		N/A		30% $\times d_b/d_f$ Rule Horizontal BM Range		50% $\times d_b/d_f$ Rule Horizontal BM Range	

Notes

- 1 Rule vertical bending moment range = $|M_{ws} - M_{wh}|$ (see Subsection 3/5 for M_{ws} and M_{wh})
- 2 Rule horizontal bending moment range = $2 \times M_h$ (see Subsection 3/7 for M_h)
- 3 For each load case pair, the stress range due to local pressure is the difference between the stress values for Local Pressure Load Cases. For example, for Load Case Pair LC1 & LC2, the stress range due to local pressure is the difference between the stress values for LC1 and LC2.
- 4 For each load case pair, the stress range is the sum of the absolute stress range values due to Vertical BM, Horizontal BM and Local Pressure Load Cases.
- 5 To account for the mean stress effect on the fatigue damage, the mean stress level can be determined using the static loads for the loading condition.
- 6 For the global finite element model, the frictional coefficient need not be considered. For the fine mesh finite element models representing supports or chocks, the frictional coefficient is to be taken as 0.3. Alternatively, the frictional coefficient may be taken from the measurement. The details of the support bearing materials, measurement procedure and measurement data are to be submitted for ABS review.

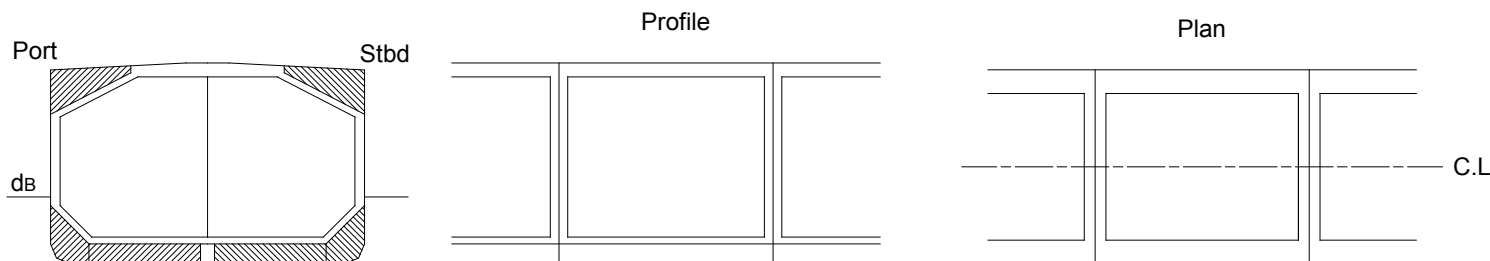
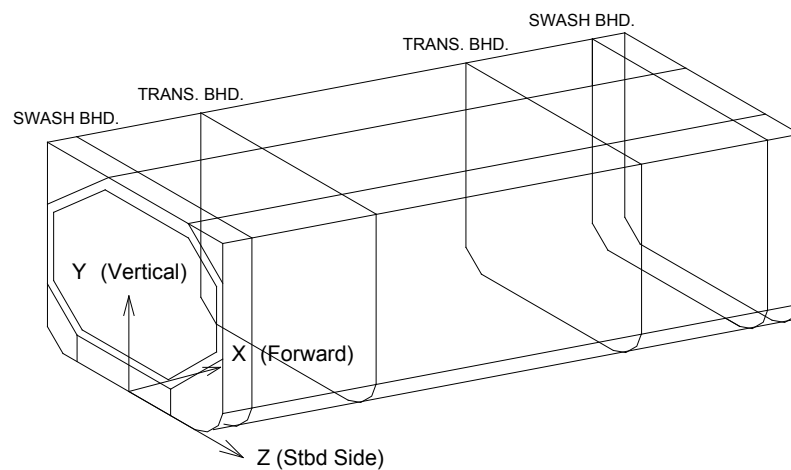
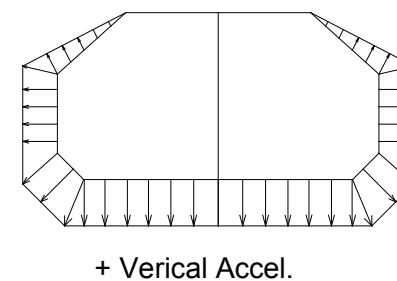


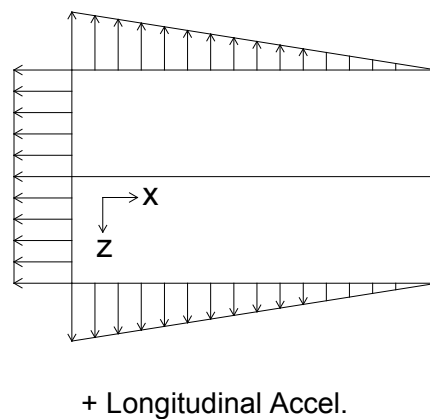
FIGURE 1
Direction of Internal Pressure due to Acceleration



Section



Plan



Plan

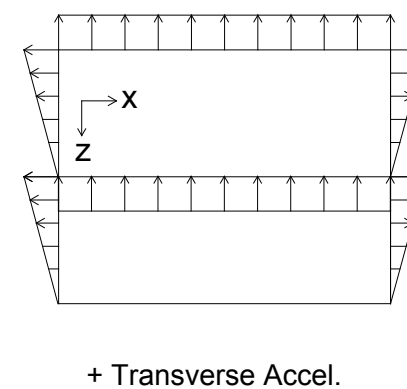
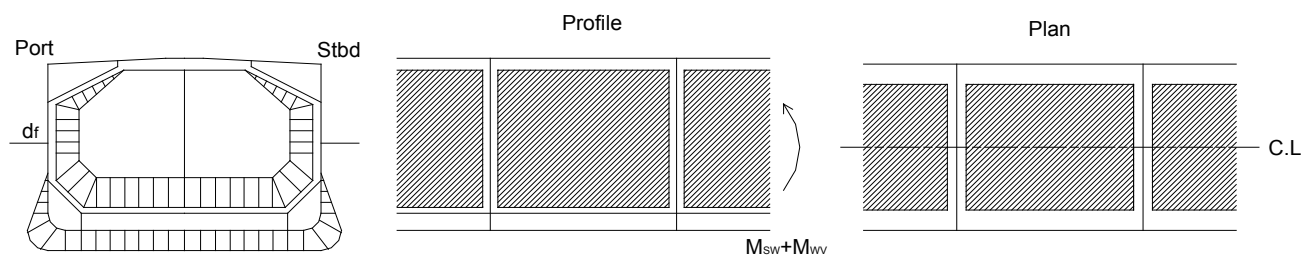


FIGURE 2
Loading Pattern (Yielding and Buckling Strength Assessment) (1 May 2009)

Load Case	1
Dominant Load Parameter	maximum sagging BM
Wave Heading (μ)	0° head
Draft (d_m)	d_f
External Pressure k_{ce}	-0.50
Longitudinal Acceleration k_{cl}	0.00
Vertical Acceleration k_{cv}	0.50
Transverse Acceleration k_{ct}	N/A
Vertical BM k_{cmv}	1.00 sagging
Horizontal BM k_{cmh}	N/A
Friction Coefficient	N/A



Load Case	2
Dominant Load Parameter	maximum hogging BM
Wave Heading (μ)	0° head
Draft (d_m)	d_f
External Pressure k_{ce}	0.50
Longitudinal Acceleration k_{cl}	0.00
Vertical Acceleration k_{cv}	-0.50
Transverse Acceleration k_{ct}	N/A
Vertical BM k_{cmv}	1.00 hogging
Horizontal BM k_{cmh}	N/A
Friction Coefficient	N/A

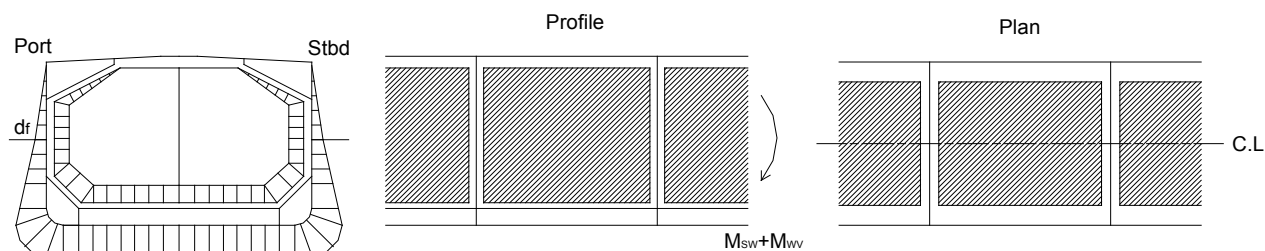
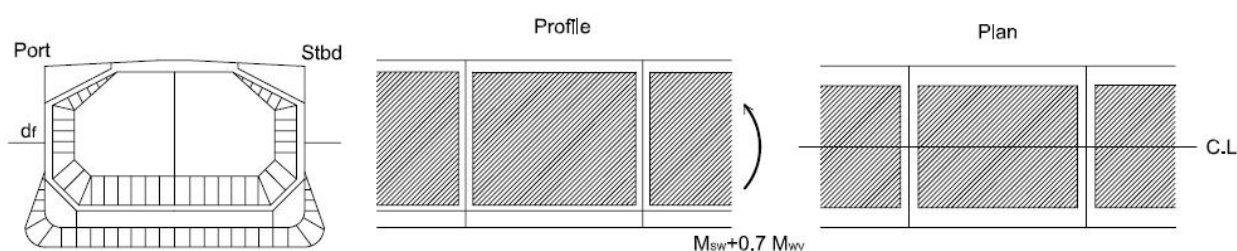


FIGURE 2 (continued)
Loading Pattern (Yielding and Buckling Strength Assessment) (1 May 2009)

Load Case	3
Dominant Load Parameter	maximum internal pressure
Wave Heading (μ)	0° head
Draft (d_m)	d_f
External Pressure k_{ce}	-0.50
Longitudinal Acceleration k_{cl}	0.00
Vertical Acceleration k_{cv}	1.00
Transverse Acceleration k_{ct}	N/A
Vertical BM k_{cmv}	0.70 sagging
Horizontal BM k_{cmh}	N/A
Friction Coefficient	N/A



Load Case	4
Dominant Load Parameter	maximum external pressure
Wave Heading (μ)	0° head
Draft (d_m)	d_f
External Pressure k_{ce}	1.00
Longitudinal Acceleration k_{cl}	0.60
Vertical Acceleration k_{cv}	-0.80
Transverse Acceleration k_{ct}	N/A
Vertical BM k_{cmv}	0.70 hogging
Horizontal BM k_{cmh}	N/A
Friction Coefficient	N/A

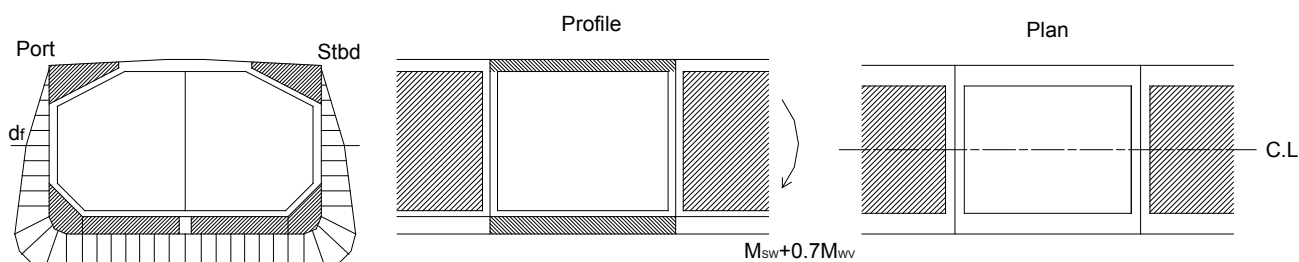
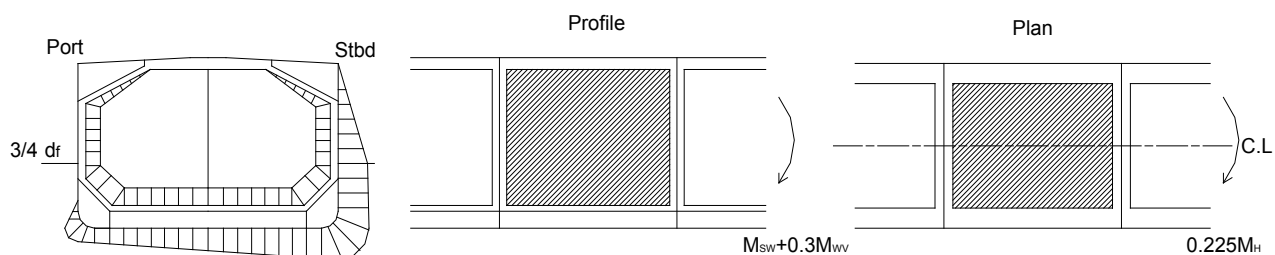


FIGURE 2 (continued)
Loading Pattern (Yielding and Buckling Strength Assessment) (1 May 2009)

Load Case	5
Dominant Load Parameter	maximum transverse acceleration
Wave Heading (μ)	90° beam
Draft (d_m)	$3/4 d_f$
External Pressure k_{ce}	1.00
Longitudinal Acceleration k_{cl}	0.00
Vertical Acceleration k_{cv}	-0.60
Transverse Acceleration k_{ct}	0.80
Vertical BM k_{cmv}	0.30 hogging
Horizontal BM k_{cmh}	0.225 port (+)
Friction Coefficient	0.10



Load Case	6
Dominant Load Parameter	maximum horizontal BM
Wave Heading (μ)	60° oblique
Draft (d_m)	$3/4 d_f$
External Pressure k_{ce}	-0.50
Longitudinal Acceleration k_{cl}	-0.40
Vertical Acceleration k_{cv}	0.60
Transverse Acceleration k_{ct}	-0.70
Vertical BM k_{cmv}	0.30 sagging
Horizontal BM k_{cmh}	0.75 port (-)
Friction Coefficient	0.10

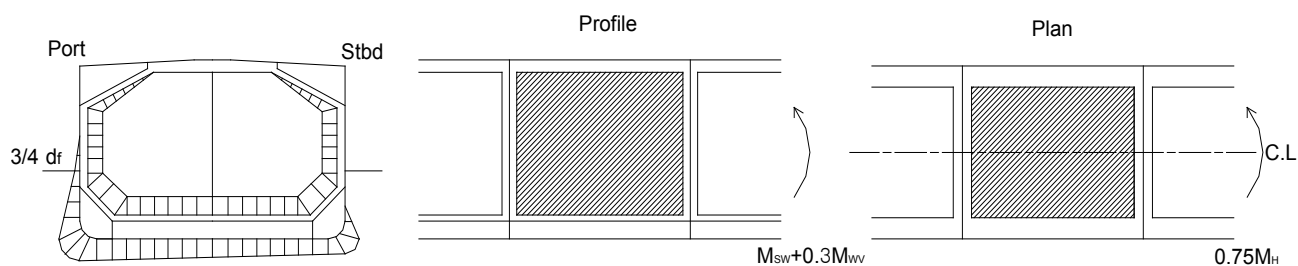
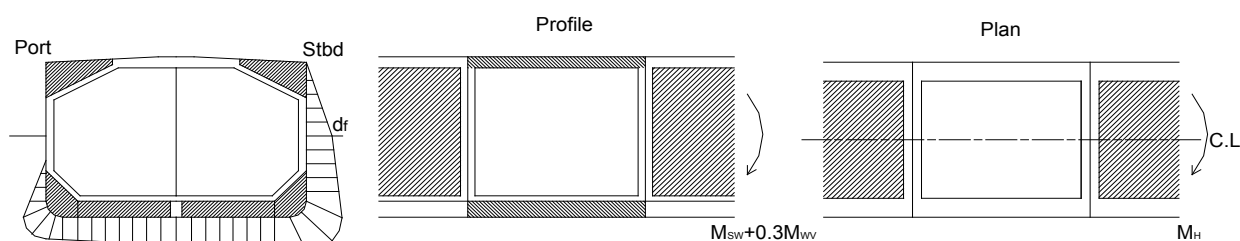


FIGURE 2 (continued)
Loading Pattern (Yielding and Buckling Strength Assessment) (1 May 2009)

Load Case	7
Dominant Load Parameter	maximum horizontal BM
Wave Heading (μ)	60° oblique
Draft (d_m)	d_f
External Pressure k_{ce}	1.00
Longitudinal Acceleration k_{cl}	0.40
Vertical Acceleration k_{cv}	-0.60
Transverse Acceleration k_{ct}	0.70
Vertical BM k_{cmv}	0.30 hogging
Horizontal BM k_{cmh}	1.00 port (+)
Friction Coefficient	N/A



Load Case	8
Dominant Load Parameter	maximum internal pressure
Wave Heading (μ)	0° head
Draft (d_m)	d_b
External Pressure k_{ce}	-0.50
Longitudinal Acceleration k_{cl}	0.00
Vertical Acceleration k_{cv}	1.00
Transverse Acceleration k_{ct}	N/A
Vertical BM k_{cmv}	0.70 sagging
Horizontal BM k_{cmh}	N/A
Friction Coefficient	N/A

