GUIDANCE NOTES ON

THE STRENGTH ASSESSMENT OF CARGO TANK STRUCTURES BEYOND 0.4L AMIDSHIPS IN OIL CARRIERS 150 METERS OR MORE IN LENGTH

MAY 2004 (Updated August 2018 – see next page)

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

ABS Plaza
16855 Northchase Drive
Houston, TX 77060 USA

Updates

August 2018 consolidation includes:

- May 2004 version plus Corrigenda/Editorials

Foreword

These Guidance Notes were developed as a direct response to requests from our clients to develop an analysis procedure for the forward and aft tank structure beyond 0.4*L*. This procedure is based on existing ABS SafeHull procedures included in the ABS Rules. It should be noted that ABS is currently working within IACS on the Joint Tanker Project (JTP) and some components of these Guidance Notes have been developed using JTP procedures. It is understood that this process will continue and once the JTP Rules mature, these Guidance Notes will be unified with respect to components such as the net thickness, loads, acceptance criteria, etc.

These Guidance Notes describe a strength assessment procedure for cargo tank structures beyond 0.4*L* amidships in oil carriers having *L* greater than 150 meters. In addition to the Rule scantlings as required by Section 5C-1-6 “Hull Structure Beyond 0.4*L* Amidships” of the ABS *Rules for Building and Classing Steel Vessels* (SVR), these Guidance Notes may be optionally applied to verify the strength adequacy of main supporting members using a set of standard design load cases. Application of the procedure is required for novel structural configurations or scantlings/details.

Terms of Use

The information presented herein is intended solely to assist the reader in the methodologies and/or techniques discussed. These Guidance Notes do not and cannot replace the analysis and/or advice of a qualified professional. It is the responsibility of the reader to perform their own assessment and obtain professional advice. Information contained herein is considered to be pertinent at the time of publication, but may be invalidated as a result of subsequent legislations, regulations, standards, methods, and/or more updated information and the reader assumes full responsibility for compliance. This publication may not be copied or redistributed in part or in whole without prior written consent from ABS.

This Page Intentionally Left Blank

GUIDANCE NOTES ON

THE STRENGTH ASSESSMENT OF CARGO TANK STRUCTURES BEYOND 0.4L AMIDSHIPS IN OIL CARRIERS 150 METERS OR MORE IN LENGTH

CONTENTS

SECTION 1 **Introduction**

This Page Intentionally Left Blank

SECTION 1 Introduction

1 Scope of Application

These Guidance Notes describe a strength assessment procedure for cargo tank structures beyond 0.4*L* amidships in oil carriers 150 meters or more in length. In addition to the Rule scantlings as required by Section 5C-1-6 "Hull Structure Beyond 0.4*L* Amidships" of the ABS *Rules for Building and Classing Steel Vessels* (*Steel Vessel Rules*), these Guidance Notes may be optionally applied to verify the strength adequacy of main supporting members using a set of standard design load cases. For designs with satisfactory service experience or designs that have been subjected to other forms of engineering analysis, these Guidance Notes need not be applied. However, application of these Guidance Notes is required for novel structural configurations or scantlings/details. The primary concern for main supporting members is the strength adequacy against external sea and internal liquid pressures while the hull girder load effects in these members tend to be less significant.

Cargo tank structures within 0.4*L* amidships are to comply with the requirements of Section 5C-1-4 "Initial Scantling Criteria" of the *Steel Vessel Rules* and Section 5C-1-5 "Total Strength Assessment" of the *Steel Vessel Rules* and are to be directly evaluated by using the ABS SafeHull System. The strength assessment procedure in these Guidance Notes is not applicable to cargo tank structures within 0.4*L* amidships.

The description of the procedure in these Guidance Notes is aided by figures for forward cargo tank structures only, but the same procedure is also applicable to aft cargo tank structures (excluding bottom slamming and green water pressures).

The parameters in these Guidance Notes are defined in ABS SafeHull units and coordinate systems. If the measurement units and/or coordinate systems are different from these specifications, conversion is to be done appropriately.

3 Overview of Strength Assessment

The core of the strength assessment procedure is the SafeHull dynamic loading concept. It is generally expected that local dynamic loads experienced by cargo tank structures beyond 0.4*L* amidships can be more severe than those within 0.4*L* amidships. Section 1, Figure 1 shows the outline of the procedure.

In these Guidance Notes, the strength assessment procedure is described in five Sections:

Section 2	SafeHull Dynamic Load Criteria
Section 3	Standard Design Load Cases
Section 4	Structural Modeling and Analysis
Section 5	Acceptance Criteria
Section 6	Documentation of Strength Assessment for Classification Review

The dynamic load criteria given in Section 2 of these Guidance Notes are consistent with those given in Section 5C-1-3 “Load Criteria” of the *Steel Vessel Rules* for oil carriers. Simplifications to the dynamic load formulae are introduced with special emphasis to application of the strength assessment procedure using recognized finite element modeling/analysis/post-processing software tools such as FEMAP, PATRAN, NASTRAN and ANSYS.

The standard design load cases given in Section 3 of these Guidance Notes represent combinations of individual design load components defined in Section 2 of these Guidance Notes for cargo tank structures beyond 0.4*L* amidships. When warranted, additional design load cases are also to be analyzed to verify the strength of main supporting members against wave impact on bow, bow flare slamming and sloshing.

Section 4 of these Guidance Notes describes the finite element modeling and analysis techniques generally used for cargo tank structures beyond 0.4*L* amidships. These techniques may be substituted by alternative techniques. It is recommended that consultation with ABS on the alternative techniques be made before commencing structural idealization.

The acceptance criteria for the strength assessment procedure are consistent with those in Section 5C-1-5 of the *Steel Vessel Rules* and also given in Section 5 of these Guidance Notes for ready reference.

Appropriate documentation of the strength assessment described in Section 6 of these Guidance Notes is essential for ABS plan approval. A complete technical report is to be prepared as supporting data of design and submitted together with the relevant plans for ABS review.

5 Coordinate Systems

Three sets of Cartesian coordinate systems are used to describe SafeHull load criteria and finite element modeling in these Guidance Notes. When alternative coordinate systems are used, attention should be paid to the default coordinate systems used in the dynamic load formulae in Section 2 of these Guidance Notes.

5.1 Ship Coordinate System for Ship Motion and External Pressure (Right Hand)

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 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.

5.3 Tank Coordinate System for Internal Pressure (Left Hand)

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 1, Figure 2 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.

5.5 Finite Element Coordinate System (Right Hand)

Origin	Intersection of the baseline, centerline and aftmost transverse planes.
X	Longitudinal distance from the origin, in cm, positive from aft to fore.
Y	Vertical distance from the origin, in cm, positive upward.
Z	Transverse (athwartship) distance, in cm, positive toward starboard.

7 Nomenclature

A_s	cross sectional area of the spring bar, in cm^2
A_{shear}	effective shear area of a hull girder cross section, in cm^2 and can be taken as the sectional area of each side shell, longitudinal bulkhead, deck, inner bottom or bottom in question
$a_{\ell e}$	effective longitudinal acceleration, in m/sec^2, positive forward
a_{te}	effective transverse acceleration, in m/sec^2, positive starboard
a_{ve}	effective vertical acceleration, in m/sec^2, positive downward
B	molded breadth, in m
b_i	half breadth at the $^1/_{10}$ draft of the *i*-th section in the heavy ballast condition, in m
b_i^*	half width of flat of bottom at the *i*-th section, in m
C_b	block coefficient at the scantling draft
d_b	draft amidships in the heavy ballast condition, in m
d_f	scantling draft, in m
d_i	draft at the *i*-th section in the heavy ballast condition, in m
d_m	draft amidships for a specific loading condition, in m
d_{oi}	$^1/_{10}$ of the section draft of the *i*-th section in the heavy ballast condition, in m
f_y	minimum specified yield point of the material, in kgf/cm^2
f_u	minimum specified tensile strength of the material, in kgf/cm^2
F_{bi}	freeboard from the highest deck at side to the load waterline (LWL) at the *i*-th section
GM	metacentric height, in m
h_s	hydrostatic pressure head in still water, in m
k_{ce}	load combination factor for external pressure

$k_{c\ell}$	load combination factor for effective longitudinal acceleration
k_{cmh}	load combination factor for design horizontal wave-induced bending moment
k_{cmv}	load combination factor for design vertical wave-induced bending moment
k_{ct}	load combination factor for effective transverse acceleration
k_{cv}	load combination factor for effective vertical acceleration
$k_{c\phi}$	load combination factor for effective pitch amplitude
$k_{c\theta}$	load combination factor for effective roll amplitude
k_r	roll radius of gyration, in m
k_s	load factor for internal pressure
L	scantling length, in m
L_{BP}	length between perpendiculars, in m
ℓ_s	length of the spring bar, in cm
ℓ_t	cargo tank length between transverse bulkheads, in cm
M_{ws}	vertical sagging wave-induced bending moment, in tf-m
M_{wh}	vertical hogging wave-induced bending moment, in tf-m
M_h	horizontal wave-induced bending moment, in tf-m
m_v	distribution factor for vertical wave-induced bending moment
m_h	distribution factor for horizontal wave-induced bending moment
N	number of floors in the double bottom of the fore cargo tank
p_e	external pressure, in kgf/cm^2
p_{gi}	green water pressure on deck at the *i*-th section, in kgf/cm^2
p_i	internal pressure, in kgf/cm^2
p_{si}	bottom slamming pressure at the *i*-th section, in kgf/cm^2
p_{nslam}	nominal slamming pressure for double bottom structure, in kgf/cm^2
p_{vp}	pressure setting on pressure/vacuum relief valve, less than 0.71 kgf/cm^2 for integral-gravity tanks
S_m	strength reduction factor, equal to 1.000, 0.950, 0.908 and 0.875 for mild steel, H32, H36 and H40, respectively
s_i	sum of one half of floor spacings on both sides of the *i*-th floor, in m
T_r	roll period, in seconds
V	75% of the design speed V_d (MCR), in knots
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)

ϕ_e	effective pitch amplitude, in deg
θ_e	effective roll amplitude, in deg
ρg	specific weight of ballast or cargo; for ballast water, 1.025 tf/m^3 is to be used and for liquid cargo, specific weight of liquid cargo is not to be less than 1.025 tf/cm^3
ω	natural angular frequency of hull girder 2-node vertical vibration in the wet mode and the heavy weather ballast draft condition, in rad/second
Δ	vessel's displacement at the scantling draft, in tf
Δ_b	vessel's displacement in the heavy ballast condition, in tf

FIGURE 1
Outline of the Strength Assessment Procedure

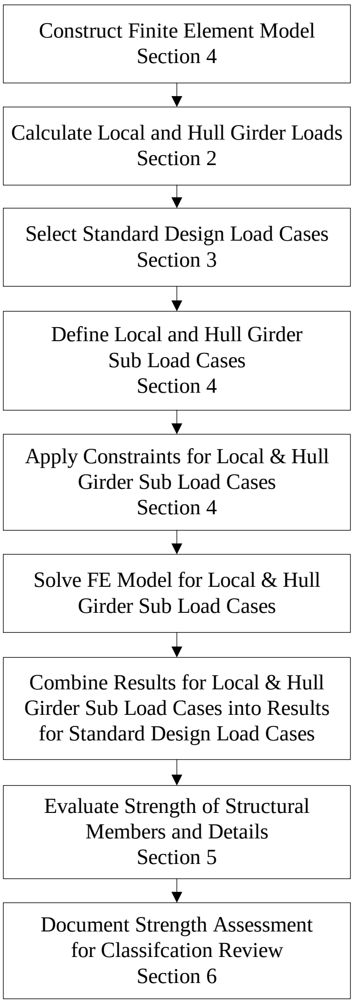
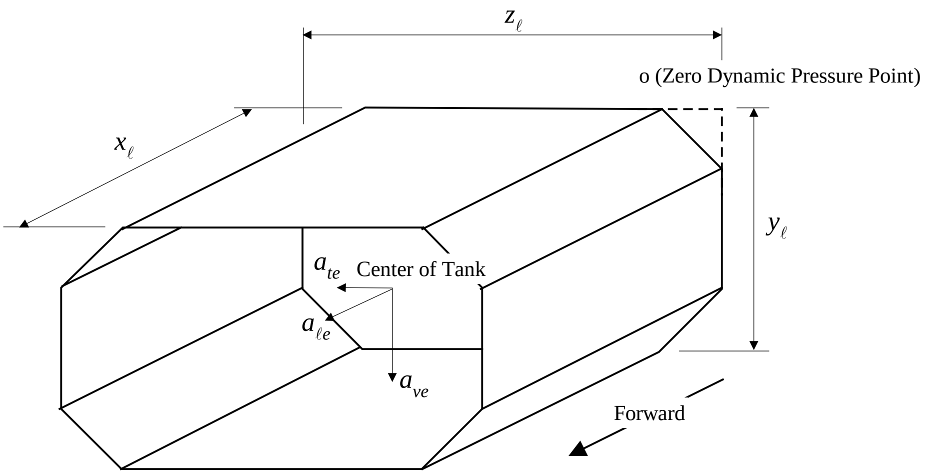


FIGURE 2
Tank Coordinate System for Internal Pressure



SECTION 2 SafeHull Dynamic Load Criteria

1 General

The dynamic load components described in this Section represent the long-term extreme values for the North Atlantic in 20 years, corresponding to a probability of exceedance of 10^{-8}. For oil carriers serving in more severe seas such as the Trans Alaskan Pipeline Service (TAPS) route, the dynamic load criteria need to be modified.

The following SafeHull dynamic load components are considered in the strength assessment procedure:

- Vertical and horizontal wave-induced bending moments
- External pressure
- Internal pressure
- Bottom slamming for fore cargo tank structures only

The formulae for vertical and horizontal wave-induced bending moments are identical to those in 3-2-1/3.5 and 5C-1-3/5.3.1 of the *Steel Vessel Rules* and are included here for ready reference. The formulae for external and bottom slamming pressures are derived from 5C-1-3/5.5 and 5C-1-3/13.3 of the *Steel Vessel Rules* and simplified to facilitate easy application of the strength assessment procedure. Effective accelerations, pitch and roll amplitudes are first calculated, and internal pressure is expressed as a combination of these dominant parameters.

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 3 of these Guidance Notes. The parameters and coordinates used in this Section are defined in Subsections 1/5 and 1/7 of these Guidance Notes.

3 Vertical Wave-induced Bending Moment

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

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

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

where

$$C_1 = 10.75 - \left(\frac{300 - L}{100}\right)^{1.5} \qquad 90 \le L < 300$$

$$= 10.75 \qquad 300 \le L < 350$$

$$= 10.75 - \left(\frac{350 - L}{150}\right)^{1.5} \qquad 350 \le L < 500$$

Refer to Section 2, Figure 1 for m_v.

5 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.

$$M_H = \pm 18.34 k_{cmh} m_h C_1 L^2 \, D C_b \times 10^{-3}$$

where C_1 is as given in Subsection 2/3 of these Guidance Notes. Refer to Section 2, Figure 2 for m_h.

7 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:

$$p_e = \rho g(h_s + 1.36 k_{ce} k_d \alpha C_1) \times 10^{-1} \geq 0$$

where

α = $0.75 - 1.25 \sin\mu$ waterline, port

= $0.2 - 0.4 \sin\mu + 0.1 \cos\mu$ bilge, port

= $0.3 - 0.2 \sin\mu$ centerline, bottom

= $0.4 - 0.1 \cos\mu$ bilge, starboard

= $1.0 - 0.25 \cos\mu$ waterline, starboard

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

C_1 is as given in Subsection 2/3 and the pressure distribution factor, $k_{\ell o}$, may be taken from Section 2, Table 1 or Section 2, Figure 3. Combination factor, k_{ce}, is found in Section 3, Table 1. A negative combination factor, k_{ce}, signifies that the wave trough is on the starboard side.

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 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 should be accounted for and can be represented by the pressure values at the following five points, as shown in Section 2, Figure 4:-

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 2, Figure 4. The zero pressure point is defined by h_1, which is equal to the dynamic pressure head or freeboard, whichever is less. However, when the vessel is in a deeper draft (see Standard Load Case 5 in Section 3), the nominal green water pressure imposed on the deck in the region from the FP to 0.25*L* aft, including the extension beyond the FP, is to be calculated at the reference section:

$$p_{gi} = 0.2\left[0.44A_i\left(\frac{VL}{C_b}\right)^{1/2} - F_{bi}\right]^{1/2}$$, not to be less than 0.21 kgf/cm²

A_i is given in Section 2, Table 2.

When a negative dynamic pressure is found, for example, at the waterline at E5 on the starboard side in Section 2, Figure 4, the zero pressure point can be defined by h_2, which can be calculated as follows: The negative pressure above the zero pressure point is ignored.

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

The external pressure on the bottom shell plating linearly varies from pressure, p_{E2} (bilge, port), to pressure, p_{E4} (bilge, starboard). 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 0.2*D* above the baseline.

9 Internal Pressure

To determine the inertial forces and added pressure heads for a completely filled cargo or ballast tank, the dominating ship motion parameters (pitch, roll and accelerations) induced by waves are to be calculated.

9.1 Effective Pitch Amplitude

$$\phi_e = 731.3\left(\frac{V}{C_b}\right)^{1/4} / L$$

ϕ_e need not to be taken more than 7.1 degrees.

9.3 Effective Roll Amplitude

$$\theta_e = \begin{cases} 0.71C_R(35 - 0.05C_{di}\Delta/1000) & T_r > 20\,\text{sec} \\ 0.71C_R(35 - 0.05C_{di}\Delta/1000)(1.5375 - 0.027T_r) & 12.5 \le T_r \le 20\,\text{sec} \\ 0.71C_R(35 - 0.05C_{di}\Delta/1000)(0.8635 + 0.027T_r) & T_r < 12.5\,\text{sec} \end{cases}$$

θ_e need not be taken more than 21.3 degrees.

where

C_R = $1.3 - 0.025V$

C_{di} = $1.06(d_m/d_f) - 0.06$

Δ = $1.025LBd_fC_b$

$$T_r = \frac{2k_r}{GM^{1/2}}$$

k_r = $0.30B$ for full loading conditions

= $0.45B$ for ballast conditions

GM = $0.12B$ for d_f

= $0.18B$ for $2/3d_f$

= $0.24B$ for $1/2d_f$

9.5 Effective Accelerations

The effective vertical, longitudinal and transverse accelerations at the center of tank content (cargo or ballast), a_{ve}, $a_{\ell e}$ and a_{te}, in m/sec^2, may be obtained from the following formulae:

$$\frac{a_{ve}}{g} = 0.71C_vk_va_o$$ positive downward

$$\frac{a_{\ell e}}{g} = 0.71C_\ell k_\ell a_o$$ positive forward

$$\frac{a_{te}}{g} = 0.71C_tk_ta_o$$ positive starboard

where

$$a_o = (0.86 + 0.048V - 0.47C_b)\left(\frac{2.4}{L^{1/2}} + \frac{34}{L} - \frac{600}{L^2}\right)$$

$$C_v = \cos\mu + \left(1 + \frac{2.4z_T}{B}\right)\frac{\sin\mu}{k_v}$$

$$k_v = \left[1 + 0.65\left(5.3 - \frac{45}{L}\right)^2\left(\frac{x_T}{L} - 0.45\right)^2\right]^{1/2}$$

$$C_\ell = 0.35 - 0.0005(L - 200)$$

$$k_\ell = 0.5 + \frac{8y_T}{L}$$

9.7 Internal Pressure

The internal pressure, p_i, positive toward outboard, for a completely filled tank, in kgf/cm^2, may be obtained from the following formula:

$$p_i = k_s \rho g \left[\left(k_{c\ell} \frac{a_{\ell e}}{g} + \frac{g_\ell}{g} \right) x_\ell + \left(k_{cv} \frac{a_{ve}}{g} + \frac{g_v}{g} \right) y_\ell + \left(k_{ct} \frac{a_{te}}{g} + \frac{g_t}{g} \right) z_\ell \right] \times 10^{-1} + p_o$$

where

p_o = $(p_{vp} - 0.21) \geq 0$ for cargo tanks

$\frac{g_\ell}{g}$ = $\sin k_{c\phi}\phi_e$

$\frac{g_t}{g}$ = $\cos k_{c\phi}\phi_e \sin k_{c\theta}\theta_e$

$\frac{g_v}{g}$ = $\cos k_{c\phi}\phi_e \cos k_{c\theta}\theta_e$

k_s is equal to 1.0 for all loads from ballast tanks. For all loads from cargo tanks, k_s is equal to 0.878 for ρg of 1.025 tf/m^3 and 1.0 for ρg of 1.14 tf/m^3. For cargo ρg between 1.025 tf/m^3 and 1.14 tf/m^3, k_s may be determined by interpretation.

For a ballast tank, a distance equivalent to $^2/_3$ of the distance from the top of the tank to the top of the overflow (minimum 0.76 m above deck) is to be added to y_ℓ.

11 Bottom Slamming Pressure

For a tanker with the heavy weather ballast draft forward less than 0.04*L*, bottom slamming is to be considered in the strength assessment of the double bottom floors and girders in the foremost cargo tank. For the strength assessment, the heavy weather ballast draft forward is to be determined by considering segregated ballast tanks only. The equivalent bottom slamming pressure for the *i*-th section, in kgf/cm^2, may be determined by the following equations:

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

where

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

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

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

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

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

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:

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

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
-0.05*L*	1.25	0.3600
FP	1.00	0.4000
0.05*L*	0.80	0.4375
0.10*L*	0.62	0.4838
0.15*L*	0.47	0.5532
0.20*L*	0.33	0.6666
0.25*L*	0.22	0.8182
0.30*L*	0.22	0.8182
Linear interpolation may be used for intermediate values.		

FIGURE 1
Distribution Factor for Vertical Wave-induced Bending Moment m_v

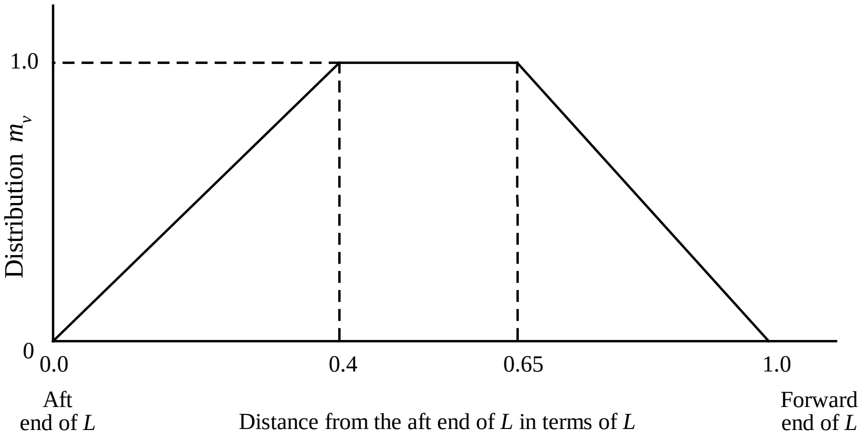


FIGURE 2
Distribution Factor for Horizontal Wave-induced Bending Moment m_h

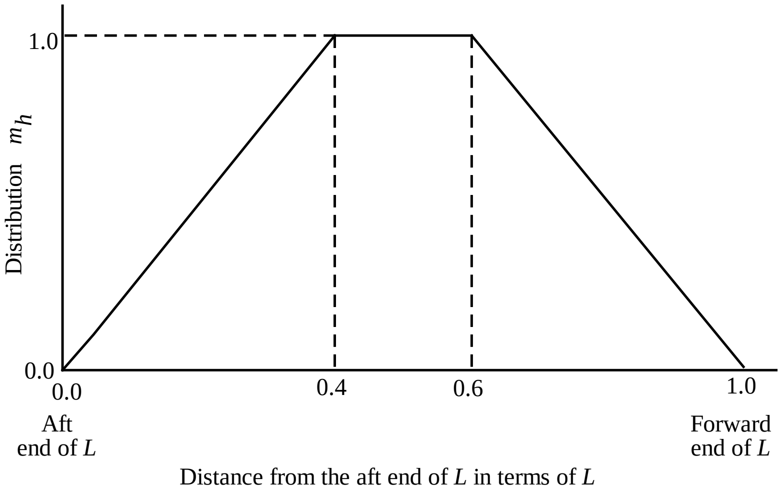


FIGURE 3
Pressure Distribution Function $k_{\ell o}$

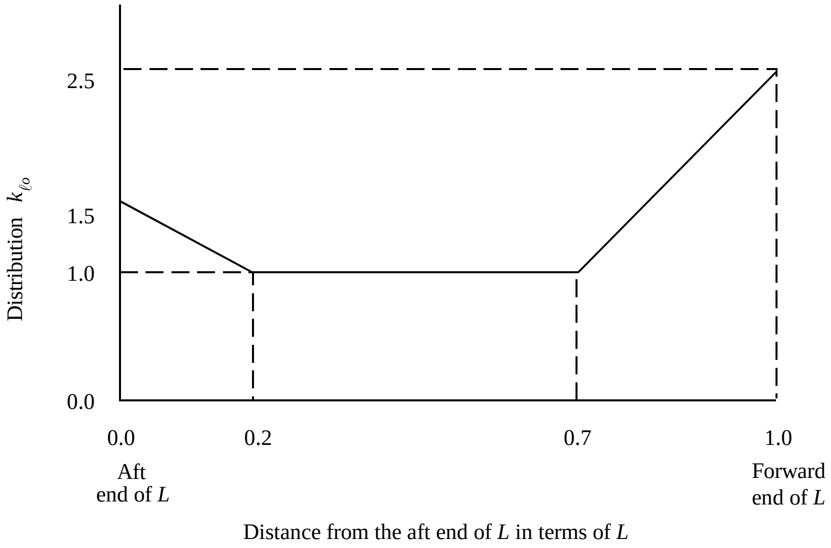
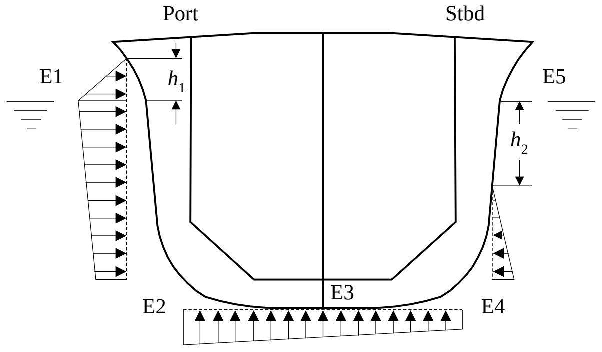


FIGURE 4
External Pressure Calculation Points



SECTION 3 Standard Design Load Cases

To assess the strength of cargo tank structure beyond 0.4*L* amidships, the standard design load cases described in this Section are to be analyzed. For fore cargo tank structures, a design load case for bottom slamming is also to be considered. Additional load cases may be required, as warranted. The standard design load cases are separately defined for oil carriers with the following tank configurations:

- Two outer longitudinal bulkheads only
- Two outer longitudinal bulkheads and a centerline longitudinal bulkhead
- Two outer longitudinal bulkheads and two inner longitudinal bulkheads

The loading patterns for the above tank configurations are shown in Section 3, Figures 1, 2 and 3. For each standard design load case, the load combination factors are specified for individual dynamic load components/dominant parameters in Section 3, 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 with the effective acceleration, roll amplitude and wave heading mirroring those of the unsymmetrical load cases in Section 3, Table 1 are to be analyzed.

TABLE 1
Standard Design Load Cases

	LC 1 a & b	*LC 2 a & b*	*LC 3 a & b*	*LC 4*	*LC 5*	*LC 6 a & b*	*LC 7* (1)
μ	90° beam sea	60°	30°	0° head sea	0° head sea	N/A	0° head sea
d_m	$2/3d_f$	$2/3d_f$	$2/3d_f$	$2/3d_f$	d_f	$1/4d_f$ (2)	N/A
k_{ce}	-0.500	-0.500	-0.500	-0.500	1.000	N/A	N/A
$k_{c\ell}$	0.000	0.200	0.225	0.250	0.250	N/A	0.000
k_{cv}	0.250	0.400	0.575	0.750	-0.375	N/A	-0.500
k_{ct}	0.750	0.400	0.200	0.000	0.000	N/A	0.000
$k_{c\theta}$	1.000	0.700	0.350	0.000	0.000	N/A	0.000
$k_{c\phi}$	0.000	0.700	0.850	1.000	0.000	N/A	0.000
k_{cmv}	0.300 sagging (3)	0.400 sagging (3)	0.600 sagging (3)	0.700 sagging (3)	0.700 hogging (3)	N/A sagging (3)	N/A
k_{cmh}	0.300 + port	1.000 + port	0.500 + port	0.000	0.000	N/A	0.000

Notes

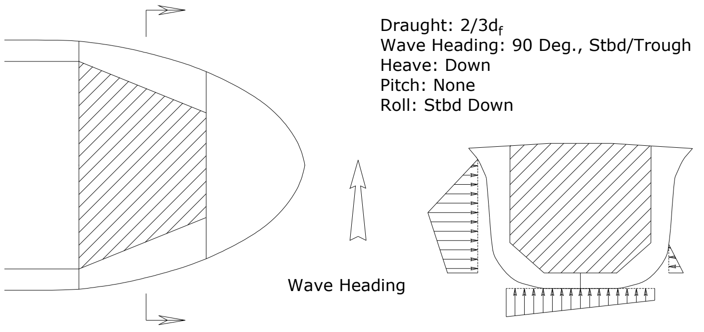
1 LC 7 is the slamming load case and only applicable to fore end cargo tank structure.

2 LC 6 a & b are the tank testing load cases. For oil carriers with only two outer longitudinal bulkheads only (inner skin), the minimum actual draft is to be used. 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 above the deck at side.

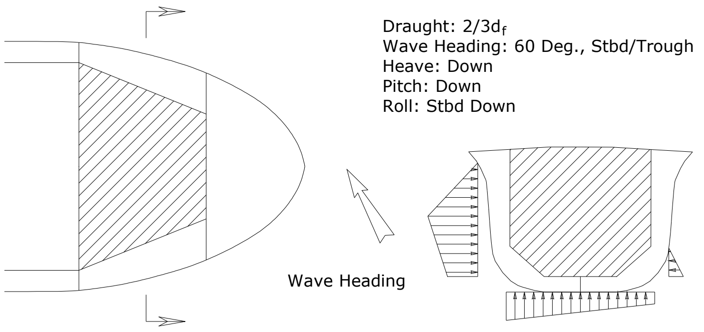
3 The maximum allowable still water bending moment at the fixed end of the model is to be used.

FIGURE 1
Standard Design Load Cases for Oil Carrier with Two Outer Longitudinal Bulkheads Only

Load Case 1


Draught: $2/3d_f$
Wave Heading: 90 Deg., Stbd/Trough
Heave: Down
Pitch: None
Roll: Stbd Down

Load Case 2


Draught: $2/3d_f$
Wave Heading: 60 Deg., Stbd/Trough
Heave: Down
Pitch: Down
Roll: Stbd Down

Load Case 3

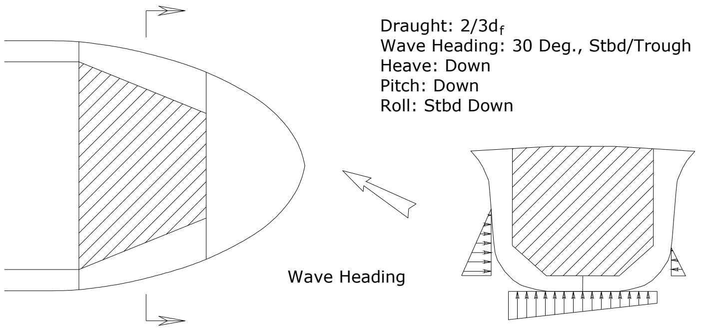
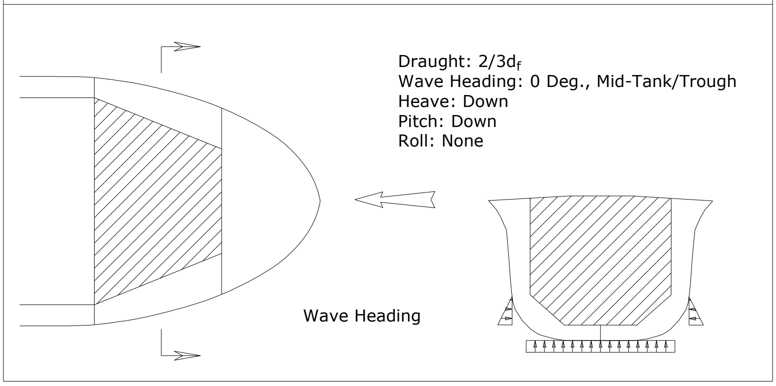

Draught: $2/3d_f$
Wave Heading: 30 Deg., Stbd/Trough
Heave: Down
Pitch: Down
Roll: Stbd Down

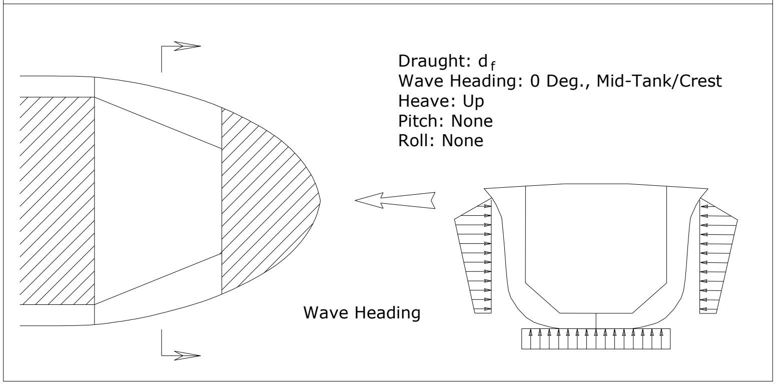
FIGURE 1 (continued) Standard Design Load Cases for Oil Carrier with Two Outer Longitudinal Bulkheads Only

Load Case 4



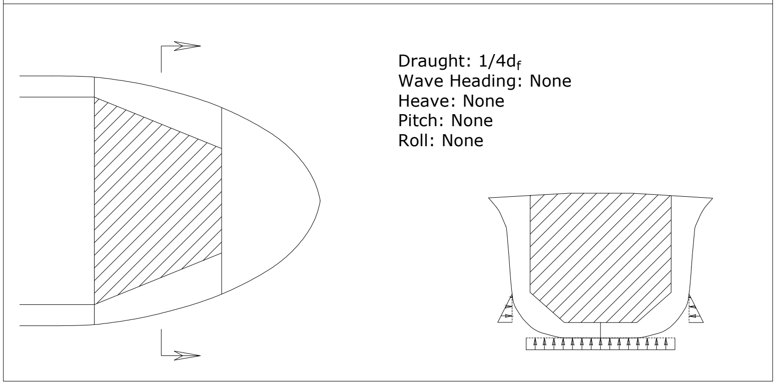
Draught: 2/3d_f
Wave Heading: 0 Deg., Mid-Tank/Trough
Heave: Down
Pitch: Down
Roll: None

Load Case 5



Draught: d_f
Wave Heading: 0 Deg., Mid-Tank/Crest
Heave: Up
Pitch: None
Roll: None

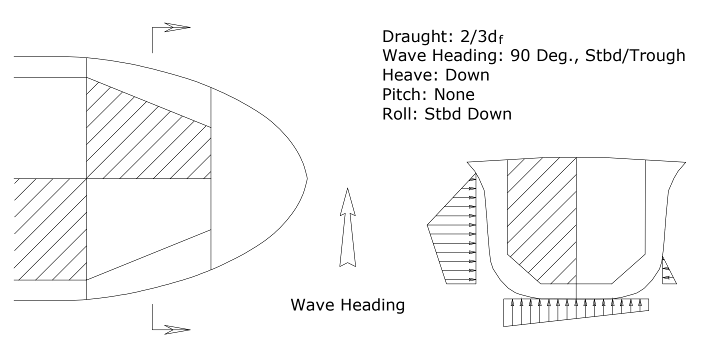
Load Case 6



Draught: 1/4d_f
Wave Heading: None
Heave: None
Pitch: None
Roll: None

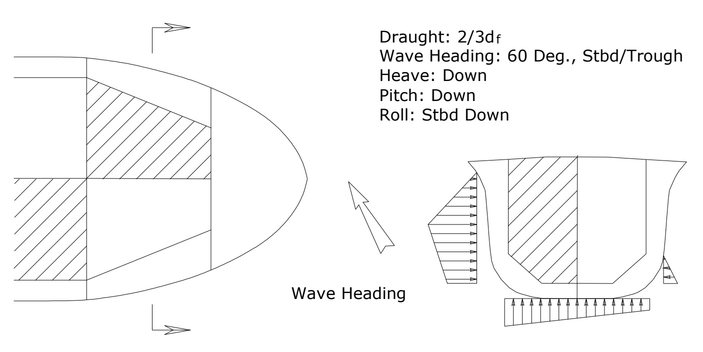
FIGURE 2
Standard Design Load Cases for Oil Carrier with Two Outer Longitudinal Bulkheads and One Centerline Longitudinal Bulkhead

Load Case 1a



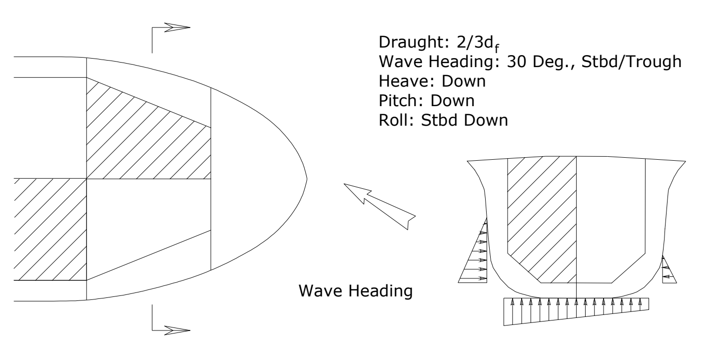
Draught: $2/3d_f$
Wave Heading: 90 Deg., Stbd/Trough
Heave: Down
Pitch: None
Roll: Stbd Down

Load Case 2a



Draught: $2/3d_f$
Wave Heading: 60 Deg., Stbd/Trough
Heave: Down
Pitch: Down
Roll: Stbd Down

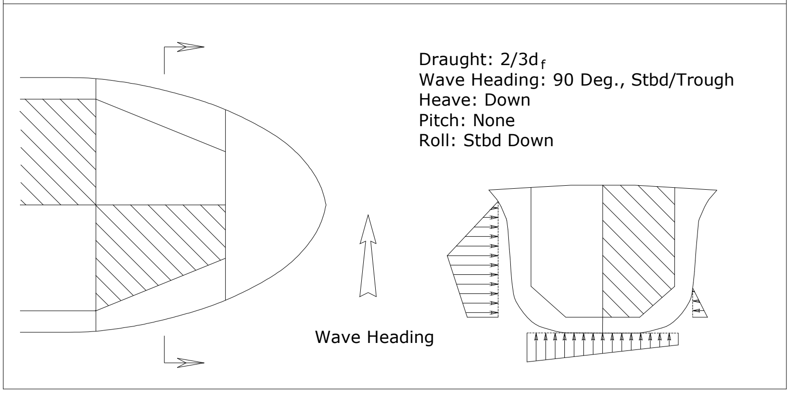
Load Case 3a



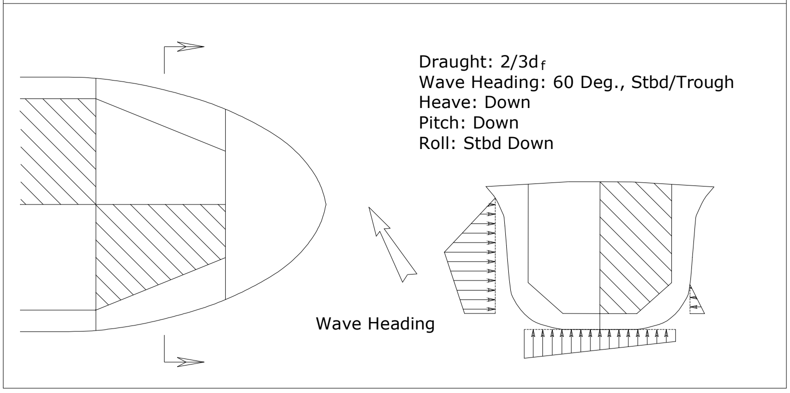
Draught: $2/3d_f$
Wave Heading: 30 Deg., Stbd/Trough
Heave: Down
Pitch: Down
Roll: Stbd Down

FIGURE 2 (continued)
Standard Design Load Cases for Oil Carrier with Two Outer Longitudinal Bulkheads and One Centerline Longitudinal Bulkhead

Load Case 1b


Draught: $2/3d_f$
Wave Heading: 90 Deg., Stbd/Trough
Heave: Down
Pitch: None
Roll: Stbd Down

Load Case 2b


Draught: $2/3d_f$
Wave Heading: 60 Deg., Stbd/Trough
Heave: Down
Pitch: Down
Roll: Stbd Down

Load Case 3b

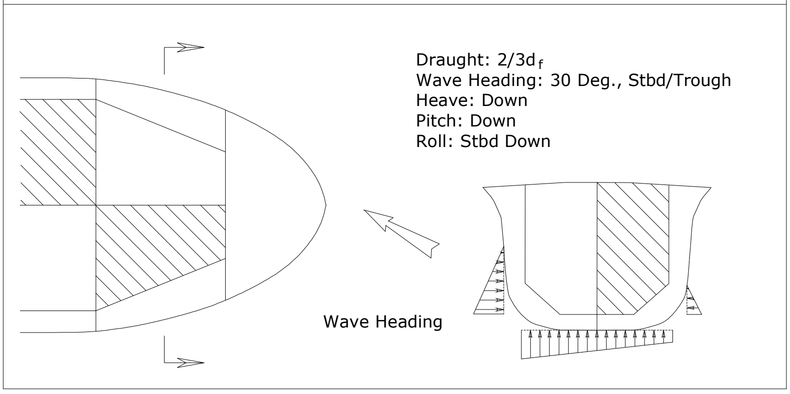
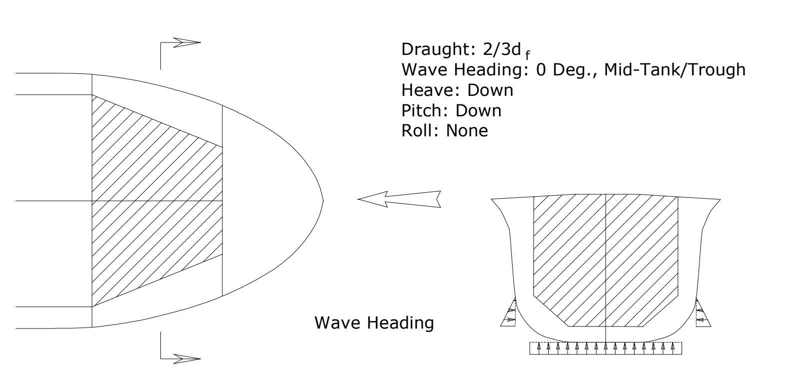

Draught: $2/3d_f$
Wave Heading: 30 Deg., Stbd/Trough
Heave: Down
Pitch: Down
Roll: Stbd Down

FIGURE 2 (continued) Standard Design Load Cases for Oil Carrier with Two Outer Longitudinal Bulkheads and One Centerline Longitudinal Bulkhead

Load Case 4



Load Case 5

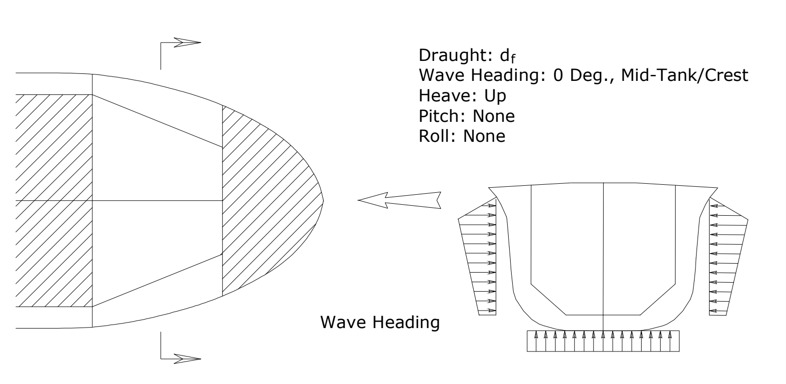
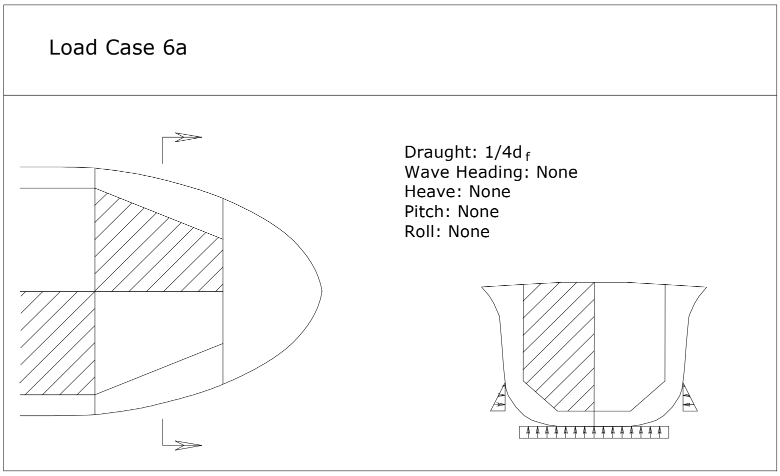


FIGURE 2 (continued) Standard Design Load Cases for Oil Carrier with Two Outer Longitudinal Bulkheads and One Centerline Longitudinal Bulkhead



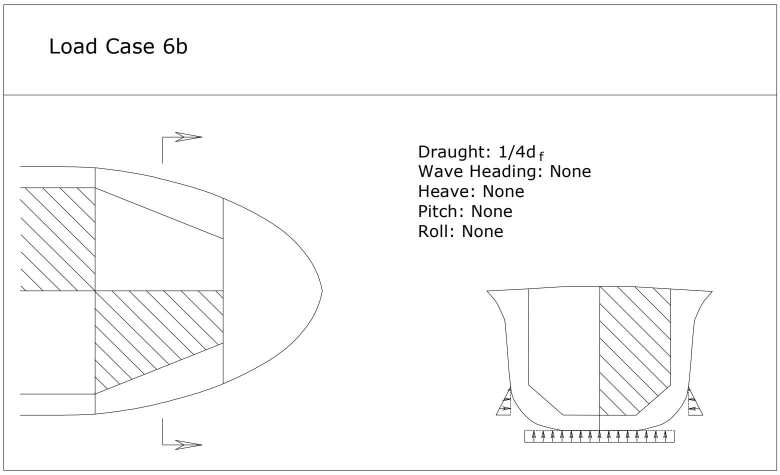
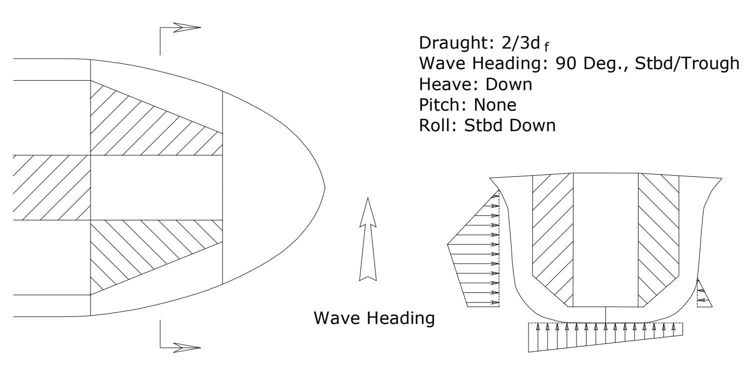


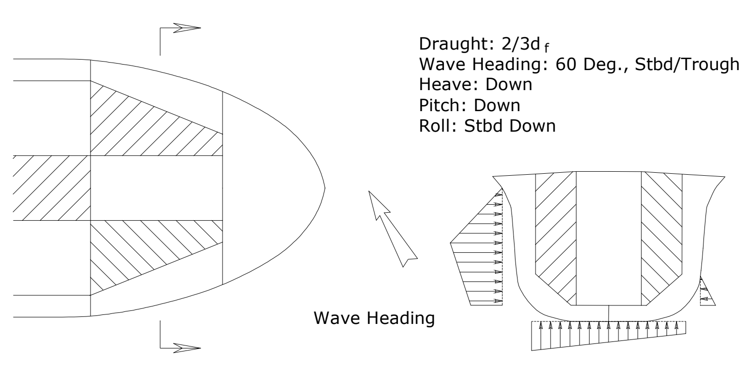
FIGURE 3
Standard Design Load Cases for Oil Carrier with Two Outer Longitudinal Bulkheads and Two Inner Longitudinal Bulkheads

Load Case 1a



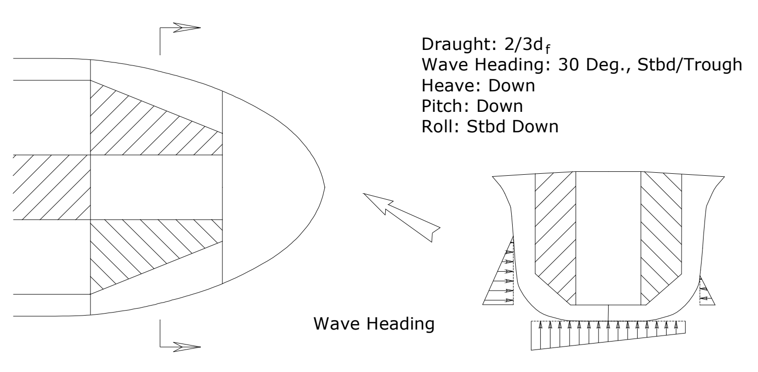
Draught: $2/3d_f$
Wave Heading: 90 Deg., Stbd/Trough
Heave: Down
Pitch: None
Roll: Stbd Down

Load Case 2a



Draught: $2/3d_f$
Wave Heading: 60 Deg., Stbd/Trough
Heave: Down
Pitch: Down
Roll: Stbd Down

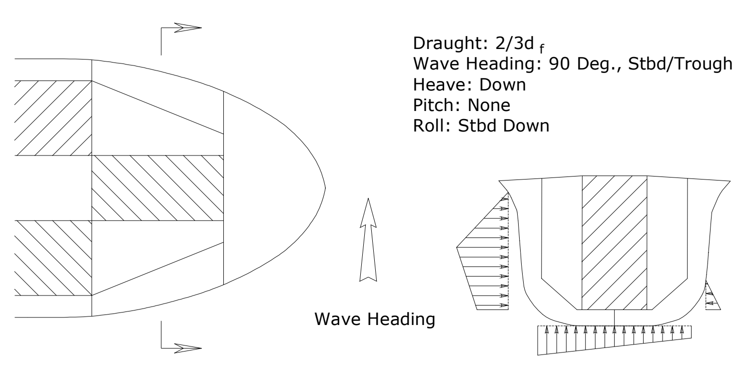
Load Case 3a



Draught: $2/3d_f$
Wave Heading: 30 Deg., Stbd/Trough
Heave: Down
Pitch: Down
Roll: Stbd Down

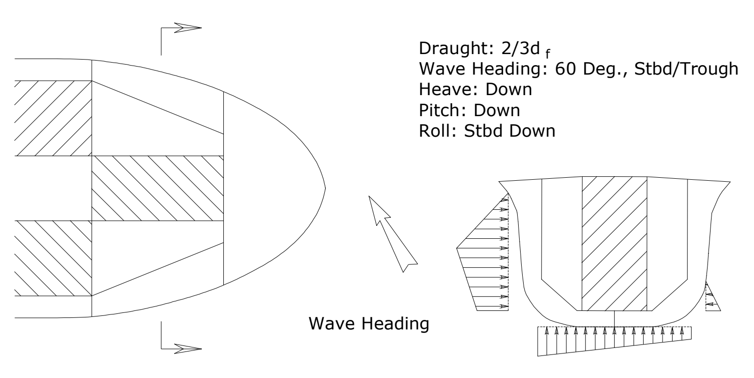
FIGURE 3 (continued) Standard Design Load Cases for Oil Carrier with Two Outer Longitudinal Bulkheads and Two Inner Longitudinal Bulkheads

Load Case 1b



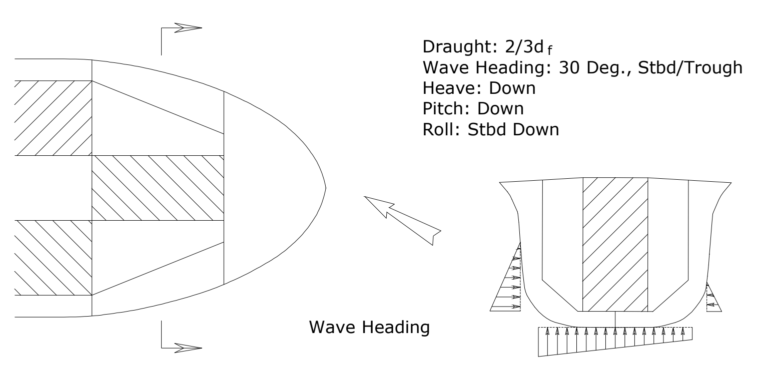
Draught: $2/3d_f$
Wave Heading: 90 Deg., Stbd/Trough
Heave: Down
Pitch: None
Roll: Stbd Down

Load Case 2b



Draught: $2/3d_f$
Wave Heading: 60 Deg., Stbd/Trough
Heave: Down
Pitch: Down
Roll: Stbd Down

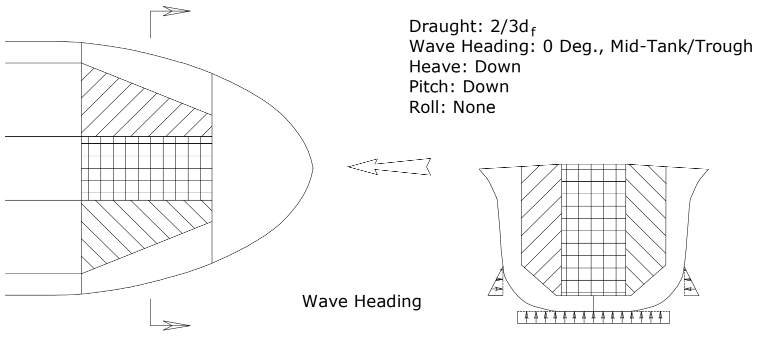
Load Case 3b



Draught: $2/3d_f$
Wave Heading: 30 Deg., Stbd/Trough
Heave: Down
Pitch: Down
Roll: Stbd Down

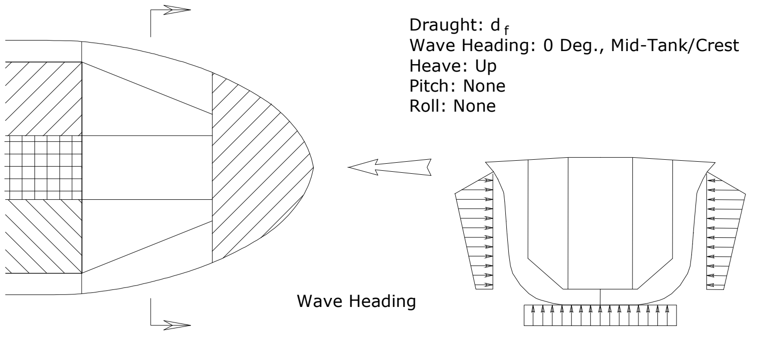
FIGURE 3 (continued)
Standard Design Load Cases for Oil Carrier with Two Outer Longitudinal Bulkheads and Two Inner Longitudinal Bulkheads

Load Case 4



Draught: 2/3d_f
Wave Heading: 0 Deg., Mid-Tank/Trough
Heave: Down
Pitch: Down
Roll: None

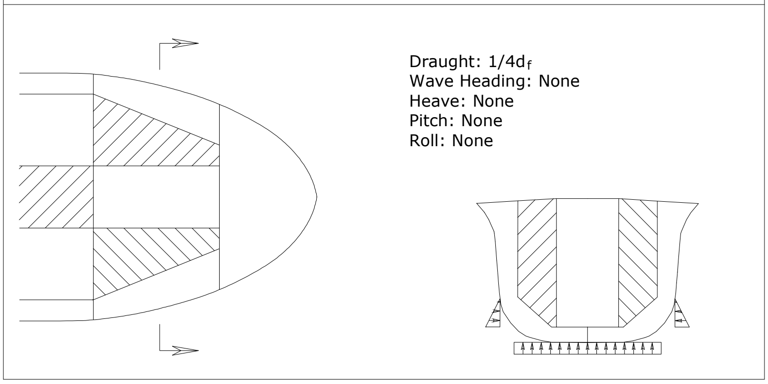
Load Case 5



Draught: d_f
Wave Heading: 0 Deg., Mid-Tank/Crest
Heave: Up
Pitch: None
Roll: None

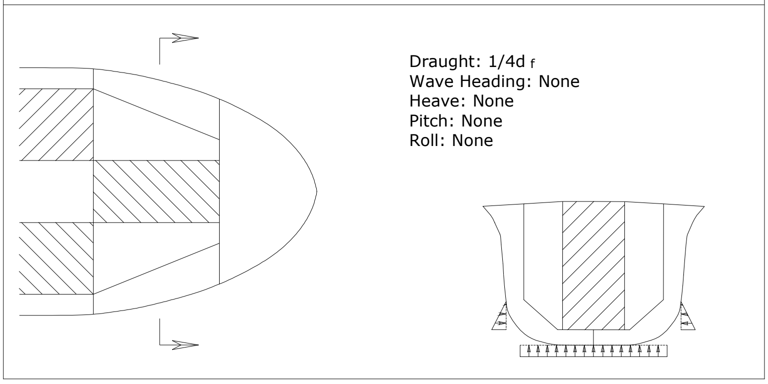
FIGURE 3 (continued)
Standard Design Load Cases for Oil Carrier with Two Outer Longitudinal Bulkheads and Two Inner Longitudinal Bulkheads

Load Case 6a



Draught: 1/4d_f
Wave Heading: None
Heave: None
Pitch: None
Roll: None

Load Case 6b



Draught: 1/4d_f
Wave Heading: None
Heave: None
Pitch: None
Roll: None

This Page Intentionally Left Blank

SECTION 4 Structural Modeling and Analysis

1 Net Ship Approach

The strength assessment procedure in these Guidance Notes is based on a “net” ship approach, wherein the nominal design corrosion values are deducted from the gross thickness. The “net” thickness or scantlings correspond to the minimum strength criteria as required by ABS Rules. In addition to the coating protection specified in the *Steel Vessel Rules* for all ballast tanks, the minimum corrosion values for plating and structural members as given in Section 4, Table 1 and Section 4, Figure 1 are to be applied. These minimum values are applied for the purpose of scantling checks, and are not to be construed as renewal standards.

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

Extra scantlings (i.e., Owner’s specified additional thickness), as included in the vessel’s design specifications, should not be used in the finite element model.

If a finite element model already constructed of gross scantlings is proposed for rapid strength assessment, the calculated stresses in the main supporting members are to be adjusted upward as follows:

- Axial stress in rod/bar elements used for modeling flanges $1.05 \times SM_g/SM_n$
- Component stresses in quadrilateral plate elements for modeling webs $1.05 \times t_g/t_n$

Where SM_g and SM_n are the gross and net section modulus of a main supporting member being evaluated, respectively. When calculating SM_g and SM_n, the effective breadth of the attached plate is not to exceed one half of the sum of the spacing on each side of the member, or 33% of the unsupported span, whichever is less. t_g and t_n are the gross and net thicknesses of the web plating, respectively. In addition, the buckling strength of individual panels is to be calculated based on the net scantlings.

3 Structural Idealization

3.1 Extent of Finite Element Model

To evaluate the main supporting members of a cargo tank structure beyond 0.4*L* amidships with reasonable accuracy, the finite element model should ideally locate the target cargo tank in the middle and extend approximately one half the length of the adjacent tanks fore and aft. Section 4, Figures 3 and 4 show the extents of typical fore and aft cargo tank finite element models, respectively.

For the fore cargo tank structure, it is recommended that the structure forward of the collision bulkhead be included in the finite element model. Otherwise, the model may be terminated at a relatively stiff cross section in the fore end structure. The aft end of the finite element model for an aft cargo tank structure may terminate at the aft transverse bulkhead of the slop tanks or engine room bulkhead.

For a cargo tank structure that is symmetrical with respect to the centerline, it is recommended that the finite element model cover both port and starboard sides of the vessel for convenience of post-processing and subsequent strength evaluation.

If the extent of a finite element model is shorter than recommended above, the boundary effects may be more significant and the carry-over load effects as a result of the adjacent tanks being loaded may not be suitably represented. In this case, strength assessment of structural members should, in principle, be carried out based on more conservative acceptance criteria. It is recommended that consultation be made with ABS on the acceptable criteria before commencing the strength evaluation using truncated models.

3.3 Finite Element Modeling

For the strength assessment of a cargo tank structure beyond 0.4*L* amidships, the finite element model should be so constructed as to capture the following structural behaviors:

- Primary hull girder bending
- Secondary bending of main supporting members between watertight boundaries
- Additional secondary bending between main supporting members

The finite element model should adequately represent the overall stiffness distribution of the main supporting members in the cargo tank structure. The model is to be prepared so that secondary in-plane bending will be accurately transmitted to supporting structural members.

Bar elements are commonly used to model longitudinals and stiffeners on watertight boundaries so that local pressures can be proportionally transmitted to main supporting members. Bar elements having the geometric properties of a stiffener should not be directly used as they are connected to the adjacent plate bending elements at the neutral axis, resulting in an incorrect moment of inertia for the stiffener/plating combination. Offset beam elements or bar elements having the correct moment of inertia (perpendicular to the attached plate) should be used. If longitudinals and stiffeners are modeled using rod (no bending stiffness) elements, local pressures on watertight boundaries are to be directly imposed on the main supporting members. Details of such load shifting are to be submitted for review.

In light of the concerns as referred to above, cargo tank structures beyond 0.4*L* amidships may be conveniently modeled using quadrilateral plate bending elements for plating, rod elements for flanges and bar elements for longitudinals/stiffeners. Quadrilateral membrane elements can also be used, provided local pressure loads do not cause singularities in the finite element model.

The number of triangular elements, or quadrilateral elements with less than ideal proportions, should be kept to a minimum and only be used to model less critical transitional areas. Critical areas should always be represented by quadrilateral elements of good proportion.

The recommended basic mesh size for capturing field stresses is one longitudinal spacing. The guidelines for a desirable meshing arrangement are listed below:

- Along the girth of a transverse cross sectional member, one element between two adjacent longitudinals or vertical stiffeners
- Longitudinally, three or more elements between two adjacent web frames fore and aft a transverse bulkhead (aspect ratio approximately equal to 1.0)

- Longitudinally, at least two elements between two adjacent web frames, sufficiently away from a transverse bulkhead (aspect ratio not to exceed 3.0)
- Three or more elements over the depth of double bottom floors, girders, side frames, side stringers, vertical webs and horizontal stringers on transverse bulkheads (aspect ratio approximately equal to 1.0)

However, to have critical structural details modeled with the desired accuracy, the mesh size is to be finer than the recommended basic mesh size. For access openings in way of suspected high stress areas or critical bracket details, element sizes of $^1/_5$ ~ $^1/_{10}$ longitudinal spacing may be required. Element sizes finer than $^1/_{10}$ longitudinal spacing are not recommended unless the stress concentration factor (SCF) at a structural detail is to be established. Any transition from relatively coarse mesh to finer mesh is to be smooth and gradual. Alternatively, the basic mesh size can be applied throughout the model, and the structural details separately evaluated either by fine mesh finite element models or justified by good in-service experience.

Away from high stress areas, it is not recommended to model an opening by deleting elements or having reduced plate thickness as the stresses obtained from such meshing arrangements tend to be unrealistic. If openings are not modeled, the finite element stresses are to be adjusted during post processing for the subsequent strength evaluation to account for reduced effective shear areas.

Section 4, Figure 4 shows one acceptable meshing arrangement for a bracket toe for calculating the field or local stress. It is generally not recommended to have the rod or bar element at the tip of the bracket toe directly connected to the attached plating. If the field stress is found approaching the stress limit, a finer mesh model of the bracket may need to be further evaluated.

Rod elements may be used to model the flanges of main supporting members and the first two rows of web stiffeners that are parallel to the flanges. If a web stiffener is sniped at one end, the effective axial area is to be 65% of the cross section area. If both ends are sniped, the effective axial area is to be taken as 30% of the cross section area.

5 Boundary Constraints for Local and Hull Girder Sub Load Cases

For each standard design load case listed in Section 3 of these Guidance Notes, the load components can be categorized into local and hull girder sub load cases. For each sub load case, the boundary constraints are different. Within a linear, elastic domain, the results for the local and hull girder sub load cases can be combined to obtain the final results of the standard design load cases.

5.1 Local Sub Load Case

The internal pressure in each ballast or cargo tank can essentially be described by linear pressure distributions in the longitudinal, transverse and vertical directions. It is recommended that these linear pressure distributions are first created as component load cases and repeatedly used to define the local sub load cases for all standard design load cases. This can generally be achieved using appropriate finite element modeling software.

The finite element model is to be supported by vertical and horizontal springs to absorb and distribute any unbalanced forces in the longitudinal and transverse directions. These springs are to be placed along continuous deck, side shell, internal longitudinal bulkheads, bottom and inner bottom. Section 4, Figure 5 illustrates the distribution and attachment of the springs to the model, the other ends of the springs are fixed. These springs may be modeled using rod elements with the cross sectional area defined as follows:

$$A_s = 0.77 \frac{A_{shear} \ell_s}{n \ell_t}$$

where n is the number of springs fitted in a cross section.

Additionally, δ_x, θ_y and θ_z at the end of the finite element model close to the midship region are to be restrained. Here, δ_x is the translational displacement in the X direction in the finite element coordinate system. θ_y and θ_z are the rotational displacements in the Y and Z directions.

Alternative methods of constraining and balancing the model may be applied upon ABS review of the details.

5.3 Hull Girder Sub Load Case

The fore and aft cargo tank structures typically extend beyond 0.4L amidships, and the design vertical and horizontal wave-induced bending moments linearly taper to zero at both ends of the scantling length. The allowable still-water bending moments often follow a similar tapering pattern. A convenient method to simulate a linearly varying hull girder bending moment is illustrated in Section 4, Figure 6 and involves the following steps:

- Fully constrain the aft end of the fore cargo tank model or the fore end of the aft cargo tank model.
- Select a relatively stiff cross section such as collision bulkhead or engine room bulkhead to apply the target hull girder bending moments at a distance X_{load} from the fully constrained end.
- Apply vertical and horizontal bending moments M_{VL} and M_{HL} at the stiff cross section.
- Apply, at the same cross section, vertical and horizontal forces F_{VL} and F_{HL}, which can be calculated from vertical and horizontal bending moments M_{VF} and M_{HF} at the fully constrained end as follows.

$$F_{VL} = (M_{VF} - M_{VL})/X_{load}$$

$$F_{HL} = (M_{HF} - M_{HL})/X_{load}$$

7 Overall Check of Finite Element Results

Before proceeding to the strength evaluation of main supporting members in accordance with the acceptance criteria given in Section 5 of these Guidance Notes, the finite element results should be checked for the overall accuracy of the finite element model and the correct transmission of the local and hull girder loads.

The deformed overall finite element model can be visually examined for the expected deformation patterns and the appearance of abnormal nodal displacements due to singularity. Correct deformation patterns are indicative of the adequacy of the boundary constraints. The finite element model can first be analyzed for the local and hull girder sub load cases, and the final results for the standard design load cases are obtained by linear combinations of these sub load cases. Therefore, multi-level visual examination of the deformed overall model can be carried out for the specified load cases.

Visual examination of the deformed main supporting members of cargo or ballast tanks should also be carried out in the same manner to ensure correct application of local pressures.

In addition to the above visual examination of the deformed overall finite element model and element representations of main supporting members and tanks, the stress magnitudes are to be compared with those calculated using simple beam theory. For the hull girder sub load cases, comparison is typically made at the deck at side, sufficiently away from the boundaries and transverse bulkheads. The stress levels of the main supporting members in the local load cases should be generally consistent with the applied local pressures.

TABLE 1
Nominal Design Corrosion Values (NDCV)

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

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 The nominal design corrosion values in the forepeak tank may be taken as 1.5 mm in determining design scantlings.

FIGURE 1
Nominal Design Corrosion Values (NDCV)

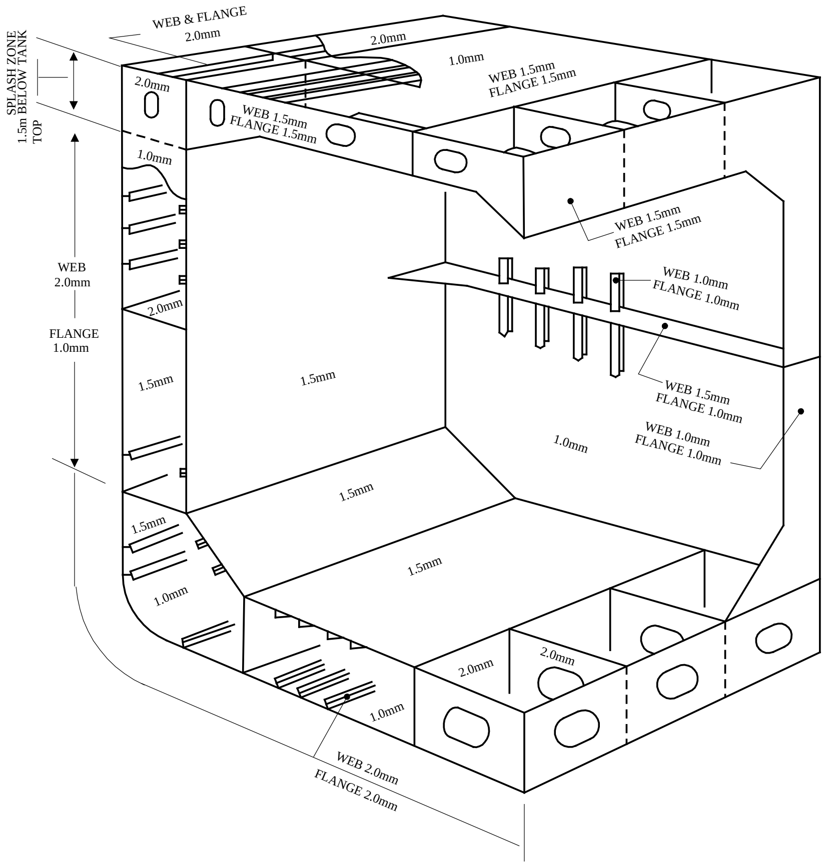


FIGURE 2
Typical Finite Element Model for Foremost Cargo Tank Structure

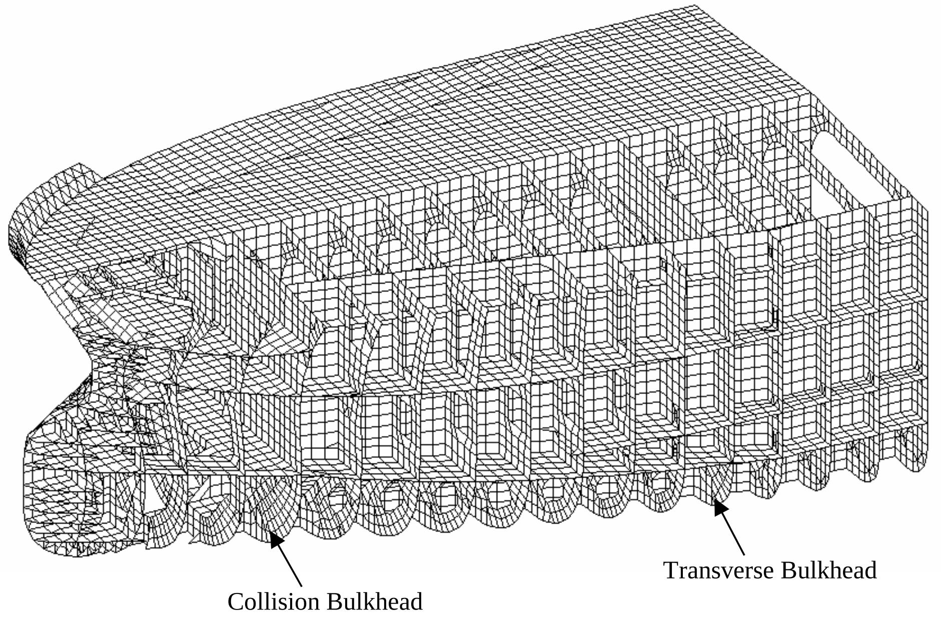


FIGURE 3
Typical Finite Element Model for Aftmost Cargo Tank Structure

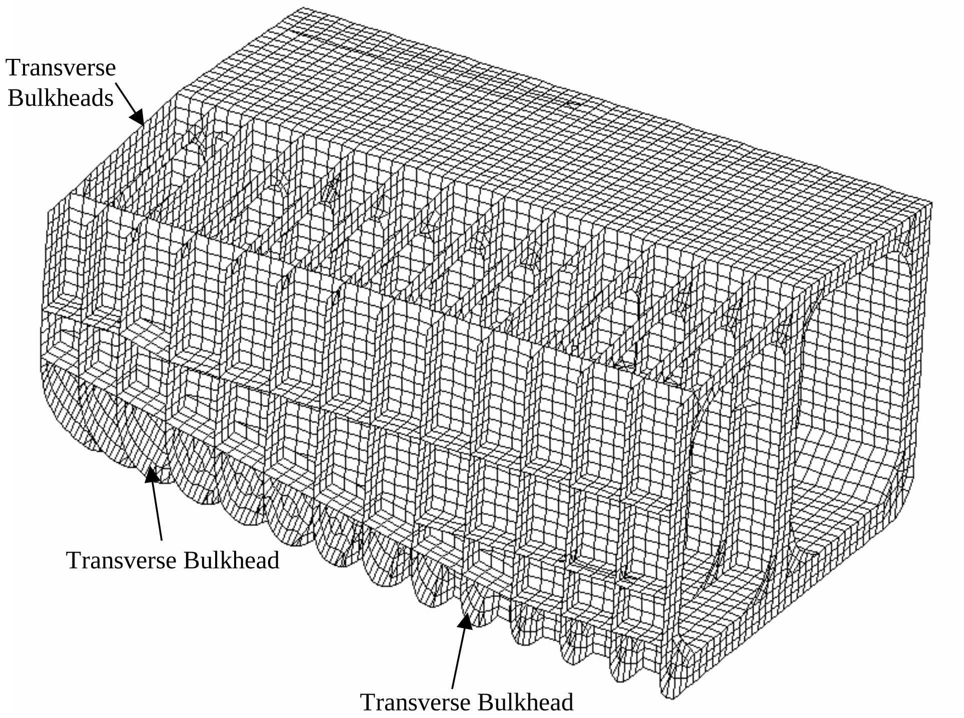


FIGURE 4
Modeling of Bracket Toe and Tapered Face Plate

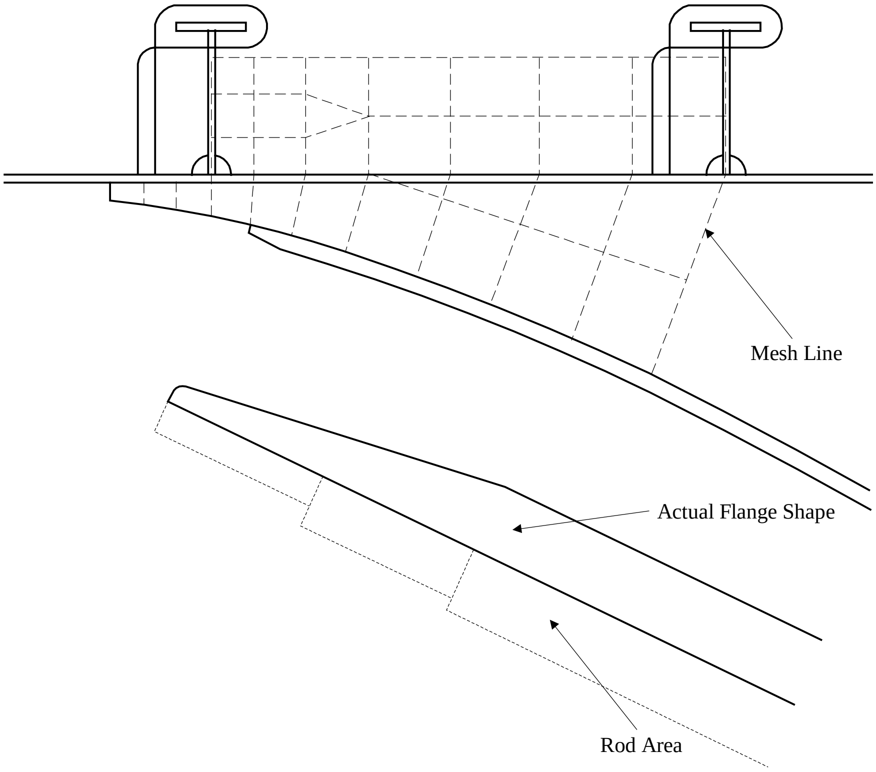
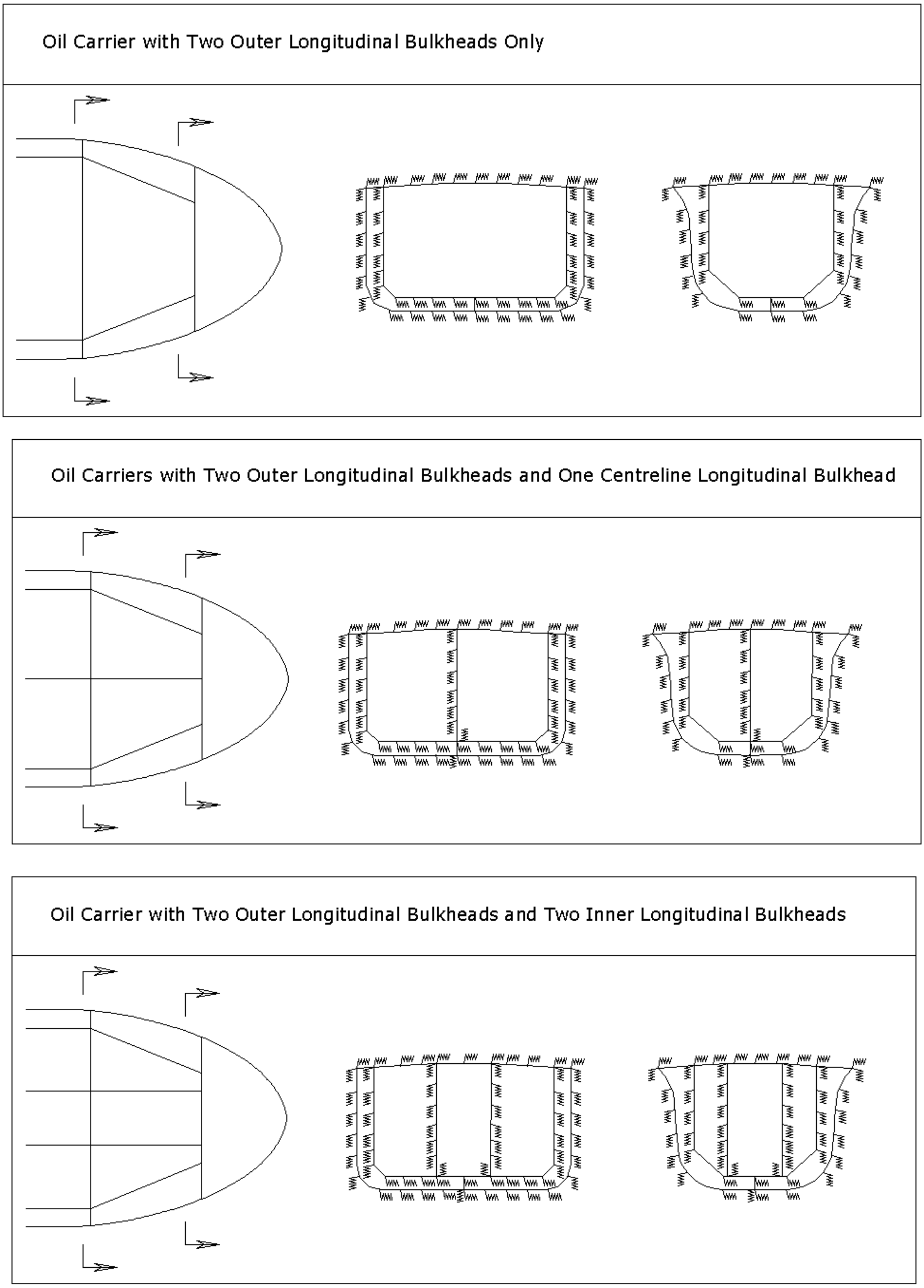


FIGURE 5
Boundary Constraints for Local Sub Load Cases

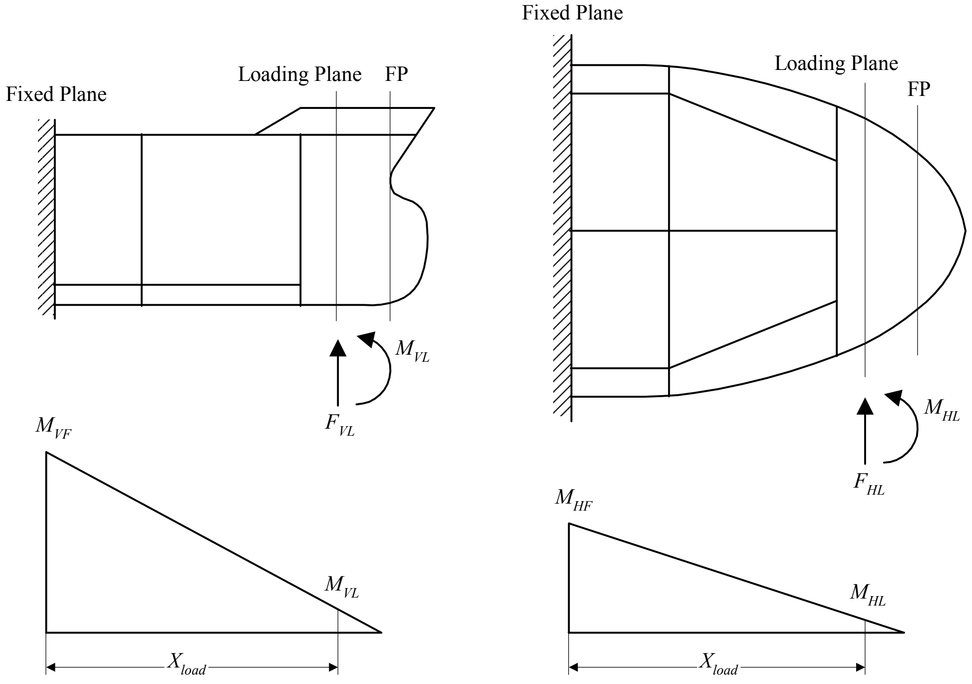


Oil Carrier with Two Outer Longitudinal Bulkheads Only

Oil Carriers with Two Outer Longitudinal Bulkheads and One Centreline Longitudinal Bulkhead

Oil Carrier with Two Outer Longitudinal Bulkheads and Two Inner Longitudinal Bulkheads

FIGURE 6
Loads and Boundary Constraints for Hull Girder Sub Load Cases



Distribution of Vertical Bending Moment

Distribution of Horizontal Bending Moment

This Page Intentionally Left Blank

SECTION 5 Acceptance Criteria

1 General

To assess the adequacy of the structural configuration and the initially selected scantlings, the main supporting members are to be reviewed for compliance with the strength criteria for yielding and buckling. Individual elements are checked for yielding while buckling is verified for individual plate panels supported along four edges by stiffeners or other structural members.

3 Yielding Failure Mode

It is generally expected that finer finite element mesh induces higher resultant stress from a linear elastic analysis. However, the increase in stress is not just a function of finite element mesh size. It may also depend on the relative stiffness of adjoining structural members and the loading pattern. When a flexible member is connected to a stiff member, the increase in stress will be higher than when two flexible members are joined together. The increase in stress will also be higher when bending is applied as compared to axial loads. In other words, the increase in stress due to a reduction in mesh size depends mainly on the expected stress gradient in the joint.

Given the recommended basic mesh of one longitudinal spacing for main supporting members and finer meshing for critical structural details such as openings and bracket toes, the resulting stresses may be categorized into the following three levels of stresses:

3.1 Field Stress

Field stresses are indicative of stress severity within main supporting members sufficiently away from structural details such as openings and bracket toes. The recommended basic mesh size for capturing field stresses is one longitudinal spacing. Element stresses directly obtained from 3D finite element models of one longitudinal spacing can be considered as field stresses. For main supporting members, field stresses are primarily due to primary hull girder deformation and secondary bending between watertight boundaries. In practice, mesh size up to $^1/_3$ longitudinal spacing is often used to calculate field stresses.

3.3 Local Stress

Local stresses reflect stress variation due to the presence of structural openings, details and discontinuities. Local stresses can be determined from elements having a mesh size in the range of 1/5 to 1/10 longitudinal spacing. This mesh size is finer than that used for determining the field stresses, but is still relatively coarse for determining stress concentration factors.

3.5 Hot-Spot Stress

A hot-spot stress is at one particular critical point in a structural detail where fatigue cracking is expected to initiate. The hot-spot stress includes stress risers due to structural discontinuities and presence of attachments, but excludes the effects of welds. To determine hot-spot stresses, the mesh size needs to be finer than $^1/_{10}$ longitudinal spacing, but not finer than plate thickness.

3.7 Allowable Stresses for Various Finite Element Mesh Sizes

The allowable stress for the recommended basic mesh size is the minimum specified yield stress f_y times the strength reduction factor S_m. Application of this allowable stress to rod and beam elements is based on axial stress while von-Mises membrane stresses for quadrilateral elements are checked.

To calculate the local stress distribution in a main supporting member, it is often necessary to model openings, details and discontinuities using various mesh sizes. In areas of high stress gradient, the allowable stresses should be adjusted according to mesh sizes and are listed in Section 5, Table 1.

TABLE 1
Allowable Stresses (kgf/cm^2) for Various Finite Element Mesh Sizes

Mesh Size	Stress Limit	Mild Steel (S_m = 1.000)	HT32 (S_m = 0.950)	HT36 (S_m = 0.908)
1 × LS	1.00 × $S_m f_y$	2400	3040	3269
$^1/_2$ × LS (1)	1.06 × $S_m f_y$	2544	3222	3465
$^1/_3$ × LS (1)	1.12 × $S_m f_y$	2688	3404	3661
$^1/_4$ × LS (1)	1.18 × $S_m f_y$	2832	3587	3857
$^1/_5$ × LS ~ $^1/_{10}$ × LS (1)	1.25 × $S_m f_y$	3000	3800	4086
Thickness (1, 2)	f_u or 1.50 × $S_m f_y$	4100	4500	4903

Notes

1 Stress limits greater than 1.0 $S_m f_y$ are to be restricted to small areas in way of structural discontinuities.

2 When the fatigue strength of the detail is found satisfactory, the hot spot stress in the detail may be allowed up to the minimum tensile strength of the material.

5 Buckling Failure Mode

Typically, three stress components should be considered in the evaluation of buckling strength of plate panels in main supporting members; namely, uniform compressive stress, f_{Lb}, ideal bending stress, f_b and total in-plane shear stress, f_{LT}. A rectangular plate panel in the finite element model consists of several elements, which may be regularly meshed without openings or less regularly meshed with openings. These stress components are essentially representative values for the whole panel and may be calculated from the in-plane displacements at the four corners of the panel.

For calculating the plate panel stresses, the following equations may be used:

$$f_1 = \frac{E}{1-\nu^2}\left[\frac{-u_1+u_2}{a}+\frac{\nu^2(u_1-u_2+u_3-u_4)}{2a}+\frac{\nu(-v_1-v_2+v_3+v_4)}{2b}\right]$$

$$f_2 = \frac{E}{1-\nu^2}\left[\frac{u_3-u_4}{a}+\frac{\nu^2(-u_1+u_2-u_3+u_4)}{2a}+\frac{\nu(-v_1-v_2+v_3+v_4)}{2b}\right]$$

$$f_{Lb} = \frac{f_1+f_2}{2} \le 0$$

$$f_b = \frac{f_1-f_2}{2}$$

$$f_{LT} = \frac{E}{4(1+\nu)}\left[\frac{-u_1-u_2+u_3+u_4}{b}+\frac{-v_1+v_2+v_3-v_4}{a}\right]$$

where

u_i = in-plane *x* displacement at one corner point in the local *x*-*y* coordinate system (i = 1, 2, 3, 4).

v_i = in-plane *y* displacement at one corner point in the local *x*-*y* coordinate system (i = 1, 2, 3, 4).

ν = Poisson ratio of the material and may be taken as 0.3 in this application for steel.

Corner 1 is assigned to the node located at the bottom left corner of the panel in the local coordinate system. The line joining Corners 1 and 2 is parallel to the *x* coordinate, and Corners 3 and 4 are numbered counterclockwise (see Section 5, Figure 1). This calculation 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 equations 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_{Lb}, f_b and f_{LT} may also be directly calculated from the component stresses for the elements in the panel.

The concept and formulae for the buckling strength criteria in this Section and Appendix 1 are identical to those in 5C-1-5/5 of the *Steel Vessel Rules* and are included here for ready reference.

5.1 Buckling Control Concepts

The buckling strength criteria are based on the following assumptions and limitations with respect to buckling control in design:

- 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 A1/7.3 of these Guidance Notes. In addition, tripping (e.g. lateral- torsional instability) is to be prevented as specified in A1/5.5.

- Face plates and flanges of main supporting members are proportioned such that local instability is prevented. (See A1/7.5 of these Guidance Notes).

- 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 Subsection A1/3 of these Guidance Notes.

- For structures that do not satisfy these assumptions, a detailed analysis of buckling strength using an acceptable method is to be submitted for review.

5.3 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 A1/7.1 of these Guidance Notes. Web stiffeners which are oriented parallel to and near the face plate, and thus subject to axial compression, are also to have adequate buckling strength, 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 limit specified below:

$$\left(\frac{f_{Lb}}{f_{cLb}}\right)^2 + \left(\frac{f_b}{f_{cb}}\right)^2 + \left(\frac{f_{LT}}{f_{cLT}}\right)^2 \le S_m$$

where

f_{Lb} = calculated uniform compressive stress, in kgf/cm^2

f_b = calculated ideal bending stresses, in kgf/cm^2

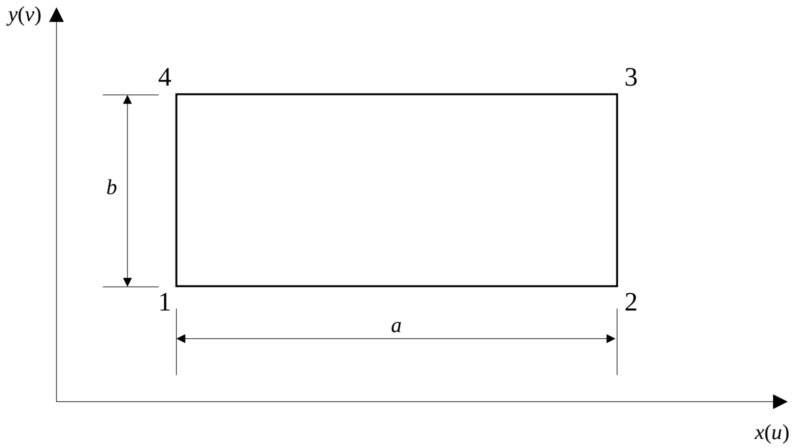
f_{LT} = calculated total in-plane shear stress, in kgf/cm^2

f_{Lb}, f_b and f_{LT} are to be calculated for the panel in question under the combined load cases specified in Section 3 (also see Subsection 5/5).

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 1.

In the determination of f_{cL}, f_{cb} and f_{cLT}, the effects of openings are to be accounted for. A practical method of determining f_{cL}, f_{cb} and f_{cLT} is the well established eigenvalue analysis method with suitable edge constraints. 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.

FIGURE 1
Coordinate System for Buckling Strength Evaluation



SECTION 6 Documentation of Strength Assessment for Classification Review

A technical report is to be prepared to document the essential information used in the strength assessment and submitted to ABS for review. As a minimum, the documentation should include the following:

- A list of reference structural drawings, including dates and versions
- The particulars of the finite element modeling, analysis and post-processing programs used
- Vessel’s design load envelope curves, such as still-water bending moment curves
- Extra scantlings as defined in vessel’s design specifications
- LCG, VCG, TCG and volume of each cargo or ballast tank
- Effective pitch and roll amplitudes
- Effective accelerations in longitudinal, transverse and vertical direction for each cargo or ballast tank
- External pressure distribution at the mid-tank cross section for $^1/_4 d_f$, $^2/_3 d_f$ and d_f as for standard design load cases 1~6
- Physical parameters and load combination factors defining standard design load cases
- Detailed description of finite element structural modeling and assumptions
- Description of material properties
- Description of load application and boundary constraints for hull girder and local sub load cases
- Plots showing finite element meshing and net scantlings
- Vertical and horizontal moments of inertia and neutral axes of the reference section
- Plots showing internal and external pressure distributions of typical cross sections and elevations
- Stress/deformation plots and verification of structural behavior under local and hull girder sub load cases
- Stress/deformation plots of overall structural model and critical areas under standard design load cases to demonstrate the acceptance criteria are not exceeded
- Results for buckling strength assessments of main supporting members
- Component, von-Mises and principal stress plots of critical structural members/details
- Recommended modifications to the reference drawings and strength assessment results for modified structural members/details

ABS may request detailed results and data files for verification and reference so that any suspected discrepancies can be quickly identified.

This Page Intentionally Left Blank

APPENDIX 1 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

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, kgf/cm^2

f_{Ei} = $K_i\,[\pi^2 E/12(1 - \nu^2)](t_n/s)^2$, kgf/cm^2

K_r = buckling coefficient, as given in Appendix 1, Table 1

E = modulus of elasticity of the material, may be taken as 2.1×10^6 kgf/cm^2 for steel

ν = Poisson's ratio, may be taken as 0.3 for steel

t_n = net thickness of the plate, in cm

s = spacing of longitudinals/stiffeners, in cm

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 kgf/cm^2

5 Deep Girders, Webs and Stiffened Brackets

5.1 Critical Buckling Stresses of Web Plates and Large Brackets

The critical buckling stresses of web plates and large brackets between stiffeners may be obtained from the equations given in Subsection A1/3 for uniaxial compression, bending and edge shear.

5.3 Effects of Cut-outs

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 sub-sections below.

5.3.1 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 the web plate between stiffeners with respect to compression and shear may be obtained from equations given in Subsection A1/3.

5.3.2 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 Subsection A1/3, 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.

5.3.3 No Reinforcement Provided

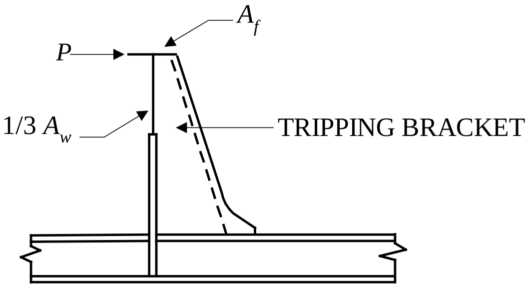
When reinforcement is not provided, the buckling strength of the web plate surrounding the cut-out may be treated as a strip of plate with one edge free and the other edge simply supported.

5.5 Tripping

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.

The 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, kgf/cm^2

= f_{ce}, for $f_{ce} \leq P_r f_y$

= $f_y [1 - P_r(1 - P_r) f_y / f_{ce}]$, for $f_{ce} > P_r f_y$

f_{ce} = $0.6E[(b_f/t_f)(t_w/d_w)^3]^{1/2}$, kgf/cm^2

A_f = net cross sectional area of the flange/face plate, in cm^2

A_w = net cross sectional area of the web, in cm^2

b_f, t_f, d_w, t_w are width and thickness of flange and web, respectively. E, P_r and f_y are as defined in Subsection A1/3.

If a tripping bracket is to be individually analyzed under the standard design load cases, the tripping force, P, acting to be supported by the bracket may be calculated by replacing $f_{c\ell}$ in the above equation with the actual axial stress in the flange.

7 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.

7.1 Stiffness of Web Stiffeners

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 that obtained from the following equations:

$i = 0.17\ell t^3(\ell/s)^3$ cm^4, for $\ell/s \leq 2.0$

$i = 0.34\ell t^3(\ell/s)^2$ cm^4, for $\ell/s > 2.0$

where

ℓ = length of stiffener between effective supports, in cm

t = required net thickness of web plating, in cm

s = spacing of stiffeners, in cm

7.3 Stiffness of Supporting Members

The net moment of inertia of the main supporting members, such as transverses and webs, is not to be 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 main supporting member, including the effective plating, cm^4

i_o = moment of inertia of the longitudinals, including the effective plating, cm^4

B_s = unsupported span of the main supporting member, cm

ℓ = unsupported span of the longitudinal, in cm

s = spacing of longitudinals, in cm

7.5 Proportions of Flanges and Face Plates

The breadth-thickness ratio of flanges and face plates of main supporting members 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, cm

t_f = net thickness of flange/face plate, cm

E and f_y are as defined in Subsection A1/3.

TABLE 1
Buckling Coefficient K_i

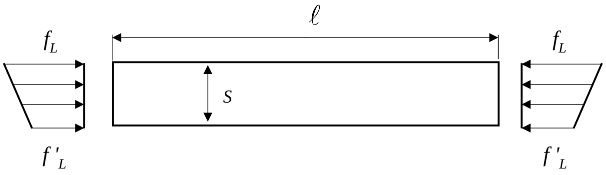
For Critical Buckling Stress Corresponding to f_L, f_T, f_b or F_{LT}

1. Plate panel between stiffeners — K_i

A Uniaxial compression

1. Long plate

$\ell \geq s$



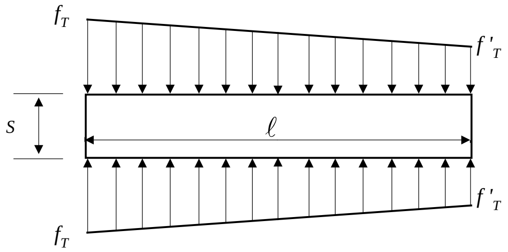
a. For f'_L, $= f_L$: $4C_1$,

b. For f'_L, $= f_L/3$: $5.8C_1$,

(see note)

2. Wide plate

$\ell \geq s$



a. For f'_T, $= f_T$: $[1 + (s/\ell)^2]^2 C_2$

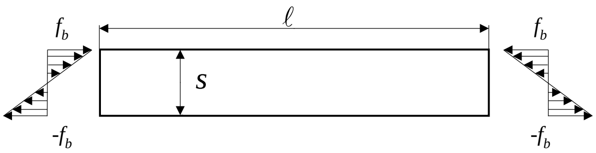
b. For f'_T, $= f_T/3$: $1.45[1 + (s/\ell)^2]^2 C_2$

(see note)

B Ideal Bending

1. Long plate

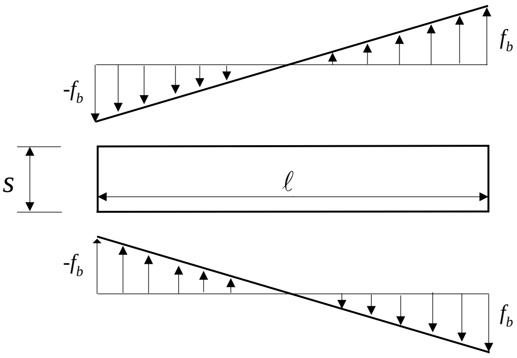
$\ell \geq s$



$24C_i$

2. Wide plate

$\ell \geq s$

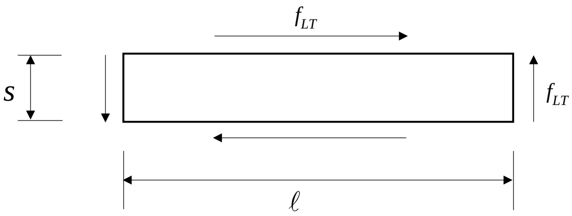


a. For $1.0 \leq \ell/s \leq 2.0$: $24\ (s/\ell)^2 C_2$

b. For $2.0 < \ell/s$: $12\ (s/\ell) C_2$

(see note)

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

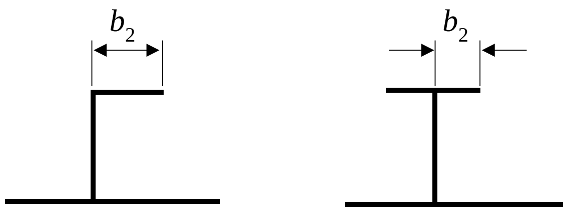
C = 0.11 for flat bars

B Ideal Bending

Same as I.B. $24C$

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.