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GUIDANCE NOTES
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GUIDELINES FOR DIRECT STRENGTH ANALYSIS OF HULL STRUCTURE OF ORE CARRIERS

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北 京
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PREFACE

In order to meet the demands for development and design of large ore carriers in the industry and cooperate with the national development and research scheme on large ore carriers, established by the original National Defense Science and Technology Commission and entrusted by the China's Society of Naval Architecture and Marine Engineering, China Classification Society carried out research and developed the Guidance Notes for Direct Strength Analysis of Hull Structure of Ore Carriers based on CCS Rules for Classification of Sea-going Steel Ships, Guidelines for Direct Strength Analysis of Double Side Skin Bulk Carriers, Guidelines for Direct Strength Analysis of Oil Tankers and Guidelines for Fatigue Strength of Ship Structure in 2009. According to the feedbacks from plan approval and classification working for multi-typed ore carriers, CCS revised the guidance notes and issued the Guidelines for Direct Strength Analysis of Hull Structure of Ore Carriers (2014 version) in the year of 2014.

As larger type of ore carriers flourishes, more comprehensive and advanced requirements on strength assessment are to be provided, therefore, on the basis of the Guidelines (2014 version), the assessment extents of block direct calculation are extended to the entire cargo hold region and engine room area, load and loading condition, model boundary and load adjustment, buckling assessment method, fatigue strength analysis method, effect of ore containing moisture on structural strength, global finite element of ship, etc., combined with the CSR rules and GBS research results, applicability research and full scale verification have been carried out, based on which the Guidelines (2016 version) is upgraded, finally.

The main contents of the Guidelines include the followings:

1) to provide the scope of application, definitions of ship type and symbols;
2) to provide wave loads and loading conditions for calculation;
3) modeling requirements, analysis extents, hull girder adjustment and allowable criteria for hold direct calculation;
4) locations of stress assessment for refined meshing, modeling requirements and allowable criteria;
5) definitions of panel buckling strength assessment, definitions of property, buckling capability and strength criteria;
6) modeling requirements for global direct calculation, definitions of loading condition, load calculation and stress criteria;
7) modeling of engine room block direct calculation, loads, hull girders adjustment and allowable criteria;
8) supplementary requirements to block direct calculation required by ore containing moisture;
9) supplementary requirements to hull structural fatigue strength assessment for ore carriers.

CONTENTS

CHAPTER 1 GENERAL
1.1 General Requirements
1.2 Definitions
1.3 Scantlings of Structural Member

CHAPTER 2 LOAD CASES
2.1 General Requirements
2.2 Dynamic Load Cases
2.3 Ship Motions and Accelerations
2.4 Hull Girder Loads
2.5 External Loads
2.6 Internal Loads
2.7 Loading Conditions

CHAPTER 3 DIRECT STRENGTH ANALYSIS OF CARGO HOLD REGION
3.1 General Requirements
3.2 Structural Modeling
3.3 FE Load Combinations
3.4 Analysis Criteria
3.5 Local Structural Strength Analysis

CHAPTER 4 BUCKLING STRENGTH ASSESSMENT
4.1 General Requirements
4.2 Type of Panel
4.3 Buckling Capability
4.4 Strength Criteria
Appendix A Stress Based Reference Stresses
Appendix B Buckling Factors and Reduction Factors of Panels

CHAPTER 5 GLOBAL FINITE ELEMENT STRENGTH ASSESSMENT FOR SHIP
5.1 General Requirements
5.2 Model Requirements
5.3 Hydrodynamic Load Calculation
5.4 Global Ship Loads Applied and Inertia Balance
5.5 Strength Assessment Criteria

Appendix 1 Direct Strength Analysis of Engine Room Structures
1.1 General Requirements
1.2 Structural Modeling
1.3 Loads
1.4 Analysis Criteria

Appendix 2 Requirements for Finite Element Calculation of Cargo Hold Carrying Ores Containing Moisture

2.1 General Requirements

2.2 Liquefied Ore Loads and Calculation Conditions

2.3 Finite Element Model

2.4 Assessment Areas and Criteria

2.5 Buckling Strength Assessment

Appendix 3 Requirements for Hull Structural Fatigue Strength Assessment of Ore Carriers

3.1 General Requirements

3.2 Loading Conditions and Loads

3.3 Simplified Stress Analysis

3.4 Finite Element Hot Spot Stress Analysis

CHAPTER 1 GENERAL

1.1 General Requirements

1.1.1 The Guidelines apply to the direct strength calculation and assessment of self-propelled ships of 150 m or over in length navigating in unrestricted service which are constructed generally with single deck, two longitudinal bulkheads and a double bottom throughout the cargo length area and intended primarily to carry ore cargoes in the centre holds only. Typical midship sections are given in Figure 1.1.1.

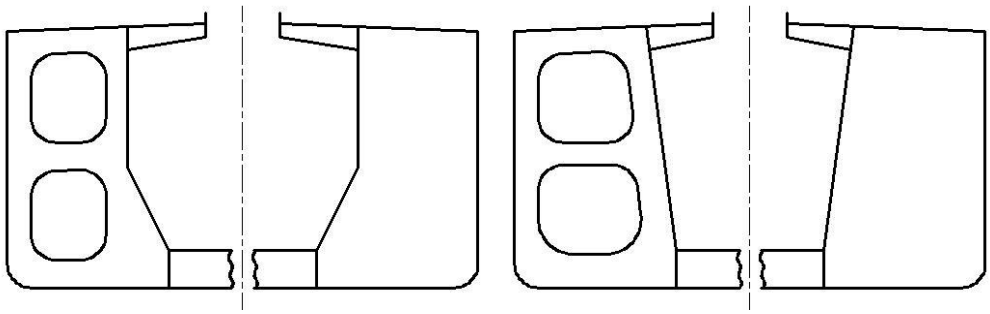


Figure 1.1.1 Typical Midship Sections of Ore Carrier

1.1.2 The Guidelines provide strength assessment requirements for primary structural members in cargo hold region and engine room area, cargo hold yield strength, refinement strength, buckling strength, global strength assessment method and supplementary requirements for cargo hold carrying ore containing moisture for ore carriers.

1.1.3 For the fatigue strength assessment of main structures in cargo hold region, refer to the relevant requirements in Appendix 3 of the Guidelines. Effects of springing and whipping on hull structural fatigue strength for ore carriers with the length of 250 m and above are to be specially considered in accordance with the requirements of CCS Guidelines for Calculation of Effects of Springing and Whipping on Hull Structural Fatigue Strength.

1.1.4 The direct calculation may adopt an applicable general procedure. Where a non-general procedure is used, reliability documentation of computer procedures is to be submitted by the applicant.

1.1.5 Documents of direct strength calculation are to be submitted to CCS for reference during examination of relevant drawings, which are to include:

(1) list of drawings used;

(2) detailed description of FE model of structure;

(3) verification of the structural model and associated physical properties;

(4) details of material properties;

(5) detailed description of boundary conditions;

(6) details of applied loads;

(7) figures and results showing structural model response related to loads;

(8) summary, including figures, of the global and local deformations;

(9) summary, including figures, showing Von Mises stress, stresses in x and y directions and shear stresses of all structural members in compliance with the strength criteria;

(10) plate buckling analysis and results;

(11) tabular output showing the results meeting or not meeting strength criteria;

(12) proposed structure modifications, including stress assessment and buckling characteristics, where necessary.

1.2 Definitions

1.2.1 Units

Mass: ton (t);

Length: metre (m);

Time: second (s);

Force: Newton (N) or kilonewton (kN);

Stress: Newton/mm^2 (N/mm^2);

Pressure: Kilonewton/m^2 (kN/mm^2).

1.2.2 Symbols

L — rule length of ship, in m, as defined in Section 1, Chapter 1, PART TWO of CCS Rules for Classification of Sea-going Steel Ships;

B — moulded breadth of ship, in m, as defined in Section 1, Chapter 1, PART TWO of CCS Rules for Classification of Sea-going Steel Ships;

D — moulded depth, in m, as defined in Section 1, Chapter 1, PART TWO of CCS Rules for Classification of Sea-going Steel Ships;

T — draught, in m, as defined in Section 1, Chapter 1, PART TWO of CCS Rules for Classification of Sea-going Steel Ships;

C_B — block coefficient, as defined in Section 1, Chapter 1, PART TWO of CCS Rules for Classification of Sea-going Steel Ships;

V — the greatest speed which the ship is designed to maintain in service at her deepest seagoing draught at the maximum propeller RPM and corresponding engine MCR (Maximum Continuous Rating);

g — gravitational acceleration, g = 9.81 m/s^2;

C_w — wave coefficient, calculated by the following equations:

$$C_w = 10.75 - \left(\frac{300 - L}{100}\right)^{1.5} \text{ for ships of } \quad 90 \le L \le 300$$

$$C_w = 10.75 \text{ for ships of } \quad 300 < L \le 350$$

$$C_w = 10.75 - \left(\frac{L - 350}{150}\right)^{1.5} \text{ for ships of } \quad 350 < L \le 500;$$

ρ — density of seawater, ρ = 1.025 t/m^3;

σ_e —Von Mises stress, in N/mm^2, $\sigma_e = \sqrt{\sigma_x^{\,2} + \sigma_y^{\,2} - \sigma_x\sigma_y + 3\tau_{xy}^{\,2}}$;

σ_x — stress of element in x direction, in N/mm^2;

σ_y — stress of element in y direction, in N/mm^2;

τ_{xy} — shear stress of element in xy planes, in N/mm^2;

σ_l — longitudinal stress of hull girder, in N/mm^2;

σ_a — axial stress of beam element, in N/mm^2;

σ_w — transverse or vertical stress of hull girder, in N/mm^2;

τ — average shear stress within overall web depth, in N/mm^2;

K — material factor, see Section 3, Chapter 1, PART TWO of CCS Rules for Classification of Sea-going Steel Ships;

E — elastic modulus of material, $E = 2.06\times10^5$ N/mm^2 for steel;

v — Poisson's ratio of material, $v = 0.3$ for steel;

T_{LC} — draught, in m, amidships for the considered load case, in m;

f_T — ratio between draught at a loading condition and scantling draught, to be taken as:

$$f_T = \frac{T_{LC}}{T_{SC}} \quad \text{but not less than 0.5;}$$

f_p — coefficient for strength assessments which is dependant on the applicable design load scenario and to be taken as:

$f_p = 1.0$ for seagoing condition design load scenario;

$f_p = 0.4$ for the harbour/sheltered water design load scenario;

R — vertical coordinate, in m, of the ship rotation centre, in m, to be taken as:

$$R = \min\left(\frac{D}{4} + \frac{T_{LC}}{2}, \frac{D}{2}\right)$$

1.2.3 The ship's geometry, motions, accelerations and loads are defined with respect to the following right-hand coordinate system, see Figure 1.2.2.1:

(1) Origin : At the intersection among the longitudinal plane of symmetry of ship, the aft end of L and the baseline;

(2) X axis: Longitudinal axis, positive forwards;

(3) Y axis: Transverse axis, positive towards portside;

(4) Z axis : Vertical axis, positive upwards.

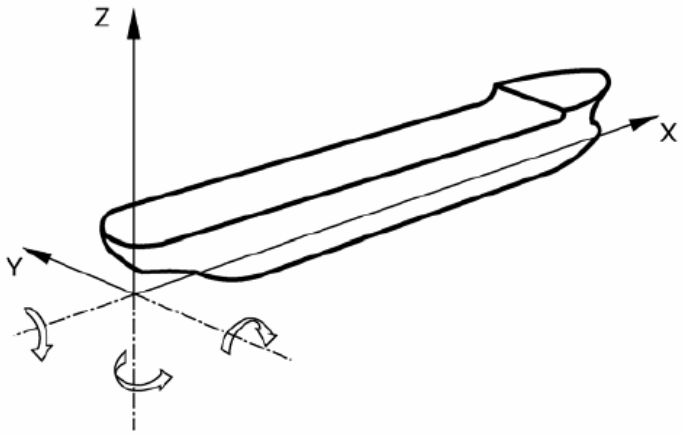


Figure 1.2.2.1 Reference Coordinate System

1.2.4 The ship motions are defined as shown in Figure 1.2.2.2:

(1) Surge is translation in the X-axis direction, positive forward;

(2) Sway is translation in the Y-axis direction, positive towards port side of ship;

(3) Heave is translation in the Z-axis direction, positive upwards;

(4) Roll motion is positive rotation about a longitudinal axis through the COG, starboard down and port up;

(5) Pitch motion is positive rotation about a transverse axis through the COG, bow down and stern up;

(6) Yaw motion is positive rotation about a vertical axis through the COG, bow moving to port

and stern to starboard.

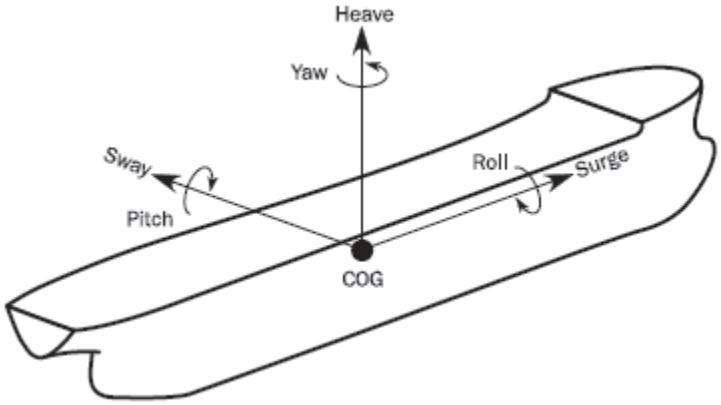


Figure 1.2.2.2 Definition of Positive Motions

1.2.5 Sign convention for hull girder loads is to be in accordance with the following requirements, see Figure 1.2.2.3.

(1) The vertical bending moments M_{sw} and M_{wv} are positive when they induce tensile stresses in the strength deck (hogging bending moment) and negative when they induce tensile stresses in the bottom (sagging bending moment).

(2) The vertical shear forces Q_{sw}, Q_{wv} are positive in the case of downward resulting forces acting aft of the transverse section and upward resulting forces acting forward of the transverse section under consideration.

(3) The horizontal bending moment M_{wh} is positive when it induces tensile stresses in the starboard side and negative when it induces tensile stresses in the port side.

(4) The torsional moment M_{wt} is positive in the case of resulting moment acting aft of the transverse section following negative rotation around the X-axis, and of resulting moment acting forward of the transverse section following positive rotation around the X-axis.

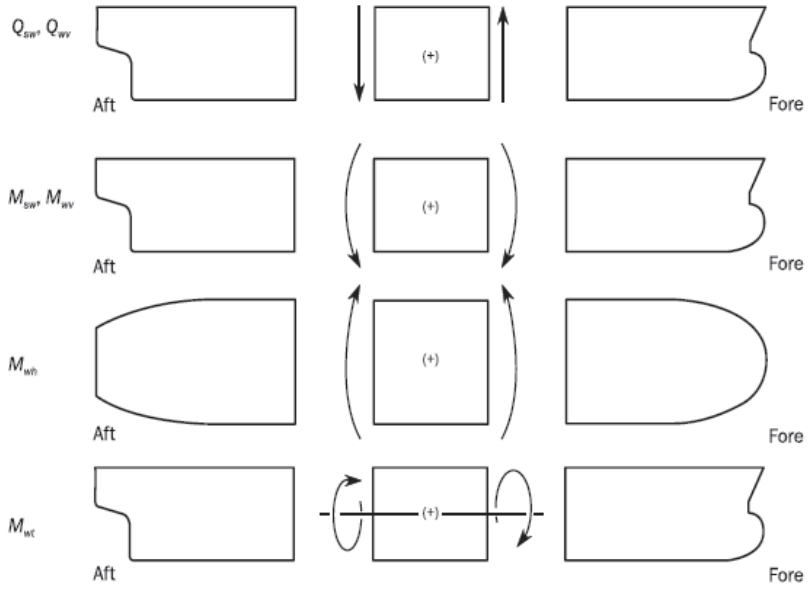


Figure 1.2.2.3 Sign Convention for Hull Girder Loads

1.3 Scantlings of Structural Member

1.3.1 Unless expressly provided otherwise, the scantlings of structural members for direct analysis of the Guidelines are the as-built scantlings, excluding the additional thickness required by shipowners.

CHAPTER 2 LOAD CASES

2.1 General Requirements

2.1.1 This Chapter provides the design loads and loading conditions of direct strength assessment for ore carriers.

2.1.2 Strength assessment means the assessment for the strength criteria, for the loads corresponding to the probability level of 10^{-8}.

2.1.3 Each design load scenario for strength assessment is composed of a Static (S) load case or a Static + Dynamic (S+D) load case, where the static and dynamic loads are dependent on the loading condition being considered.

2.1.4 Each load parameter in load cases is to be calculated in accordance with the following requirements:

(1) dynamic load cases are defined in 2.2 of this Chapter;

(2) ship motion and acceleration are defined in 2.3 of this Chapter;

(3) hull girder loads are defined in 2.4 of this Chapter;

(4) external loads are defined in 2.5 of this Chapter;

(5) internal loads are defined in 2.6 of this Chapter;

(6) loading conditions are defined in 2.7 of this Chapter.

2.2 Dynamic Load Cases

2.2.1 The following Equivalent Design Waves (EDW) are to be used to generate the dynamic load cases for structural assessment:

2.2.1.1 HSM load cases:

HSM-1and HSM-2: Head sea EDWs that minimise and maximise the vertical wave bending moment amidships respectively.

2.2.1.2 HAS load cases:

HSA-1 and HSA-2: Head sea EDWs that maximise and minimise the head sea vertical acceleration at FP respectively.

2.2.1.3 FSM load cases:

FSM-1 and FSM-2: Following sea EDWs that minimise and maximise the vertical wave bending moment amidships respectively.

2.2.1.4 BSR load case:

BSR-1P and BSR-2P: Beam sea EDWs that minimise and maximise the roll motion downward and upward on the port side respectively with waves from the port side.

BSR-1S and BSR-2S: Beam sea EDWs that maximise and minimise the roll motion downward and upward on the starboard side respectively with waves from the starboard side.

2.2.1.5 BSP load cases:

BSP-1P and BSP-2P: Beam sea EDWs that maximise and minimise the hydrodynamic pressure at the waterline amidships on the port side respectively.

BSP-1S and BSP-2S: Beam sea EDWs that maximise and minimise the hydrodynamic pressure at the waterline amidships on the starboard side respectively.

2.2.1.6 OST load cases:

OST-1P and OST-2P: Oblique sea EDWs that minimise and maximise the torsional moment at 0.25L from the AE with waves from the port side respectively.

OST-1S and OST-2S: Oblique sea EDWs that maximise and minimise the torsional moment at 0.25*L* from the AE with waves from the starboard side respectively.

2.2.1.7 OSA load cases:

OSA-1P and OSA-2P: Oblique sea EDWs that maximise and minimise the pitch acceleration with waves from the port side respectively.

OSA-1S and OSA-2S: Oblique sea EDWs that maximise and minimise the pitch acceleration with waves from the starboard side respectively.

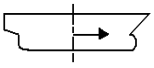
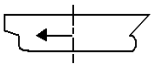
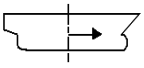
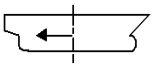
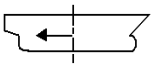
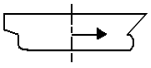
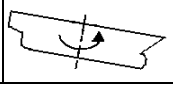
Note 1: 1 and 2 denote the maximum or the minimum dominate load component for each EDW.

Note 2: P and S denote that the weather side is on port side and on starboard side respectively.

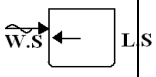
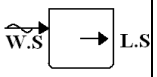
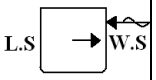
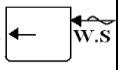
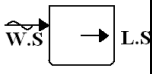
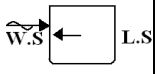
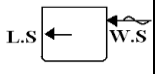
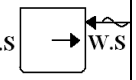
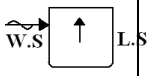
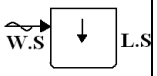
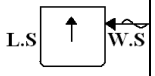
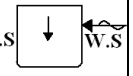
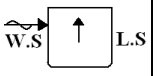
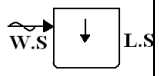
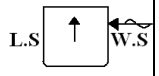
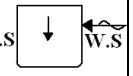
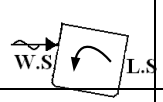
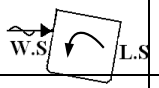
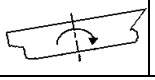
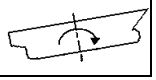
2.2.2 The ship motions responses and the global loads corresponding to each dynamic load case are shown in Tables 2.2.2.1 to 2.2.2.3.

Ship Responses for HSM, HSA and FSM load Cases - Strength Assessment

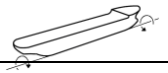
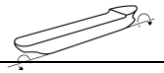
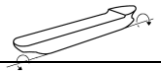
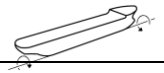
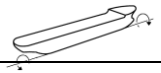
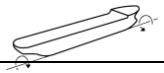
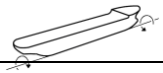
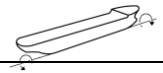
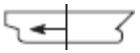
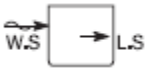
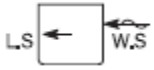
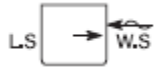
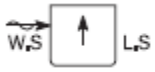
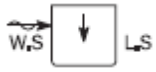
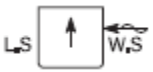
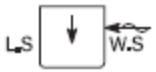
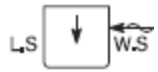
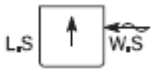
Table 2.2.2.1

Load case	HSM-1	HSM-2	HSA-1	HSA-2	FSM-1	FSM-2
EDW	HSM		HSA		FSM	
Heading	Head		Head		Following	
Effect	Maximum bending moment		Maximum vertical acceleration		Maximum bending moment	
VWBM	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging
VWSF	Negative-aft Positive-fore	Positive-aft Negative-fore	Negative-aft Positive-fore	Positive-aft Negative-fore	Negative-aft Positive-fore	Positive-aft Negative-fore
HWBM	-	-	-	-	-	-
TM	-	-	-	-	-	-
Surge	To stern	To bow	To stern	To bow	To bow	To stern
a_{surge}						
Sway	-	-	-	-	-	-
a_{sway}	-	-	-	-	-	-
Heavy	Down	Up	Down	Up	-	-
a_{heave}					-	-
Roll	-	-	-	-	-	-
a_{roll}	-	-	-	-	-	-
Pitch	Bow down	Bow up	Bow down	Bow up	Bow down	Bow up
a_{pitch}						

Ship Response to BSR and BSP Load Cases – Strength Assessment **Table 2.2.2.2**

Load case	BSR-1P	BSR-2P	BSR-1S	BSR-2S	BSP-1P	BSP-2P	BSP-1S	BSP-2S
EDW	BSR		BSR		BSP		BSP	
Heading	Beam				Beam			
Effect	Maximum roll				Maximum pressure at waterline			
VWBM	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging
VWSF	Negative-aft Positive-fore	Positive-aft Negative-fore	Negative-aft Positive-fore	Positive-aft Negative-fore	Negative-aft Positive-fore	Positive-aft Negative-fore	Negative-aft Positive-fore	Positive-aft Negative-fore
HWBM	stbd tensile	Port tensile	Port tensile	Stbd tensile	Stbd tensile	Port tensile	Port tensile	Stbd tensile
TM	-	-	-	-	-	-	-	-
Surge	-	-	-	-	-	-	-	-
a_{surge}	-	-	-	-	-	-	-	-
Sway	To starboard	To portside	To portside	To starboard	To starboard	To portside	To portside	To starboard
a_{sway}								
Heavy	Down	Up	Down	Up	Down	Up	Down	Up
a_{heave}								
Roll	Portside down	Portside up	Starboard down	Starboard up	Portside down	Portside up	Starboard down	Starboard up
a_{roll}								
Pitch	-	-	-	-	Bow down	Bow up	Bow down	Bow up
a_{pitch}	-	-	-	-				

Ship Response to OST and OSA Load Cases – Strength Assessment **Table 2.2.2.3**

Load case	OST-1P	OST-2P	OST-1S	OST-2S	OSA-1P	OSA-2P	OSA-1S	OSA-2S
EDW	OST				OSA			
Heading	Oblique				Oblique			
Effect	Maximum torsional moment				Maximum pitch acceleration			
VWBM	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging
VWSF	Negative-aft Positive-fore	Positive-aft Negative-fore	Negative-aft Positive-fore	Positive-aft Negative-fore	Positive-aft Negative-fore	Negative-aft Positive-fore	Positive-aft Negative-fore	Negative-aft Positive-fore
HWBM	Port tensile	Stbd tensile	Stbd tensile	Port tensile	Stbd tensile	Port tensile	Port tensile	Stbd tensile
TM								
Surge	To bow	To stern	To bow	To stern	To bow	To stern	To bow	To stern
a_{surge}								
Sway	-	-	-	-	To portside	To starboard	To starboard	To portside
a_{sway}	-	-	-	-				
Heavy	Down	Up	Down	Up	Up	Down	Up	Down
a_{heave}								
Roll	Portside down	Portside up	Starboard down	Starboard up	Portside down	Portside up	Starboard down	Starboard up
a_{roll}								
Pitch	Bow up	Bow down	Bow up	Bow down	Bow up	Bow down	Bow up	Bow down
a_{pitch}								

2.2.3 The load combination factors of equivalent design wave, LCF for the global loads and inertial load components are defined in Tables 2.2.3.1 to 2.2.3.3.

Load Combination Factor for HSM, HSA and FSM Load Cases - Strength Assessment

Table 2.2.3.1

Load component		LCF	HSM-1	HSM-2	HSA-1	HSA-2	FSM-1	FSM-2
Hull girder loads	M_{WV}	C_{WV}	-1	1	-0.7	0.7	$-0.4f_T$-0.6	$0.4f_T$+0.6
	Q_{WV}	C_{QW}	$-1.0f_{lp}$	$1.0f_{lp}$	$-0.6f_{lp}$	$0.6f_{lp}$	$-1.0f_{lp}$	$1.0f_{lp}$
	M_{WH}	C_{WH}	0	0	0	0	0	0
	M_{WT}	C_{WT}	0	0	0	0	0	0
Longitudinal accelerations	a_{surge}	C_{XS}	$0.3-0.2f_T$	$0.2f_T$-0.3	0.2	-0.2	$0.2-0.4f_T$	$0.4f_T$-0.2
	$a_{pitch-x}$	C_{XP}	-0.7	0.7	$-0.4f_T$ -0.4	$0.4f_T$ +0.4	0.15	-0.15
	gsinφ	C_{XG}	0.6	-0.6	$0.4f_T$+0.4	$-0.4f_T$-0.4	-0.2	0.2
Transverse accelerations	a_{sway}	C_{YS}	0	0	0	0	0	0
	a_{roll-y}	C_{YR}	0	0	0	0	0	0
	gsinθ	C_{YG}	0	0	0	0	0	0
Vertical accelerations	a_{heave}	C_{ZH}	$0.5f_T$-0.15	$0.15-0.5f_T$	$0.4f_T$-0.1	$0.1-0.4f_T$	0	0
	a_{roll-z}	C_{ZR}	0	0	0	0	0	0
	$a_{pitch-z}$	C_{ZP}	-0.7	0.7	$-0.4f_T$-0.4	$0.4f_T$+0.4	0.15	-0.15

Load Combination Factors for BSR and BSP Load Cases - Strength Assessment

Table 2.2.3.2

Load component		LCF	BSR-1P	BSR-2P	BSR-1S	BSR-2S
Hull girder loads	M_{WV}	C_{WV}	$0.1-0.2f_T$	$0.2f_T$ -0.1	$0.1-0.2f_T$	$0.2f_T$ -0.1
	Q_{WV}	C_{QW}	$(0.1-0.2f_T)$ f_{lp}	$(0.2f_T$ -0.1) f_{lp}	$(0.1-0.2f_T)$ f_{lp}	$(0.2f_T$ -0.1) f_{lp}
	M_{WH}	C_{WH}	$1.2-1.1f_T$	$1.1f_T$ -1.2	$1.1f_T$ -1.2	$1.2-1.1$ f_T
	M_{WT}	C_{WT}	0	0	0	0
Longitudinal accelerations	a_{surge}	C_{XS}	0	0	0	0
	$a_{pitch-x}$	C_{XP}	0	0	0	0
	gsinφ	C_{XG}	0	0	0	0
Transverse accelerations	a_{sway}	C_{YS}	$0.2-0.2f_T$	$0.2f_T$ -0.2	$0.2f_T$ -0.2	$0.2-0.2f_T$
	a_{roll-y}	C_{YR}	1	-1	-1	1
	gsinθ	C_{YG}	-1	1	1	-1
Vertical accelerations	a_{heave}	C_{ZH}	$0.7-0.4f_T$	$0.4f_T$-0.7	$0.7-0.4f_T$	$0.4f_T$-0.7
	a_{roll-z}	C_{ZR}	1	-1	1	-1
	$a_{pitch-z}$	C_{ZP}	0	0	0	0

Load component		LCF	BSP-1P	BSP-2P	BSP-1S	BSP-2S
Hull girder loads	M_{WV}	C_{WV}	$0.3-0.8f_T$	$0.8f_T$-0.3	$0.3-0.8f_T$	$0.8f_T$-0.3
	Q_{WV}	C_{QW}	$(0.3-0.8f_T)$ f_{lp}	$(0.8f_T$-0.3) f_{lp}	$(0.3-0.8f_T)$ f_{lp}	$(0.8f_T$-0.3) f_{lp}
	M_{WH}	C_{WH}	$0.7-0.7f_T$	$0.7f_T$ -0.7	$0.7f_T$ -0.7	$0.7-0.7f_T$
	M_{WT}	C_{WT}	0	0	0	0
Longitudinal	a_{surge}	C_{XS}	0	0	0	0

accelerations	$a_{pitch-x}$	C_{XP}	0.1-0.3f_T	0.3f_T -0.1	0.3f_T -0.1	0.1-0.3f_T
	gsinφ	C_{XG}	0.3f_T -0.1	0.1-0.3f_T	0.3f_T -0.1	0.1-0.3f_T
Transverse accelerations	a_{sway}	C_{YS}	-0.9	0.9	0.9	-0.9
	a_{roll-y}	C_{YR}	0.3	-0.3	-0.3	0.3
	gsinθ	C_{YG}	-0.2	0.2	0.2	-0.2
Vertical accelerations	a_{heave}	C_{ZH}	1	-1	1	-1
	a_{roll-z}	C_{ZR}	0.3	-0.3	-0.3	0.3
	$a_{pitch-z}$	C_{ZP}	0.1-0.3f_T	0.3f_T-0.1	0.1-0.3f_T	0.3f_T-0.1

Load Combination Factors for OST and OSA Load Cases - Strength Assessment

Table 2.2.3.3

Load component		LCF	OST-1P	OST-2P	OST-1S	OST-2S
Hull girder loads	M_{WV}	C_{WV}	-0.3-0.2f_T	0.3+0.2f_T	-0.3-0.2f_T	0.3+0.2f_T
	Q_{WV}	C_{QW}	(-0.35-0.2f_T)f_{lp}	(0.35+0.2f_T)f_{lp}	(-0.35-0.2f_T)f_{lp}	(0.35+0.2f_T)f_{lp}
	M_{WH}	C_{WH}	-0.9	0.9	0.9	-0.9
	M_{WT}	C_{WT}	-f_{lp-OST}	f_{lp-OST}	f_{lp-OST}	-f_{lp-OST}
Longitudinal accelerations	a_{surge}	C_{XS}	0.1f_T -0.15	0.15-0.1f_T	0.1f_T -0.15	0.15-0.1f_T
	$a_{pitch-x}$	C_{XP}	0.7-0.3f_T	0.3f_T -0.7	0.7-0.3f_T	0.3f_T -0.7
	gsinφ	C_{XG}	0.2f_T-0.45	0.45-0.2f_T	0.2f_T-0.45	0.45-0.2f_T
Transverse accelerations	a_{sway}	C_{YS}	0	0	0	0
	a_{roll-y}	C_{YR}	0.4f_T-0.25	0.25-0.4f_T	0.25-0.4f_T	0.4f_T-0.25
	gsinθ	C_{YG}	0.1-0.2f_T	0.2f_T-0.1	0.2f_T-0.1	0.1-0.2f_T
Vertical accelerations	a_{heave}	C_{ZH}	0.2f_T-0.05	0.05-0.4f_T	0.2f_T-0.05	0.05-0.4f_T
	a_{roll-z}	C_{ZR}	0.4f_T-0.25	0.25-0.4f_T	0.25-0.4f_T	0.4f_T-0.25
	$a_{pitch-z}$	C_{ZP}	0.7-0.3f_T	0.3f_T-0.7	0.7-0.3f_T	0.3f_T-0.7

Load component		LCF	OSA-1P	OSA-2P	OSA-1S	OSA-2S
Hull girder loads	M_{WV}	C_{WV}	0.75-0.5f_T	-0.75+0.5f_T	0.75-0.5f_T	-0.75+0.5f_T
	Q_{WV}	C_{QW}	(0.6-0.4f_T) f_{lp}	(-0.6+0.4f_T) f_{lp}	(0.6-0.4f_T) f_{lp}	(-0.6+0.4f_T) f_{lp}
	M_{WH}	C_{WH}	0.55+0.2f_T	-0.55-0.2f_T	-0.55-0.2f_T	0.55+0.2f_T
	M_{WT}	C_{WT}	-f_{lp-OSA}	f_{lp-OSA}	f_{lp-OSA}	-f_{lp-OSA}
Longitudinal accelerations	a_{surge}	C_{XS}	0.1f_T -0.45	0.45-0.1f_T	0.1f_T -0.45	0.45-0.1f_T
	$a_{pitch-x}$	C_{XP}	1.0	-1.0	1.0	-1.0
	gsinφ	C_{XG}	-1.0	1.0	-1.0	1.0
Transverse accelerations	a_{sway}	C_{YS}	-0.2 -0.1f_T	0.2+0.1f_T	0.2+0.1f_T	-0.2 -0.1f_T
	a_{roll-y}	C_{YR}	0.3-0.2f_T	0.2f_T -0.3	0.2f_T -0.3	0.3-0.2f_T
	gsinθ	C_{YG}	0.1f_T-0.2	0.1-0.2f_T	0.2-0.1f_T	0.1f_T-0.2
Vertical accelerations	a_{heave}	C_{ZH}	-0.2f_T	0.2f_T	-0.2f_T	0.2f_T
	a_{roll-z}	C_{ZR}	0.3-0.2f_T	0.2f_T-0.3	0.2f_T-0.3	0.3-0.2f_T
	$a_{pitch-z}$	C_{ZP}	1.0	-1.0	1.0	-1.0

where:

f_{xL} — ratio between X-coordinate of the load point and L, to be taken as:

$f_{xL} = \frac{x}{L}$, but not to be taken less than 0.0 or greater than 1.0;

f_T — ratio between draught at a loading condition and scantling draught, as defined in Chapter 1, Section 2;

f_{lp} — factor depending on longitudinal position along the ship, to be taken as:

$f_{lp} = 1.0$ for $x/L \le 0.5$

$f_{lp} = -1.0$ for $x/L > 0.5$;

$f_{lp\text{-}OST}$ — factor for the longitudinal distribution of the torsional moment for the OST load case, to be taken as:

$f_{lp\text{-}OST} = 5 f_{xL}$ for $x/L < 0.2$

$f_{lp\text{-}OST} = 1.0$ for $0.2 \le x/L < 0.4$

$f_{lp-OST} = -7.6 f_{xL} + 4.04$ for $0.4 \le x/L < 0.65$

$f_{lp-OST} = -0.9$ for $0.65 \le x/L < 0.85$

$f_{lp-OST} = 6 f_{xL} - 6$ for $0.85 \le x/L$;

$f_{lp\text{-}OSA}$ — factor for the longitudinal distribution of the torsional moment for the OSA load case, to be taken as:

$f_{lp-OSA} = -(0.2 + 0.3 f_T)$ for $x/L < 0.4$

$f_{lp-OSA} = -(0.2 + 0.3 f_T)(11.5 f_{xL} - 5.6)$ for $0.4 \le x/L \le 0.6$

$f_{lp-OSA} = 1.3(0.2 + 0.3 f_T)$ for $0.6 \le x/L$.

2.3 Ship Motions and Accelerations

2.3.1 Ship motions

2.3.1.1 Roll motion

The roll period T_θ, in s, to be taken as:

$$T_\theta = \frac{2.3\pi k_r}{\sqrt{gGM}}$$

Roll angle θ, in °, to be taken as:

$$\theta = \frac{9000\left(1.25 - 0.025 T_\theta\right) f_p f_{BK}}{\left(B + 75\right)\pi}$$

where:

f_{BK} — to be taken as:

f_{BK} = 1.2 for ship without bilge keel;

f_{BK} = 1.0 for ship with bilge keel;

k_r — roll radius of gyration, in m, unless provided in the considered loading condition, the values in Table 2.3.1.1 are to be adopted;

GM — metacentric height, in m, unless provided in the considered loading condition, the values in Table 2.3.1.1 are to be adopted.

Recommended Values of K_r and GM **Table 2.3.1.1**

Loading condition(1)		T_{LC}	k_r	GM
Full load condition	Homogeneous light cargo	T_{SC}	0.35B	0.12B
	Homogeneous heavy cargo		0.42B	0.25B
Heavy ballast condition		T_{BAL-H}	0.40B	0.25B
Normal ballast condition		T_{BAL}	0.45B	0.33B

(1) For Multi-port (MP) loading conditions with draught greater than or equal to 0.9T_{SC}, the values of k_r and GM, unless provided in the loading manual, are to be taken as those from the most appropriate full load condition.

(2) For Multi-port (MP) loading conditions with draught between T_{BAL-H} and 0.9T_{SC}, the values of k_r and GM, unless provided in the loading manual, are to be obtained by linear interpolation, based on the draught, between the heavy ballast condition and the most appropriate full load condition.

(3) For Multi-port (MP) loading conditions with a draught below T_{BAL-H}, the values of k_r and GM for the heavy ballast condition are to be used.

2.3.1.2 Pitch motion

The pitch period T_φ, in s, to be taken as:

$$T_\varphi = \sqrt{\frac{2\pi\lambda_\varphi}{g}}$$

where:

$$\lambda_\varphi = 0.6(1 + f_T)L$$

The pitch angle φ, in °, to be taken as:

$$\varphi = 1350 f_p L^{-0.94} \left\{ 1.0 + \left(\frac{2.57}{\sqrt{gL}} \right)^{1.2} \right\}$$

2.3.2 Ship accelerations at the centre of gravity

2.3.2.1 Acceleration parameter

The ship acceleration parameter a is to be taken as:

$$a_0 = (1.58 - 0.47C_B)\left(\frac{2.4}{\sqrt{L}} + \frac{34}{L} - \frac{600}{L^2} \right)$$

2.3.2.2 Surge acceleration

The longitudinal acceleration due to surge, in m/s^2, is to be taken as:

$$a_{surge} = 0.2 f_p a_0 g$$

2.3.2.3 Sway acceleration

The transverse acceleration due to sway, in m/s^2, is to be taken as:

$$a_{sway} = 0.3 f_p a_0 g$$

2.3.2.4 Heave acceleration

The vertical acceleration due to heave, in m/s^2, is to be taken as:

$$a_{heave} = f_p a_0 g$$

2.3.2.5 Roll acceleration

The roll acceleration, a_{roll}, in rad/s^2, is to be taken as:

$$a_{roll} = f_p \theta \frac{\pi}{180}\left(\frac{2\pi}{T_\theta}\right)^2$$

where:

θ — roll angle using f_p equal to 1.0.

2.3.2.6 Pitch acceleration

The pitch acceleration, a_{pitch}, in rad/s^2, is to be taken as:

$$a_{pitch} = f_p\left(\frac{3.1}{\sqrt{gL}} + 1.0\right)\varphi\frac{\pi}{180}\left(\frac{2\pi}{T_\varphi}\right)^2$$

where:

φ — pitch angle using f_p equal to 1.0.

2.3.3 Accelerations for dynamic load cases

2.3.3.1 Longitudinal acceleration

The transverse acceleration at any position for each dynamic load case, in m/s^2, is to be taken as:

$$a_X = -C_{XG} g \sin\varphi + C_{XS} a_{surge} + C_{XP} a_{pitch}(z - R)$$

2.3.3.2 Vertical acceleration

The vertical acceleration at any position for each dynamic load case, in m/s^2, is to be taken as:

$$a_Y = C_{YG} g \sin\theta + C_{YS} a_{sway} - C_{YR} a_{roll}(z - R)$$

2.3.3.3 Vertical acceleration

The vertical acceleration at any position for each dynamic load case, in m/s^2, is to be taken as:

$$a_Z = C_{ZH} a_{heave} + C_{ZR} a_{roll} y - C_{ZP} a_{pitch}(x - 0.45L)$$

2.3.4 Envelope accelerations

2.3.4.1 Longitudinal acceleration

The envelope longitudinal acceleration, $a_{x\text{-}env}$, in m/s^2, at any position, is to be taken as:

$$a_{x-env} = 0.7\sqrt{a_{surge}^2 + \left[\frac{L}{325}\left(g\sin\varphi + a_{pitch-x}\right)\right]^2}$$

where:

$a_{pitch\text{-}x}$ — longitudinal acceleration due to pitch, in m/s^2:

$$a_{pitch-x} = a_{pitch}(z - R).$$

2.3.4.2 Transverse acceleration

The envelope transverse acceleration, $a_{y\text{-}env}$, in m/s^2, at any position, is to be taken as:

$$a_{y-env} = \sqrt{a_{sway}^2 + \left(g \sin\theta + a_{roll-y}\right)^2}$$

where:

a_{roll-y} — transverse acceleration due to roll, in m/s^2:

$$a_{roll-y} = a_{roll}(z - R).$$

2.3.4.3 Vertical acceleration

The envelope vertical acceleration, a_{z-env}, in m/s^2, at any position, is to be taken as:

$$a_{z-env} = \sqrt{a_{heave}^2 + \left(\left(0.3 + \frac{L}{325}\right)a_{pitch-z}\right)^2 + (1.2a_{roll-z})^2}$$

where:

$a_{pitch-z}$ — vertical acceleration due to pitch, in m/s^2:

$$a_{pitch-z} = a_{pitch}(x - 0.45L);$$

a_{roll-z} — vertical acceleration due to roll, in m/s^2:

$$a_{roll-z} = a_{roll}\, y.$$

2.4 Hull girder loads

2.4.1 General

2.4.1.1 The hull girder loads for the static (S) design load scenarios is to be taken as the still water loads defined in [2.4.2].

2.4.1.2 The total hull girder loads for the static plus dynamic (S+D) design load scenarios are to be derived for each dynamic load case and are to be taken as the sum of the still water loads defined in [2.4.2] and the dynamic loads defined in [2.4.3].

2.4.2 Vertical still water hull girder loads

2.4.2.1 The designer is to provide the permissible still water bending moment and shear force for sea-going and harbour/sheltered water operations, and not less than the values required in 2.4.2.2 and 2.4.2.3.

2.4.2.2 The hull girder hogging and sagging still water bending moments are to be calculated by the following equations.

Hogging condition:

$$M_{sw-h-min} = f_{sw}\left(171 C_w L^2 B(C_B + 0.7)10^{-3} - M_{wv-h-mid}\right)$$

Sagging condition:

$$M_{sw-s-min} = -0.85 f_{sw}\left(171 C_w L^2 B(C_B + 0.7)10^{-3} + M_{wv-s-mid}\right)$$

where:

$M_{wv-h-mid}$ — vertical wave bending moment for strength assessment in hogging condition, as defined in [2.4.3.1], using f_p and f_m equal to 1.0;

$M_{wv-s-mid}$ — vertical wave bending moment for strength assessment in sagging condition, as defined in [2.4.3.1], using f_p and f_m equal to 1.0;

f_{sw} — distribution factor along the ship length. To be taken as, see Figure 2.4.2.1:

f_{sw} = 0.0 for $x \le 0$;

f_{sw} = 0.15 for $x = 0.1L$;

f_{sw} = 1.0 for $0.3L \le x \le 0.7L$;

f_{sw} = 0.15 for $x = 0.9L$;

f_{sw} = 0.0 for $x \ge L$;

Intermediate values of f_{sw} are to be obtained by linear interpolation.

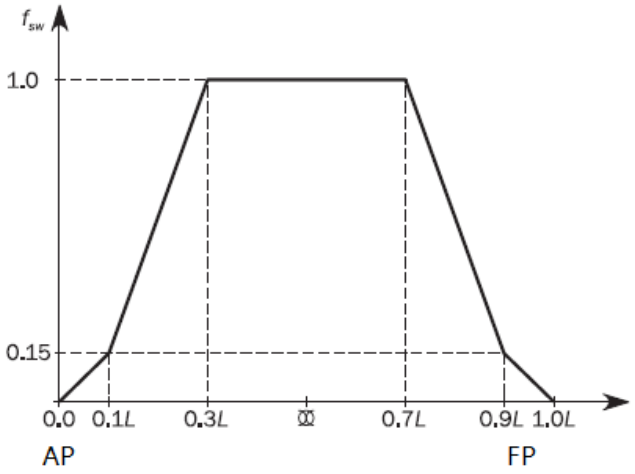


Figure 2.4.2.1 Distribution Factor f_{sw}

2.4.2.3 The permissible values of hogging and sagging still water bending moments and still water shear forces in harbour/sheltered water are to be properly increased. The increased values are to be taken as 50% of wave bending moment and wave shear force stipulated in the Guidelines.

2.4.3 Dynamic hull girder loads

2.4.3.1 The vertical wave bending moments at any longitudinal position, in kNm, are to be taken as:

Hogging condition:

$$M_{wv-h} = 0.19 f_{nl-vh} f_m f_p C_w L^2 B C_B$$

Sagging condition:

$$M_{wv-s} = -0.19 f_{nl-vs} f_m f_p C_w L^2 B C_B$$

where:

$f_{nl\text{-}vh}$ — cofficient considering nonlinear effects applied to hogging, to be taken as:

$f_{nl\text{-}h}$ = 1.0, for strength assessment

$f_{nl\text{-}vs}$ — coefficient considering nonlinear effects applied to sagging, to be taken as:

$$f_{nl\text{-}s} = 0.58 \frac{(C_B + 0.7)}{C_B}$$

f_m — distribution factor for vertical wave bending moment along the ship's length, to be taken as:

f_m = 0.0 for $x \le 0$

f_m = 1.0 for $0.4L \le x \le 0.65L$

f_m = 0.0 for $x \ge L$

Intermediate values of f_m are to be obtained by linear interpolation (see Figure 2.4.3.1).

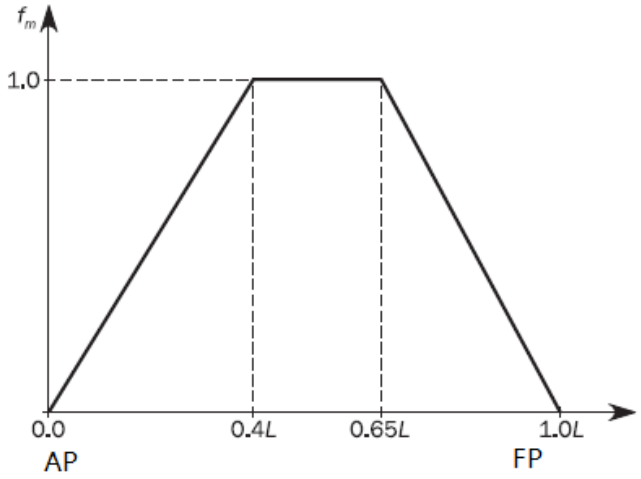


Figure 2.4.3.1 Distribution Factor f_m

2.4.3.2 The vertical wave shear forces at any longitudinal position, in kN, are to be taken as:

$$Q_{wv-pos} = 0.52 f_{q-pos} f_p C_w LBC_B$$

$$Q_{wv-neg} = -0.52 f_{q-neg} f_p C_w LBC_B$$

where:

$f_{q\text{-}pos}$ — distribution factor along the ship length for positive wave shear force, to be taken as:

$f_{q\text{-}pos}$ = 0.0, for $x \le 0$

$f_{q\text{-}pos} = 0.92 f_{nl-h}$, for $0.2L \le x \le 0.3L$

$f_{q\text{-}pos}$ = 0.7, for $0.4L \le x \le 0.6L$

$f_{q\text{-}pos} = 1.0 f_{nl-s}$, for $0.7L \le x \le 0.85L$

$f_{q\text{-}pos}$ = 0.0, for $x \ge L$

Intermediate values of $f_{q\text{-}pos}$ are to be obtained by linear interpolation, see Figure 2.4.3.2.

$f_{q\text{-}neg}$ — distribution factor along the ship length for negative wave shear force, to be taken as:

$f_{q\text{-}neg}$ = 0.0, for $x \le 0$

$f_{q\text{-}neg} = 0.92 f_{nl-s}$, for $0.2L \le x \le 0.3L$

$f_{q\text{-}neg}$ = 0.7, for $0.4L \le x \le 0.6L$

$f_{q\text{-}neg} = 1.0 f_{nl-h}$, for $0.7L \le x \le 0.85L$

$f_{q\text{-}neg}$ = 0.0, for $x \geq L$

Intermediate values of $f_{q\text{-}neg}$ are to be obtained by linear interpolation, see Figure 2.4.3.3.

$f_{nl\text{-}vh}$ and $f_{nl\text{-}vs}$ — coefficient considering nonlinear effects defined in [3.1.1].

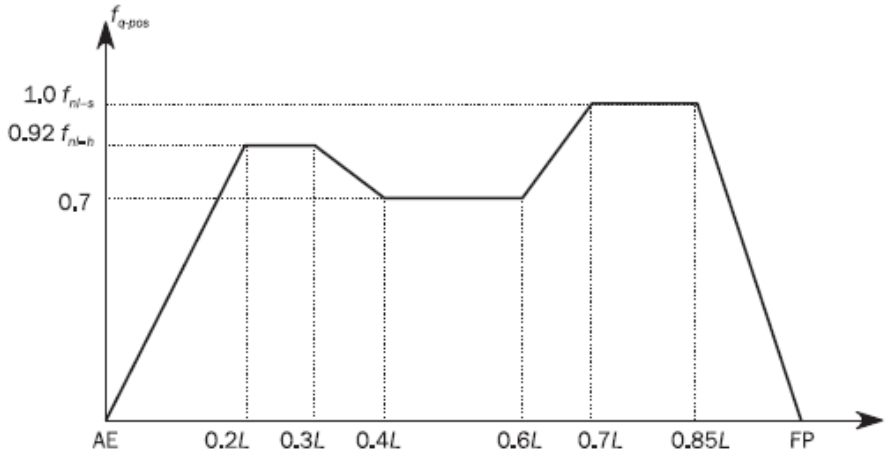


Figure 2.4.3.2 Distribution Factor of Positive Vertical Shear Force $f_{q\text{-}pos}$

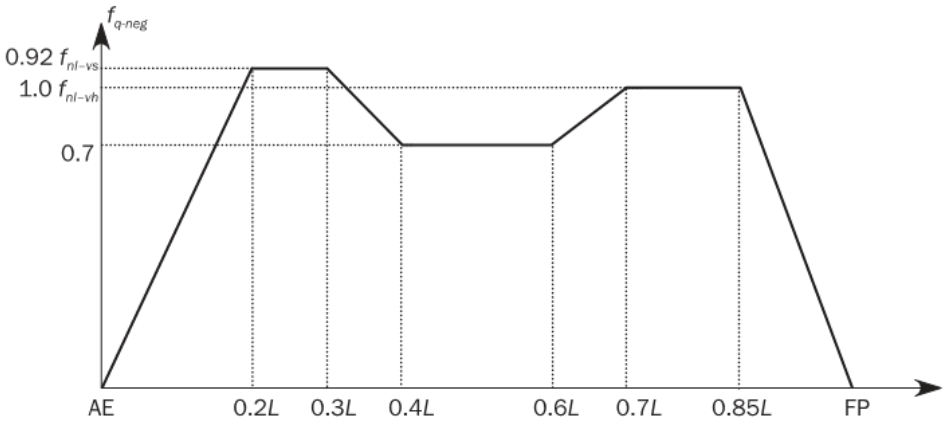


Figure 2.4.3.3 Distribution Factor of Negative Vertical Shear Force $f_{q\text{-}neg}$

2.4.3.3 The horizontal wave bending moment at any longitudinal position, M_{wh}, in kNm, is to be taken as:

$$M_{wh} = f_{nlh} f_p \left(0.31 + \frac{L}{2800}\right) f_m C_w L^2 T_{LC} C_B$$

where:

f_{nlh} — coefficient considering nonlinear effect to be taken as:

f_{nlh}= 0.9, for strength assessment;

f_m — distribution factor defined in [2.4.3.1].

2.4.3.4 The wave torsional moment at any longitudinal position with respect to the ship baseline, M_{wt}, in kNm, is to be taken as:

$$M_{wt} = f_p \left(M_{wt1} + M_{wt2}\right)$$

where:

$$M_{wt1} = 0.4 f_{t1} C_w \sqrt{\frac{L}{T_{LC}}} B^2 D C_B;$$

$$M_{wt2} = 0.22 f_{t2} C_w L B^2 C_B;$$

f_{t1}, f_{t2} — distribution factors, to be taken as:

f_{t1}=0, for $x < 0$

$$f_{t1} = \left| \sin\left(\frac{2\pi x}{L}\right) \right|, \text{ for } \ 0 \le x \le L$$

f_{t1}=0, for $x > L$

f_{t2}=0, for $x < 0$

$$f_{t2} = \sin^2\left(\frac{\pi x}{L}\right), \text{ for } \ 0 \le x \le L$$

f_{t2}=0, for $x > L$

2.4.4 Hull girder loads for dynamic load cases

2.4.4.1 The vertical wave bending moment, $M_{wv\text{-}LC}$, in kNm, to be used for each dynamic load case in Section 2.2 in this Chapter is defined in Table 2.4.4.1.

Vertical Wave Bending Moment for Dynamic Load Cases

Table 2.4.4.1

Load combination factor	$M_{wv\text{-}LC}$
$C_{WV} \geq 0$	$f_\beta C_{WV} M_{wv-h}$
$C_{WV} < 0$	$f_\beta C_{WV} \lvert M_{wv-s} \rvert$

where:

f_β — heading correction factor, to be taken as:

f_β = 0.8 for BSR and BSP load cases for the extreme sea loads design load scenario;

f_β = 1.0 for HSM, HSA, FSM, OST and OSA load cases for the extreme sea loads design load scenario;

C_{WV} — load combination factor for vertical wave bending moment, to be taken as specified in Section 2.2 of this Chapter;

$M_{wv\text{-}h}$, $M_{wv\text{-}s}$ — hogging and sagging vertical wave bending moment taking account of the considered design load scenario, as defined in [2.4.3.1].

2.4.4.2 The vertical wave shear force, $Q_{wv\text{-}LC}$, in kN, to be used for each dynamic load case in Section 2.2 of this Chapter, is defined in Table 2.4.4.2.

Vertical Wave Shear Force for Dynamic Load Cases

Table 2.4.4.2

Load combination factor	$Q_{wv\text{-}LC}$
$C_{QW} \geq 0$	$f_\beta C_{QW} Q_{wv-pos}$

$C_{QW} < 0$	$f_\beta C_{QW} \lvert Q_{wv-neg} \rvert$

where:

f_β — heading correction factor, to be taken as 2.4.4.1;

C_{QW} — load combination factor for vertical wave shear force, to be taken as specified in Section 2.2 in this Chapter;

$Q_{wv\text{-}pos}$, $Q_{wv\text{-}neg}$ — Positive and negative vertical wave shear force taking account of the considered design load scenario, as defined in [2.4.3.2].

2.4.4.3 The horizontal wave bending moment, $M_{wh\text{-}LC}$, in kNm, to be used for each dynamic load case defined in Section 2.2 of this Chapter, is to be taken as:

$$M_{wh-LC} = f_\beta C_{WH} M_{wh}$$

where:

f_β — heading correction factor, to be taken as 2.4.4.1;

C_{WH} — load combination factor for horizontal wave shear force, to be taken as specified in Section 2.2 in this Chapter;

M_{wh} — horizontal wave bending moment taking account of the appropriate design load scenario, as defined in [2.4.3.3].

2.4.4.4 The wave torsional moment, $M_{wt\text{-}LC}$, in kNm, to be used for each dynamic load case defined in Ch 4, Sec 2, is to be taken as:

$$M_{wt-LC} = f_\beta C_{WT} M_{wt}$$

where:

f_β — heading correction factor, to be taken as 2.4.4.1;

C_{WH} — load combination factor for wave torsional moment, to be taken as specified in Section 2.2 in this Chapter;

M_{wt} — wave torsional moment taking account of the appropriate design load scenario, as defined in [2.4.3.4].

2.5 External Loads

2.5.1 Total sea pressure

2.5.1.1 The external pressure P_{ex} at any load point of the hull, in kN/m^2, for the static (S) design load scenarios, is to be taken as:

$$P_{ex} = P_S \text{ , but not less than 0}$$

2.5.1.2 The total pressure P_{ex} at any load point of the hull for the static plus dynamic (S+D) design load scenarios, in kN/m^2, is to be derived from each dynamic load case and is to be taken as:

$$P_{ex} = P_S + P_W \text{ , but not less than 0}$$

where:

P_S — hydrostatic pressure, kN/m^2, defined in [2.5.2];

P_W — wave pressure, in kN/m^2, defined in [2.5.3].

2.5.2 Hydrostatic pressure

2.5.2.1 The hydrostatic pressure, P_S at any load point, in kN/m^2, is obtained from Table 2.5.2.1. See also Figure 2.5.2.1.

Hydrostatic Pressure, P_S **Table 2.5.2.1**

Location	Hydrostatic pressure, P_S, in kN/m^2
$z \le T_{LC}$	$\rho g(T_{LC} - z)$
$z > T_{LC}$	0

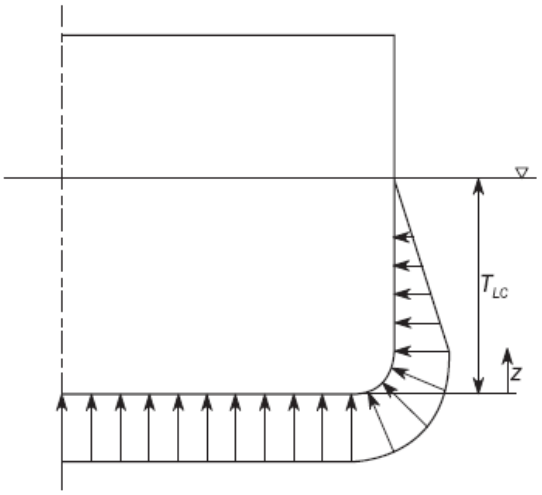


Figure 2.5.2.1 Hydrostatic Pressure, P_S

2.5.3 External dynamic sea pressures

2.5.3.1 Hydrodynamic pressures for HSM load cases

The hydrodynamic pressures, P_W, for HSM-1 and HSM-2 load cases, at any load point, in kN/m^2, are to be obtained from Table 2.5.3.1. See also Figure 2.5.3.1 and Figure 2.5.3.2.

Hydrodynamic Pressures for HSM Load Cases **Table 2.5.3.1**

	Wave pressure, in kN/m^2		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
HSM-1	$P_W = \max(-P_{HS}, \rho g(z - T_{LC}))$	$P_W = P_{W,WL} - g(z\text{-}T_{LC})$	$P_W = 0$
HSM-2	$P_W = \max(P_{HS}, \rho g(z - T_{LC}))$		

where:

$P_{W,WL}$ — wave pressure at the waterline, in kN/m2, for the considered dynamic load case:

$$P_{W,WL} = P_W \quad \text{, for } z = T_{LC}$$

h_W — water head equivalent to the pressure at waterline, in m, to be taken as:

$$h_W = \frac{P_{W,WL}}{\rho g}$$

$$P_{HS} = f_p f_{nl} f_h k_a k_p f_{yz} C_w \sqrt{\frac{L_0 + \lambda - 125}{L}}$$

f_{nl} — coefficient considering non-linear effects, to be taken as:

- For extreme sea loads design load scenario:

  f_{nl} = 0.7 at f_{XL}= 0.0

  f_{nl} = 0.9 at f_{XL}= 0.3

  f_{nl} = 0.9 at f_{XL}= 0.7

  f_{nl} = 0.6 at f_{XL}= 1.0.

Intermediate values are obtained by linear interpolation.

f_{yz} — girth distribution coefficient, to be taken as:

$$f_{yz} = \frac{z}{T_{LC}} + f_{yB} + 1$$

f_{yB} — ratio between *Y*-coordinate of the load point and B_x, to be taken as:

$f_{yB} = 0.0$, but not less than 1.0

$f_{yB} = \frac{|2y|}{B_x}$, but not greater than 1.0, and $f_{yB} = 0.0$ when $B_x = 0.0$

f_{yB1} — ratio between *Y*-coordinate of the load point and *B*, to be taken as:

$f_{yB} = \frac{|2y|}{B}$, but not greater than 1.0.

B_x — moulded breadth at the waterline, in m, at the considered cross section;

f_h — coefficient to be taken:

$$f_h = 3.0(1.21 - 0.66 f_T)$$

k_a — amplitude coefficient in the longitudinal direction of the ship, to be taken as:

$$k_a = (0.5 + f_T)\left\{\left(3 - 2\sqrt{f_{yB}}\right) - \frac{20}{9} f_{xL}\left(7 - 6\sqrt{f_{yB}}\right)\right\} + \frac{2}{3}(1 - f_T), \quad \text{for} \quad f_{xL} < 0.15$$

$k_a = 1.0$, for $0.15 \le f_{xL} < 0.7$

$$k_a = 1 + (f_{xL} - 0.7)\left\{\left(\frac{40}{3} f_T - 5\right) + 2(1 - f_{yB})\left[\frac{18}{C_B} f_T (f_{xL} - 0.7) - 0.25(2 - f_T)\right]\right\}, \text{ for } \quad f_{xL} \ge 0.7$$

λ — wave length of the dynamic load case, in m, to be taken as:

$$\lambda = 0.6(1 + f_T)L$$

k_p — phase coefficient to be obtained from Table 2.5.3.2. Intermediate values are to be interpolated.

k_p Values for HSM Load Cases **Table 2.5.3.2**

f_{xL}	0	$0.3-0.1f_T$	$0.35-0.1f_T$	$0.8-0.2f_T$	$0.9-0.2f_T$	1.0
k_p	$-0.25f_T(1+f_{yB})$	-1	1	1	-1	-1

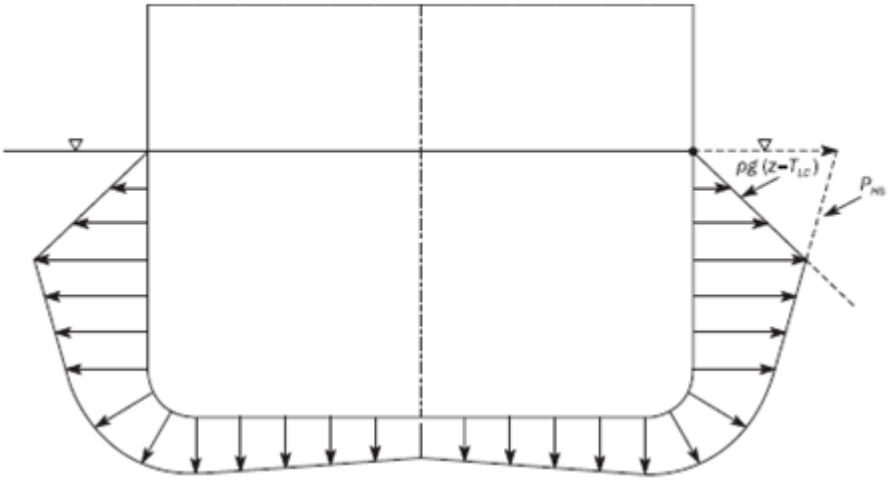


Figure 2.5.3.1 Transverse Distribution of Dynamic Pressure Amidships for HSM-1, HSA-1 And FSM-1 Load Cases

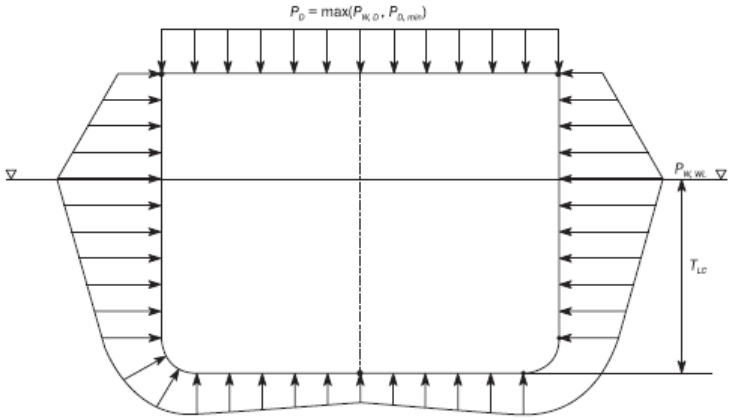


Figure 2.5.3.2 Transverse Distribution of Dynamic Pressure Amidships for HSM-2, HSA-2 And FSM-2 Load Cases

2.5.3.2 Hydrodynamic pressures for HSA load cases

The hydrodynamic pressures, P_W, for HSA-1 and HSA-2 load cases at any load point, in kN/m^2, are to be obtained from Table 2.5.3.3. See also Figure 2.5.3.3 and Figure 2.5.3.2.

Hydrodynamic Pressures for HSA Load Cases **Table 2.5.3.3**

	Water pressure, in kN/m^2

Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
HSA-1	$P_W = \max(-P_{HS}, \rho g(z - T_{LC}))$	$P_W = P_{W,WL} - g(z\text{-}T_{LC})$	$P_W = 0$
HSA-2	$P_W = \max(P_{HS}, \rho g(z - T_{LC}))$		

where:

$$P_{HS} = f_p f_{nl} f_h k_a k_p f_{yz} C_w \sqrt{\frac{L_0 + \lambda - 125}{L}}$$

f_{nl} — coefficient considering non-linear effects, to be taken as defined in 2.5.3.1;

f_{yz} — girth distribution coefficient, to be taken as:

$$f_{yz} = \frac{z}{T_{LC}} + f_{yB} + 1;$$

f_h — coefficient, to be taken as:

$$f_h = 2.4(1.21 - 0.66 f_T);$$

k_a — amplitude coefficient in the longitudinal direction of the ship, to be taken as defined in 2.5.3.1;

λ — wave length of the dynamic load case, in m, to be taken as:

$$\lambda = 0.6(1 + f_T)L;$$

k_p — phase coefficient to be obtained from Table 2.5.3.4. Intermediate values are to be interpolated.

k_p Values for HSA Load Cases **Table 2.5.3.4**

f_{xL}	0	$0.3 - 0.1 f_T$	$0.5 - 0.2 f_T$	$0.8 - 0.2 f_T$	$0.9 - 0.2 f_T$	1.0
k_p	$1.5 - f_T - 0.5 f_{yB}$	-1	1	1	-1	-1

2.5.3.3 Hydrodynamic pressures for FSM load cases

The hydrodynamic pressures, P_W, for FSM-1 and FSM-2 load cases, at any load point, in kN/m^2, are to be obtained from Table 2.5.3.5. See also Figure 2.5.3.1 and Figure 2.5.3.2.

Hydrodynamic Pressures for FSM Load Cases **Table 2.5.3.5**

	Water pressure, in kN/m^2		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
FSM-1	$P_W = \max(-P_{FS}, \rho g(z - T_{LC}))$	$P_W = P_{W,WL} - g(z\text{-}T_{LC})$	$P_W = 0$
FSM-2	$P_W = \max(P_{FS}, \rho g(z - T_{LC}))$		

where:

$$P_{FS} = f_p f_{nl} f_h k_a k_p f_{yz} C_w \sqrt{\frac{L_0 + \lambda - 125}{L}}$$

f_{nl} — coefficient considering non-linear effects, to be taken as:

f_{nl} = 0.9 for extreme sea loads design load scenario;

f_{yz} — girth distribution coefficient, to be taken as:

$$f_{yz} = \frac{z}{T_{LC}} + f_{yB} + 1;$$

f_h — coefficient, to be taken as:

$$f_h = 2.6;$$

k_a — amplitude coefficient in the longitudinal direction of the ship, to be taken as:

$$k_a = 1 + (3.75 - 2f_T)(1 - 5f_{xL})(1 - f_{yB}), \text{ for } f_{xL} < 0.2;$$

$$k_a = 1.0, \text{ for } 0.2 \le f_{xL} < 0.9;$$

$$k_a = 1 + 20(1 - f_{yB})(f_{xL} - 0.9), \text{ for } f_{xL} \ge 0.9;$$

λ — wave length of the dynamic load case, in m, to be taken as:

$$\lambda = 0.6(1 + 2/3\, f_T)L;$$

k_p — phase coefficient to be obtained from Table 2.5.3.6. Intermediate values are to be interpolated.

k_p Values for FSM Load Cases **Table 2.5.3.6**

f_{xL}	0	$0.35 - 0.1f_T$	$0.5 - 0.2f_T$	0.75	0.8	1.0
k_p	$-0.75 - 0.25f_{yB}$	-1	1	1	-1	$-0.75 - 0.25f_{yB}$

2.5.3.4 Hydrodynamic pressures for BSR load cases

The wave pressures, P_W, for BSR-1 and BSR-2 load cases, at any load point, in kN/m^2, are to be obtained from Table 2.5.3.7. See also Figure 2.5.3.3 and Figure 2.5.3.4.

Hydrodynamic Pressures for BSR Load Cases **Table 2.5.3.7**

	Water pressure, in kN/m^2		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
BSR-1P	P_W =max (P_{BSR}, $g(z\text{-}T_{LC})$)	$P_W = P_{W,WL}$ - $g(z\text{-}T_{LC})$	$P_W = 0$
BSR-2P	P_W = max (-P_{BSR}, $g(z\text{-}T_{LC})$)		
BSR-1S	P_W = max (P_{BSR}, $g(z\text{-}T_{LC})$)		
BSR-2S	P_W = max (-P_{BSR}, $g(z\text{-}T_{LC})$)		

where:

For BSR-1P and BSR-2P load cases:

$$P_{BSR} = f_\beta f_{nl}\left(10y\sin\theta + 0.88 f_p C_w \sqrt{\frac{L_0+\lambda-125}{L}}\left(f_{yB1}+1\right)\right)$$

For BSR-1S and BSR-2S load cases:

$$P_{BSR} = f_\beta f_{nl}\left(-10y\sin\theta + 0.88 f_p C_w \sqrt{\frac{L_0+\lambda-125}{L}}\left(f_{yB1}+1\right)\right)$$

f_{nl} — coefficient considering non-linear effect, to be taken as f_{nl} = 1.0;

λ — wave length of the dynamic load case, in m, to be taken as:

$$\lambda = \frac{g}{2\pi}T_\theta^2 .$$

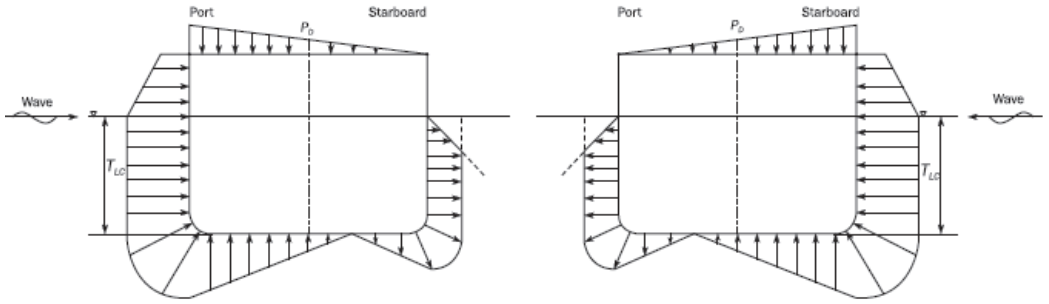


Figure 2.5.3.3 Transverse Distribution of Dynamic Pressure Amidships for BSR-1P (Left) and BSR-1S (Right) Load Cases

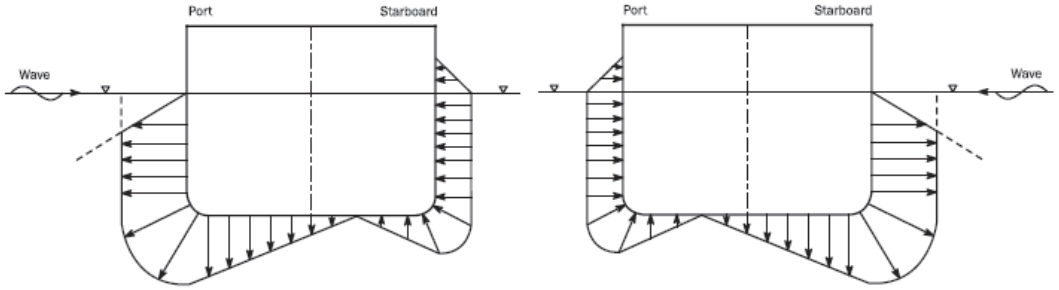


Figure 2.5.3.4 Transverse Distribution of Dynamic Pressure Amidships for BSR-2P (Left) and BSR-2S (Right) Load Cases

2.5.3.5 Hydrodynamic pressures for BSP load cases

The wave pressures, P_W, for BSP-1 and BSP-2 load cases, at any load point, in kN/m^2, are to be obtained from Table 2.5.3.8. See also Figure 2.5.3.5 and Figure 2.5.3.6.

Hydrodynamic Pressures for BSP Load Cases **Table 2.5.3.8**

	Water pressure, in kN/m^2		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
BSP-1P	P_W =max (P_{BSP}, $\rho g(z\text{-}T_{LC})$)	$P_W = P_{W,WL}$ - $g(z\text{-}T_{LC})$	$P_W = 0$
BSP-2P	P_W = max (-P_{BSP}, $\rho g(z\text{-}T_{LC})$)		
BSP-1S	P_W = max (P_{BSP}, $\rho g(z\text{-}T_{LC})$)		

BSP-2S	P_W = max (-P_{BSP}, $\rho g(z\text{-}T_{LC})$)		

where:

$$P_{BSP} = 4.5 f_\beta f_p f_{nl} f_{yz} C_w \sqrt{\frac{L_0 + \lambda - 125}{L}}$$

λ — wave length of the dynamic load case, in m, to be taken as:
$\lambda = 0.2(1+2f_T)L$;

f_{yz} — Girth distribution coefficient, to be obtained from Table 2.5.3.9:

Girth Distribution Coefficient, f_{yz} for BSP Load Cases **Table 2.5.3.9**

Transverse position	BSP-1P, BSP-2P	BSP-1S, BSP-2S
$y \geq 0$	$f_{yz} = 2\frac{z}{T_{LC}} + 2.5 f_{yB} + 0.5$	$f_{yz} = \frac{2}{3}\frac{z}{T_{LC}} + \frac{1}{2} f_{yB} + 0.5$
$y < 0$	$f_{yz} = \frac{2}{3}\frac{z}{T_{LC}} + \frac{1}{2} f_{yB} + 0.5$	$f_{yz} = 2\frac{z}{T_{LC}} + 2.5 f_{yB} + 0.5$

f_{nl} — coefficient considering non-linear effect, to be taken as:

- For extreme sea loads design load scenario:

f_{nl} = 0.6 at f_{XL}= 0.0
f_{nl} = 0.8 at f_{XL}= 0.3
f_{nl} = 0.8 at f_{XL}= 0.7
f_{nl} = 0.6 at f_{XL}= 1.0

Intermediate values are obtained by linear interpolation.

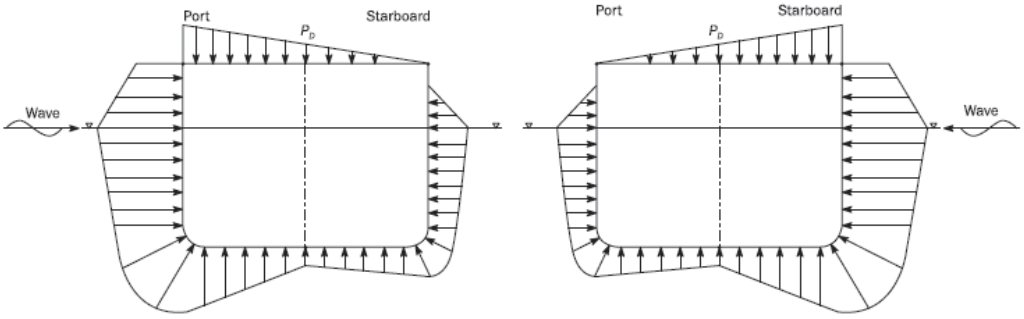


Figure 2.5.3.5 Transverse Distribution of Dynamic Pressure Amidships for BSP-1P (Left) and BSP-1S (Right) Load Cases

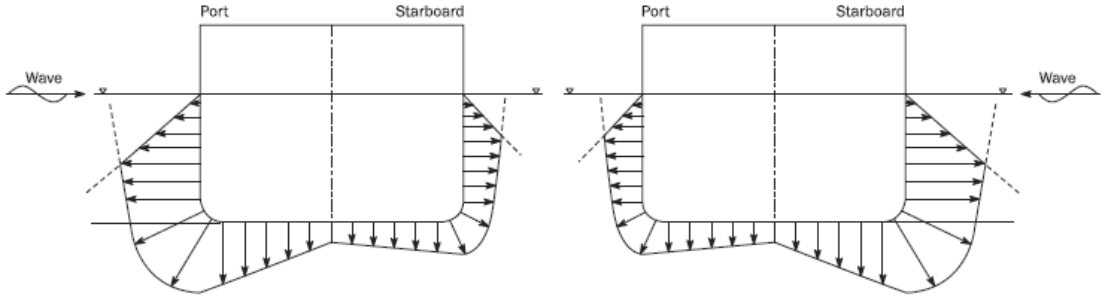


Figure 2.5.3.6 Transverse Distribution of Dynamic Pressure Amidships for BSP-2P (Left) and BSP-2S (Right) Load Cases

2.5.3.6 Hydrodynamic pressures for OST load cases

The wave pressures, P_W, for OST-1 and OST-2 load cases, at any load point are to be obtained, in kN/m^2, from Table 2.5.3.10. See also Figure 2.5.3.7 and Figure 2.5.3.8.

Hydrodynamic Pressures for OST Load Cases **Table 2.5.3.10**

	Water pressure, in kN/m^2		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
OST-1P	P_W =max (P_{OST}, $\rho g(z\text{-}T_{LC})$)	$P_W = P_{W,WL}$ - $g(z\text{-}T_{LC})$	$P_W = 0$
OST--2P	P_W = max (-P_{OST}, $\rho g(z\text{-}T_{LC})$)		
OST--1S	P_W = max (P_{OST}, $\rho g(z\text{-}T_{LC})$)		
OST--2S	P_W = max (-P_{OST}, $\rho g(z\text{-}T_{LC})$)		

where:

$$P_{OST} = 1.38 f_p f_{nl} k_a k_p f_{yz} C_w \sqrt{\frac{L_0 + \lambda - 125}{L}}$$

f_{yz} — girth distribution coefficient, to be obtained from Table 2.5.3.11;

f_{nl} — coefficient considering non-linear effect, to be taken as: f_{nl} = 0.8;

λ — wave length of the dynamic load case, in m, to be taken as:

$\lambda = 0.45L$;

Girth Distribution Coefficient, f_{yz} for OST Load Cases **Table 2.5.3.11**

Transverse position	OST-1P, OST-2P	OST -1S, OST -2S
$y \ge 0$	$5\frac{z}{T_{LC}} + 3.5 f_{yB} + 1.5$	$1.5\frac{z}{T_{LC}} + 1.5$
$y < 0$	$1.5\frac{z}{T_{LC}} + 1.5$	$5\frac{z}{T_{LC}} + 3.5 f_{yB} + 1.5$

k_a — Amplitude coefficient in the longitudinal direction of the ship, to be obtained from Table 2.5.3.12:

***ka* Values for OST Load Cases** **Table 2.5.3.12**

Transverse positon	Longitudinal position	OST-1P, OST-2P	OST -1S, OST -2S
$y \ge 0$	$f_{xL} \le 0.2$	$1.0 + 3.5(1 - f_{yB})(1 - 5 f_{xL})$	$1.0 + [3.5 - (4 f_T - 0.5) f_{yB}](1 - 5 f_{xL})$
	$0.2 < f_{xL} \le 0.8$	1.0	1.0
	$f_{xL} > 0.8$	1.0	$1.0 + 4(1 - f_T)(5 f_{xL} - 4) f_{yB}$
$y < 0$	$f_{xL} \le 0.2$	$1.0 + [3.5 - (4 f_T - 0.5) f_{yB}](1 - 5 f_{xL})$	$1.0 + 3.5(1 - f_{yB})(1 - 5 f_{xL})$

Transverse positon	Longitudinal position	OST-1P, OST-2P	OST -1S, OST -2S
	$0.2 < f_{xL} \le 0.8$	1.0	1.0
	$f_{xL} > 0.8$	$1.0+4(1-f_T)(5f_{xL}-4)f_{yB}$	1.0

k_p — phase coefficient to be obtained from Table 2.5.3.13, the intermediate values are to be interpolated:

k_p Values for OST Load Cases **Table 2.5.3.13**

Transverse position	f_{xL}	OST-1P; OST-2P	OST-1S; OST-2S
$y \ge 0$	0.0	1.0	1.0
	0.2	1.0	$1.0+(0.75-1.5f_T)f_{yB}$
	0.4	-1.0	$-1.0+(1.75-0.5f_T)f_{yB}$
	0.5	-1.0	$-1.0+(1.75-0.5f_T)f_{yB}$
	0.7	$-0.1+(1.6f_T-1.5)f_{yB}$	$-0.1+(0.25-0.3f_T)f_{yB}$
	0.9	$0.8+0.2f_{yB}$	$0.8-(0.9f_T+0.85)f_{yB}$
	1.0	$-1.0+f_{yB}$	$-1.0+(0.5-0.5f_T)f_{yB}$
$y < 0$	0.0	1.0	1.0
	0.2	$1.0+(0.75-1.5f_T)f_{yB}$	1.0
	0.4	$-1.0+(1.75-0.5f_T)f_{yB}$	-1.0
	0.5	$-1.0+(1.75-0.5f_T)f_{yB}$	-1.0
	0.7	$-0.1+(0.25-0.3f_T)f_{yB}$	$-0.1+(1.6f_T-1.5)f_{yB}$
	0.9	$0.8-(0.9f_T+0.85)f_{yB}$	$0.8+0.2f_{yB}$
	1.0	$-1.0+(0.5-0.5f_T)f_{yB}$	$-1.0+f_{yB}$

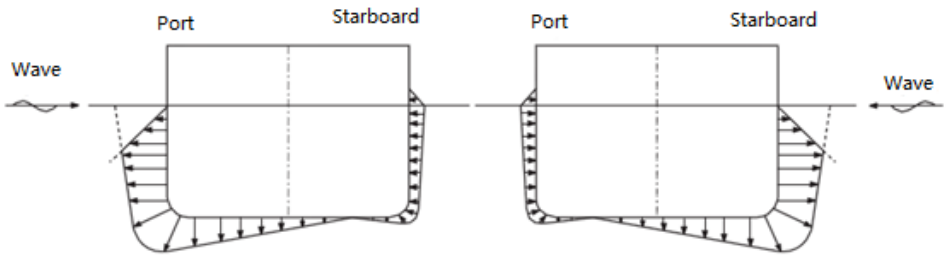


Figure 2.5.3.7 Transverse Distribution of Dynamic Pressure Amidships for OST-1P (Left) and OST-1S (Right) Load Cases

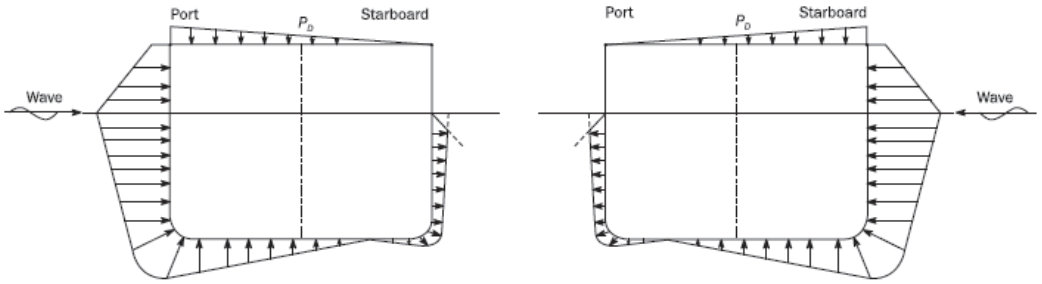


Figure 2.5.3.8 Transverse Distribution of Dynamic Pressure Amidships for OST-2P (Left) and OST-2S (Right) Load Cases

2.5.3.7 Hydrodynamic pressures for OSA load cases

The wave pressures, P_W, for OSA-1 and OSA-2 load cases, at any load point, in kN/m^2, are to be obtained from Table 2.5.3.14. See also Figure 2.5.3.9 and Figure 2.5.3.10.

Hydrodynamic Pressures for OSA Load Cases **Table 2.5.3.14**

	Water pressure, in kN/m^2		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
OSA-1P	P_W =max (P_{OSA}, $\rho g(z\text{-}T_{LC})$)	$P_W = P_{W,WL}$ - $g(z\text{-}T_{LC})$	$P_W = 0$
OSA-2P	P_W = max (-P_{OSA}, $\rho g(z\text{-}T_{LC})$)		
OSA-1S	P_W = max (P_{OSA}, $\rho g(z\text{-}T_{LC})$)		
OSA-2S	P_W = max (-P_{OSA}, $\rho g(z\text{-}T_{LC})$)		

where:

$$P_{OSA} = 0.81 f_p f_{nl} k_a k_p f_{yz} C_w \sqrt{\frac{L_0 + \lambda - 125}{L}} (1 + 0.5 f_T)$$

λ — wave length of the dynamic load case, in m, to be taken as:

$\lambda = 0.7L$;

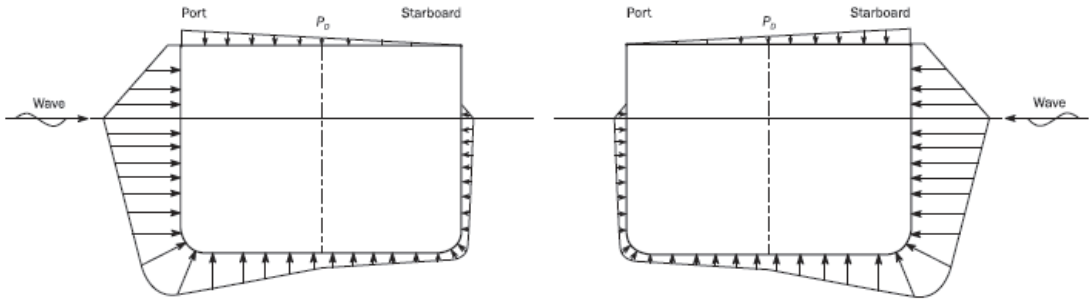


Figure 2.5.3.9 Transverse Distribution of Dynamic Pressure Amidships for OSA-1P (Left) and OSA-1S (Right) Load Cases

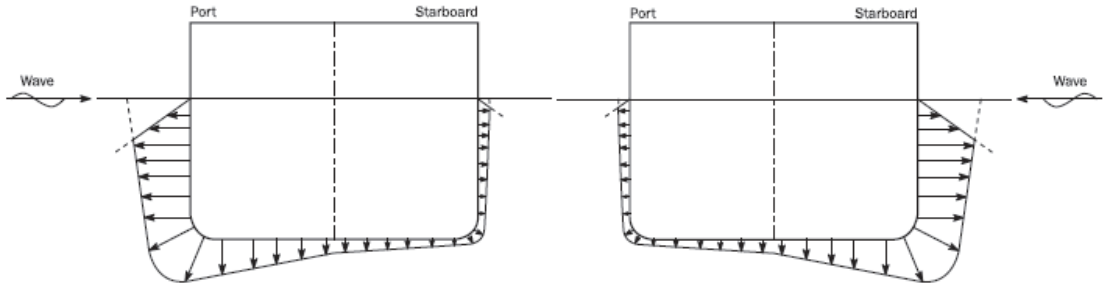


Figure 2.5.3.10 Transverse Distribution of Dynamic Pressure Amidships for OSA-2P (Left) and OSA-2S (Right) Load Cases

f_{nl} — coefficient considering non-linear effect, to be taken as:

f_{nl} = 0.5 at f_{XL}= 0.0;

f_{nl} = 0.8 at f_{XL}= 0.3;

f_{nl} = 0.8 at f_{XL}= 0.7;

f_{nl} = 0.6 at f_{XL}= 1.0;

Intermediate values are obtained by linear interpolation;

f_{yz} — girth distribution coefficient, to be obtained from Table 2.5.3.15:

Girth Distribution Coefficient, f_{yz} for OSA Load Cases Table 2.5.3.15

Transverse position	OSA-1P, OSA-2P	OSA -1S, OSA -2S
$y \geq 0$	$5.5\frac{z}{T_{LC}} + 5.3 f_{yB} + 2.2$	$0.9\frac{z}{T_{LC}} + 0.4 f_{yB} + 2.2$
$y < 0$	$0.9\frac{z}{T_{LC}} + 0.4 f_{yB} + 2.2$	$5.5\frac{z}{T_{LC}} + 5.3 f_{yB} + 2.2$

k_a — amplitude coefficient in the longitudinal direction of the ship, to be obtained from Table 2.5.3.16;

k_p — Phase coefficient to be obtained from Table 2.5.3.17. Intermediate values are to be interpolated;

k_a Values for OSA Load Cases Table 2.5.3.16

Transverse position	Longitudinal position	OST-1P, OST-2P	OST -1S, OST -2S

$y \geq 0$	$f_{xL} \leq 0.2$	$1.0+3(2-f_T)(1-5f_{xL})(1-f_{yB})$	$1.0+3(2-f_T)(1-5f_{xL})$ $+\{(28f_{xL}-5)$ $+3f_T(1-5f_{xL})\}f_{yB}$
	$0.2 < f_{xL} \leq 0.5$	1.0	$1.0+(1-2f_{xL})f_{yB}$
	$0.5 < f_{xL} \leq 0.8$	1.0	$1.0+1.5(2f_{xL}-1)f_{yB}$
	$f_{xL} \geq 0.8$	$1.0+(f_{xL}-0.8)(1-f_{yB})A$	$1.0+\{1.5(2f_{xL}-1)$ $-(f_{xL}-0.8)A\}f_{yB}$ $+(f_{xL}-0.8)A$
$y < 0$	$f_{xL} \leq 0.2$	$1.0+3(2-f_T)(1-5f_{xL})$ $+\{(28f_{xL}-5)$ $+3f_T(1-5f_{xL})\}f_{yB}$	$1.0+3(2-f_T)(1-5f_{xL})(1-f_{yB})$
	$0.2 < f_{xL} \leq 0.5$	$1.0+(1-2f_{xL})f_{yB}$	1.0
	$0.5 < f_{xL} \leq 0.8$	$1.0+1.5(2f_{xL}-1)f_{yB}$	1.0
	$f_{xL} \geq 0.8$	$1.0+\{1.5(2f_{xL}-1)$ $-(f_{xL}-0.8)A\}f_{yB}$ $+(f_{xL}-0.8)A$	$1.0+(f_{xL}-0.8)(1-f_{yB})A$
where: $A=22-15f_T+3[22(f_{xL}-0.8)-0.25(2-f_T)]$			

k_p Values for OSA Load Cases **Table 2.5.3.17**

Transverse position	f_{xL}	OSA-1P; OSA-2P	OSA-1S; OSA-2S
$y \geq 0$	0.0	$0.75-0.5f_{yB}$	0.75
	0.2	$f_T-0.25+(1.25-f_T)f_{yB}$	$f_T-0.25+(0.35f_T-0.47)f_{yB}$
	0.4	1.0	$1.0+(2.7f_T-3.2)f_{yB}$
	0.5	$1.25-0.5f_T+(0.5f_T-0.25)f_{yB}$	$1.25-0.5f_T+(2.7f_T-3.2)f_{yB}$
	0.6	$1.5-f_T+(f_T-1.07)f_{yB}$	$1.5-f_T+(2.68f_T-3.19)f_{yB}$
	0.85	$0.5f_T-1.25+(0.25-0.5f_T)f_{yB}$	$0.5f_T-1.25+(0.2-0.1f_T)f_{yB}$
	1.0	$0.5f_T-1.25+(0.25-0.5f_T)f_{yB}$	$0.5f_T-1.25+(0.2-0.1f_T)f_{yB}$

$y<0$	0.0	0.75	$0.75-0.5f_{yB}$
	0.2	$f_T-0.25+(0.35f_T-0.47)f_{yB}$	$f_T-0.25+(1.25-f_T)f_{yB}$
	0.4	$1.0+(2.7f_T-3.2)f_{yB}$	1.0
	0.5	$1.25-0.5f_T+(2.7f_T-3.2)f_{yB}$	$1.25-0.5f_T+(0.5f_T-0.25)f_{yB}$
	0.6	$1.5-f_T+(2.68f_T-3.19)f_{yB}$	$1.5-f_T+(f_T-1.07)f_{yB}$
	0.85	$0.5f_T-1.25+(0.2-0.1f_T)f_{yB}$	$0.5f_T-1.25+(0.25-0.5f_T)f_{yB}$
	1.0	$0.5f_T-1.25+(0.2-0.1f_T)f_{yB}$	$0.5f_T-1.25+(0.25-0.5f_T)f_{yB}$

2.5.4 Green sea pressure on exposed deck

2.5.4.1 The external dynamic pressure due to green sea loading, P_D, at any point of an exposed deck, in kN/m^2, for the static plus dynamic (S+D) design load scenarios is to be derived for each dynamic load case and is to be taken as defined in 2.5.4.3 to 2.5.4.4 The external dynamic pressure due to green sea loading, P_D, at any point of an exposed deck for the static (S) design load scenarios is zero.

2.5.4.2 If a breakwater is fitted on the exposed deck, no reduction in the green sea pressure is allowed for the area of the exposed deck located aft of the breakwater.

2.5.4.3 HSM, HAS and FSM load cases

The external pressure, P_D, for HSM, HSA and FSM load cases, at any load point of an exposed deck is to be obtained, in kN/m^2, from the following formula, see Figure 2.5.3.1 and Figure 2.5.3.2:

$$P_D = \chi P_W$$

where:

$P_W = P_{W,D}$, but not to be less than $P_{D\text{-}min}$;

$P_{W,D}$ — pressure, in kN/m^2, obtained at side of the exposed deck for HSM, HSA and FSM load cases as defined in [2.5.3];

$P_{D\text{-}min}$ — minimum exposed deck pressure, in kN/m^2, obtained from Table 2.5.4.1, to be taken as:

- For cargo hold analysis according to Chapter 3, $P_{D\text{-}min}$=0.0;
- For other cases, $P_{D\text{-}min}$ as defined in Table 2.5.4.1;

χ — coefficient defined in Table 2.5.4.2.

Minimum Pressures on Exposed Decks for HSM, HSA, FSM Load Cases

Table 2.5.4.1

Location	Minimum pressure on exposed deck $P_{D\text{-}min}$, in kN/m ²	
	$L_{LL} \geq$ 100m	L_{LL}<100m
$x_{LL} / L_{LL} \leq 0.75$	34.3	14.9 + 0.195 L_{LL}
$x_{LL} / L_{LL} > 0.75$	$34.3 + (14.8 + a(L_{LL} - 100))\left(4\frac{x_{LL}}{L_{LL}} - 3\right)$	$12.2 + \frac{L_{LL}}{9}\left(5\frac{x_{LL}}{L_{LL}} - 2\right) + 3.6\frac{x_{LL}}{L_{LL}}$

where:

a — coefficient, to be taken as:

a = 0.356 for Type A, Type B-60 and Type B-100 freeboard ships

a = 0.0726 for Type B freeboard ships

x_{LL} — X-coordinate of the load point measured from the aft end of the freeboard length L_{LL}.

Coefficient for Pressure on Exposed Decks **Table 2.5.4.2**

Exposed deck location	φ
Freeboard deck	1.00
Superstructure deck including forecastle deck	0.75
1st tier of deckhouse	0.56
2nd tier of deckhouse	0.42
3rd tier of deckhouse	0.32
4th tier of deckhouse	0.25
5th tier of deckhouse	0.20
6th tier of deckhouse	0.15
7th tier of deckhouse and above	0.10

2.5.4.4 BSR, BSP, OST and OSA load cases

The external pressure, P_D, for BSR, BSP, OST and OSA load cases at any load point of an exposed deck is to be obtained, in kN/m^2, by linear interpolation between the pressures at the port and starboard deck edges (see also Figure 2.5.3.3, Figure 2.5.3.5, Figure 2.5.3.8 and Figure 2.5.3.9):

$$P_{D,stb} = \chi P_{W,D-stb}$$

$$P_{D,pt} = \chi P_{W,D-pt}$$

where:

$P_{W,D\text{-}stb}$ — pressure obtained at starboard deck edge for BSR, BSP, OST or OSA load cases as defined in [2.5.3], as appropriate;

$P_{W,D\text{-}pt}$ — pressure obtained at port deck edge for BSR, BSP, OST and OSA load cases as defined in [2.5.3], as appropriate;

X — coefficient defined in Table 2.5.4.2.

2.6 Internal Loads

2.6.1 Pressures due to liquids

2.6.1.1 The internal pressure due to liquid acting on any load point of a tank and ballast hold boundary, in kN/m^2, for the static (S) design load scenarios, is to be taken as:

$$P_{in} = P_{ls}\text{, but not to be less than 0}$$

2.6.1.2 The internal pressure due to liquid acting on any load point of a tank and ballast hold boundary, in kN/m^2, for the static plus dynamic (S+D) design load scenarios is to be derived for each dynamic load case and is to be taken as:

$$P_{in} = P_{ls} + P_{ld}\text{, but not to be less than 0}$$

where:

P_{ls} — static pressure due to liquid in tanks, in kN/m ², as defined in [2.6.1.3];

P_{ld} — dynamic pressure due to liquid in tanks, in kN/m ², as defined in [2.6.1.4].

2.6.1.3 The static pressure, P_{ls} due to liquid in tanks and ballast holds, in kN/m^2, is to be taken as:

$$P_{ls} = \rho_L g\left(z_{top} - z + 0.5h_{air}\right)$$

where:

h_{air} — height of air pipe or overflow pipe above the top of the tank, in m.

2.6.1.4 The dynamic pressure, P_{ld} due to liquid in tanks and ballast holds, in kN/m^2, is to be taken as:

$$P_{ld} = f_\beta \rho_L[a_Z(z_0 - z) + a_X(x_0 - x) + a_Y(y_0 - y)]$$

where:

l_{fs} — cargo tank length at the top of the tank or length of the ballast hold hatch coaming, in m;

b_{top} — cargo tank breadth at the top of the tank or breadth of the ballast hold hatch coaming, in m, determined at mid length of the tank or ballast hold hatch coaming;

x_0 — X coordinate, in m, of the reference point;

y_0 — Y coordinate, in m, of the reference point;

z_0 — Z coordinate in m, of the reference point.

The reference point is to be taken as the point with the highest value of V_j, calculated for all points that define the upper boundary of the tank or ballast hold as follows:

$$V_j = a_X\left(x_j - x_G\right) + a_Y\left(y_j - y_G\right) + \left(a_Z + g\right)\left(z_j - z_G\right)$$

where:

x_j: X coordinate, in m, of the point j on the upper boundary of the tank or ballast hold;

y_j: Y coordinate, in m, of the point j on the upper boundary of the tank or ballast hold;

z_j: Z coordinate, in m, of the point j on the upper boundary of the tank or ballast hold.

2.6.2 Characteristics of dry bulk cargo hold

2.6.2.1 The main geometrical parameters of a dry bulk cargo hold for ore carrier is shown in Figure 2.6.2.1.

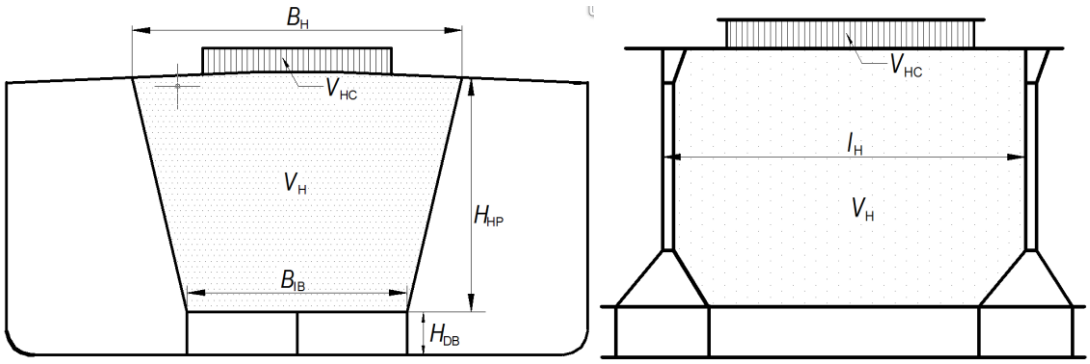


Figure 2.6.2.1 Definition of Cargo Hold Parameters for Ore Carrier

B_H — breadth of the cargo hold, in m, measured at the connection between longitudinal bulkhead top at mid-length of the cargo hold and main deck, see Figure 2.6.2.1;

l_H — length of the cargo hold, in m, at the centreline between the transverse bulkheads. It is to be measured from the corresponding frame of corrugation, if corrugated bulkhead is fitted;

B_{IB} — breadth of inner bottom, in m, measured at mid-length of the cargo hold, see Figure 2.6.2.1;

D_1 — distance, in m, from the baseline to the freeboard deck at side amidships;

h_C — height of bulk cargo, in m, from the inner bottom to the upper surface of bulk cargo;

h_{DB} — height, in m, of the double bottom at the centreline, measured at mid-length of the cargo hold, see Figure 2.6.2.1;

h_{HP} — vertical distance, in m, from the inner bottom at centreline to the upper intersection of hopper tank and side shell or inner side, determined at mid length of the considered cargo hold, as shown in Figure 2.6.2.1;

V_{Full} — volume, in m^3, of dry bulk cargo hold up to top of the hatch coaming, taken as:

$V_{Full} = V_H + V_{HC}$;

V_H — volume, in m^3, of cargo hold up to level of the intersection of the main deck with the hatch coaming excluding the volume enclosed by hatch coaming, see Figure 2.6.2.1;

V_{HC} — volume, in m^3, of the hatch coaming, from the level of the intersection of the main deck with the hatch side coaming to the top of the hatch coaming, determined for the cargo hold at midship, as shown in Figure 2.6.2.1;

V_{TS} — Total volume, in m^3, of the portion of the lower bulkhead stools within the cargo hold length l_H and inboard of the hopper tanks;

x_G, y_G, z_G — X, Y and Z coordinates, in m, of the volumetric centre of gravity of the tank or fully filled cargo hold, i.e. V_{Full}, considered with respect to the reference coordinate system defined in Ch 1, Sec 1, [1.2.3]. In case of partially filled cargo hold, x_G, y_G, z_G to be taken as follows:

x_G, y_G — volumetric centre of gravity of the cargo hold;

$$z_G = h_{DB} + h_{C-cl}/2;$$

z_C — height of the upper surface of the cargo above the baseline in way of the load point, in m, to be taken as:

$z_C = h_{DB} + h_C$;

α — angle, in deg., between panel considered and the horizontal plane;

Ψ — assumed angle of repose, in deg., of bulk cargo (considered drained and removed); to be taken as:

$\Psi = 30°$ in general;

$\Psi = 35°$ for iron ore;

$\Psi = 25°$ for cement;

K_C — coefficient, to be taken as:

$K_C = \cos^2\alpha + (1 - \sin\psi)\sin^2\alpha$, for inner bottom, hopper tank, transverse and longitudinal bulkheads, lower stool, vertical upper stool;

$K_C = 0$, for topside tank, main deck and sloped upper stool;

ρ_c — density of bulk cargo, in t/m^3;

ρ_L — density of liquid in the tank and ballast hold, in t/m^3;

ρ_{ST} — density of steel, in t/m^3, to be taken as 7.8.

2.6.2.2 The definitions of a fully and partially filled dry bulk cargo holds are as follow:

a) Fully filled hold:

The dry bulk cargo density is such that the cargo hold is filled up to the top of the hatch coaming, as shown in Figure 2.6.2.2.

The upper surface of the cargo and its effective height in the hold h_C are to be determined in accordance with [2.6.2.3].

b) Partially filled hold:

The cargo density is such that the cargo hold is not filled up to the top of the hatch coaming, as shown in Figure 2.6.2.3 and Figure 2.6.2.4.

The upper surface of the cargo and its effective height in the hold h_C are to be determined in accordance with [2.6.2.4].

2.6.2.3 Definition of the upper surface of dry bulk cargo for full cargo holds

For a fully filled cargo hold as defined in [2.6.2.2], including non-prismatic holds, the effective upper surface of the cargo is an equivalent horizontal surface at h_C, in m, above inner bottom at centreline.

The value of h_C is to be calculated at mid length of the cargo hold at the midship, is to be kept constant over the cargo hold region area and is determined as follows:

$$h_C = h_{HPU} + h_0$$

where:

$$h_0 = \frac{S_A}{B_H}$$

$$S_A = S_0 + \frac{V_{HC}}{\ell_H}$$

S_0 — shaded area, in m^2, above the lower intersection of topside tank and side shell or inner side, as the case may be, and up to the level of the intersection of the main deck with the hatch coaming, determined for the cargo hold at the midship as shown in Figure 2.6.2.2;

H_{HPU} — vertical distance, in m, measured from inner bottom to the lower edge of upper stool.

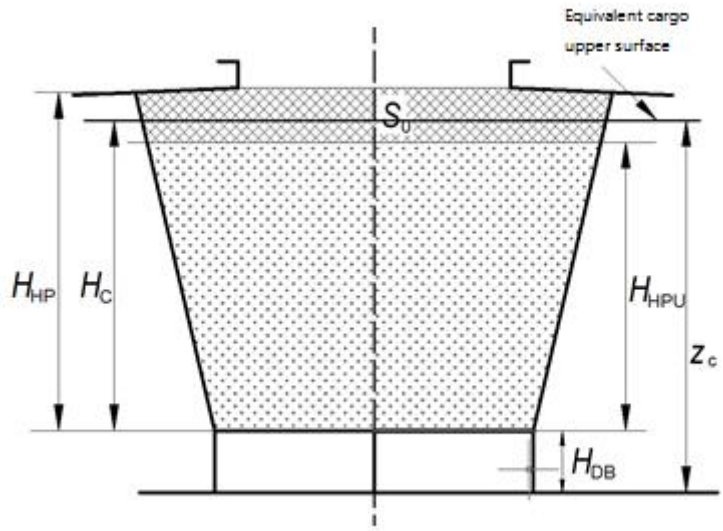


Figure 2.6.2.2 Definition of Effective Upper Surface of Cargo for a Full Cargo Hold

2.6.2.4 Definition of upper surface of dry bulk cargo for partially filled cargo holds

For any partially filled cargo hold, as defined in [2.6.2.2], including non-prismatic holds, the effective upper surface of the cargo is to be made of three parts: one central horizontal surface of breadth $B_H/2$, in m, at a height h_C, in m, above the inner bottom.

A sloped surface at each side with an angle $\psi/2$, in degrees, between the central horizontal surface, and the side shell or inner hull, as shown in Figure 2.6.2.3, or the hopper plating, as shown in Figure 2.6.2.4, as the case may be.

The height of cargo surface h_C, in m, is to be calculated at mid length of the considered cargo hold and is to be taken as constant over the length of the hold as follows:

For $|y| \le \frac{B_H}{4}$: $h_C = h_{C-CL}$

For $\frac{B_H}{4} < |y| \le \frac{B_2}{2}$: $h_C = h_{C-CL} - \left(|y| - \frac{B_H}{2}\right)\tan\left(\frac{\varphi}{2}\right)$

For $|y| > \frac{B_2}{2}$: $h_C = 0$

where:

h_1 — height, in m, to be taken as:

$$h_1 = \frac{M}{\rho_C \cdot B_H \ell_H} - \left(\frac{B_H + B_{IB}}{2B_H}\right)h_{HPL} - \frac{3}{16}B_H \tan\frac{\Psi}{2} + \frac{V_{TS}}{B_H \ell_H}$$

For $h_1 \ge 0$, see Figure 2.6.2.3:

$$h_{C-CL} = h_{HPL} + h_1 + h_2$$

$$h_2 = \frac{B_H}{4}\tan\frac{\Psi}{2}$$

$$B_2 = B_H$$

For $h_1 < 0$, see Figure 2.6.2.4:

$$h_{C-CL} = h_{11} + h_{22}$$

$$h_{11} = h_{HP}\left(\frac{B_2 - B_{IB}}{B_H - B_{IB}}\right)$$

$$h_{22} = \left(\frac{B_2}{2} - \frac{B_H}{4}\right)\tan\frac{\Psi}{2}$$

$$B_2 = \sqrt{\frac{\frac{1}{l_H}\left(\frac{M}{\rho_C} + V_{TS}\right) + \frac{1}{2}\left(\frac{h_{HP}\cdot B_{IB}^2}{B_H - B_{IB}}\right) + \frac{B_H^2}{16}\tan\frac{\Psi}{2}}{\frac{1}{2}\left[\left(\frac{h_{HP}}{B_H - B_{IB}}\right) + \frac{1}{2}\tan\frac{\Psi}{2}\right]}}$$

$h_{C\text{-}CL}$ — height, in m, of the cargo surface at the centreline, as shown in Figure 2.6.2.3 and Figure 2.6.2.4;

B_2 — maximum breadth of the cargo, in m, as shown in Figure 2.6.2.3 and Figure 2.6.2;

M — mass, in t, of the bulk cargo being considered.

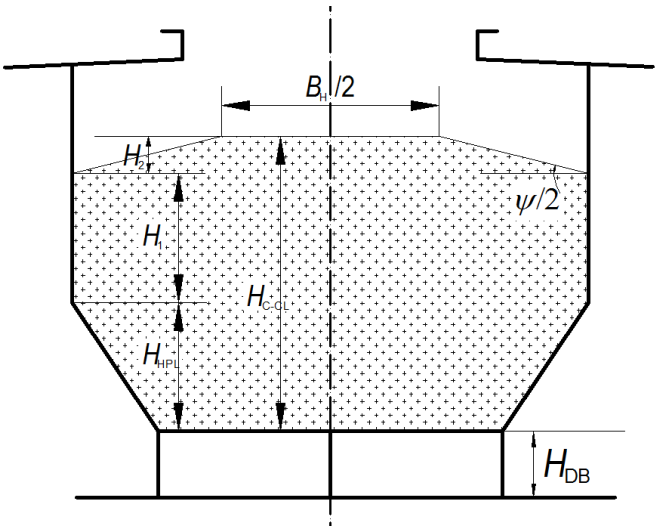


Figure 2.6.2.3 Definition of the Effective Upper Surface of Cargo for a Partially Filled Cargo Hold When $h_1 \geq 0$

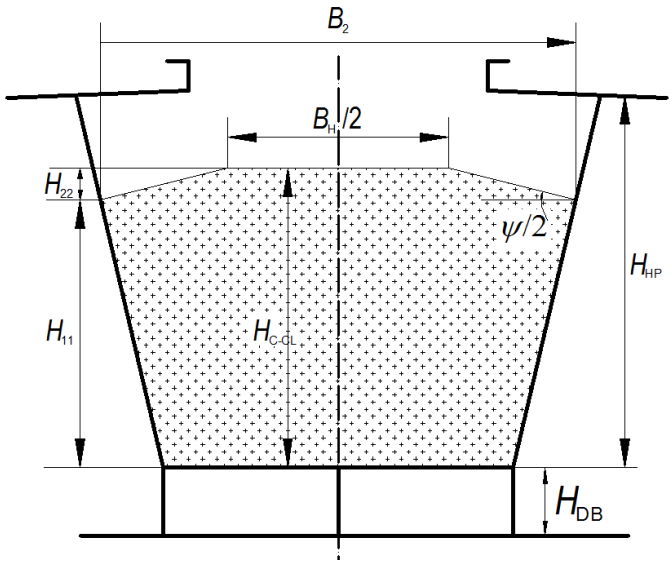


Figure 2.6.2.4 Definition of the Effective Upper Surface of Cargo for a Partially Filled Cargo Hold When $h_1 < 0$

2.6.2.5 FE application

The following process is to be applied for the bulk cargo pressure loads used in FE analysis:

a) Determine h_c according to [2.6.2.3] for fully filled cargo hold or [2.6.2.4] for partially filled cargo hold.

b) Determine the corresponding static pressure as defined in [2.6.3.2] and static shear pressure as defined in [2.5.2] using ρ_C and apply them in the FE model.

c) Calculate the actual mass of cargo, M_{actual}, in t.

d) Determine the effective cargo density, in t/m^3:

$$\rho_{eff} = \frac{M}{M_{actual}} \rho_C$$

e) Calculate the final pressure distribution and shear load using ρ_{eff} instead of ρ_C.

2.6.3 Dry bulk cargo pressures

2.6.3.1 The total pressure due to dry bulk cargo acting on any load point of a cargo hold boundary, in kN/m^2, is to be taken as:

$P_{in} = P_{bs}$, for strength assessment of intact conditions for static (S) design load scenarios, given in Ch 2, Sec 7.

$P_{in} = P_{bs} + P_{bd}$, for strength assessment of intact conditions for static plus dynamic (S+D) design load scenarios, but not less than 0.

where:

P_{bs} — static pressure due to dry bulk cargo, in kN/m^2, as defined in [2.6.3.2];

P_{bd} — dynamic inertial pressure due to dry bulk cargo in cargo holds, in kN/m^2, as defined in [2.6.3.3].

Static and dynamic pressures as defined in [2.6.3.2] and [2.6.3.3] for FE analysis are to be determined using ρ_{eff} instead of ρ_C.

2.6.3.2 Dry bulk cargo static pressure

The dry bulk cargo static pressure P_{bs}, in kN/m^2, is to be taken as:

$$P_{bs} = \rho_C g K_C (z_C - z), \text{ but not less than 0.}$$

2.6.3.3 Dry bulk cargo dynamic pressure

The dry bulk cargo dynamic pressure P_{bd}, in kN/m^2, for each load case is to be taken as:

$$P_{bd} = f_\beta \rho_C \left[0.25 a_X (x_G - x) + 0.25 a_Y (y_G - y) + K_C a_Z (z_C - z) \right], \text{ for } z \le z_C$$

$$P_{bd} = 0.0, \text{ for } z > z_C$$

2.6.4 Dry bulk cargo shear load

2.6.4.1 For FE strength assessment of cargo hold, the following shear load pressures are to be considered in addition to the dry bulk cargo pressures defined in [2.6.3] when the load point elevation, z, is lower or equal to z_c:

- For static (S) design load scenarios: Static shear load, due to gravitational forces acting on hopper tanks and lower stools plating, as defined in [2.6.4.2].
- For static plus dynamic (S+D) design load scenarios: The following dynamic shear load pressures:

  $P_{bs\text{-}s} + P_{bs\text{-}d}$ for the hopper tank and the lower stool plating, as defined in [2.6.4.3];

  $P_{bs\text{-}dx}$ for the inner bottom plating in the longitudinal direction, as defined in [2.6.4.4];

  $P_{bs\text{-}dy}$ for the inner bottom plating in the transverse direction, as defined in [2.6.4.4].
- The global design load scenarios for ships are to be considered of the effect of shear load due to accelerations along X and Y directions on the hopper tank plating, see [2.6.4.5].

Shear loads as defined in [2.6.4.2] to [2.6.4.5] for FE analysis are to be determined using ρ_{eff} instead of ρ_C.

2.6.4.2 Static shear load on the hopper tank plating, inclining longitudinal bulkhead and lower stool plating

The static shear load pressure, $P_{bs\text{-}s}$ (positive downward to the plating) due to dry bulk cargo gravitational forces acting on hopper tank plating, inclining longitudinal bulkhead and lower stool plating, in kN/m^2, is to be taken as:

$$P_{bs-s} = \rho_C g \frac{(1 - K_C)(z_C - z)}{\tan \alpha}$$

2.6.4.3 Dynamic shear load on the hopper tank and lower stool plating

The dynamic shear load pressure, $P_{bs\text{-}d}$ (positive downward to the plating) due to dry bulk cargo forces on the hopper tank plating or inclining longitudinal bulkhead and lower stool plating, in

kN/m^2, for each dynamic load case is to be taken as:

$$P_{bs-d} = f_\beta \rho_C a_Z \frac{(1-K_C)(z_C - z)}{\tan\alpha}$$

2.6.4.4 Dynamic shear load along the inner bottom plating for FE analyses

The dynamic shear load pressures, $P_{bs\text{-}dx}$ in the longitudinal direction (positive to bow) due to dry bulk cargo forces acting along the inner bottom plating, in kN/m^2, for each dynamic load case is to be taken respectively as:

$$P_{bs-dx} = -0.75 f_\beta \rho_C a_X h_C$$

The dynamic shear load pressures, $P_{bs\text{-}dy}$ in the transverse direction (positive to port) due to dry bulk cargo forces acting along the inner bottom plating, in kN/m^2, for each dynamic load case is to be taken respectively as:

$$P_{bs-dy} = -0.75 f_\beta \rho_C a_Y h_C$$

2.6.4.5 For the global FE strength assessment, the load balance requirement is to be considered, and the inner plating, hopper tank plating or inclining longitudinal bulkhead, lower stool plating are to take into account shear load due to accelerations along *X* and *Y* directions. Shear load on any sloping plate is to be calculated by the following equations:

a) horizontal direction:

$$P = -0.75\rho_C a_X h_C \cos\alpha \cdot \cos\alpha_X - 0.75\rho_C a_Y h_C \cos\alpha \cdot \cos\alpha_Y$$

b) vertical direction to inner bottom:

$$P = -0.75\rho_C a_X h_C \sin\alpha_X - 0.75\rho_C a_Y h_C \sin\alpha_Y$$

where: α_X — angle, in deg., between horizontal direction of sloping plate and *X* direction;

α_Y — angle, in deg., between horizontal direction of sloping plate and *Y* direction.

2.7 Loading Conditions

2.7.1 Design load scenarios for strength assessment

2.7.1.1 The principal design load scenarios are given in Table 2.7.1.1.

Principal Design Load Scenarios Table 2.7.1.1

Design load scenario		Harbour and sheltered water and testing	Seagoing conditions with extreme sea loads
Load components		Static (S)	Static +Dynamic (S+D)
Hull girder load	*VBM*	$M_{sw\text{-}p}$	$M_{sw} + M_{wv\text{-}LC}$
	HBM	-	$M_{wh\text{-}LC}$
	VSF	$Q_{sw\text{-}p}$	$Q_{sw} + Q_{wv\text{-}LC}$

	TM		-	$M_{wt\text{-}LC}$
Local load	P_{ex}	External deck for green sea	-	P_D
		Hull envelope	P_S	$P_S + P_W$
	P_{in}	Ballast tank	Max（P_{ls}, P_{ST}）	$P_{ls} + P_{ld}$
		Other tanks		
		Cargo holds	P_{bs}	$P_{bs} + P_{bd}$

2.7.2 Loading conditions

2.7.2.1 The typical FE yield strength calculation conditions for cargo holds are to be in accordance with the requirements in Tables 2.7.2.1 to 2.7.2.3.

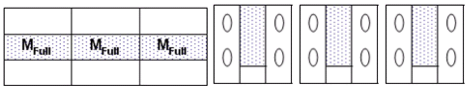
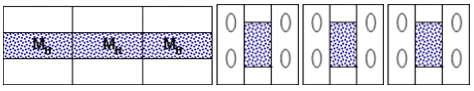
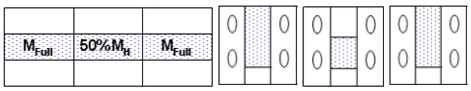
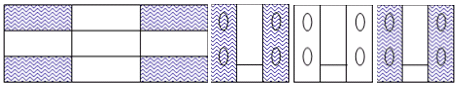
2.7.2.2 For the Multiport conditions not involved in the Loading Manual, MP1, MP2, MP3, MP4, MP5, MP6 and MP7 may not be checked.

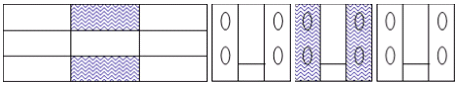
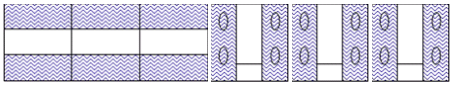
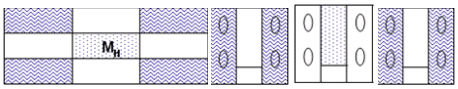
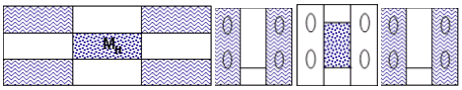
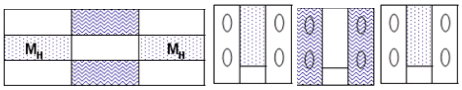
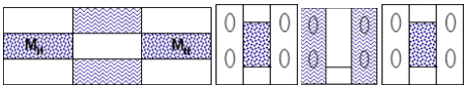
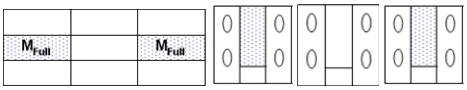
2.7.2.3 In addition to the typical loading conditions required in Tables 2.7.2.1 to 2.7.2.3, other special conditions in the Loading Manual are to be also taken into consideration.

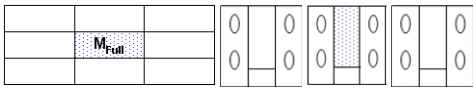
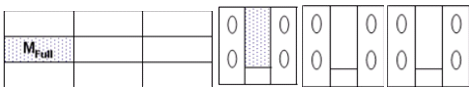
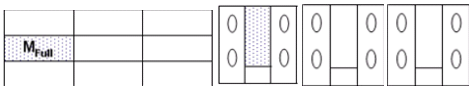
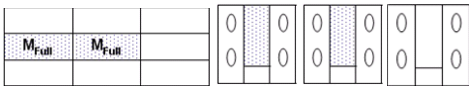
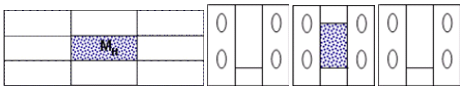
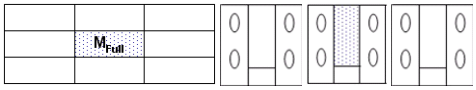
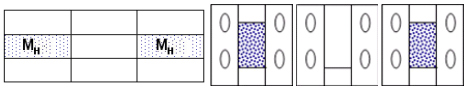
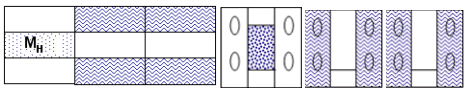
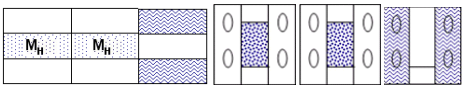
2.7.2.4 For the ships intended to be assigned class notation of EL100, harbour conditions in the process of quick loading are to be supplemented. If other more severe loading conditions in the quick loading manual exist, structural strength direct calculation is also to be carried out.

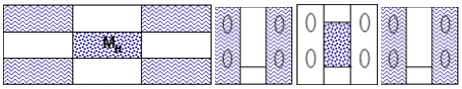
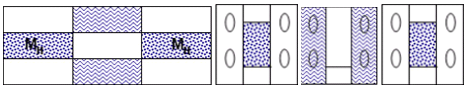
2.7.2.5 For the Multiport condition, if the draught value in actual loading manual is more dangerous than 0.67*Ts* and 0.75*Ts*, the actual value is to be taken.

FE Load Combinations Applicable to Midship Cargo Hold Region Table 2.7.2.1

No.	Description	Loading pattern	Draught	Still water shear force	Still water bending moment	Wave condition
1	Full load homogeneous - light cargo		T_{SC}	100%	100%(1) SAG	HSM-1 BSP-1P OST-1P
2	Full load homogeneous – heavy cargo		T_{SC}	100%	100%(1) SAG	BSP-1P OST-1P
3	Slack load		T_{SC}	100%	0	BSP-1P
				100%	100% SAG	HSM-1
4	Ballast-1		$T_{BAL\text{-}N}$	100% MAX SFLC	100% Hog	HSM-2 FSM-2
				100%	100% Hog	BSR-1P OST-1P

5	Ballast-2		T_{BAL-N}	N/A	100% Hog	FSM-2 BSR-1P OST-1P
6	Ballast-3		T_{BAL-H}	100%	100% SAG	HSM-1 BSR-1P BSP-1P
7	Multiport-1		0.75 T_{SC}	100%	100% SAG	HSM-1 FSM-1 BSP-1P OST-1P
				100%	100% HOG	HSM-2 FSM-2 OST-2P
8	Multiport-2		0.75 T_{SC}	100%	100% SAG	HSM-1 FSM-1 BSP-1P OST-1P
				100%	100% Hog	HSM-2 FSM-2 OST-2P
9	Multiport-3		0.75 T_{SC}	100%	100% SAG	HSM-1 BSP-1P OST-1P
				100%	100% Hog	HSM-2 FSM-2 OST-2P
10	Multiport-4		0.75 T_{SC}	100%	100% SAG	HSM-1 BSP-1P OST-1P
				100%	100% Hog	HSM-2 FSM-2 OST-2P
11	Multiport-5		0.75 T_{SC}	100%	100% SAG	BSP-1P OST-1P
				100% MAX SFLC	100% HOG	HSM-2 FSM-2
				100%	100% HOG	OST-2P

12	Multiport-6		0.67 T_{SC}	100%	100% SAG	BSP-1P OST-1P
13	Multiport-7		0.67 T_{SC}	100%	100% SAG	BSP-1P BSR-1P OST-1P
				100%	100% HOG	HSM-2 FSM-2 BSR-1P OST-1P
14	Harbour-1		0.67 T_{SC}	100%	100% SAG	N/A
				100%	100% HOG	N/A
15	Harbour-2		0.67 T_{SC}	100%	100% SAG	N/A
				100%	100% Hog	N/A
16	Harbour-3		0.67 T_{SC}	100% MAX SFLC	100% SAG	N/A
				100% MAX SFLC	100% HOG	N/A
17	Harbour-4		0.67 T_{SC}	100% MAX SFLC	100% SAG	N/A
				100% MAX SFLC	100% HOG	N/A
18	Harbour-5		0.83 T_{SC}	100% MAX SFLC	100% SAG	N/A
				100% MAX SFLC	100% HOG	N/A
19	Harbour-6		0.75 T_{SC}	100%	100% SAG	N/A
				100%	100% HOG	N/A
20	Harbour-7		0.83 T_{SC}	100%	100% SAG	N/A
				100%	100%	N/A

					HOG	
21	Harbour-8		0.75 T_{SC}	100%	100% SAG	N/A
				100%	100% HOG	N/A
22	Harbour-9		0.83 T_{SC}	100%	100% SAG	N/A
				100%	100% HOG	N/A

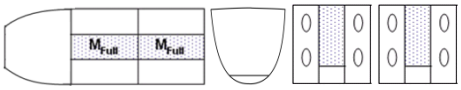
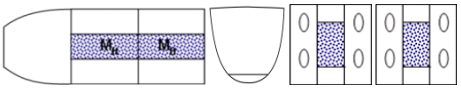
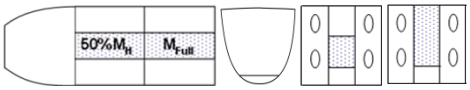
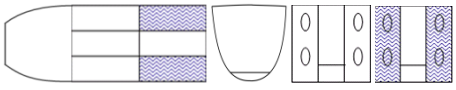
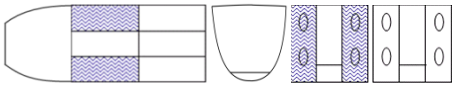
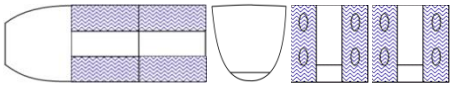
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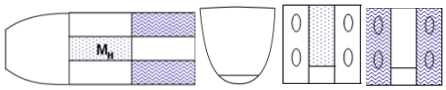
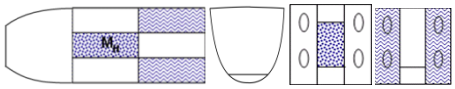
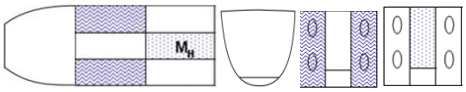
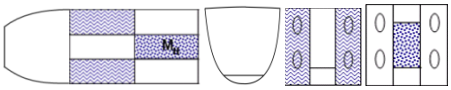
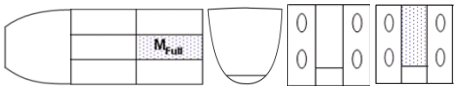
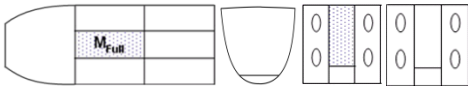
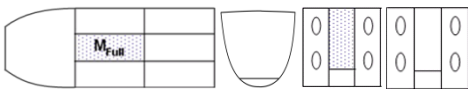
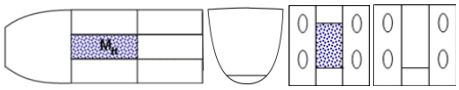
(1) Still water shear force of 100%MAX SFLC is the adjustment condition of shear force.

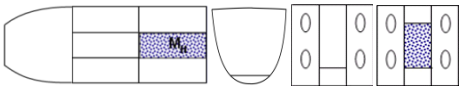
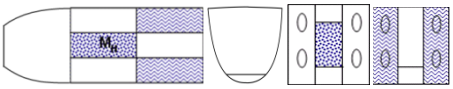
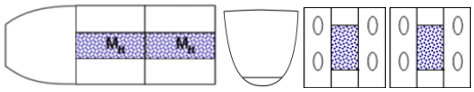
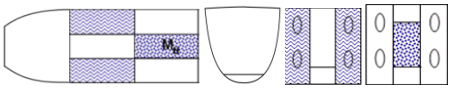
(2) 100% still water shear force is the shear force judgment condition, to be carried out in accordance with Chapter 3.

(3) Harbour-4 ~ Harbour-9 conditions are to be checked for the ore carriers applying for the class notation of EL100.

FE Load Combinations Applicable to Aftmost Cargo Hold Region Table 2.7.2.2

No.	Description	Loading pattern	Draught	Still water shear force	Still water bending moment	Wave condition
1	Full load homogeneous - light cargo		T_{SC}	100%	80% SAG	FSM-1 BSP-1P OST-1P OSA-1P
2	Full load homogeneous – heavy cargo		T_{SC}	100%	80% SAG	FSM-1 BSP-1P OST-1P
3	Slack load		T_{SC}	100%	100%	FSM-1 BSP-1P OST-1P
4	Ballast-1(1)		T_{BAL-N}	100%	100% Hog	HSM-2 FSM-1 BSP-1P OST-1P OSA-1P
5	Ballast-2(1)		T_{BAL-N}	100%	100% SAG	FSM-1 BSR-1P OST-1P
6	Ballast-3(1)		T_{BAL-H}	100%	100% SAG	HSM-1 BSR-1P BSP-1P

7	Multiport-1		0.75 T_{SC}	100%	50% SAG	HSM-1 BSP-1P OST-1P
				100%	50% HOG	HSM-1 OST-1P
8	Multiport-2		0.75 T_{SC}	100%	50% SAG	HSM-1 BSP-1P OSA-1P
				100%	50% Hog	HSM-1 OST-1P
9	Multiport-3		0.75 T_{SC}	100%	50% SAG	FSM-1 OST-1P
				100%	50% Hog	FSM-1 BSR-1P OSA-1P
10	Multiport-4		0.75 T_{SC}	100%	50% SAG	FSM-1 OST-1P
				100%	50% Hog	FSM-1 BSR-1P OSA-1P
11	Multiport-5		0.67 T_{SC}	100%	30% SAG	FSM-1 OST-1P
				100%	30% Hog	FSM-1 BSR-1P OSA-1P
12	Multiport-6		0.67 T_{SC}	100%	60% HOG	BSP-1P
				100% MAX SFLC	30% HOG	HSM-2
				100% MAX SFLC	0	HSM-1
13	Harbour-1		0.67 T_{SC}	100% MAX SFLC	50% SAG	N/A
				100%	100% Hog	N/A
14	Harbour-2		0.67 T_{SC}	100% MAX SFLC	50% SAG	N/A

				100% MAX SFLC	100% HOG	N/A
15	Harbour-3		0.83 T_{SC}	100%	100% SAG	N/A
				100%	50% HOG	N/A
16	Harbour-4		0.83 T_{SC}	100%	50% SAG	N/A
				100%	50% HOG	N/A
17	Harbour-5		0.83 T_{SC}	100%	100% SAG	N/A
				100%	50% HOG	N/A
18	Harbour-6		0.83 T_{SC}	100%	50% SAG	N/A
				100%	50% HOG	N/A

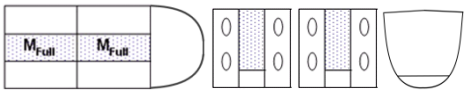
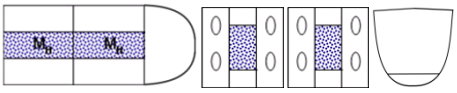
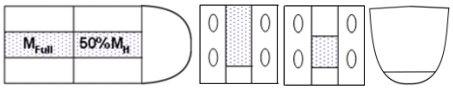
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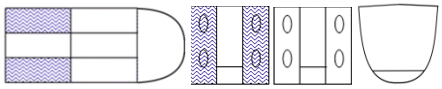
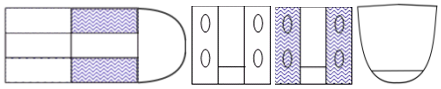
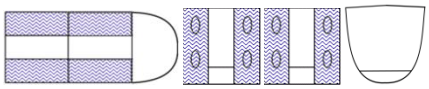
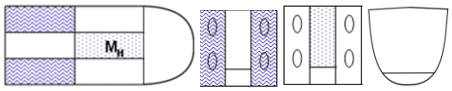
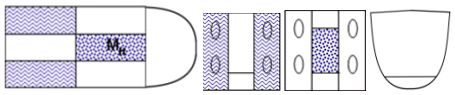
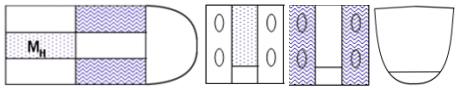
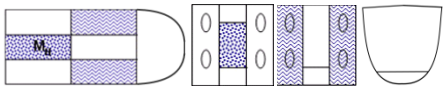
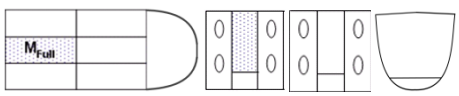
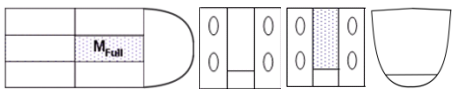
(1) The loading condition is to be assessed if it is required in the Loading Manual.

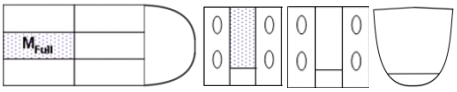
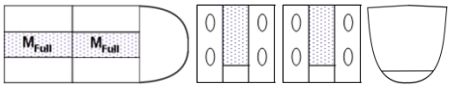
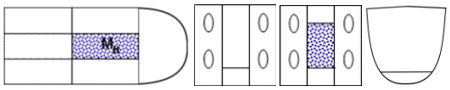
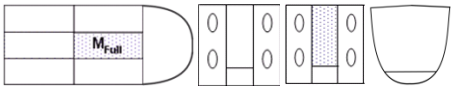
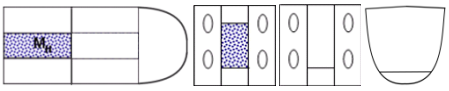
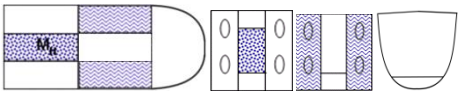
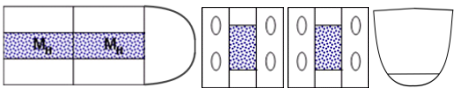
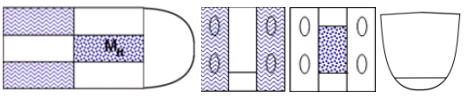
(2) Harbour-4 ~ Harbour-6 conditions are to be checked for the ore carriers applying for the class notation of EL100.

(3) In principle, the required adjustment in shear force of harbour MAX SFLC condition is to be done at forward bulkhead of engine room.

FE Load Combinations Applicable to Foremost Cargo Hold Region Table 2.7.2.3

No.	Description	Loading pattern	Draught	Still water shear force	Still water bending moment	Wave condition
1	Full load homogeneous - light cargo		T_{SC}	100%	60%(1) SAG	HSM-1 BSP-1P OST-1P OSA-2P
2	Full load homogeneous – heavy cargo		T_{SC}	100%	60%(1) SAG	HSM-1 BSP-1P OST-1P OSA-2P
3	Slack load		T_{SC}	100%	60%(1) SAG	HSM-1 BSP-1P OSA-2P

4	Ballast-1[(1)]		T_{BAL-N}	100%	100% Hog	HSM-1 HSM-2 BSP-1P BSR-1P OSA-2P
5	Ballast-2[(1)]		T_{BAL-N}	100%	100% Sag	HSM-1 BSP-1P BSR-1P OSA-2P
6	Ballast-3[(1)]		T_{BAL-H}	100%	100% SAG	HSM-1 BSP-1P BSR-1P OSA-2P
7	Multiport-1		0.75 T_{SC}	50%	100% SAG	HSM-1 FSM-1 BSP-1P OSA-2P
8	Multiport-2		0.75 T_{SC}	50%	100% SAG	HSM-1 FSM-1 BSP-1P OSA-2P
9	Multiport-3		0.75 T_{SC}	100%	50% SAG	HSM-1 FSM-1 BSP-1P OSA-2P
10	Multiport-4		0.75 T_{SC}	100%	50% SAG	HSM-1 FSM-1 BSP-1P OSA-2P
11	Multiport-5		0.83 T_{SC}	100%	60% SAG	HSM-1 FSM-1 BSP-1P OSA-2P
12	Multiport-6		0.67 T_{SC}	100% 100% MAX SFLC	60% HOG 60% HOG	BSP-1P OST-2P OSA-2P HSM-2

				100% MAX SFLC	0	HSM-1
13	Harbour-1		0.67 T_{SC}	100%	100% SAG	N/A
				100%	100% HOG	N/A
14	Harbour-2		0.67 T_{SC}	100%	100% SAG	N/A
				100%	100% Hog	N/A
15	Harbour-3		0.67 T_{SC}	100% MAX SFLC	100% SAG	N/A
				100% MAX SFLC	100% HOG	N/A
16	Harbour-4		0.67 T_{SC}	100% MAX SFLC	100% SAG	N/A
				100% MAX SFLC	100% HOG	N/A
17	Harbour-5		0.83 T_{SC}	100%	100% SAG	N/A
				100%	100% HOG	N/A
18	Harbour-6		0.75T_{SC}	100%	100% SAG	N/A
				100%	100% HOG	N/A
19	Harbour-7		0.83T_{SC}	100%	100% SAG	N/A
				100%	100% HOG	N/A
20	Harbour-8		0.75 T_{SC}	100%	100% SAG	N/A
				100%	100% HOG	N/A

Notes:

(1) The loading condition is to be assessed if it is required in the Loading Manual.

(2) Harbour-4 ~ Harbour-8 conditions are to be checked for the ore carriers applying for the class notation of EL100.

(3) In principle, the required adjustment in shear force of harbour MAX SFLC condition is to be done at forward bulkhead.

CHAPTER 3 DIRECT STRENGTH ANALYSIS OF CARGO HOLD REGION

3.1 General Requirements

3.1.1 Direct strength assessment is to be carried out for primary structural members in cargo hold region for an ore carrier with the length of 150 m and above based on three-dimensional FE analysis.

3.1.2 FE analysis is to include the two following parts:

3.1.2.1 Cargo hold analysis to assess the strength of longitudinal hull girder structural members, primary supporting structural members and bulkheads.

3.1.2.2 Fine mesh analysis to assess detailed stress levels in local structural details.

3.1.3 The strength assessment performed with finite element analysis is to verify that the scantlings comply with the acceptance criteria specified in this Chapter for:

3.1.3.1 Cargo hold structural analysis performed in accordance with 3.2 to 3.4 in Chapter 3;

3.1.3.2 Local structural analysis performed in accordance with 3.5 in Chapter 3.

3.1.4 A flow diagram of direct structural strength analysis for cargo hold is shown in Figure 3.1.1.

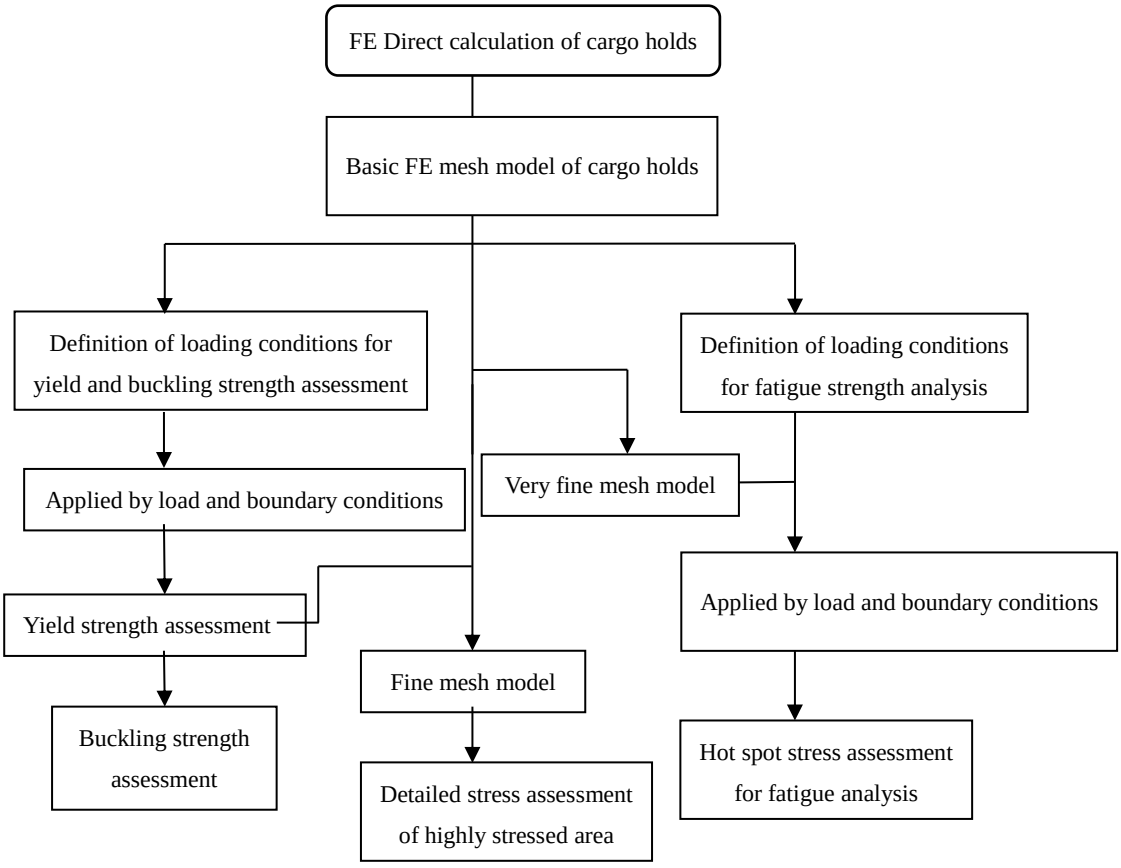


Figure 3.1.1 Flow Diagram of Direct FE Analysis for Cargo Hold

3.1.4 Used finite element types

3.1.4.1 The structural assessment is to be based on linear finite element analysis of three-dimensional structural models. The general types of finite elements to be used in the finite element analysis are given in Table 3.1.4.1.

Types of Finite Element **Table 3.1.4.1**

Type of finite element	Description
Rod (or truss) element	Line element with axial stiffness only and constant cross sectional area along the length of the element
Beam element	Line element with axial, torsional and bi-directional shear and bending stiffness and with constant properties along the length of the element
Shell (or plate) element	Shell element with in-plane stiffness and out-of-plane bending stiffness with constant thickness

3.1.4.2 Two node line elements and four node shell elements are, in general, considered sufficient for the representation of the hull structure. The mesh requirements given in this Chapter are based on the assumption that these elements are used in the finite element models. However, higher order elements may also be used.

3.2 Structural Modeling

3.2.1 Objectives and scopes

3.2.1.1 The cargo hold structural strength analysis is used for the assessment of scantlings of longitudinal hull girder structural members, primary supporting members and bulkheads within the cargo hold region. This section gives the requirements for cargo hold structural strength analysis.

3.2.1.2 For the purpose of FE structural assessment and load application, the cargo hold region contains the following cargo hold regions, which may vary depending on the ship length and cargo hold arrangement.

- Midship cargo hold region,
- Foremost cargo hold(s),
- Aftmost cargo hold(s).

3.2.1.3 For the purpose of the FE analysis, the mid-hold is defined as the middle hold(s) of the three cargo hold length FE model. In case of foremost and aftmost cargo hold assessment, the mid-hold represents the foremost and aftmost cargo hold respectively.

3.2.1.4 The scantling assessment is carried out according to the requirements in this Chapter for each individual cargo hold using the FE load combinations defined in Ch 2, Sec 7 applicable to the considered cargo hold.

3.2.2 Members to be modelled

3.2.2.1 All main longitudinal and transverse structural elements are to be modelled. These include:

- Inner and outer shell,
- Deck,
- Inner bottom plating,
- Double bottom floors and girders,
- Transverse and vertical web frames,
- Hatch coamings,
- Stringers,
- Transverse and longitudinal bulkhead structures,

- Other primary supporting members,
- Other structural members which contribute to hull girder strength.

3.2.2.2 All plates and stiffeners on the structure, including web stiffeners, are to be modelled. Brackets which contribute to primary supporting member strength and the size of which is not less than the typical mesh size (*s*-by-*s*) described in [3.2.4.1], are to be modelled.

3.2.3 Extent of model

3.2.3.1 Except the foremost and aftermost cargo hold models, the longitudinal extent of the cargo hold FE model is to cover three cargo hold lengths. The transverse bulkheads at the ends of the model are to be modelled. Where corrugated transverse bulkheads are fitted, the model is to include the extent of the bulkhead stool structure forward and aft at the model ends and stringers of transverse bulkhead of ballast tanks.

3.2.3.2 The foremost and the aftmost cargo holds are located at the middle of the FE models as follows, as practical as possible:

• Foremost cargo hold: from the after bulkhead of the cargo hold no. 2 to the ship's foremost cross section where the reinforced ring or web frame remains continuous from the base line to the strength deck.

• Aftermost cargo hold: from the after bulkhead of the engine room to the forward bulkhead of no. N-1 cargo hold, where N is the number of holds or sets of holds numbered from forward to aft.

• If the ratio of length of target cargo hold to that of adjacent cargo hold exceeds 1:1.5, appropriate section of adjacent cargo hold is to be considered as model extending area, the cargo hold parameters and loading parameters corresponding to load calculation are to be taken according to the actual parts.

3.2.3.3 In general, the finite element model is to represent the geometry of the hull form. In the midship cargo hold region, the finite element model may be prismatic provided the mid-hold has a prismatic shape.

3.2.3.4 In the foremost cargo hold model, the hull form forward of the transverse section at the middle of the fore part up to the model end may be modelled with a simplified geometry. The transverse section at the middle of the fore part up to the model end may be extruded out to the fore model end.

3.2.3.5 In the aftmost cargo hold model, the hull form aft of the middle of the machinery space may be modelled with a simplified geometry. The section at the middle of the machinery space may be extruded out to its aft bulkhead.

3.2.3.6 When the hull form is modelled by extrusion, the geometrical properties of the transverse section located at the middle of the considered space (fore or machinery space) are copied along the simplified model. The transverse web frames are to be considered along this extruded part with the same properties as the ones in the fore part or in the machinery space, and the continuity of longitudinal structural members are to be kept.

3.2.3.7 Both port and starboard sides of the ship are to be modelled.

3.2.3.8 The full depth of the ship is to be modelled including primary supporting members above the upper deck, trunks, forecastle and/or cargo hatch coaming, if any. The superstructure or deck house in way of the machinery space and the bulwark are not required to be included in the model.

3.2.4 FE model of cargo holds

3.2.4.1 The element type is to be modeled according to the following principles:

(1) Stiffeners bearing lateral load are modeled by beam elements, and those not bearing lateral

load are modeled by rod elements.

(2) All areas of inner and outer shell plating, deep webs of transverse rings, stringers, plane bulkhead web stiffeners, frames, other members as well as corrugation bulkheads and bulkhead stools are to be modeled by plate elements. Triangular elements are to be minimized during modeling. In particular in highly stressed areas and in such areas around openings, at bracket connection and at hopper connections where significant stress gradient is predicted, triangle elements are to be avoided as far as possible.

(3) The aspect ratio of plate element is not to exceed 3, and to be close to 1 in the highly stressed areas or areas where significant stress gradient is predicted as far as possible.

3.2.4.2 The FE mesh is to follow the stiffening system as far as practicable, so as to represent the actual plate panels between stiffeners. The element meshing is to be in accordance with the following principles.

(1) One element between every longitudinal stiffener for bottom plating, side shell plating, deck, longitudinal bulkhead, inner bottom plating, longitudinally, the element length is not to be greater than twice longitudinal spaces; One element between every vertical stiffener on transverse bulkheads for transverse bulkheads and wash bulkheads of side tanks; One element between every web stiffener on transverse and vertical web frames, cross ties and stringers.

(2) At least three elements over the depth of double bottom girders and floors, transverse web frames, vertical web frames of side tanks and their horizontal stringers and cross ties of side tanks. Where the web depth is less, representation using two elements over the depth is acceptable provided that there is at least one element between every web stiffener. The mesh size of adjacent structural members is to be matched with.

(3) The mesh on the hopper tank web frame is to be fine enough to represent the shape of the web ring opening; the curvature of free edge on large brackets of primary support members is to be modelled accurately to avoid unrealistic high stress due to geometry discontinuities.

(4) Corrugated bulkheads and bulkhead stools are to be modelled by shell plate element, diaphragms in the stools and internal longitudinal and vertical stiffeners on the stool plating are to be included in the model. The shell element mesh on the flange and web of the corrugation is in general to follow the stiffener spacing inside the bulkhead stool.

(5) The stiffening system modeling by beam element is to be matched with actual structures, the deviation direction of bending center or shearing center is to be in consistent with that of normal line of attached plating, and is to be coordinated with plate element.

(6) Non continuous stiffeners are to be modelled as continuous stiffeners, i.e. the height web reduction in way of the snip ends are not to be modelled.

(7) Web stiffeners of primary supporting members are to be modelled. Where these stiffeners are not in line with the primary FE mesh, it is sufficient to place the line element along the nearby nodal points provided that the adjusted distance does not exceed 0.2 times the stiffener spacing under consideration. The stresses and buckling utilisation factors obtained need not be corrected for the adjustment. Buckling stiffeners on large brackets, deck transverses and stringers parallel to the flange are to be modelled. These stiffeners may be modelled using rod elements.

(8) Methods of representing openings and manholes in webs of primary supporting members are to be in accordance with Table 3.2.4.1.

Representation of Openings in Primary Supporting Member Webs Table 3.2.4.1

Criteria	Modelling decision
$h_0/h < 0.5$ and $g_0 < 2.0$	Openings do not need to be modelled
Manholes	The manholes are to be judged according to the geometric dimension of openings, generally modelled by removing the adequate FE
$h_0/h \geq 0.5$ or $g_0 \geq 2.0$	The geometry of the opening is to be modelled

where:

$$g_0 = \left(1 + \frac{l_0^2}{2.6(h - h_0)^2}\right)$$

l_0: Length of opening parallel to primary supporting member web direction, in m, see Figure 3.2.4.1. For sequential openings where the distance, d_o between openings is less than 0.25 h, the length l_o is to be taken as the length across openings as shown in Figure 3.2.4.2

h_0: Height of opening parallel to depth of web, in m, see Figure 3.2.4.1 and Figure 3.2.4.2.

h: Height of web of primary supporting structural members in way openings, in m, see Figure 3.2.4.1 and Figure 3.2.4.2.

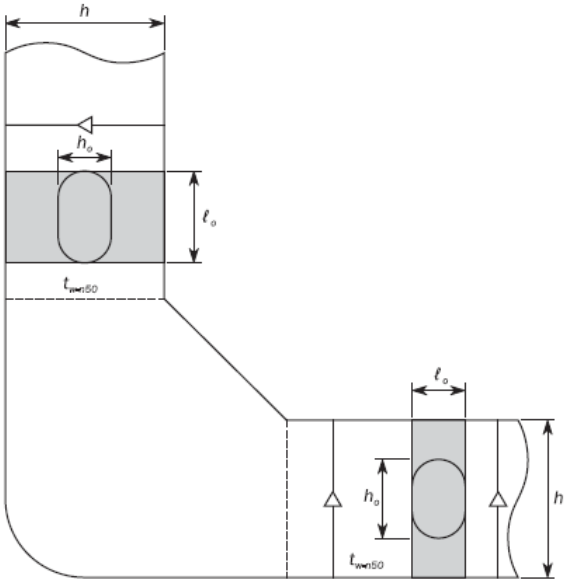


Figure 3.2.4.1 Openings in Web

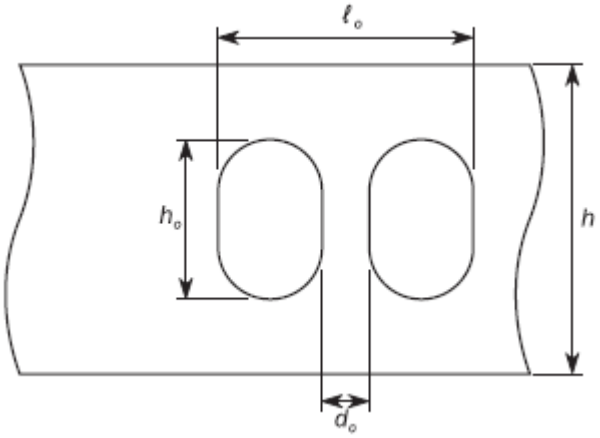


Figure 3.2.4.2 Length l_0 for Sequential Openings with $d_o < h/4$

3.2.4.3 The as-built scantlings are to be applied for the FE model, to fully reflect the strength-based stiffening, however, scantling or reinforcement for the special design as requested by the shipowner is not to be considered.

3.2.4.4 Membrane stress, i.e. mid-surface stress of bending plate elements, is applied as permissible stress criteria for plate element. Axial stress is employed for beam element.

3.2.5 Boundary conditions

3.2.5.1 All boundary conditions described in this Section are in accordance with the global coordinate system defined in Ch 1, Sec 2.

3.2.5.2 The boundary conditions given in this Section are applicable to cargo hold finite element model analyses in cargo hold region.

3.2.5.3 The boundary conditions consist of the rigid links at model ends, point constraints and end-beams. The rigid links connect the nodes on the longitudinal members at the model ends to an independent point at neutral axis in centreline. The boundary conditions to be applied at the ends of the cargo hold FE model, except for the foremost cargo hold, are given in Table 3.2.5.1. For the foremost cargo hold analysis, the boundary conditions to be applied at the ends of the cargo hold FE model are given in Table 3.2.5.2.

Boundary Constraints at Model Ends Except the Foremost Cargo Hold Models

Table 3.2.5.1

Location	Translation			Rotation		
	δ_x	δ_y	δ_z	θ_x	θ_y	θ_z
Aft end						
Independent point	—	Fix	Fix	M_{T-end}	—	—
Cross section	—	Rigid link	Rigid link	Rigid link	—	—
	End beam, see [3.2.5.4]					
Fore end						
Independent point	—	Fix	Fix	Fix	—	—
Intersection of centreline and inner bottom	Fix	—	—	—	—	—
Cross section	—	Rigid link	Rigid link	Rigid link	—	—
	End beam, see [3.2.5.4]					
Note 1: [-] means no constraint applied (free). Note 2: See Figure 3.2.5.1						

Boundary Constraints at Model Ends of the Foremost Cargo Hold Models

Table 3.2.5.2

Location	Translation			Rotation		
	δ_x	δ_y	δ_z	θ_x	θ_y	θ_z
Aft end						
Independent point	—	Fix	Fix	Fix	—	—
Intersection of centreline and inner bottom	Fix	—	—	—	—	—

Cross section	—	Rigid link	Rigid link	Rigid link	—	—
	End beam, see [3.2.5.4]					
Fore end						
Cross section	—	Rigid link	Rigid link	Rigid link	—	—
Independent point	—	Fix	Fix	M_{T-end}	—	—
Note 1: [-] means no constraint applied (free). Note 2: See Figure 3.2.5.1. Note 3: Boundary constraints in fore end are to be located at the most forward reinforced ring or web frame which remains continuous from the base line to the strength deck.						

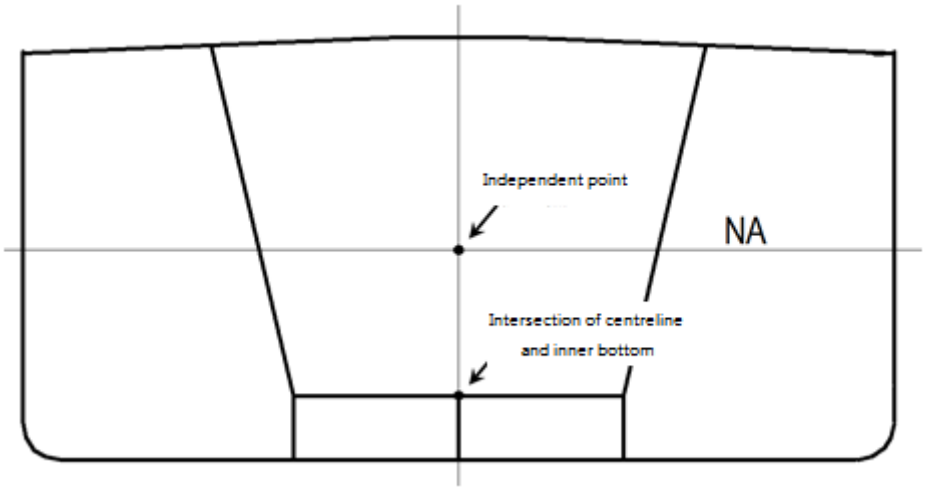


Figure 3.2.5.1 Boundary Conditions Applied at the Model End Sections

3.2.5.4 End constraint beams are to be modelled at the both end sections of the model along all longitudinally continuous structural members and along the cross deck plating of bulk carriers. An example of end beams at one end for a double hull bulk carrier is shown in Figure 3.2.5.2.

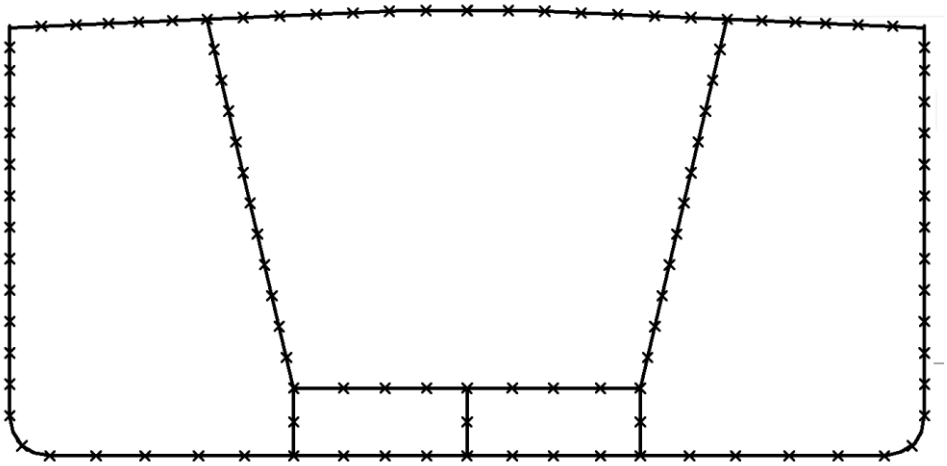


Figure 3.2.5.2 End Constraint Beams

3.2.5.5 The properties of beams are calculated at fore and after sections separately and all beams at each end section have identical properties as follows:

- Net moment of inertia: $I_{yy} = I_{zz} = I_{xx}(J) = 1/25$ of the vertical hull girder moment of inertia of fore/aft end cross sections based on the net FE model.
- Net cross sectional area:A_y and $A_z = 1/80$ of the fore/aft end cross sectional areas based on the net FE model.

where:

I_{yy} : moment of inertia about local beam *Y* axial, in m^4;

I_{zz} : moment of inertia about local beam *Z* axial, in m^4;

$I_{xx}(J)$: torsional inertia, in m^4;

A_y : shear area in local beam *Y* direction, in m^2;

A_z : shear area in local beam *Z* direction, in m^2.

3.3 FE Load Combinations

3.3.1 Design load combinations

3.3.1.1 A FE load combination is defined as a loading pattern, a draught, a value of still water bending and shear force, associated with a given dynamic load case.

3.3.1.2 For cargo hold structural strength analysis, the design load combinations specified in Ch 2, Sec 7 are to be used for considered ship type and considered cargo hold regions.

3.3.1.3 Each design load combination given in Ch 2, Sec 7 consists of a loading pattern and dynamic load cases as given in Ch 2, Sec 2. Each load combination requires the application of the structural weight, internal and external pressures and hull girder loads. For seagoing condition, both static and dynamic load components (S+D) are applied. For harbour and tank testing condition, only static load components (S) are applied.

3.3.1.4 Where the loading conditions specified by the designer are not covered by the load combinations given in Ch 2, Sec 7, these additional loading conditions are to be examined according to the procedure in Chapter 2 and this Chapter.

3.3.2 Load application

3.3.2.1 Effect of the weight of hull structure is to be included in static loads, but is not to be included in dynamic loads. Density of steel is to be taken as given in Ch 2, Sec 6.

3.3.2.2 Unless otherwise mentioned in this Section, the sign of moments and shear force is to be in accordance with the sign convention defined in Ch 2, Sec 1.

3.3.2.3 External pressure is to be calculated for each load case in accordance with Ch 2, Sec 5. External pressures include static sea pressure, wave pressure and green sea pressure.

3.3.2.4 Internal pressure is to be calculated for each load case in accordance with Ch 2, Sec 6 for design load scenarios given in Ch 2, Sec 7, Table 1. Internal pressures include static dry and liquid cargo, ballast and other liquid pressure, setting pressure on relief valve and dynamic pressure of dry and liquid cargo, ballast and other liquid pressure due to acceleration.

3.3.2.5 Constant pressure, calculated at the element's centroid, is applied to the shell element of the loaded surfaces, e.g. outer shell and deck for external pressure and tank/hold boundaries for internal pressure. Alternately, pressure can be calculated at element nodes applying linear pressure distribution within elements.

3.3.3 Hull girder loads

3.3.3.1 Each loading condition is to be associated with its corresponding hull girder loads which is to be applied to the model according to the procedure described in [3.3.4] for shear force and bending moment and in [3.3.5] for torsional moment. The hull girder loads are the combinations of still water hull girder loads and wave induced hull girder loads as specified in Ch 2, Sec 7. For each required FE load combination, the wave induced hull girder loads are to be calculated with the Load Combination Factors (LCFs), specified in Ch 2, Sec 2.

3.3.3.2 Target hull girder vertical bending moment

The target hull girder vertical bending moment, $M_{v\text{-}targ}$, in kNm, at a longitudinal position for a given FE load combination is taken as:

$$\mathrm{M}_{v-targ} = C_{BM-LC} M_{sw} + M_{wv-LC}$$

where:

$\mathrm{C}_{\mathrm{BM\text{-}LC}}$: percentage of permissible still water bending moment applied for the load combination under consideration as given in Ch 2, Sec 7;

M_{sw}: permissible still water bending moments in kNm, at the considered longitudinal position for seagoing and harbour conditions as defined in Ch. 2, 2.4.2;

$\mathrm{M}_{\mathrm{wv\text{-}LC}}$: vertical wave bending moment in kNm, for the dynamic load case under consideration, calculated in accordance with Ch 2, 2.4.3;

$\mathrm{M}_{\mathrm{v\text{-}targ}}$: the values are to be taken as:

- Midship cargo hold region: the maximum hull girder bending moment within the mid-hold(s) for each individual cargo hold for each given FE load combination as defined in Ch 2, Sec 7;
- Outside midship cargo hold region: the values at all web frame and transverse bulkhead positions of the FE model under consideration.

Both $C_{BM\text{-}LC}$ M_{sw} *and* $M_{wv\text{-}LC}$ are either in sagging or in hogging condition according to the FE load combinations given in the tables of Ch 2, Sec 7.

3.3.3.3 Target hull girder shear force

The target hull girder vertical shear force at the aft and forward transverse bulkheads of the mid-hold, $Q_{targ\text{-}aft}$ and $Q_{targ\text{-}fwd}$, in kN, for a given FE load combination is taken as:

- $\mathrm{Q}_{\mathrm{fwd}} \geq \mathrm{Q}_{\mathrm{aft}}$:

$$\mathrm{Q}_{targ-aft} = C_{SF-LC} \cdot Q_{sw-neg} - \Delta Q_{swa} + f_\beta |C_{QW}| Q_{wv-neg}$$
$$\mathrm{Q}_{targ-fwd} = C_{SF-LC} \cdot Q_{sw-pos} + \Delta Q_{swf} + f_\beta |C_{QW}| Q_{wv-pos}$$

- $Q_{fwd} < Q_{aft}$:

$$\mathrm{Q}_{targ-aft} = C_{SF-LC} \cdot Q_{sw-pos} - \Delta Q_{swa} + f_\beta |C_{QW}| Q_{wv-pos}$$
$$\mathrm{Q}_{targ-fwd} = C_{SF-LC} \cdot Q_{sw-neg} + \Delta Q_{swf} + f_\beta |C_{QW}| Q_{wv-neg}$$

where:

Q_{fwd}, Q_{aft}: vertical shear forces, in kN, due to the local loads respectively at the forward and aft bulkhead position of the mid-hold, as defined in [4.4.7];

$\mathrm{C}_{\mathrm{SF\text{-}LC}}$: percentage of permissible still water shear force as given in Ch 2, Sec 7, for the FE load combination under consideration;

$\mathrm{Q}_{\mathrm{sw\text{-}pos}}$, $\mathrm{Q}_{\mathrm{sw\text{-}neg}}$: positive and negative permissible still water shear forces, in kN, at any longitudinal position for seagoing and harbour conditions;

$\Delta\mathrm{Q}_{\mathrm{swf}}$: shear force correction for permissible still water shear force

without considering non-homogeneous loading, to be taken as:

$Q_{swf} = 0$;

shear force correction for permissible still water force which has carried out non-homogeneous loading, for the considered FE loading pattern at the forward bulkhead taken as:

minimum of the absolute values of ΔQ_{mdf}, calculated at forward bulkhead for the mid-hold and the value calculated at aft bulkhead of the forward cargo hold taken as:

$$\Delta Q_{swf} = \mathrm{Min}(|\Delta \mathrm{Q}_{mdf}|_{Mid}, |\Delta \mathrm{Q}_{mdf}|_{Fwd})$$

where: $\Delta \mathrm{Q}_{mdf}$ to be taken as:

$$\Delta Q_{mdf} = C_d \alpha \left(\frac{M}{B_H l_H} - \rho T_{LC,mn} \right)$$

where: C_d — distribution factor, taken as:

$C_d = -1$, at the aft end of the considered cargo hold except for aftmost cargo hold;

$C_d = 1$, at the fore end of the considered cargo hold except for foremost cargo hold;

C_d: linearly distributed at internal of considered cargo hold:

$C_d = 0$ at mid-length of the cargo hold;

$C_d = 0$ at the fore bulkhead of the foremost cargo hold;

$C_d = 0$ at the aft bulkhead of the aftmost cargo hold;

C_d: linearly distributed at other locations;

α — coefficient, taken as:

$$\alpha = g \frac{l_0 b_0}{2 + \varphi \frac{l_0}{b_0}}$$

M — mass, in t, in the hold in way of the considered transverse section for the considered loading condition. M is to include the mass of ballast water and fuel oil located directly below the flat portion of the inner bottom, if any, excluding the portion under the bulkhead stool;

B_H __breadth of the cargo hold, in m;

l_H — length of the cargo hold, in m;

l_0, b_0 __ length and breadth, respectively, in m, of the flat portion of the double bottom in way of the hold considered; b_0 is to be measured on the hull transverse section at the middle of the hold;

$\varphi = 1.38 + 1.55g\frac{l_0}{b_0}$, but not greater than 3.7;

$T_{LC,mh}$ __ draught, in m, measured vertically on the hull transverse section at the middle of the hold considered, from the moulded baseline to the waterline in the loading condition considered;

ΔQ_{CF} __shear force correction for the full hold;

ΔQ_{CE} __shear force correction for the empty hold;

ΔQ_{swa}: shear force correction for permissible still water shear force without considering non-homogeneous loading, ΔQ_{swa}=0;
shear force correction for permissible still water force which has carried out non-homogeneous loading, for the considered FE loading pattern at the forward bulkhead taken as:
minimum of the absolute values of ΔQ_{mdf} calculated at aft bulkhead for the mid-hold and the value calculated at forward bulkhead of the aft cargo hold taken as, of which the ΔQ_{mdf} is defined as above.

$$Q_{swa} = \text{Min}(|\Delta Q_{mdf}|_{Mid}, |\Delta Q_{mdf}|_{Aft})$$

f_β: wave heading factor, as given in Ch 2, Sec 4;

C_{QW}: load combination factor for vertical wave shear force, as given in Ch 2, Sec 2;

Q_{wv-pos}, Q_{wv-neg}: positive and negative vertical wave shear forces, in kN, as defined in Ch 2, Sec 4, [3.2.1];

$Q_{targ-aft}$ and $Q_{targ-fwd}$: to be taken at after and forward transverse bulkheads of the mid-hold under consideration.

3.3.3.4 Target hull girder horizontal bending moment

The target hull girder horizontal bending moment, $M_{h\text{-}targ}$, in kNm, for a given FE load combination is taken as:

$$\mathrm{M}_{h-targ} = M_{wh-LC}$$

where:

M_{wh-LC}: horizontal wave bending moment, in kNm, for the dynamic load case under consideration, calculated in accordance with Ch 2, Sec 4, [3.5.4].

The values of $M_{wh\text{-}LC}$ are taken as:

• Midship cargo hold region: the value calculated for the middle of the individual cargo hold under consideration.

• Outside midship cargo hold region: the values calculated at all web frame and transverse bulkhead positions of the FE model under consideration.

3.3.3.5 Target hull girder torsional moment

The target hull girder torsional moment, $M_{wt\text{-}targ}$, in kNm, for the dynamic load cases OST and OSA is the value at the target location taken as:

$$\mathrm{M}_{wt-targ} = M_{wt-LC}(x_{targ})$$

where:

$M_{wt-LC}(x)$: wave torsional moment, in kNm, for the dynamic load case OST and OSA, defined in Ch 2, Sec 4, [3.5.5], calculated at *x* position;

$\mathrm{x}_{\mathrm{targ}}$: target location for hull girder torsional moment taken as:

- For midship cargo hold region:
  - If $\mathrm{x}_{\mathrm{mid}} \leq 0.531\mathrm{L}$: after bulkhead of the mid-hold;
  - If $\mathrm{x}_{\mathrm{mid}} > 0.531\mathrm{L}$: forward bulkhead of the mid-hold;
- Outside midship cargo hold region:

  The transverse bulkhead of mid-hold where the following formula is minimum:

$$\frac{M_{wt-LC}(x_{bhd})}{|M_{wt-LC}(x_{bhd})|} \cdot [M_{wt-LC}(x_{bhd}) - M_{T-FEM}(x_{bhd})]$$

$\mathrm{x}_{\mathrm{mid}}$: X-coordinate, in m, of the mid-hold centre;

x_{bhd}: X-coordinate, in m, of the after or forward transverse bulkhead of mid-hold.

For dynamic load cases other than OST and OSA and for all dynamic load cases of oil tankers, hull girder torsional moment $M_{wt\text{-}targ}$, at middle of mid-hold is to be adjusted to zero.

3.3.4 Hull girder load adjustment

3.3.4.1 General

The procedure given in this sub-article [3.3.4] describes how to adjust the hull girder horizontal bending moment, vertical force and vertical bending moment distribution on the three cargo hold FE model to achieve the required target values at required locations. The hull girder load target values are specified in [3.3.3].

The target locations for hull girder shear force are at the transverse bulkheads of the mid-hold. The final adjusted hull girder shear force at the target location should not exceed the target hull girder shear force.

The target location for hull girder bending moment is, in general, located at the centre of the mid-hold. If the maximum value of bending moment is not located at the centre of the mid-hold, the final adjusted maximum bending moment within the mid-hold is not to exceed the target hull girder bending moment.

3.3.4.2 Local load distribution

The following local loads are to be applied for the calculation of hull girder shear and bending moments:

a) Ship structural steel weight distribution over the length of the cargo hold model (static loads). The structural steel weight is to be calculated based on the FE model of as-built thickness, as used in the cargo hold FE model.

b) Weight of cargo and ballast (static loads).

c) Static sea pressure, dynamic wave pressure and, where applicable, green sea load. For the harbour/tank testing load cases, only static sea pressure needs to be applied.

d) Dynamic cargo and ballast loads for seagoing load cases.

With the above local loads applied to the FE model, the FE nodal forces are obtained through FE loading procedure. The 3D nodal forces will then be lumped to each longitudinal station to generate the one dimension local load distribution. The longitudinal stations are located at transverse bulkheads/frames and typical longitudinal FE model nodal locations in between the frames according to the cargo hold model mesh size requirement. Any intermediate nodes created for modelling structural details are not treated as the longitudinal stations for the purpose of local load distribution. The nodal forces within half of forward and half of afterward of longitudinal station spacing are lumped to that station. The lumping process will be done for vertical and horizontal nodal forces separately to obtain the lumped vertical and horizontal local loads, f_{vi} and f_{hi}, at thelongitudinal station *i*.

3.3.4.3 Hull girder forces and bending moment due to local loads

With the local load distribution, the hull girder load longitudinal distributions are obtained by assuming the model is simply supported at model ends. The reaction forces at both ends of the model and longitudinal distributions of hull girder shear forces and bending moments induced by local loads at any longitudinal station are determined by the following formulae:

$$R_{V_fore} = -\frac{\sum_j (x_i - x_{aft}) f_{vi}}{x_{fore} - x_{aft}} \qquad R_{V_aft} = \sum_i f_{vi} + R_{V_fore}$$

$$R_{H_fore} = \frac{\sum_j (x_i - x_{aft}) f_{hi}}{x_{fore} - x_{aft}} \qquad R_{H_aft} = -\sum_i f_{hi} + R_{H_fore}$$

$$F_l = \sum_i f_{li}$$

$$Q_{V_FEM}(x_j) = R_{V_aft} - \sum_i f_{hi} \quad \text{for } x_i < x_j$$

$$Q_{H_FEM}(x_j) = R_{H_aft} \mp \sum_i f_{hi} \quad \text{for } x_i < x_j$$

$$M_{V\text{-}FEM}(x_j) = (x_j - x_{aft}) R_{V_aft} - \sum_i (x_j - x_i) f_{vi} \quad \text{for } x_i < x_j$$

$$M_{H\text{-}FEM}(x_j) = (x_j - x_{aft}) R_{H_aft} + \sum_i (x_j - x_i) f_{hi} \quad \text{for } x_i < x_j$$

where:

R_{V_aft}、R_{V_fore}、R_{H_aft}、R_{H_fore}: vertical and horizontal reaction forces at the aft and fore ends, in kN;

x_{aft}: *X*-coordinate of the aft end support, in m;

x_{fore}: *X*-coordinate of the fore end support, in m;

f_{vi}: lumped vertical local load at longitudinal station *i* as defined in [3.3.4.2], in kN;

f_{hi}: lumped horizontal local load at longitudinal station i as defined in [3.3.4.2], in kN;

F_l: total net longitudinal force of the model, in kN;

f_{li}: lumped longitudinal local load at longitudinal station i as defined in [3.3.4.2], in kN;

x_j: X-coordinate, in m, of considered longitudinal station j;

x_i: X-coordinate, in m, of longitudinal station i.

$Q_{V_FEM}(x_j)$、$Q_{H_FEM}(x_j)$、$M_{V-FEM}(x_j)$、$M_{H-FEM}(x_j)$: vertical and horizontal shear forces, in kN, and bending moments, in kNm, at longitudinal station xj created by the local loads applied on the FE model. The sign convention for reaction forces is that a positive creates a positive shear force.

3.3.4.4 Longitudinal unbalanced force

In case total net longitudinal force of the model, F_l, is not equal to zero, the counter longitudinal force, $(F_x)_j$, is to be applied at one end of the model, where the translation on X-direction, δ_x, is fixed, by distributing longitudinal axial nodal forces to all hull girder bending effective longitudinal elements, as follows:

$$(F_x)_j = \frac{F_l}{A_x}\frac{A_j}{n_j}$$

where:

$(F_x)_j$: axial force applied to a node of the j-th element, in kN;

F_l: total net longitudinal force of the model, as defined in [3.3.4.3], in kN;

A_j: net cross sectional area of the j-th element, in m^2;

A_x: net cross sectional area of fore end section, in m^2:

$$A_x = \sum_j A_j$$

n_j: number of nodal points of j-th element on the cross section, $n_j = 1$ for beam element, $n_j = 2$ for 4-node shell element.

3.3.4.5 Hull girder shear force adjustment procedure

The hull girder shear force adjustment procedure defined in this requirement applies to all FE load combinations given in Ch 2, Sec 7. The FE load combinations not directly covered by the load combination tables of Ch 2, Sec 7 are to be considered on a case by case basis.

The two following methods are to be used for the shear force adjustment:

• Method 1 (M1): for shear force adjustment at one bulkhead of the mid-hold as given in [3.3.4.6],

• Method 2 (M2): for shear force adjustment at both bulkheads of the mid-hold as given in [3.3.4.7].

For the considered FE load combination, the method to be applied is to be selected as follows:

• For maximum shear force load combination (Max SFLC), the method 1 applies at the bulkhead mentioned in Table 3.3.4.1 if the shear force after the adjustment with method 1 at the other bulkhead does not exceed the target value. Otherwise, the Method 2 applies.

• For other shear force load combination:

  • The shear force adjustment is not requested when the shear forces at both bulkheads are lower or equal to the target values.

  • The method 1 applies when the shear force exceeds the target at one bulkhead and the shear force at the other bulkhead after the adjustment with method 1 does not exceed the target value.

Otherwise the Method 2 applies,

• The Method 2 applies when the shear forces at both bulkheads exceed the target values.

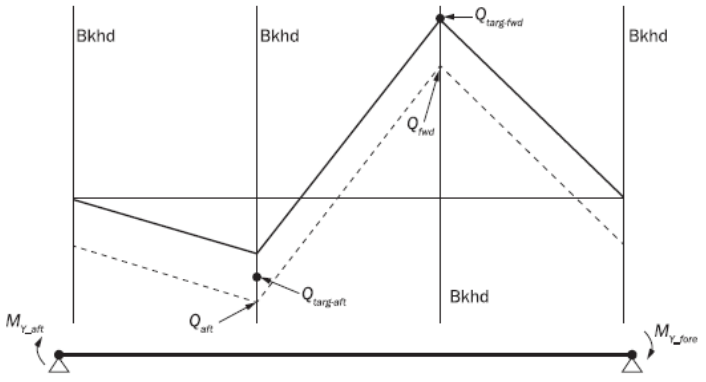
The "maximum shear force load combination" is indicated by "Max SFLC" in load combination table of Ch 2, Sec 7. Non maximum shear force load combination is the "other shear force combination". These load combinations are not indicated in the load combination table of Ch 2, Sec 7.

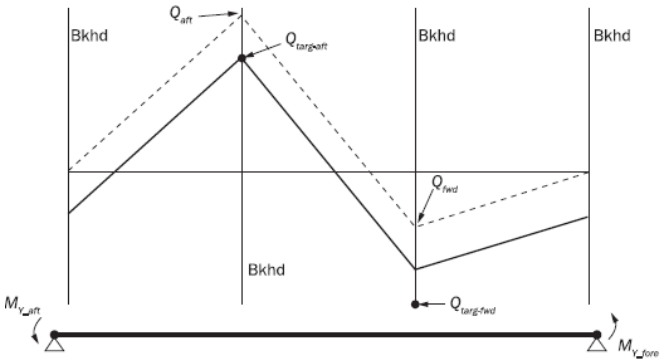
Mid-Hold Bulkhead Location for Shear Force Adjustment **Table 3.3.4.1**

Design loading conditions	Bulkhead location	$M_{wv\text{-}LC}$	Condition on Q_{fwd}	Mid-hold bulkhead for SF adjustment
Seagoing conditions	$X_{b-aft} > 0.5L$	<0 (Sagging)	$Q_{fwd} > Q_{aft}$	Fwd
			$Q_{fwd} \leq Q_{aft}$	Aft
		>0 (Hogging)	$Q_{fwd} > Q_{aft}$	Aft
			$Q_{fwd} \leq Q_{aft}$	Fwd
	$X_{b-fwd} < 0.5L$	<0 (Sagging)	$Q_{fwd} > Q_{aft}$	Aft
			$Q_{fwd} \leq Q_{aft}$	Fwd
		>0 (Hogging)	$Q_{fwd} > Q_{aft}$	Fwd
			$Q_{fwd} \leq Q_{aft}$	Aft
	$X_{b-aft} \leq 0.5L$ and $X_{b-fwd} \geq 0.5L$	-	-	(1)
Harbour and testing conditions	Whatever the location		-	(1)

(1) For the FE load combinations covered by the load combination tables of Ch 2, Sec 7, the bulkhead where the shear force adjustment is to be done is indicated in those tables.

Vertical Shear Force Adjustment by Application of Vertical Bending Moments M_{Y_Aft} and M_{Y_Fore} for Method 1 **Table 3.3.4.2**

Vertical shear force diagram	Target position in mid-hold
	Forward bulkhead



Aft bulkhead

Vertical shear force after adjustment

Vertical shear force due to local loads

3.3.4.6 Method 1 for shear force adjustment at one bulkhead

The required adjustments in shear force at following transverse bulkheads of the mid-hold are given by:

- Aft bulkhead

$$M_{Y_aft} = M_{Y_fore} = \frac{(X_{fore} - X_{aft})}{2}(Q_{targ-aft} - Q_{aft})$$

- Foreward bulkhead

$$M_{Y_aft} = M_{Y_fore} = \frac{(X_{fore} - X_{aft})}{2}(Q_{targ-fwd} - Q_{fwd})$$

where:

M_{Y_aft}, M_{Y_fore} : vertical bending moment, in kNm, to be applied at the aft and fore ends in accordance with [3.3.4.10], to enforce the hull girder vertical shear force adjustment as shown in Table 3.3.4.2. The sign convention is that of the FE model axis;

Q_{aft}: vertical shear force, in kN, due to local loads at aft bulkhead location of mid-hold, $xb_{_aft}$, resulting from the local loads calculated according to [4.4.3].

Since the vertical shear force is discontinued at the transverse bulkhead location, Q_{aft} is the maximum absolute shear force between the stations located right after and right forward of the aft bulkhead of mid-hold;

Q_{fwd}: vertical shear force, in kN, due to local loads at the forward bulkhead location of mid-hold, x_{b_fwd}, resulting from the local loads calculated according to [3.3.4.3].

Since the vertical shear force is discontinued at the transverse bulkhead location, Q_{fwd} is the maximum absolute shear force between the stations located right after and right forward of the forward bulkhead of mid-hold.

3.3.4.7 Method 2 for vertical shear force adjustment at both bulkheads

The required adjustments in shear force at both transverse bulkheads of the mid-hold are to be made by applying:

• Vertical bending moments, M_{Y_aft}, M_{Y_fore} at model ends and,

• Vertical loads at the transverse frame positions as shown in Table 3.3.4.4 in order to generate vertical shear forces, ΔQ_{aft} and ΔQ_{fwd}, at the transverse bulkhead positions.

Table 3.3.4.3 shows examples of the shear adjustment application due to the vertical bending moments and to vertical loads.

$$M_{Y_aft} = M_{Y_fore} = \frac{(X_{fore} - X_{aft})}{2}(Q_{targ-fwd} - Q_{fwd})$$

$$M_{Y_aft} = \frac{X_{fore} - X_{aft}}{2} . \frac{Q_{targ-fwd} - Q_{fwd} + Q_{targ-aft} - Q_{aft}}{2}$$

$$M_{Y_fore} = M_{Y_aft}$$

$$\Delta Q_{fwd} = \frac{Q_{targ-fwd} - Q_{fwd} - (Q_{targ-aft} - Q_{aft})}{2}$$

$$\Delta Q_{aft} = -\Delta Q_{fwd}$$

where:

M_{Y_aft}, M_{Y_fore} : vertical bending moment, in kNm, to be applied at the aft and fore ends in accordance with [3.3.4.10], to enforce the hull girder vertical shear force adjustment. The sign convention is that of the FE model axis;

Q_{aft}: adjustment of shear force, in kN, at aft bulkhead of mid-hold;

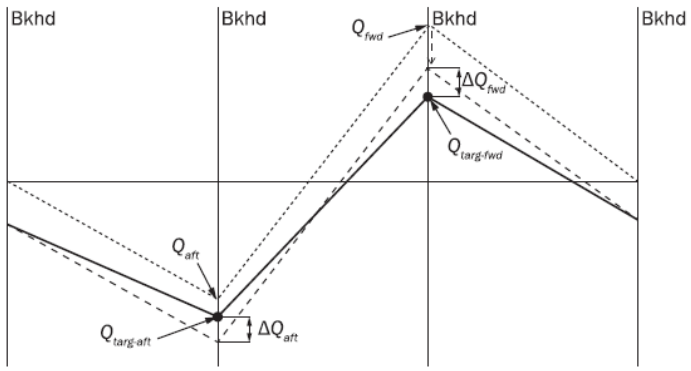
Q_{fwd}: adjustment of shear force, in kN, at fore bulkhead of mid-hold.

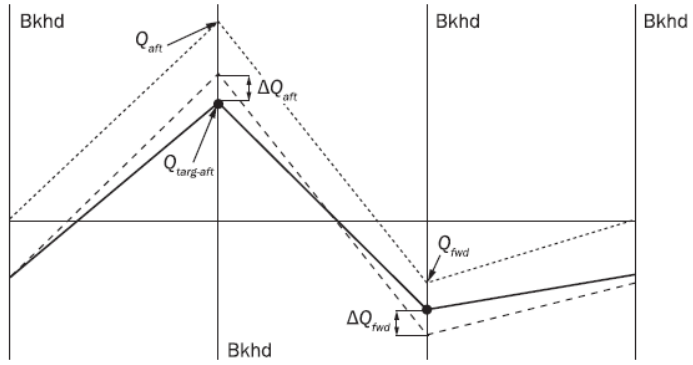
The above adjustments in shear forces, ΔQ_{aft} and ΔQ_{fwd}, at the transverse bulkhead positions are to be generated by applying vertical loads at the transverse frame positions as shown in Table 3.3.4.4. The transverse frame positions correspond to the floors. Vertical correction loads are not to be applied to any transverse tight bulkheads, any frames forward of the forward cargo hold and any frames aft of the aft cargo hold of the FE model.

The vertical loads to be applied to each transverse frame to generate the increase/decrease in shear force at the bulkheads may be calculated as shown in Table 3.3.4.4. In case of uniform frame spacing, the amount of vertical force to be distributed at each transverse frame may be calculated in accordance with Table 3.3.4.5.

Target and Required Shear Force Adjustment by Applying Vertical Forces

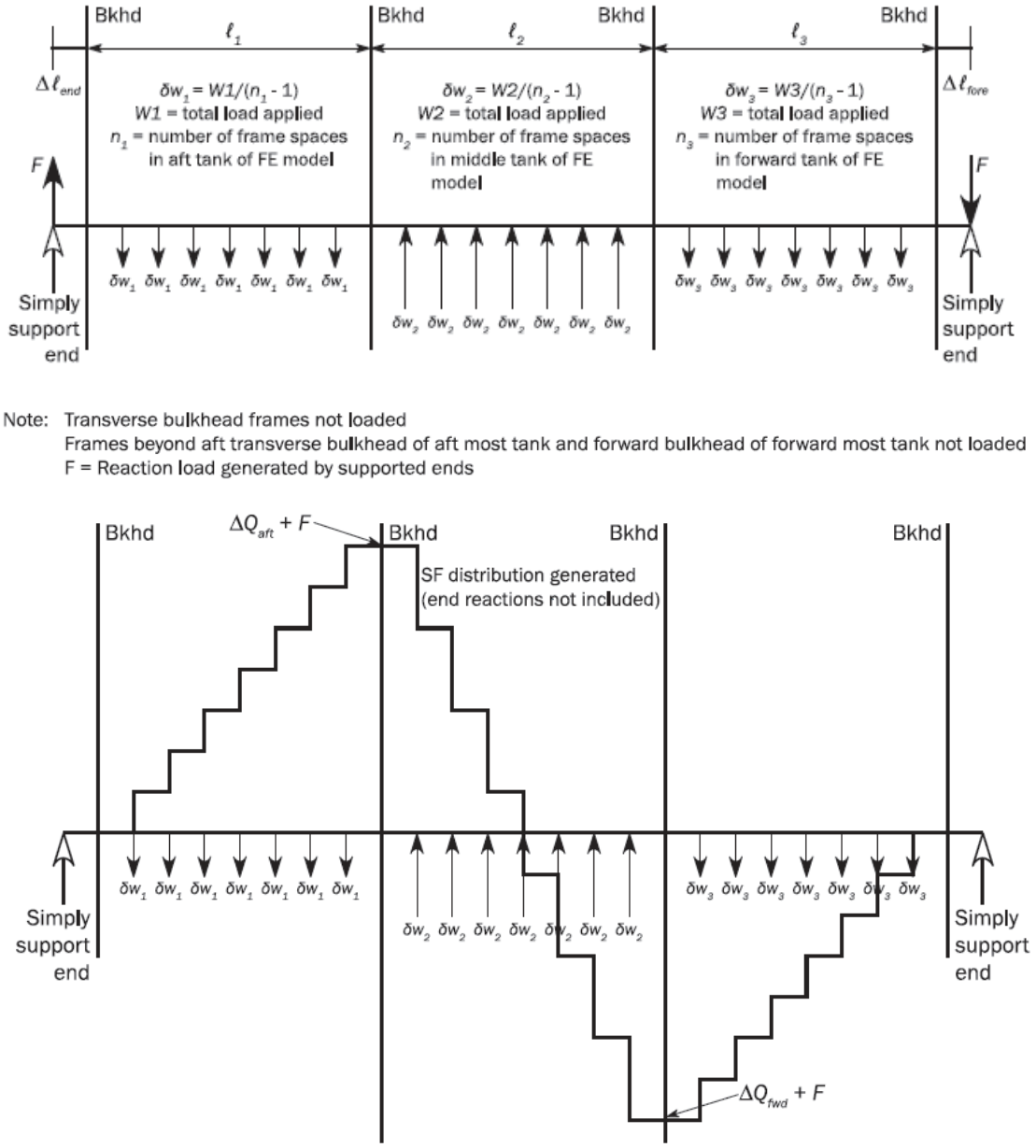
Table 3.3.4.3

Vertical shear force diagram	Aft Bhd	Fore bhd
	SF target	SF target
	$Q_{targ-aft}$ (-ve)	$Q_{targ-fwd}$ (+ve)

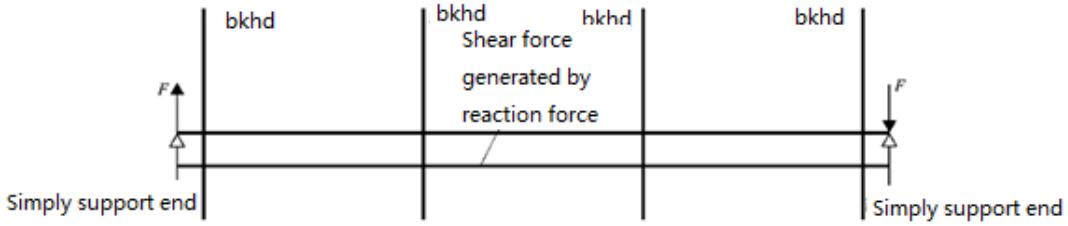
	$Q_{targ-aft}$ (+ve)	$Q_{targ-fwd}$ (-ve)
Vertical shear force after both adjustments Vertical shear force after adjustment by use of M_{Y-aft} and M_{Y-fore} Vertical shear force due to local load		
Note 1: -ve means nagetive. Note 2: +ve means positive.		

Distribution of Adjusting Vertical Force at Frames

and Resulting Shear Force Distribution **Table 3.3.4.4**



Shear Force distribution due to adjusting vertical force at frames



Note: $F = 0$ if $\ell_1 = \ell_3$ and $\Delta\ell_{fore} = \Delta\ell_{end}$, and loads are symmetrical about mid-length of model

Note 1: For definition of symbols, see Table 8.

Formulae for Calculation of Vertical Loads for Adjusting Vertical Shear Forces

Table 3.3.4.5

$\delta w_1 = \frac{\Delta Q_{aft}(2l - l_2 - l_3) + \Delta Q_{fwd}(l_2 + l_3)}{(n_1 - 1)(2l - l_1 - 2l_2 - l_3)}$	$F = 0.5\left(\frac{W1(l_2 + l_1) - W3(l_2 + l_3)}{l}\right)$
$\delta w2 = \frac{(W1 + W3)}{(n_2 - 1)} = \frac{(\Delta Q_{aft} - \Delta Q_{fwd})}{(n_2 - 1)}$	
$\delta w3 = \frac{-\Delta Q_{fwd}(2l - l_1 - l_2) - \Delta Q_{aft}(l_1 + l_2)}{(n_3 - 1)(2l - l_1 - 2l_2 - l_3)}$	

where:

l_1 : length of aft cargo hold of model, in m;

l_2 : length of mid-hold of model, in m;

l_3 : length of forward cargo hold of model, in m;

Q_{aft} : required adjustment in shear force, in kN, at aft bulkhead of middle hold, see [4.4.7];

Q_{fwd} : required adjustment in shear force, in kN, at fore bulkhead of middle hold, see [4.4.7];

F : end reactions, in kN, due to application of vertical loads to frames;

W_1 : total evenly distributed vertical load, in kN, applied to aft hold of FE model, $(n_1 - 1)\delta w_1$;

W_2 : total evenly distributed vertical load, in kN, applied to mid-hold of FE model, $(n_2 - 1)\delta w_2$;

W_3 : total evenly distributed vertical load, in kN, applied to forward hold of FE model, $(n_3 - 1)\delta w_3$;

n_1 : number of frame spaces in aft cargo hold of FE model;

n_2 : number of frame spaces in mid-hold of FE model;

n_3 : number of frame spaces in forward cargo hold of FE model;

δ_{W1} : distributed load, in kN, at frame in aft cargo hold of FE model;

δ_{W2} : distributed load, in kN, at frame in mid-hold of FE model;

δ_{W3} : distributed load, in kN, at frame in forward cargo hold of FE model;

Δl_{end} : distance, in m, between end bulkhead of aft cargo hold to aft end of FE model;

Δl_{fore} : distance, in m, between fore bulkhead of forward cargo hold to forward end of FE model;

l : total length, in m, of FE model including portions beyond end bulkheads:= $l_1 + l_2 + l_3 + \Delta l_{end} + l_{fore}$.

Note 1: Positive direction of loads, shear forces and adjusting vertical forces in the formulae is in accordance with Table 3.3.4.2 and Table 3.3.4.3.

Note 2: W1 + W3 = W2.

Note 3: The above-mentioned equations only apply to the situation with same frame spacing in their respective cargo holds. The length and frame spacing for each cargo hold may be different.

If non-uniform frame spacing is used within each cargo hold, the average frame spacing l_{av-i} is used to calculate the average distributed frame loads $\delta w_{av\text{-}i}$, according to Table 3.3.4.4, where i = 1, 2, 3 for each hold. Then $\delta w_{av\text{-}i}$ is redistributed to the non-uniform frame as follows:

$\delta w_i^k = \delta w_{av\text{-}i} \frac{l_{av\text{-}i}^k}{l_{av\text{-}i}}$ k=1,2,…,$n_i - 1$, *ni* – 1 for each frame in cargo hold i, i=1, 2, 3

where:

l_{av-i}: average frame spacing, in m, calculated as l_i/n_i, in cargo hold *i* with *i* = 1, 2, 3.

l_i: length, in m, of the cargo hold *i* with *i* = 1, 2, 3 as defined in Table 3.3.4.4;

n_i: number of frame spacing in cargo hold *i* with *i* = 1, 2, 3 as defined in Table 3.3.4.4;

δw_{av-i}: average uniform frame spacing, in m, distributed force calculated according to Table 3.3.4.4 with the average frame spacing l_{av-i} in cargo hold *i* with *i* = 1, 2, 3;

δw_i^k: distributed load, in kN, for non-uniform frame k in cargo hold I;

l_{av-i}^k: equivalent frame spacing, in m, for each frame k with k = 1, 2,..., n_i - 1, in cargo hold i, taken as:

$l_{av-i}^k = l_i^1 - \frac{l_{av-i} l_i^1}{l_i^1 + l_i^{n_i}} + \frac{l_i^2}{2}$ for k=1 (first frame), in cargo hold i

$l_{av-i}^k = \frac{l_i^k}{2} + \frac{l_i^{k+1}}{2}$ for k=2, 3……n_i -2 in cargo hold i

$l_{av-i}^k = l_i^{n_i} - \frac{l_{av-i} l_i^{n_i}}{l_i^1 + l_i^{n_i}} + \frac{l_i^{n_i-1}}{2}$ for k=n_i -1 (last frame), in cargo hold i.

l_i^k: frame spacing, in m, between the frame *k* - 1 and *k* in the cargo hold *i*.

The required vertical load δw_i for a uniform frame spacing or δw_i^k for non-uniform frame spacing, are to be applied by following the shear flow distribution at the considered cross section. For a frame section under vertical load δ_{wi}, the shear flow, q_f, at the middle point of the element is calculated as:

$$q_{f-k} = \frac{\delta w_i}{I_y} Q_k$$

where:

q_{f-k}: shear flow calculated at the middle of the *k*-th element of the transverse frame, in N/mm;

δw_i: distributed load at each transverse frame location for *i*-th cargo hold, *i* = 1, 2, 3, as defined in Table 3.3.4.4;

I_y: moment of inertia of the hull girder cross section, in mm^4;

Q_k: first moment about neutral axis of the accumulative section area starting from the open end (shear stress free end) of the cross section to the point s_k for shear flow q_{f-k} in mm^3, taken as:

$$Q_k = \int_0^{s_k} z_{neu} t \ ds$$

z_{neu}: vertical distance from the integral point, *s*, to the vertical neutral axis;

t : net thickness, in mm, of the plate at the integral point of the cross section.

The distributed shear force at *j*-th FE grid of the transverse frame, F_{grid}, is obtained from the shear flow of the connected elements as following:

$$F_{j-grid} = \sum_{k=1}^{n} q_{f-k} \frac{l_k}{2}$$

where:

l_k: length of the *k*-th element of the transverse frame connected to the grid *j*, in mm;

n: total number of elements connect to the grid *j*.

The shear flow has direction along the cross section and therefore the distributed force, F_{grid}, is a vector force. For vertical hull girder shear correction, the vertical and horizontal force components calculated with above mentioned shear flow method need to be applied to the cross section.

3.3.4.8 Procedure to adjust vertical and horizontal bending moments for midship cargo hold region

In case the target vertical bending moment needs to be reached, an additional vertical bending moment is to be applied at both ends of the cargo hold FE model to generate this target value in the mid-hold of the model. This end vertical bending moment is given as follows:

$$M_{v-end} = M_{v-targ} - M_{v-peak}$$

where:

$\mathrm{M_{v-end}}$: additional vertical bending moment, in kNm, to be applied to both ends of FE model in accordance with [4.4.10];

M_{v-targ}: hogging (positive) or sagging (negative) vertical bending moment, in kNm, as specified in [3.3.3.2];

M_{v-peak}: maximum or minimum bending moment, in kNm, within the length of the mid-hold due to the local loads described in [3.3.4.3] and due to the shear force adjustment as defined in [3.3.4.5];

$M_{v\text{-}peak}$ is to be taken as the maximum bending moment if $M_{v\text{-}targ}$ is hogging (positive) and as the minimum bending moment if $M_{v\text{-}targ}$ is sagging (negative).

$M_{v\text{-}peak}$ is to be calculated as follows based on a simply supported beam model:

$$\mathrm{M_{v-peak}} = Extremum\left\{M_{v_FEM}(x) + M_{lineload} + M_{Y_aft}\left(2\frac{x - x_{aft}}{x_{fore} - x_{aft}} - 1\right)\right\}$$

$M_{v_FEM}(x)$: vertical bending moment, in kNm, at position *x*, due to the local loads as described in [3.3.4.3];

M_{Y_aft}: end bending moment, in kNm, to be taken as:

When Method 1 is applied: the value as defined in [3.3.4.6];

When Method 2 is applied: the value as defined in [3.3.4.7];

Otherwise: $M_{Y_{aft}=}0$;

$M_{lineload}$: vertical bending moment, in kNm, at position *x*, due to application of vertical line loads at frames according to Method 2, to be taken as:

$$M_{lineload} = -(x - x_{aft})F - \sum_i (x - x_i)\,\delta w_i, \text{ for } x_i < x$$

F: reaction force, in kN, at model ends due to application of vertical loads to frames as defined in Table 7;

x: *X*-coordinate, in m, of frame in way of the mid-hold;

δw_i: vertical load, in kN, at web frame station *i* applied to generate required shear force.

In case the target horizontal bending moment needs to be reached, an additional horizontal bending moment is to be applied at the ends of the cargo tank FE model to generate this target

value within the mid-hold. The additional horizontal bending moment is to be taken as:

$$M_{h-end} = M_{h-targ} - M_{h-peak}$$

M_{h-end}: additional horizontal bending moment, in kNm, to be applied to both ends of the FE model according to [4.4.10];

M_{h-targ}: horizontal bending moment, as defined in [3.3.3.4];

M_{h-peak}: maximum or minimum horizontal bending moment, in kNm, within the length of the mid-hold due to the local loads described in [3.3.4.3].

$M_{h\text{-}peak}$ is to be taken as the maximum horizontal bending moment if $M_{h\text{-}targ}$ is positive (starboard side in tension) and as the minimum horizontal bending moment if $M_{h\text{-}targ}$ is negative (port side in tension).

$M_{h\text{-}peak}$ is to be calculated as follows based on a simply supported beam model:

M_{h-peak}= Extremum { $M_{H_FEM}(x)$ }.

$M_{H_FEM}(x)$: horizontal bending moment, in kNm, at position *x*, due to the local loads as described in [3.3.4.3].

The vertical and horizontal bending moments are to be calculated over the length of the mid-hold to identify the position and value of each maximum/minimum bending moment.

3.3.4.9 Procedure to adjust vertical and horizontal bending moments outside midship cargo hold region

To reach the vertical hull girder target values at each frame and transverse bulkhead position, as defined in [3.3.3.2], the vertical bending moment adjustments, m_{vi}, are to be applied at web frames and transverse bulkhead positions of the finite element model, as shown in Figure 19. The vertical bending moment adjustment at each longitudinal location, *i*, is to be calculated as follows:

$$f(i) = -M_{v-targ}(i) + M_{v-FEM}(i) + M_{lineload}(i) \mp M_{Y-aft}.\left(2\frac{X_{i-}X_{aft}}{X_{fore} - X_{aft}} - 1\right)$$

$$\mathrm{m_{vi}} = \frac{f(i) + f(i+1)}{2}\sum_{j=0}^{i-1} m_{vj}$$

$$m_{v-end} = -\sum_{j=0}^{n_t} m_{vj}$$

where:

i: index corresponding to the *i*-th station, starting from i =1 at the aft end section up to n_t;

n_t: total number of longitudinal stations where the vertical bending moment adjustment, m_{vi}, is applied;

$\mathrm{m_{vi}}$: vertical bending moment adjustment, in kNm, to be applied at transverse frame or bulkhead at station *i*;

$\mathrm{m_{v-end}}$: vertical bending moment adjustment, in kNm, to be applied, at the fore end section (n_t+1 station);

m_{vj}: argument of summation to be taken as:

$m_{v0} = 0$ for *j=0*;

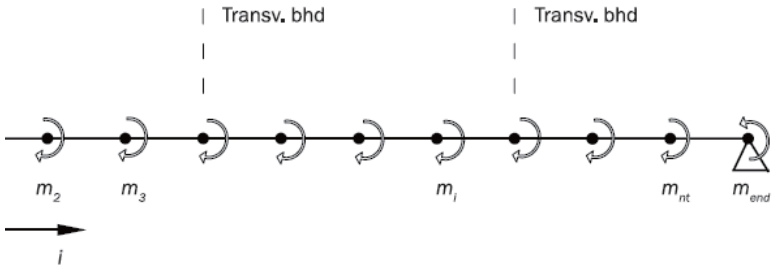
$m_{vj} = m_{hi}$ for *j=i*;

$M_{v-targ}(i)$: required target vertical bending moment, in kNm, at station *i*, calculated in

accordance with [3.3.3.2];

$M_{v-FEM}(i)$: vertical bending moment distribution, in kNm, at station *i* due to local loads as given in [3.3.4.3];

$M_{lineload}(i)$: vertical bending moment, in kNm, at station i, due to the line load for the vertical shear force correction as required in [3.3.4.8].



m_{hi} can be substituted to m_{vi} in this figure.

Figure 3.3.4.1 Adjustments of Bending Moments Outside Midship Cargo Hold Region

To reach the horizontal hull girder target values at each frame and transverse bulkhead position as defined in [3.3.4.3], the horizontal bending moment adjustments, m_{hi}, are to be applied at web frames and transverse bulkhead positions of the finite element model, as shown in Figure 3.3.4.1. The horizontal bending moment adjustment at each longitudinal location, *i*, is to be calculated as follows:

$$f(i) = M_{h-targ}(i) - M_{H-FEM}(i)$$

$$\mathrm{m_{hi}} = \frac{f(i) + f(i+1)}{2} - \sum_{j=0}^{i-1} m_{hj}$$

$$m_{h-end} = -\sum_{j=0}^{n_t} m_{hj}$$

where:

i: longitudinal location for bending moment adjustments, m_{hi};

n_t: total number of longitudinal stations where the horizontal bending moment adjustment, m_{hi}, is applied;

m_{hi}: horizontal bending moment adjustment, in kNm, to be applied at transverse frame or bulkhead at station *i*;

m_{h-end}: horizontal bending moment adjustment, in kNm, to be applied at the fore end section (n_t+1 station);

m_{hj}: argument of summation to be taken as:

$m_{h0} = 0$ for *j=0*;

$m_{hj} = m_{hi}$ or *j=i*;

$M_{h-targ}(i)$: required target horizontal bending moment, in kNm, at station *i*, calculated in accordance with [4.3.4];

$M_{H-FEM}(i)$: horizontal bending moment distribution, in kNm, at station *i* due to local loads as given in [4.4.3].

The vertical and horizontal bending moment adjustments, m_{vi} and m_{hi}, are to be applied at all web frames and bulkhead positions of the FE model. The adjustments are to be applied in FE model by

distributing longitudinal axial nodal forces to all hull girder bending effective longitudinal elements in accordance with [3.3.4.10].

3.3.4.10 Application of bending moment adjustments on the FE model

The required vertical and horizontal bending moment adjustments are to be applied to the considered cross section of the cargo hold model by distributing longitudinal axial nodal forces to all hull girder bending effective longitudinal elements of the considered cross section:

- For vertical bending moment:

$$(\mathrm{F_x})_i = \frac{M_v}{I_{y-n50}} \frac{A_i}{n_i} z_i$$

- For horizontal bending moment:

$$(\mathrm{F_x})_i = \frac{M_h}{I_{z-n50}} \frac{A_i}{n_i} y_i$$

where:

M_v: vertical bending moment adjustment, in kNm, to be applied to the considered cross section of the model;

M_h: horizontal bending moment adjustment, in kNm, to be applied to the considered cross section the ends of the model;

$(\mathrm{F_x})_i$: axial force, in kN, applied to a node of the *i*-th element;

I_y: hull girder vertical moment of inertia, in m^4, of the considered cross section about its horizontal neutral axis;

I_z: hull girder horizontal moment of inertia, in m^4, of the considered cross section about its vertical neutral axis;

z_i: vertical distance, in m, from the neutral axis to the centre of the cross sectional area of the *i*-th element;

y_i: horizontal distance, in m, from the neutral axis to the centre of the cross sectional area of the *i*-th element;

A_i: cross sectional area, in m^2, of the *i*-th element;

n_i: number of nodal points of *i*-th element on the cross section, $n_i = 1$ for beam element, $n_i = 2$ for 4- node shell element.

For cross sections other than cross sections at the model end, the average area of the corresponding *i*-th elements forward and aft of the considered cross section is to be used.

3.3.5 Procedure to adjust hull girder torsional moments

3.3.5.1 General

The procedure in this sub-article describes how to adjust the hull girder torsional moment distribution on the cargo hold FE model to achieve the target torsional moment at the target location. The hull girder torsional moment target values are given in [3.3.3.5].

3.3.5.2 Torsional moment due to local loads

Torsional moment, in kNm, at longitudinal station *i* due to local loads, $\mathrm{M}_{T\text{-}FEMi}$, in kNm, is determined by the following formula:

$$\mathrm{M}_{T-FEMi} = \sum_k [f_{hik}(z_{ik} - z_r)] - \sum_k (f_{vik} y_{ik})$$

where:

M_{T-FEMi}: lumped torsional moment, in kNm, due to local load at longitudinal station *i*;

z_r:
vertical coordinate of torsional reference point, in m, to be taken as $z_r = 0$.

f_{hik}: horizontal nodal force, in kN, of node *k* at longitudinal station *i*;

f_{vik}: vertical nodal force, in kN, of node *k* at longitudinal station *i*;

y_{ik}: *Y*-coordinate, in m, of node *k* at longitudinal station *i*;

z_{ik}: *Z*-coordinate, in m, of node *k* at longitudinal station *i*;

M_{T-FEM0}: lumped torsional moment, in kNm, due to local load at aft end of the FE model (forward end for foremost cargo hold model), taken as:

$M_{T-FEMO} = \sum_k [f_{h0k}(z_{0k} - z_r)] - \sum_k (f_{v0k} y_{0k}) + R_{H_fwd} \cdot (z_{ind} - z_r)$ for foremost cargo hold model

$M_{T-FEMO} = \sum_k [f_{h0k}(z_{0k} - z_r)] - \sum_k (f_{v0k} y_{0k}) + R_{H_aft} \cdot (z_{ind} - z_r)$ for the other cargo hold models

R_{H_fwd}: horizontal reaction forces, in kN, at the forward end, as defined in [3.3.4.3];

R_{H_aft}: horizontal reaction forces, in kN, at the aft end, as defined in [3.3.4.3];

z_{ind}: vertical coordinate, in m, of independent point as defined in [3.2.5].

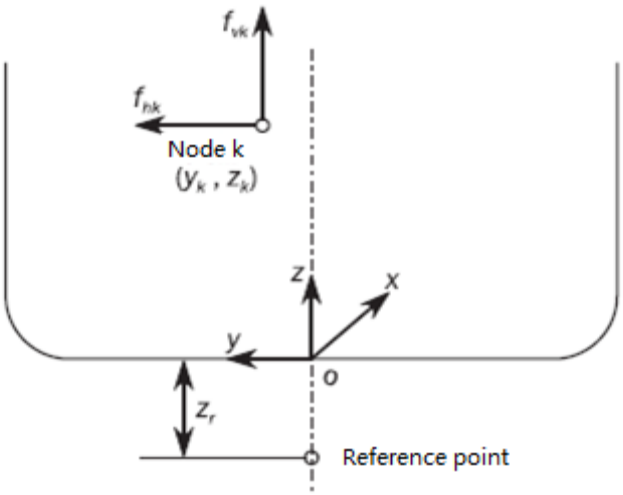


Figure 3.3.5.1 Station Forces and Acting Location of Torsional Moment at Section

3.3.5.3 Hull girder torsional moment

The hull girder torsional moment, $M_{T\text{-}FEM}(x_j)$, in kNm, is obtained by accumulating the station torsional moment from the aft end section (forward end for foremost cargo hold model) as follows:

$$M_{T-FEM}(x_j) = \sum_i M_{T-FEMi}$$

- when $x_i \geq x_j$ for foremost cargo hold model
- when $x_i < x_j$ otherwise.

where:

$M_{T-FEM}(x_j)$: hull girder torsional moment, in kNm, at longitudinal station x_j;

x_j: *X*-coordinate, in m, of considered longitudinal station *j*.

The torsional moment distribution given in [3.3.5.2], has a step at each longitudinal station.

3.3.5.4 Procedure to adjust hull girder torsional moment to target value

The torsional moment is to be adjusted by applying a hull girder torsional moment $M_{T\text{-}end}$ in kNm,

at the independent point of the aft end section of the model (forward end for foremost cargo hold model), given as follows:

$$M_{T-end} = M_{wt-targ} - M_{wt}(x_{targ})$$

where:

x_{targ}: X-coordinate, in m, of the target location for hull girder torsional moment, as defined in [3.3.3.5];

$M_{wt-targ}$: target hull girder torsional moment, in kNm, specified in [3.3.3.5], to be achieved at the target location;

$M_{wt}(x_{targ})$: hull girder torsional moment, in kNm, at target location due to local loads.

Due to the step of hull girder torsional moment at each longitudinal station, the hull girder torsional moment is to be selected from the values aft and forward of the target location as follows: Maximum value for positive torsional moment and minimum value for negative torsional moment.

3.4 Analysis Criteria

3.4.1 Evaluation areas

3.4.1.1 Verification of results against the acceptance criteria is to be carried out within the longitudinal extent of the mid-hold, including mid-hold intact corrugated bulkhead structure (intact lower stool and upper stool), horizontal girder of transeverse bulkhead in ballast tank, as shown in Figure 3.4.1.1. For the foreward hold model, the fore end of evaluation extent is to collision bulkhead of foreward hold.

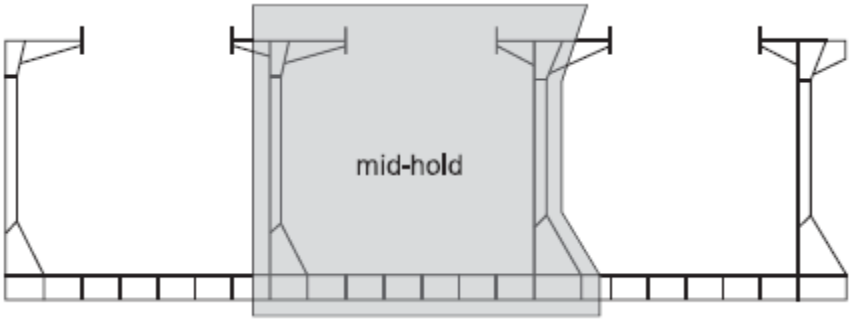


Figure 3.4.1.1 Longitudinal Extent of Evaluation Area

3.4.1.2 The following structural elements within the evaluation area are to be verified with the criteria given in [3.4.2]:

- All hull girder longitudinal structural members,
- All primary supporting structural members and bulkheads within the mid-hold,
- All structural members being part of the transverse bulkheads, such as:
  - stool structure and its connected longitudinal girders and double bottom floors, and local longitudinal girders,
  - horizontal girders of plane bulkhead in side hold and their attached transverse structures,
- All structural members being part of the forward transverse bulkhead of the machinery space and all hull girder longitudinal structural members aft of this transverse bulkhead within the extent of 15% of the aftmost cargo hold length.

3.4.2 Yield strength assessment

3.4.2.1 For all plates of the structural members defined in [3.4.1.2], the von Mises stress, σ_{vm}, in N/mm^2, is to be calculated based on the membrane normal and shear stresses of the shell element. The stresses are to be evaluated at the element centroid of the mid-plane (layer), as follows:

$$\sigma_{vm} = \sqrt{\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2}$$

where:

σ_x, σ_y: element normal membrane stresses, in N/mm^2;

τ_{xy}: element shear stress, in N/mm^2.

3.4.2.2 For beams and rod elements, the axial stress, σ_{axial}, in N/mm^2, is to be calculated based on axial force alone. The axial stress is to be evaluated at the middle of element length.

3.4.2.3 Coarse mesh stress criteria

The hull structural unit of target hold is to be in compliance with the following criteria:

$$\lambda_y \leq \begin{matrix} 1.0 & S+D \\ 1.0 & S \end{matrix}$$

where:

λ_y: yield utilisation factor:

$\lambda_y = \frac{\sigma_{vm}}{R_y}$ for shell elements in general;

$\lambda_y = \frac{|\sigma_{axial}|}{R_y}$ for rod or beam elements in general;

σ_{vm}: Von Mises stress, in N/mm^2;

σ_{axial}: axial stress in rod or beam element, in N/mm^2;

R_y: yield limit of material, to be taken as $R_y = 220/k$.

3.4.2.4 The yield check criteria for the flange of primary supporting members are to be based on axial stress.

3.4.2.5 Where the von Mises stress of the elements in the cargo hold FE model in way of the area under investigation by fine mesh exceeds the yield criteria, average Von Mises stress, obtained from the fine mesh analysis, calculated over an area equivalent to the mesh size of the cargo hold finite element model is to satisfy the yield criteria above.

3.4.2.6 In way of cut-outs, yield utilisation factor is to be obtained with shear stress correction. Except as indicated in 3.4.2.7, the element shear stress in way of cut-outs in webs is to be corrected for loss in shear area in accordance with the following formula. The corrected element shear stress is to be used to calculate the Von Mises stress of the element for verification against the yield criteria.

$$\tau_{cor} = \frac{h\, t_{mod0}}{A_{shr}} \tau_{elem}$$

where:

τ_{cor}: corrected element shear stress, in N/mm^2;

h: height of web of girder, in mm, in way of opening, see Table 1. Where the geometry of the opening is modelled, h is to be taken as the height of web of the girder deducting the height of the modelled opening;

t_{mod}: modelled web thickness, in mm, in way of opening;

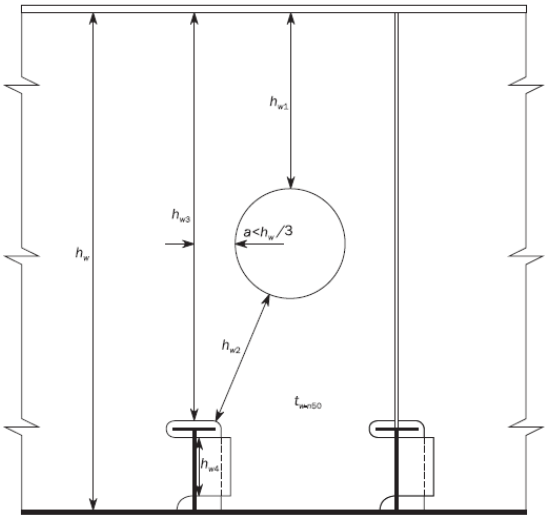
A_{shr}: effective net shear area of web, in mm^2, taken as the web area deducting the area lost of all openings, including slots for stiffeners, calculated by the following equation:

$$A_{shr} = (h_w + t_f + t_p)t_w$$

where: t_f :thickness of face plating for primary supporting members, in mm;

t_p : thickness of shell plating in way of supporting members, in mm;

h_w : web height after deducting the opening, calculated by the following diagram:



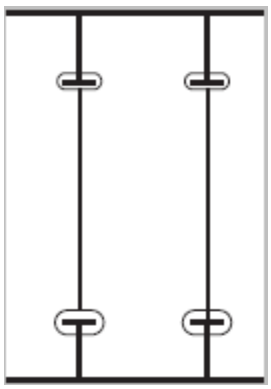
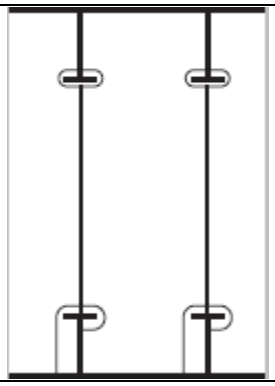
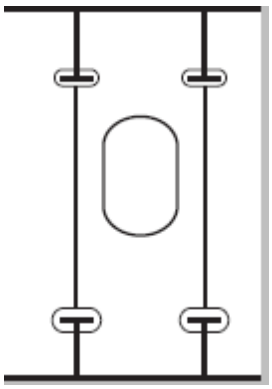
τ_{elem}: element shear force, in N/mm^2, before correction.

3.4.2.7 Exceptions for shear stress correction for openings

Correction of element shear stress due to presence of cut-outs is not required for cases given in Table 3.4.2.1 provided λ_y/C_r complies with the criteria given in [3.4.2.3].

Exceptions for Shear Stress Correction **Table 3.4.2.1**

Identification	Figure	Difference between modelled shear area and the net effective shear area in % of the modelled shear area $\frac{A_{FEM} - A_{shr}}{A_{shr}} \cdot 100\%$	Reduction factor for yield criteria, c_r

Upper and lower slots for local support stiffeners fitted with lugs or collar plates		$< 15\%$	0.85
Upper or lower slots for local support stiffeners fitted with lugs or collar plates		$< 20\%$	0.80
In way of opening, upper and lower slots for local support stiffeners fitted with collar plates		$< 40\%$	0.60
A_{shr}: Effective net shear area of the web, in mm^2, taken as the web area without the all opening areas and without the slots for stiffeners.			

3.5 Local Structural Strength Analysis

3.5.1 General requirements

3.5.1.1 The detailed stress assessment of primary members in cargo hold area is to be carried out according to the requirements of this Section.

3.5.2 Locations for assessment

3.5.2.1 Refined mesh FE analysis is to be carried out for the specified location.

3.5.2.2 If the corresponding stress of specified location exceeds 90% allowable stress in the hold model analysis, refined mesh FE analysis is to be carried out. The refining locations are as follows:

(a) in way of connection of longitudinal bulkhead and inner bottom plating;

(b) in way of knuckle of longitudinal bulkhead;

(c) in way of connection of longitudinal bulkhead and deck;

(d) in way of connection of corrugated transverse bulkhead and lower stool;
(e) in way of lower stool and inner bottom;
(f) in way of hatch corners;
(g) in way of toe ends of stringers for plane transverse bulkhead;
(h) in way of connection of vertical stiffener of plane transverse bulkhead and deck longitudinals, outer bottom longitudinals;
(i) in way of openings in highly stressed areas.

3.5.3 FE models

3.5.3.1 The global cargo hold model is to be in accordance with the requirements of 3.2.2.

3.5.3.2 Where the sub-model method is used for refining, the minimum extent of sub-model is to be such that boundaries of the sub-model correspond to the locations of adjacent primary supporting members.

3.5.3.3 The mesh size in the fine mesh zones is not to be greater than 50×50 mm.

3.5.3.4 The extent of the fine mesh zone is not to be less than 10 elements in all directions from the area under investigation. A smooth transition of mesh density from fine mesh zone to the boundary of the fine mesh model is to be maintained.

3.5.3.5 All plating within the fine mesh zone is to be represented by shell elements. The aspect ratio of elements within the fine mesh zone is to be kept as close to 1 as possible. Variation of mesh density within the fine mesh zone and the use of triangular elements are to be avoided. In all cases, the elements within the fine mesh model are to have an aspect ratio not exceeding 3. Distorted elements, with element corner angles of less than $45°$ or greater than $135°$, are to be avoided. Stiffeners inside the fine mesh zone are to be modelled using shell elements. Stiffeners outside the fine mesh zones may be modelled using beam elements.

3.5.4 Fine mesh strength criteria

3.5.4.1 Reference stress is Von Mises stress, σ_{vm}, which is to be calculated based on the membrane normal and shear stresses of the shell element evaluated at the element centroid. The stresses are to be evaluated at the mid plane of the element.

3.5.4.2 The maximum permissible stresses are based on the mesh size of 50×50 mm as specified in [3.5.3]. Where a smaller mesh size is used, an area weighted Von Mises stress calculated over an area equal to the specified mesh size may be used to compare with the permissible stresses. The averaging is to be based only on elements with their entire boundary located within the desired area. The average stress is to be calculated based on stresses at element centroid; stress values obtained by interpolation and/or extrapolation are not to be used. Stress averaging is not to be carried across structural discontinuities and abutting structure.

3.5.4.3 The permissible fine mesh stress criteria are to meet the following requirements:

$$\lambda_y \leq 1.7 \quad \text{for element not adjacent to welds}$$

$$\lambda_y \leq 1.5 \quad \text{for element adjacent to welds}$$

where:

λ_f: Fine mesh yield utilization factor:

$\lambda_f = \frac{\sigma_{vm}}{R_Y}$ for shell element in general;

$\lambda_f = \frac{|\sigma_{axial}|}{R_Y}$ for rod element in general:

σ_{vm}: Von Mises stress, in N/mm^2;

σ_{axial}: axial stress of rod element, in N/mm^2.

CHAPTER 4 BUCKLING STRENGTH ASSESSMENT

4.1 General Requirements

4.1.1 General provisions

(1) This Chapter contains the strength criteria for buckling and ultimate strength of local supporting members, primary supporting members and other structures such as pillars, corrugated bulkheads and brackets.

(2) For each structural member, the characteristic buckling strength is to be taken as the most unfavourable/critical buckling failure mode.

(3) Unless otherwise specified, the scantling requirements of structural members in this Chapter are based on net scantling obtained by removing t_r from the gross offered thickness, where t_r is defined in 4.1.5(1).

(4) In this Chapter, compressive and shear stresses are to be taken as positive, tension stresses are to be taken as negative. Unless otherwise specified, the stress in this Chapter are the corrected stress σ_A, as defined in 4.1.5(2).

(5) Buckling capacity obtained in this Chapter gives a lower bound estimate of ultimate capacity, or the maximum load the panel can carry without suffering major permanent set.

(6) Buckling capacity assessment in this Chapter utilises the positive elastic post-buckling effect for plates and accounts for load redistribution between the structural components, such as between plating and stiffeners. For slender structures, the capacity calculated using this method is typically higher than the ideal elastic buckling stress (minimum Eigen value). Accepting elastic buckling of structural components in slender stiffened panels implies that large elastic deflections and reduced in-plane stiffness will occur at higher buckling utilisation levels.

(7) The buckling check methods and conclusions may be acceptable in accordance with the other technical standards with the consent of CCS.

4.1.2 Scope of application

(1) The buckling assessment of stiffened panels and corrugated plating structures in this Chapter are to be carried out in accordance with the following requirements:

① FE buckling analysis for stiffened and unstiffened panels, corrugated bulkhead structures, refer to 4.2;

② Buckling capacity calculation for plating, stiffeners, struts, pillars and cross ties, corrugated bulkhead structures, refer to 4.3;

③ Buckling assessment criteria for stiffened and unstiffened panels, struts, pillars and cross ties, corrugated bulkhead structures, refer to 4.4.

(2) Stiffener

The buckling check of the stiffeners referred to in this Chapter is applicable to the stiffener fitted along the long edge of the buckling panel.

(3) Enlarged stiffener

Enlarged stiffeners, with or without web stiffening, used for Permanent Means of Access (PMA) are to comply with the following requirements:

4.1.3 Assessment methods

The buckling assessment is carried out according to one of the two methods taking into account different boundary condition types:

• Method A: All the edges of the elementary plate panel are forced to remain straight (but free to move in the in-plane directions) due to the surrounding structure/neighbouring plates.

• Method B: The edges of the elementary plate panel are not forced to remain straight due to low in-plane stiffness at the edges and/or no surrounding structure/neighbouring plates.

4.1.4 Buckling utilisation factor

The utilisation factor, η, is defined as the ratio between the applied loads and the corresponding ultimate capacity or buckling strength.

For combined loads, the utilisation factor, η_{act}, is to be defined as the ratio of the applied equivalent stress and the corresponding buckling capacity, and is to be taken as:

$$\eta_{act} = \frac{W_{act}}{W_u} = \frac{1}{\gamma_c} \tag{0.1}$$

where: W_{act} — applied equivalent stress, in N/mm^2;

W_u — equivalent buckling capacity;

γ_c — stress multiplier factor at failure, as defined in 4.3 of this Chapter.

For each typical failure mode, the corresponding capacity of the panel is calculated by applying the actual stress combination and then increasing or decreasing the stresses proportionally until collapse.

Figure 4.1.4 illustrates the buckling capacity and the buckling utilisation factor of a structural member subject to σ_x and σ_y stresses.

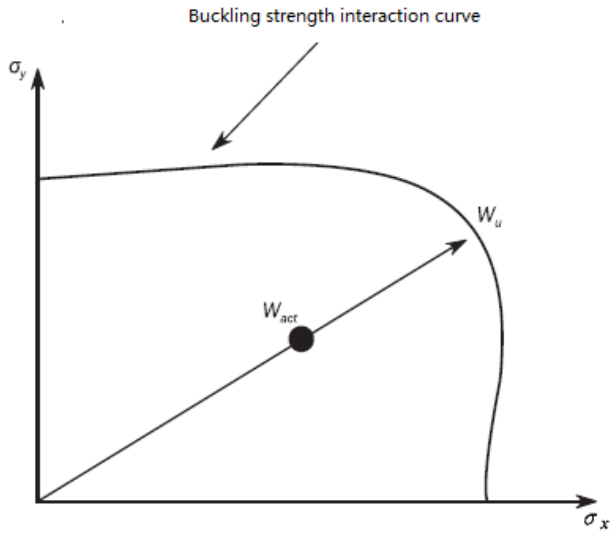


Figure 4.1.4 Example of Buckling Capacity and Buckling Utilization Factor

4.1.5 Thickness reduction and stress correction

(1) Thickness reduction

In this Chapter, all structures such as panels, stiffeners, etc. are to deduct the appropriate standard thickness reduction, t_r, indicated in Table 4.1.5.

Standard Thickness Reduction Used to Calculate Critical Buckling Stress

Table 4.1.5

Location		Thickness reduction, in mm
Ballast tank within 1.5 m of weathertightness deck	One side connected with ballast water	1.0
	Both sides connected with ballast water	2.0
Other locations		1.0

(2) Stress correction

When the buckling assessment is carried out, stresses, including positive stress, shear force, etc., are to be obtained based on hold or global FE calculation, and corrected as following:

$$\sigma_A = \frac{\sigma t}{t - t_r} \tag{0.2}$$

where: σ_A: working stress for buckling calculation;

σ: stress obtained by FE calculation;

t: thickness of original plate used for FE calculation;

t_r : standard thickness reduction listed in Table 4.1.5.

4.1.6 Buckling assessment requirements of global FE analysis

For global FE analysis, buckling assessment is to be verified based on the following two steps:

(1) Buckling assessment is to be carried out for certain critical structural areas (focused on the areas with higher buckling utilization factor which is found in hold FE analysis, i.e. buckling utilization factor is greater than 95% of the criteria), in order to satisfy the relevant requirements. If not, buckling assessment is to be further extended to the corresponding structural positions, even to the global structure, in order to satisfy the relevant requirements.

(2) The global buckling assessment results of relevant structures are to be compared with the corresponding hold FE buckling assessment results. If the buckling utilization factor given by the global FE buckling assessment is much higher than hold assessment (i.e. above 20%, and the factor is greater than 95% of the criteria), buckling assessment is also to be further extended to the corresponding structural positions, even to the global structure, in order to satisfy the relevant requirements.

In addition , for the structural areas beyond the hold FE assessment, buckling assessment is to be carried out in the global FE analysis.

4.2 Type of Panel

4.2.1 Symbols

η_{all} — allowable buckling utilization factor, defined in 4.4.1 of this Chapter;

α — aspect ratio of the plate panel, defined in 4.3 of this Chapter.

4.2.2 General provisions

(1) The requirements of this Section apply for the buckling assessment of direct strength analysis of the structural members subjected to compressive stress, shear stress and lateral pressure.

(2) Structural elements

The plate panel of hull structure is to be modelled as stiffened or unstiffened panel, and Method A and Method B as defined in 4.1.3 of this Chapter are to be used according to the panel positions and stiffener arrangement. For certain typical hull structures, panel definition and assessment method are to be in accordance with Table 4.2.2 and Figure 4.2.2(1) to Figure 4.2.2(4).

Panel Definition and Assessment Method for Structural Element

Table 4.2.2

Structural elements	Assessment method	Normal panel definition
Longitudinal structures, see Figure 4.2.2(1)		
Longitudinally stiffened panels Shell envelope Deck Inner hull	SP-A	Length: between web frames Width: between primary supporting members

Hopper tank side Longitudinal bulkheads		
Double bottom longitudinal girders in line with longitudinal bulkhead or connected to hopper tank side	SP-A	Length: between web frames Width: full web depth
Web of double bottom longitudinal girders not in line with longitudinal bulkhead or not connected to hopper tank side	SP-B	Length: between web frames Width: full web depth
Web of horizontal girders in double side space connected to hopper tank side	SP-A	Length: between web frames Width: full web depth
Web of horizontal girders in double side space not connected to hopper tank side	SP-B	Length: between web frames Width: full web depth
Web of single skin longitudinal girders or stringers	UP-B	Plate between local stiffeners/face plate/PSM
Transverse structure, see Figure 4.2.2(2)		
Web of transverse deck frames including brackets	UP-B	Plate between local stiffeners/face plate/PSM
Vertical web in double side space	SP-B	Length: full web depth Width: between primary supporting members
Irregularly stiffened panels, e.g. web panels in way of hopper tank and bilge	UP-B	Plate between local stiffeners/face plate/PSM
Double bottom floors	SP-B	Length: full web depth Width: between primary supporting members
Vertical web frame including brackets	UP-B	Plate between vertical web stiffeners/face plate/PSM
Cross tie web plate	UP-B	Plate between vertical web stiffeners/face plate/PSM
Transverse bulkhead, see Figure 4.2.2(3)		
Regularly stiffened bulkhead panels inclusive the secondary buckling stiffeners perpendicular to the regular stiffener (such as carlings)	SP-A	Length: between primary supporting members Width: between primary supporting members
Irregularly stiffened bulkhead panels, e.g. web panels in way of hopper tank and bilge	UP-B	Plate between local stiffeners/face plate
Web plate of bulkhead stringers including brackets	UP-B	Plate between web stiffeners /face plate
Cross deck, see Figure 4.2.2(4)		
Upper/lower stool including stiffeners	SP-A	Length: between internal web diaphragms

		Width: length of stool side
Stool internal web diaphragm	UP-B	Plate between local stiffeners /face plate /PSM
Cross deck	SP-A	Plate between local stiffeners/ PSM
Notes: ①SP and UP stand for stiffened and unstiffened panel respectively. ②A and B stand for Method A and Method B respectively.		

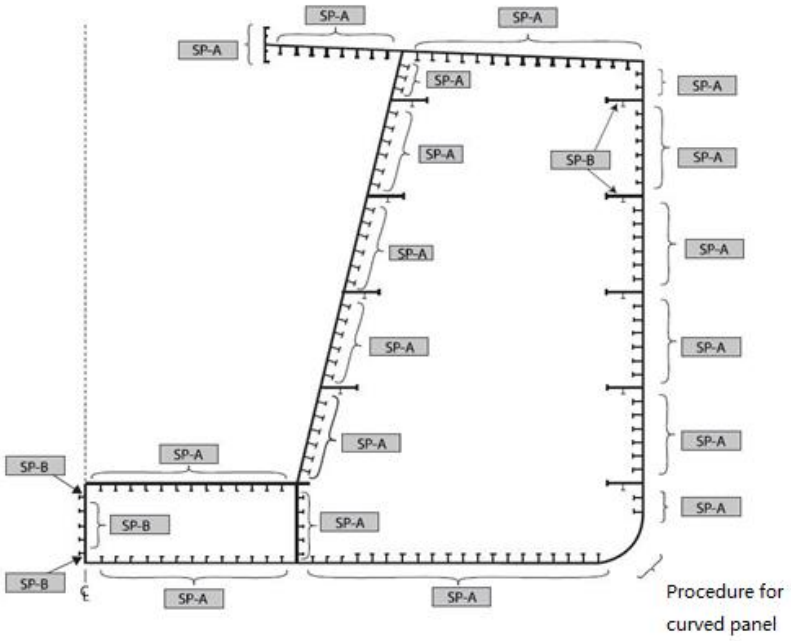


Figure 4.2.2(1) Longitudinal Plates for Typical Ore Carriers

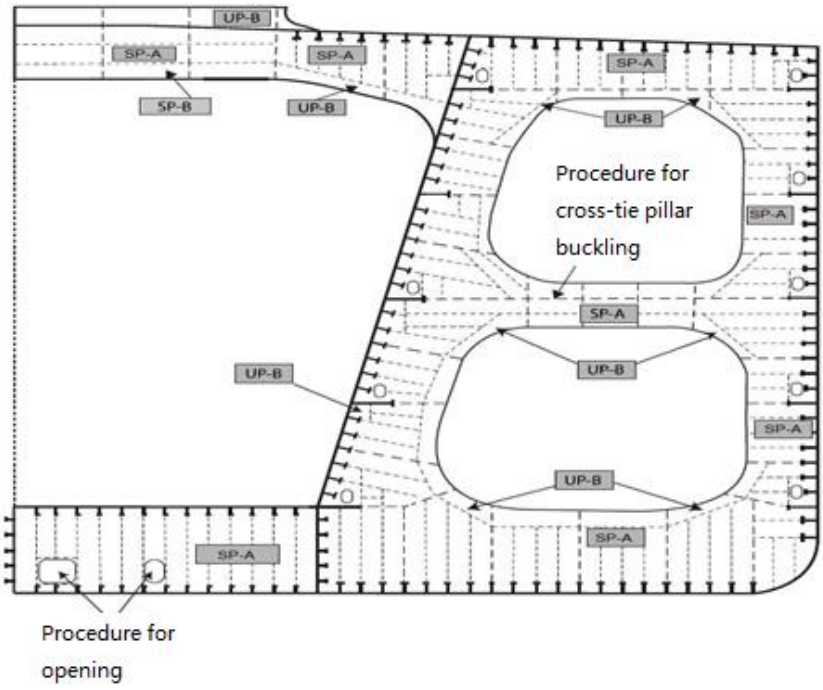


Figure 4.2.2(2) Transverse Web Frames for Typical Ore Carriers

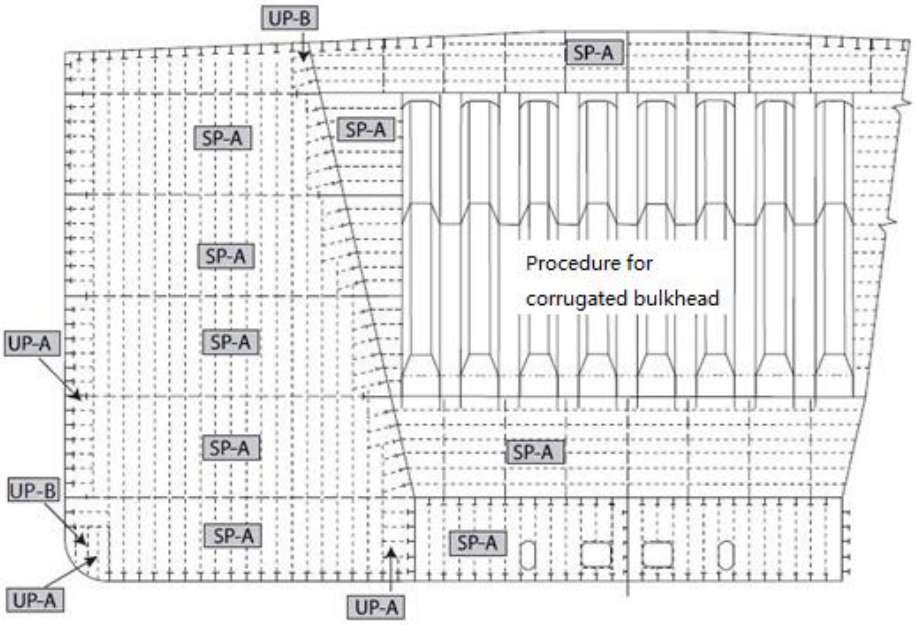


Figure 4.2.2(3) Transverse Bulkhead for Typical Ore Carriers

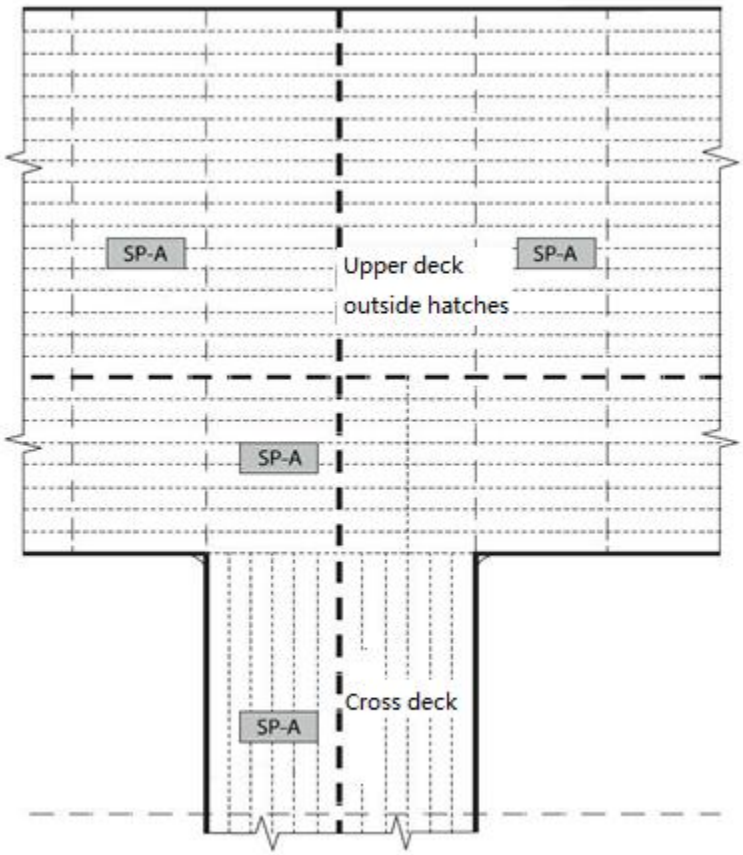


Figure 4.2.2(4) Corrugated Bulkhead and Cross Deck

4.2.3 Stiffened/unstiffened panels

(1) Idealization of stiffened panel

① To represent the overall buckling behaviour, each stiffener with attached plate is to be modelled as a stiffened panel of the extent defined in Table 4.2.2.

② If the stiffener properties or stiffener spacing varies within the stiffened panel, the calculations are to be performed separately for all configurations of the panels, i.e. for each stiffener and plate between the stiffeners. Plate thickness, stiffener properties and stiffener spacing at the considered location are to be assumed for the whole panel.

(2) Idealization of unstiffened panels

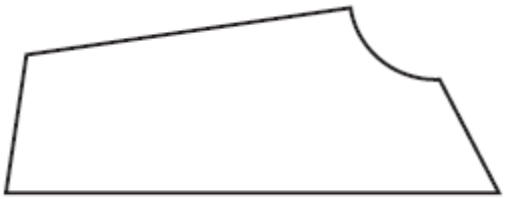
In way of web frames, stringers and brackets, the geometry of the panel (i.e. plate bounded by web stiffeners/face plate) may not have a rectangular shape. In this case, an equivalent rectangular panel is to be defined according to 4.2.3(2)① for irregular geometry and 4.2.3(2)② for triangular geometry and to comply with buckling assessment.

① Modelling of an unstiffened panel with irregular geometry

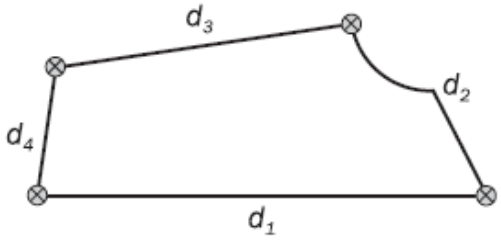
Unstiffened panels with irregular geometry are to be idealised to equivalent panels for plate buckling assessment according to the following procedure:

a. The four corners closest to a right angle, 90 °, in the bounding polygon for the plate

are identified.

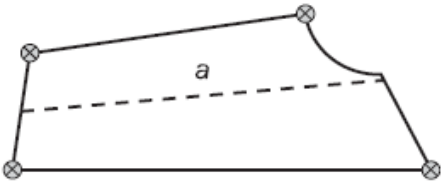


b. The distances along the plate bounding polygon between the corners are calculated, i.e. the sum of all the straight line segments between the end points.



c. The pair of opposite edges with the smallest total length is identified, i.e. minimum of $d_1 + d_3$ and $d_2 + d_4$.

d. A line joins the middle points of the chosen opposite edges (i.e. a mid point is defined as the point at half the distance from one end). This line defines the longitudinal direction for the capacity model. The length of the line defines the length of the capacity model, *a* measured from one end point.



e. The length of shorter side, *b* in mm, is to be taken as:

$$b = A / a$$

where:

A — area of the plate, in mm^2;

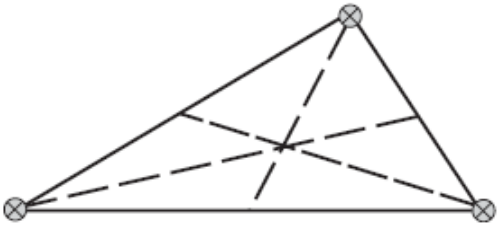
a — length defined in d, in mm.

f. The stresses from the direct strength analysis are to be transformed into the local coordinate system of the equivalent rectangular panel. These stresses are to be used for the buckling assessment.

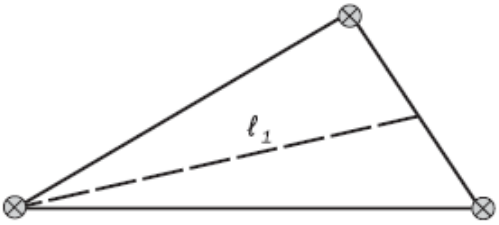
② Modelling of an unstiffened plate panel with triangular geometry

Unstiffened panels with triangular geometry are to be idealised to equivalent panels for plate buckling assessment according to the following procedure:

a. Medians are constructed as shown below.



b. The longest median is identified. This median the length of which is l_1, in mm, defines the longitudinal direction for the capacity model.

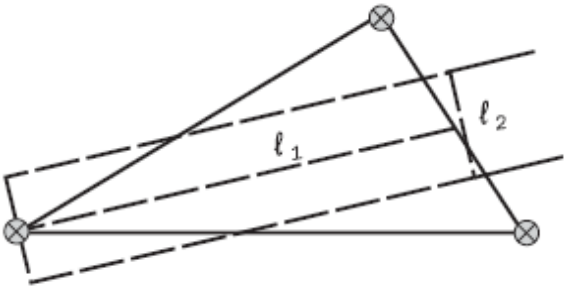


c. The width of the model, l_2, in mm, is to be taken as:

$$l_2 = A / l_1$$

where:

A — area of the plate, in mm^2.



d. The lengths of shorter side, *b*, and of the longer side, *a*, in mm, of the equivalent rectangular plate panel are to be taken as:

$$b = \frac{l_2}{C_{tri}}$$

$$a = l_1 C_{tri}$$

where:

$$C_{tri} = 0.4\frac{l_2}{l_1} + 0.6$$

e. The stresses from the direct strength analysis are to be transformed into the local coordinate system of the equivalent rectangular panel and are to be used for the buckling assessment of the equivalent rectangular panel.

(3) Average thickness of plate panel

Where the plate thickness along a plate panel is not constant, the panel used for the buckling

assessment is to be modelled with a weighted average thickness taken as:

$$t_{avr} = \frac{\sum_{1}^{n} A_i t_i}{\sum_{1}^{n} A_i} \tag{0.3}$$

where:

A_i — area of the *i*-th plate element;

t_i — thickness of the *i*-th plate element;

n — number of finite elements defining the buckling plate panel.

(4) Yield stress of the plate panel

The panel yield stress R_{eH_P} is taken as the minimum value of the specified yield stresses of the elements within the plate panel.

(5) Reference stress

The stress distribution is to be taken from the direct strength analysis and the actual stress is applied to the buckling model after it is corrected according to 4.1.5(2). The reference stresses are to be calculated using the stress based reference stresses as defined in Appendix A of this Chapter.

(6) Lateral pressure

The lateral pressure applied to the direct strength analysis is also to be applied to the buckling assessment. Where the lateral pressure is not constant over a buckling panel defined by a number of finite plate elements, an average lateral pressure, N/mm^2, is calculated using the following formula:

$$P_{avr} = \frac{\sum_{1}^{n} A_i P_i}{\sum_{1}^{n} A_i} \tag{0.4}$$

where:

A_i — area of the *i*-th plate element, in mm^2;

P_i — lateral pressure of the *i*-th plate element, in N/mm^2;

n — number of finite elements in the buckling panel.

4.2.4 Corrugated bulkhead

(1) Buckling failure modes

Three buckling failure modes are to be assessed on corrugated bulkheads:

① Corrugation overall column buckling, refer to Table 4.2.4(1), as appropriate;

② Corrugation flange panel buckling;

③ Corrugation web panel buckling.

Application of Overall Column Buckling for Corrugated Bulkhead

Table 4.2.4(1)

	Corrugation Orientation	
	Horizontal	Vertical
Longitudinal bulkhead	Required	Required, when subjected to local vertical forces (e.g. crane loads)
Transverse bulkhead	Required	

(2) Reference stress

① Each corrugation flange and web panel is to be assessed;

② The membrane stresses at element centroid are to be used, and the actual stress is applied to the buckling assessment after it is corrected according to 4.1.5(2);

④ The maximum normal stress parallel to the corrugation, σ_x,, is the maximum of the two following stresses:

a. The normal stress parallel to the corrugation taken at *b*/2 from the corrugation ends,

b. The normal stress parallel to the corrugation within the mid span of the corrugation.

Due to the area near the corrugation ends has greater stress gradient, the representative stress in way of *b/2* is to be taken for buckling check, other than the local high stress.

Where the corrugation end is fitted with a shedder plate, the normal stress parallel to the corrugation at end is to be taken at the position defined as following: firstly, find mid breadth of shedder plate and flange (web) respectively and obtain their intersection; secondly, take the point at *b*/2 from the intersection along the mid breadth of flange (or web). The diagram of typical structure is shown in Figures 4.2.4(1) and 4.2.4(2).

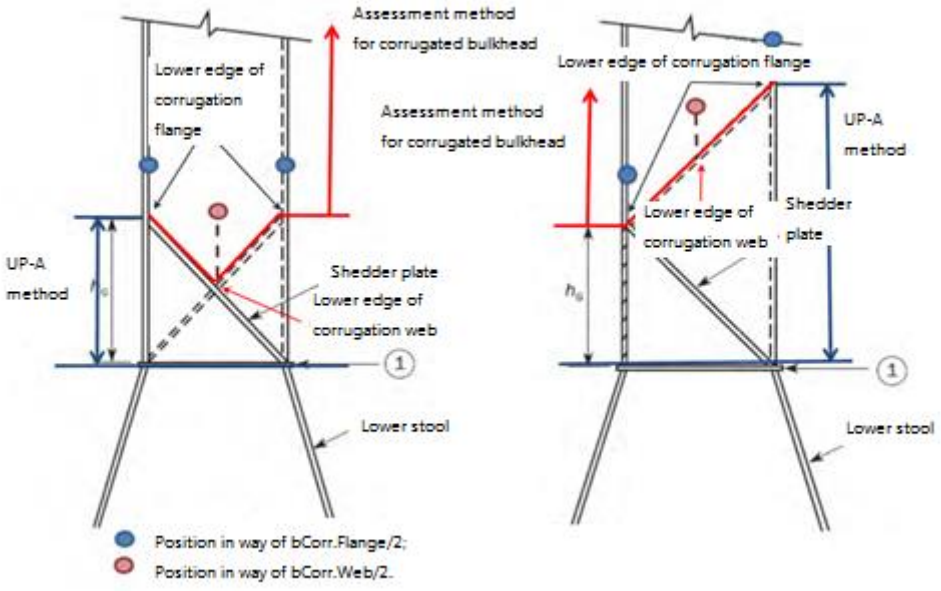


Figure 4.2.4(1) Points at *b/2* of Symmetric and Asymmetric Shedder Plates

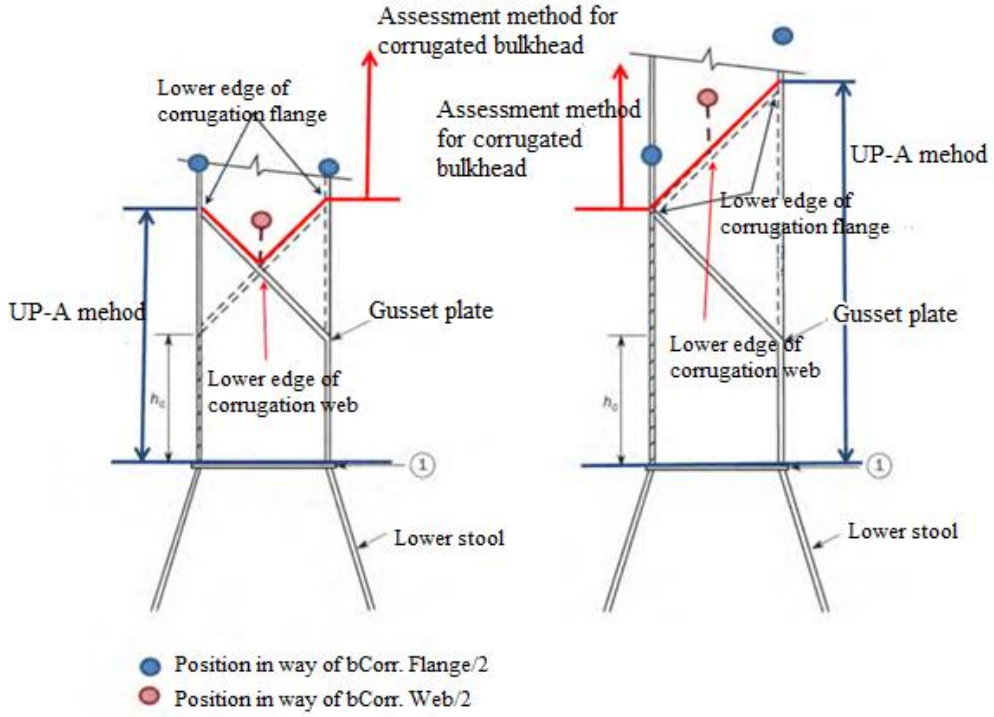


Figure 4.2.4(2) Points at *b/2* of Symmetric and Asymmetric Shedder Plates/Gusset Plates

The maximum shear stress is the shear stress which is the maximum at the corrugation flange (or web) as defined above for the normal stress.

The in-plane stresses, σ_x and σ_y, and shear stress, τ, are to be taken as the element stresses averaged over the width of the considered member (flange or web) at the considered location.

When the stress value at *b*/2 from ends cannot be obtained directly from FE element, the stress at this location is to be obtained by interpolation. This interpolation is to be made on elements extending over a distance equal to 3*b* to a point located at *b*/2 from the end of the corrugation or from the intersection of the shedder plate if fitted, measured at the mid breadth of the flange or of the web. The interpolations of the in-plane stresses, σ_x and σ_y, are to be made in accordance with A.1.3(1) of Appendix A in this Chapter.

The shear stress at *b*/2 is obtained by linear interpolation between the elements most close to '*b*/2' location. For the application of this requirement, *b* is defined as follows:

b — width of the considered member of the corrugation, i.e. flange or web.

④ Where more than one plate thicknesses are used for flange panel, maximum stress is to be obtained for each thickness range and to be checked with the buckling criteria for each thickness.

4.3 Buckling Capability

4.3.1 Symbols

A_s —sectional area of the stiffener (without attached plating), in mm^2;

a — length of the longer side of the plate panel, in mmm, see B.1.2 of Appendix B in this Chapter;

b — length of the shorter side of the plate panel, in mm, see B.1.2 of Appendix B in this Chapter;

d — length of the side parallel to the axis of the cylinder corresponding to the curved plate panel, in mm, as shown in B.1.3 of Appendix B in this Chapter;

b_{eff} — effective width of the attached plating of a stiffener, in mm, as defined in 4.3.3(3)⑤;

$b_{eff\,1}$ — effective width of the attached plating of a stiffener, in mm, without the shear lag effect taken as:

$$b_{eff1} = \begin{cases} C_x b & \text{for } \sigma_x > 0 \\ b & \text{for } \sigma_x \le 0 \end{cases}$$

C_x — reduction factor of the considered stiffener according to case ① defined in Table B.1.2 in Appendix B;

b_f — breadth of the stiffener flange, in mm;

b_1, b_2 — width of plate panel on each side of the considered stiffener, in mm;

e_f — distance from attached plating to centre of flange, in mm, as shown in Figure 4.3.1, to be taken as:

$$e_f = \begin{cases} h_w & \text{for flat bar profile;} \\ h_w - 0.5t_f & \text{for bulb profile;} \\ h_w + 0.5t_f & \text{for angle and TEE profile.} \end{cases}$$

F_{long} — coefficient defined in 4.3.3(2)④;

F_{tran} — coefficient defined in 4.3.3(2)⑤;

h_w — depth of stiffener web, in mm, as shown in Figure 4.3.3(1);

l_s — span, in mm, of stiffener equal to spacing between primary supporting members;

R — radius of curved plate panel, in mm;

R_{eH_P} — specified minimum yield stress of the plate in N/mm^2;

R_{eH_S} — specified minimum yield stress of the stiffener in N/mm^2;

S — partial safety factor to be taken as:

S = 1.1 for structures which are exposed to local concentrated loads (e.g. container loads on hatch covers, foundations);

S = 1.0 for all other cases;

t_p — thickness of plate panel, in mm;

t_w — stiffener web thickness, in mm;

t_f — flange thickness, in mm;

x axis — local axis of a rectangular buckling panel parallel to its long edge;

y axis — local axis of a rectangular buckling panel perpendicular to its long edge;

α — aspect ratio of the plate panel, defined in Table B.1.2 of Appendix B, to be taken as:

$$\alpha = \frac{a}{b}$$

β — coefficient, to be taken as:

$$\beta = \frac{1-\psi}{\alpha}$$

ω — coefficient, to be taken as:

$$\omega = Min(3;\alpha)$$

σ_x — stress applied on the edge along *x* axis of the buckling panel, in N/mm^2;

σ_y — stress applied on the edge along y axis of the buckling panel, in N/mm^2;

σ_1 — maximum stress, in N/mm^2;

σ_2 — minimum stress, in N/mm^2;

σ_E — elastic buckling reference stress, in N/mm^2, to be taken as:

(1) For the application of plate limit state according to 4.3.3(2)①:

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_p}{b}\right)^2$$

(2) For the application of curved plate panels according to 4.3.3(2)⑥:

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_p}{d}\right)^2$$

τ — applied shear stress, in N/mm^2;

τ_c — buckling strength in shear, in N/mm^2, as defined in 4.3.3(2)③;

ψ — edge stress ratio to be taken as:

$$\psi = \frac{\sigma_2}{\sigma_1}$$

γ — stress multiplier factor acting on loads. When the factor is such that the loads reach the interaction formulae, $\gamma = \gamma_c$;

γ_c — stress multiplier factor at failure.

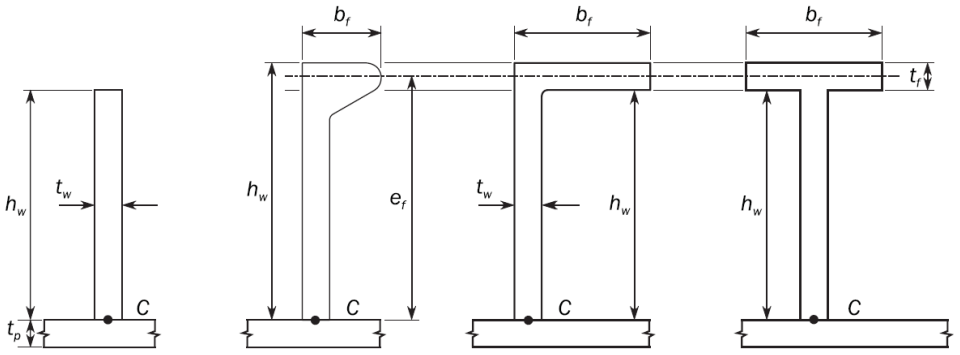


Figure 4.3.1 Stiffener Cross Sections

4.3.2 General

(1) This Section contains the methods for determination of the buckling capacity of plate panels, stiffeners, primary supporting members, struts, pillars, cross ties and corrugated bulkheads.

(2) For the application of this section, the stresses σ_x, σ_y and τ applied on the structural members are defined in 4.2.3(5) and 4.2.4(2):

(3) Ultimate buckling capacity

The ultimate buckling capacity is calculated by applying the actual stress combination and then increasing or decreasing the stresses proportionally until the interaction formulae defined in 4.3.3(1), 4.3.3(2)and 4.3.3(3)④ are equal to 1.0.

(4) Buckling utilization factor

The buckling utilisation factor of the structural member is equal to the highest utilisation factor obtained for the different buckling modes.

(5) Lateral pressure

The lateral pressure is to be considered as constant in the buckling strength assessment.

4.3.3 Plates and stiffeners

(1) Overall stiffened panel buckling capacity

The elastic stiffened panel limit state is based on the following interaction formula:

$$\frac{P_Z}{c_f} = 1 \tag{0.5}$$

where: c_f and P_Z are defined in (3)④.

(2) Plate buckling capability

① Plate limit state

The plate limit state is based on the following interaction formulae:

$$\begin{gathered}
\left(\frac{\gamma_{c1}\sigma_x S}{\sigma_{cx}}\right)^{e_0} - B\left(\frac{\gamma_{c1}\sigma_x S}{\sigma_{cx}}\right)^{e_0/2}\left(\frac{\gamma_{c1}\sigma_y S}{\sigma_{cy}}\right)^{e_0/2} + \left(\frac{\gamma_{c1}\sigma_y S}{\sigma_{cy}}\right)^{e_0} + \left(\frac{\gamma_{c1}|\tau| S}{\tau_c}\right)^{e_0} = 1 \\
\left(\frac{\gamma_{c2}\sigma_x S}{\sigma_{cx}}\right)^{2/\beta_p^{0.25}} + \left(\frac{\gamma_{c2}|\tau| S}{\tau_c}\right)^{2/\beta_p^{0.25}} = 1 \quad \text{对} \sigma_x \geq 0 \\
\left(\frac{\gamma_{c3}\sigma_y S}{\sigma_{cy}}\right)^{2/\beta_p^{0.25}} + \left(\frac{\gamma_{c3}|\tau| S}{\tau_c}\right)^{2/\beta_p^{0.25}} = 1 \quad \text{对} \sigma_y \geq 0 \\
\frac{\gamma_{c4}|\tau| S}{\tau_c} = 1
\end{gathered} \tag{0.6}$$

with:

$$\gamma_c = \min(\gamma_{c1}, \gamma_{c2}, \gamma_{c3}, \gamma_{c4}) \tag{0.7}$$

where:

σ_x, σ_y — applied normal stress to the plate panel, in N/mm^2, to be taken as defined in 4.3.3(2)⑦;

τ — applied shear stress to the plate panel, in N/mm^2;

σ_{cx} — ultimate buckling stress, in N/mm^2, in direction parallel to the longer edge of the buckling panel as defined in 4.3.3(2)③;

σ_{cy} — ultimate buckling stress, in N/mm^2, in direction parallel to the shorter edge of the buckling panel as defined in 4.3.3(2)③;

$\gamma_{c1},\gamma_{c2},\gamma_{c3},\gamma_{c4}$ — stress multiplier factors at failure for each of the above different limit states. γ_{c1} and γ_{c2} are only to be considered when $\sigma_x \geq 0$ and $\sigma_y \geq 0$ respectively;

B — coefficient given in Table 4.3.3(1);
e_0 — coefficient given in Table 4.3.3(1);
β_p — Plate slenderness parameter taken as:

$$\beta_p = \frac{b}{t_p}\sqrt{\frac{R_{eH_P}}{E}}$$

Definition of Coefficients *B* and e_0 **Table 4.3.3(1)**

Applied stress	B	e_0
$\sigma_x \geq 0$ and $\sigma_y \geq 0$	$0.7-0.3\beta_p/\alpha^2$	$2/\beta_p^{0.25}$
$\sigma_x < 0$ or $\sigma_y < 0$	1.0	2.0

② Reference degree of slenderness
The reference degree of slenderness is to be taken as:

$$\lambda = \sqrt{\frac{R_{eH_P}}{K\sigma_E}} \tag{0.8}$$

K — buckling factor, as defined in Table B.1.2 and B.1.3 in Appendix B of this Chapter.
③ Ultimate buckling stresses
The ultimate buckling stresses of plate panels, in N/mm^2, are to be taken as:

$$\begin{aligned}\sigma_{cx} &= C_x R_{eH_P}\\ \sigma_{cy} &= C_y R_{eH_P}\end{aligned} \tag{0.9}$$

The ultimate buckling stress of plate panels subject to shear, in N/mm^2, is to be taken as:

$$\tau_c = C_\tau \frac{R_{eH_P}}{\sqrt{3}} \tag{0.10}$$

where:
C_x, C_y, C_τ — reduction factor, defined in Table B.1.2 of Appendix B in this Chapter.

For the 1st Equation of 4.3.3(2)①, when $\sigma_x < 0$ or $\sigma_y < 0$, the reduction factors are to be taken as: $C_x = C_y = C_\tau = 1$.

For other cases:
a. For SP-A and UP-A, C_y is calculated according to Table B.1.2 of Appendix B in this Chapter by using

$$c_1 = \left(1-\frac{1}{\alpha}\right) \geq 0$$

b. For SP-B and UP-B, C_y is calculated according to Table B.1.2 of Appendix B in this

Chapter by using

$$c_1 = 1$$

c. For corrugation of corrugated bulkheads, C_y is calculated according to Table B.1.2 of Appendix B in this Chapter by using

$$c_1 = \left(1 - \frac{1}{\alpha}\right) \geq 0$$

The boundary conditions for plates are to be considered as simply supported, see cases ①, ② and ⑮ of Table B.1.2 of Appendix B in this Chapter. If the boundary conditions differ significantly from simple support, a more appropriate boundary condition can be applied according to the different cases of Table B.1.2 of Appendix B in this Chapter subject to the agreement of CCS.

④ Correction factor, F_{long}

The correction factor F_{long} depending on the edge stiffener types on the longer side of the buckling panel is defined in Table 4.3.3(2). An average value of F_{long} is to be used for plate panels having different edge stiffeners. For stiffener types other than those mentioned in Table 4.3.3(2), the value of c is to be agreed by CCS. In such case, value of c higher than those mentioned in Table 4.3.3(2) can be used, provided it is verified by buckling strength check of panel using non-linear FE analysis and deemed appropriate by CCS.

Correction Factor, F_{long} **Table 4.3.3(2)**

<table>
<tr><th colspan="3">Structural element types</th><th>F_{long}</th><th>c</th></tr>
<tr><td colspan="3">Stiffened panel</td><td>1.0</td><td>N/A</td></tr>
<tr><td rowspan="6">Stiffened Panel</td><td colspan="2">Stiffener not fixed at both ends</td><td>1.0</td><td>N/A</td></tr>
<tr><td rowspan="5">Stiffener fixed at both ends</td><td>Flat bar (1)</td><td rowspan="4">If $\frac{t_w}{t_p} > 1$, $F_{long} = c + 1$;
If $\frac{t_w}{t_p} \leq 1$, $F_{long} = c\left(\frac{t_w}{t_p}\right)^3 + 1$</td><td>0.1</td></tr>
<tr><td>Bulb profile</td><td>0.3</td></tr>
<tr><td>Angle profile</td><td>0.4</td></tr>
<tr><td>T profile</td><td>0.3</td></tr>
<tr><td>Girder of high rigidity (e.g. bottom transverse)</td><td>1.4</td><td>N/A</td></tr>
<tr><td colspan="5">Note (1):
t_w is web thickness, in mm, without the correction defined in 4.3.3(3)②.</td></tr>
</table>

⑤ Correction factor, F_{tran}

The correction factor, F_{tran} is to be taken equal to 1.0.

⑥ Curved plate panels

This requirement for curved plate limit state is applicable when $R/t \leq 2500$. Otherwise, the requirement for plate limit state given in 4.3.3(2)① is applicable.

The curved plate limit state is based on the following interaction formula:

$$\left(\frac{\gamma_c \sigma_{ax} S}{C_{ax} R_{eH_P}}\right)^{1.25} - 0.5 \cdot \left(\frac{\gamma_c \sigma_{ax} S}{C_{ax} R_{eH_P}}\right)\left(\frac{\gamma_c \sigma_{tg} S}{C_{tg} R_{eH_P}}\right) + \left(\frac{\gamma_c \sigma_{tg} S}{C_{tg} R_{eH_P}}\right)^{1.25} + \left(\frac{\gamma_c \tau \sqrt{3} S}{C_{\tau} R_{eH_P}}\right)^2 = 1.0 \qquad (0.11)$$

where:

σ_{ax} — applied axial stress to the cylinder corresponding to the curved plate panel, in N/mm^2. In case of tensile axial stresses, $\sigma_{ax} = 0$;

σ_{tg} — applied tangential stress to the cylinder corresponding to the curved plate panel, in N/mm^2. In case of tensile tangential stresses, $\sigma_{tg} = 0$;

C_{ax}, C_{tg}, C_{τ} — buckling reduction factor of the curved plate panel, as defined in Table B.1.3 of Appendix B in this Chapter.

The stress multiplier factor, γ_c, of the curved plate panel need not be taken less than the stress multiplier factor, γ_c, for the expanded plane plate panel according to 4.3.3(2)①.

⑦ Applied normal stress to plate panel

The normal stress, σ_x and σ_y, in N/mm^2, to be applied for the plate panel capacity calculation as given in 4.3.3(2)① are to be taken as follows:

For FE analysis, the reference stresses as defined in 4.2.3(5);

For grillage analysis where the stresses are obtained based on beam theory, the stresses taken as:

$$\sigma_x = \frac{\sigma_{xb} + \nu \sigma_{yb}}{1 - \nu^2}$$
$$\sigma_y = \frac{\sigma_{yb} + \nu \sigma_{xb}}{1 - \nu^2} \qquad (0.12)$$

where:

σ_{xb}, σ_{yb} — stress, in N/mm^2, from grillage beam analysis respectively along x or y axis of the attached buckling panel;

τ — shear stress, in N/mm^2, used to calculate panel capability in 4.3.3(2)①, to be taken as:

For FE analysis, the reference shear stresses as defined in 4.3.3(3)④ of this Chapter;

For grillage beam analysis, $\tau = 0$ in the attached buckling panel.

(3) Stiffener buckling capability

① Buckling mode

The following buckling modes are to be checked:

a. Stiffener induced failure (*SI*);
b. Associated plate induced failure (*PI*).

② Web thickness of flat bar

For accounting the decrease of the stiffness due to local lateral deformation, the effective web thickness of flat bar stiffener, in mm, is to be used in 4.3.3(3)④ for the calculation of the sectional area, A_s, the section modulus, Z, and the moment of inertia, I, of the

stiffener and is taken as:

$$t_{w_red} = t_w\left(1-\frac{2\pi^2}{3}\left(\frac{h_w}{s}\right)^2\left(1-\frac{b_{eff1}}{s}\right)\right) \tag{0.13}$$

③ Idealisation of bulb profile

Bulb profiles are to be considered as equivalent angle profiles, as defined by:

$$h_w = h'_w - \frac{h'_w}{9.2} + 2$$

$$b_f = \alpha\left(t'_w + \frac{h'_w}{6.7} - 2\right)$$

$$t_f = \frac{h'_w}{9.2} - 2$$

$$t_w = t'_w$$

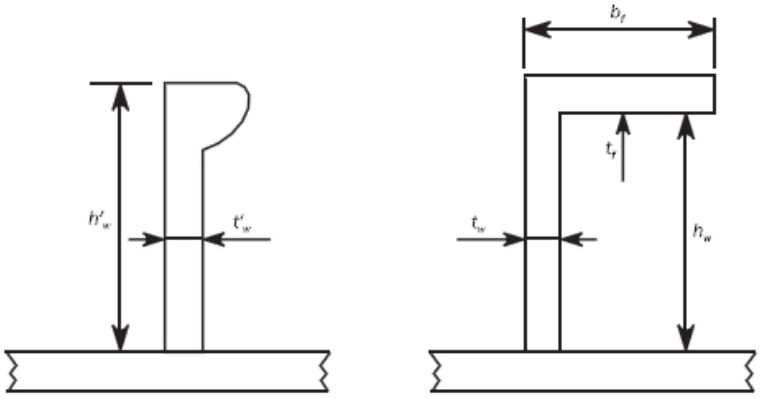
where:

h'_w, t'_w — height and thickness of bulb steel, in mm, indicated in Figure 4.3.3(2);

α — coefficient, to be taken as:

$$\alpha = 1.1 + \frac{(120 - h'_w)^2}{3000} \text{ for } h'_w \le 120$$

$$\alpha = 1.0 \text{ for } h'_w > 120$$



Bulb Profile Equivalent Angle Profile

Figure 4.3.3(2) Bulb Profile and Equivalent Angle Profile

⑤ Ultimate buckling capacity

Where $\sigma_a + \sigma_b + \sigma_w > 0$, the ultimate buckling capacity for stiffeners is to be checked according to the following interaction formula:

$$\frac{\gamma_c\sigma_a + \sigma_b + \sigma_w}{R_{eH}} S = 1 \tag{0.14}$$

where:

σ_a — effective axial stress, in N/mm^2, at mid span of the stiffener, acting on the stiffener with its attached plating:

$$\sigma_a = \sigma_x \frac{st_p + A_s}{b_{eff1} t_p + A_s}$$

σ_x — nominal axial stress, in N/mm^2, acting on the stiffener with its attached plating:

a. For FE analysis, σ_x is the FE corrected stress as defined in 4.3.3(2)⑦ in the attached plating in the direction of the stiffener axis;

b. For grillage beam analysis, σ_x is the stress acting along the x-axis of the attached buckling panel;

R_{eH} — specified minimum yield stress of the stiffener in N/mm^2:

a. $R_{eH} = R_{eH_S}$ for stiffener induced failure (*SI*);

b. $R_{eH} = R_{eH_P}$ for associated plate induced failure (*PI*);

σ_b — bending stress in the stiffener, in N/mm^2:

$$\sigma_b = \frac{M_o + M_1}{1000Z}$$

Z — net section modulus of stiffener, in cm^3, including effective width of plating according to 4.3.3(3)⑤, to be taken as:

a. The section modulus calculated at the top of stiffener flange for stiffener induced failure (SI);

b. The section modulus calculated at the attached plating for plate induced failure (PI);

C_{PI} — plate induced failure pressure coefficient:

a. $C_{PI} = 1$ if the lateral pressure is applied on the side opposite to the stiffener;

b. $CPI = -1$ if the lateral pressure is applied on the same side as the stiffener;

C_{SI} — Stiffener induced failure pressure coefficient:

a. $C_{SI} = -1$ if the lateral pressure is applied on the side opposite to the stiffener;

b. $C_{SI} = 1$ if the lateral pressure is applied on the same side as the stiffener;

M_1 — bending moment, in N-mm, due to the lateral load *P*:

a. for continuous stiffener:

$$M_1 = C_i \frac{|P| sl_s^2}{24 \cdot 10^3}$$

b. for sniped stiffener:

$$M_1 = C_i \frac{|P| sl_s^2}{8 \cdot 10^3}$$

P — lateral load, in kN/m^2, means the average pressure of attached plate defined in 4.2.3(6) of this Chapter;

C_i — pressure coefficient:

a. $C_i = C_{SI}$ for stiffener induced failure (*SI*);

b. $C_i = C_{PI}$ for plate induced failure *(PI)*;

M_0 — bending moment, in N-mm, due to the lateral deformation *w* of stiffener:

$$M_0 = F_E\left(\frac{P_z w}{c_f - P_z}\right) \text{ with } c_f - P_z > 0$$

F_E — ideal elastic buckling force of the stiffener, in N.

$$F_E = \left(\frac{\pi}{l_s}\right)^2 EI \cdot 10^4$$

I — moment of inertia, in cm^4, of the stiffener including effective width of attached plating according to 4.3.3(3)⑤. I is to comply with the following requirement:

$$I \geq \frac{st_p^{\ 3}}{12 \cdot 10^4}$$

t_p — thickness of plate, in mm, to be taken as the thickness of the considered EPP on one side of the stiffener;

P_z — nominal lateral load, in N/mm^2, acting on the stiffener due to stresses, σ_x, σ_y and τ, in the attached plating in way of the stiffener mid span:

$$P_z = \frac{t_p}{s}\left(\sigma_{xl}\left(\frac{\pi s}{l_s}\right)^2 + 2c\gamma\sigma_y + \sqrt{2}\tau_1\right)$$

$$\sigma_{xl} = \gamma\sigma_x\left(1 + \frac{A_s}{st_p}\right)$$

$$\tau_1 = \gamma|\tau| - t_p\sqrt{R_{eH_P}E\left(\frac{m_1}{a^2} + \frac{m_2}{b^2}\right)} \geq 0$$

σ_y — stress applied on the edge along y axis of the buckling panel, in N/mm^2, but not less than 0:

a. For FE analysis, σ_y is the FE corrected stress as defined in 4.3.3(3)⑥ in the attached plating in the direction perpendicular to the stiffener axis;

b. For grillage beam analysis, σ_y is the stress acting along the y-axis of the attached buckling panel;

τ — applied shear stress, in N/mm^2:

a. For FE analysis, τ is the reference shear stress of the attached plating as defined in 4.2.3(5) of this Chapter;

b. For grillage beam analysis, τ = 0 in the attached buckling panel;

m_1, m_2 — coefficients taken equal to:

$$\begin{cases} m_1 = 1.47 & m_2 = 0.49 \quad \text{for} \quad \alpha \geq 2 \\ m_1 = 1.96 & m_2 = 0.37 \quad \text{for} \quad \alpha < 2 \end{cases}$$

c — factor taking into account the stresses in the attached plating acting perpendicular to the stiffener's axis:

$$c = \begin{cases} 0.5(1+\psi) & \text{for} \quad 0 \le \psi \le 1 \\ \dfrac{1}{2(1-\psi)} & \text{for} \quad \psi < 0 \end{cases}$$

ψ — edge stress ratio for case ② according to Table B.1.2 of Appendix B in this Chapter;

w — deformation of stiffener, in mm:

$$w = w_0 + w_1$$

w_0 — assumed imperfection, in mm, to be taken as:

a. $w_0 = l_s / 1000$ in general;

b. $w_0 = -w_{na}$ for stiffeners sniped at both ends considering stiffener induced failure (*SI*);

c. $w_0 = w_{na}$ for stiffeners sniped at both ends considering plate induced failure (PI);

w_{na} — distance from the mid-point of attached plating to the neutral axis of the stiffener calculated with the effective width of the attached plating according to 4.3.3(3)⑤;

w_1 — deformation of stiffener, in mm, at mid-point of stiffener span due to lateral load *P*. In case of uniformly distributed load, w_1 is to be taken as:

a. $w_1 = C_i \dfrac{|P| s l_s^4}{384 \cdot 10^7 EI}$ in general;

b. $w_1 = C_i \dfrac{5|P| s l_s^4}{384 \cdot 10^7 EI}$ for stiffeners sniped at both ends;

c_f — elastic support provided by the stiffener, in N/mm^2:

$$c_f = F_E \left(\frac{\pi}{l_s} \right)^2 (1 + c_p)$$

$$c_p = \frac{1}{1 + \dfrac{0.91}{c_{xa}} \left(\dfrac{12 I}{s\, t_p^{\,3}} 10^4 - 1 \right)}$$

c_{xa} — coefficient to be taken as:

a. $c_{xa} = \left[\dfrac{l_s}{2s} + \dfrac{2s}{l_s} \right]^2$ if $l_s \ge 2s$

b. $c_{xa} = \left[1+\left(\frac{l_s}{2s}\right)^2\right]^2$ if $l_s < 2s$

σ_w — stress due to torsional deformation, in N/mm^2, to be taken as:

a. For stiffener induced failure (*SI*):

$$\sigma_w = Ey_w\left(\frac{t_f}{2}+h_w\right)\Phi_0\left(\frac{\pi}{l_s}\right)^2\left(\frac{1}{1-\frac{0.4R_{eH_S}}{\sigma_{ET}}}-1\right)$$

b. For plate induced failure *(PI)*:

$$\sigma_w = 0$$

y_w — distance, in mm, from centroid of stiffener cross section to the free edge of stiffener flange, to be taken as:

a. $y_w = \frac{t_w}{2}$ for flat bar;

b. $y_w = b_f - \frac{h_w t_w^2 + t_f b_f^2}{2A_s}$ for angle and bulb profile;

c. $y_w = \frac{b_f}{2}$ for T profile;

Φ_0 — coefficient, to be taken as:

$$\Phi_0 = \frac{l_s}{h_w}10^{-3}$$

σ_{ET} — reference stress for torsional buckling, in N/mm^2:

$$\sigma_{ET} = \frac{E}{I_p}\left(\frac{\varepsilon\pi^2 I_\omega 10^2}{l_s^2}+0.385I_T\right)$$

I_p —polar moment of inertia of the stiffener, in cm^4, about point *C* as shown in Figure 4.3.1, as defined in Table 4.3.3(3);

I_T —St. Venant's moment of inertia of the stiffener, in cm^4, as defined in Table 4.3.3(3);

I_ω —sectional moment of inertia of the stiffener, in cm^6, about point *C* as shown in Figure 4.3.1, as defined in Table 4.3.3(3);

ε — degree of fixation, to be taken as:

$$\varepsilon = 1+\frac{\left(\frac{l_s}{\pi}\right)^2 10^{-3}}{\sqrt{I_\omega\left(\frac{0.75s}{t_p^3}+\frac{e_f-0.5t_f}{t_w^3}\right)}}$$

A_w — web area, in mm^2;

A_f — flange area, in mm^2.

Moments of Inertia for Typical Cross Section **Table 4.3.3(3)**

Cross sectional properties	Flat bar(1)	Bulb, angle and T profiles
I_P	$\frac{h_w^3 t_w}{3 \cdot 10^4}$	$\left(\frac{A_w (e_f - 0.5t_f)^2}{3} + A_f e_f^2 \right) 10^{-4}$
I_T	$\frac{h_w t_w^3}{3 \cdot 10^4} \left(1 - 0.63 \frac{t_w}{h_w} \right)$	$\frac{(e_f - 0.5t_f) t_w^3}{3 \cdot 10^4} \left(1 - 0.63 \frac{t_w}{e_f - 0.5t_f} \right)$ + $\frac{b_f t_f^3}{3 \cdot 10^4} \left(1 - 0.63 \frac{t_f}{b_f} \right)$
I_ω	$\frac{h_w^3 t_w^3}{36 \cdot 10^6}$	$\frac{A_f e_f^2 b_f^2}{12 \cdot 10^6} \left(\frac{A_f + 2.6A_w}{A_f + A_w} \right)$ for bulb and angle profiles $\frac{b_f^3 t_f e_f^2}{12 \cdot 10^6}$ for T profile
Note (1): t_w is web thickness, in mm. t_{w_red} as defined in 4.3.3(3)② is not to be used in this table.		

⑥ Effective width of attached plating

The effective width of attached plating of stiffeners, b_{eff}, in mm, is to be taken as:

$$b_{eff} = \begin{cases} \min(C_x b, \chi_s s) & \text{for} \quad \sigma_x > 0 \\ \chi_s s & \text{for} \quad \sigma_x \le 0 \end{cases} \tag{0.15}$$

where: χ_s is the effective width coefficient, to be taken as:

$$\chi_s = \begin{cases} \min \left[\frac{1.12}{1 + \frac{1.75}{\left(\frac{l_{eff}}{s} \right)^{1.6}}}; 1.0 \right] & \text{for} \quad \frac{l_{eff}}{s} \ge 1 \\ 0.407 \frac{l_{eff}}{s} & \text{for} \quad \frac{l_{eff}}{s} < 1 \end{cases}$$

l_{eff} — effective length of the stiffener, in mm, taken as:

a. $l_{eff} = \frac{l_s}{\sqrt{3}}$ for stiffener fixed at both ends;

b. $l_{eff} = 0.75 l_s$ for stiffener simply supported at one end and fixed at the other;

c. $l_{eff} = l_s$ for stiffener simply supported at both ends.

⑦ FE corrected stresses for stiffener capacity

When the reference stresses σ_x and σ_y obtained by FE analysis according to 4.2.3(5) and 4.2.4(2) are both compressive, they are to be corrected according to the following formulae:

If $\sigma_x < \nu\sigma_y$:

$$\sigma_{xcor} = 0$$
$$\sigma_{ycor} = \sigma_y$$

If $\sigma_y < \nu\sigma_x$:

$$\sigma_{xcor} = \sigma_x$$
$$\sigma_{ycor} = 0$$

In other cases:

$$\sigma_{xcor} = \sigma_x - \nu\sigma_y$$
$$\sigma_{ycor} = \sigma_y - \nu\sigma_x$$

(4) Primary supporting members

① Web plate in way of openings

The web plate of primary supporting members with openings is to be assessed for buckling based on the combined axial compressive and shear stresses.

The web plate adjacent to the opening on both sides is to be considered as individual unstiffened plate panels as shown in Table 4.3.3(4).

The interaction formulae of 4.3.3(2) are to be used with:

$$\sigma_x = \sigma_{av}$$
$$\sigma_y = 0 \qquad (0.16)$$
$$\tau = \tau_{av}$$

where:

σ_{av} — weighted average compressive stress, in N/mm^2, in the area of web plate being considered of cases ① and ② or ③ in Table B.1.2 of Appendix B in this Chapter.

For the application of Table 4.3.3(4), the weighted average shear stress is to be taken as:

a. Opening modelled in primary supporting members:

τ_{av} — weighted average shear stress, in N/mm^2, in the area of web plate being considered , i.e. *P1*, *P2*, or *P3* as shown in Table 4.3.3(4);

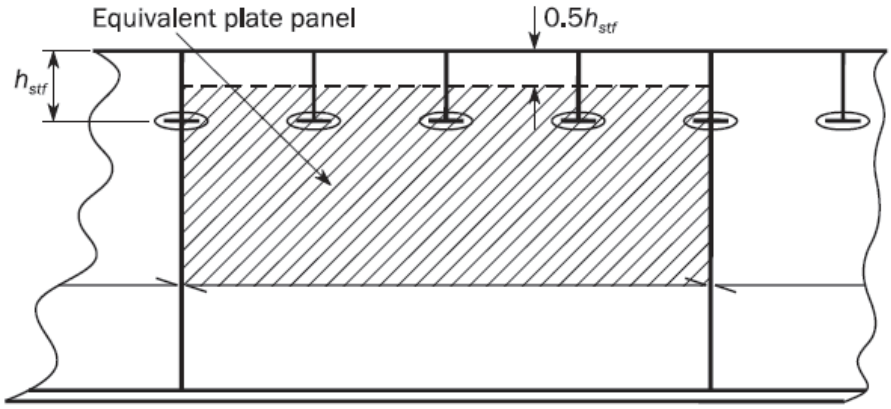
b. Opening not modelled in primary supporting members:

τ_{av} — weighted average shear stress, in N/mm^2, given in Table 4.3.3(4).

② Reduction factors of web plate in way of openings

The reduction factors, C_x or C_y in combination with, C_τ of the plate panel(s) of the web adjacent to the opening is to be taken as shown in Table 4.3.3(4).

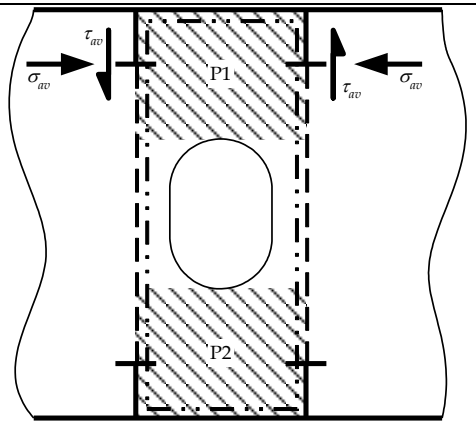
③ The equivalent plate panel of web plate of primary supporting members crossed by perpendicular stiffeners is to be idealised as shown in Figure 4.3.3(3).

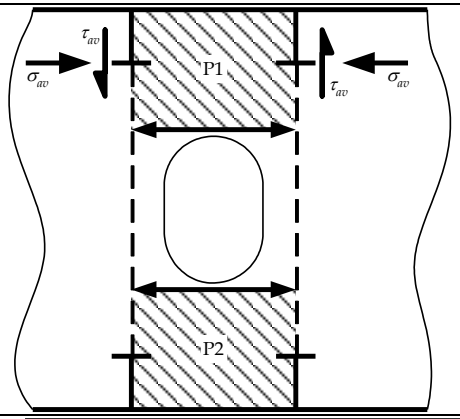
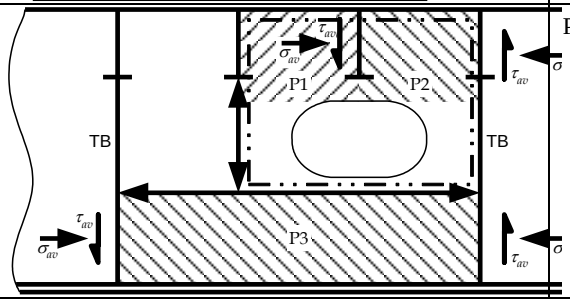


Note: The correction of panel breadth is applicable also for other slot configurations provided that the web or collar plate is attached to at least one side of the passing stiffener.

Figure 4.3.3(3) Web Plate Idealization for Primary Structural Members

Buckling Reduction Factors **Table 4.3.3(4)**

Configuration		C_x, C_y	C_τ	
			Opening modelled in PSM	Opening not modelled in PSM
(a) Without edge reinforcements:		Separate reduction factors are to be applied to areas *P1* and *P2* using case ③ or case ⑥ in Table B.1.2 of Appendix B of this Chapter, with edge stress ratio: Ψ=1.0	Separate reduction factors are to be applied to areas *P1* and *P2* using case ⑱ or case ⑲ in Table B.1.2 of Appendix B in this Chapter	When case ⑰ of Table B.1.2 of Appendix B in this Chapter is applicable: A common reduction factor is to be applied to areas *P1* and *P2* using case ⑰ with: $\tau_{av} = \tau_{av}(web)$; When case ⑰ of Table B.1.2 of Appendix B in this Chapter is not applicable: Separate reduction factors are to be applied to areas *P1* and *P2* using case ⑱ or case ⑲ with: $\tau_{av} = \tau_{av}(web)h/(h-h_0)$

(b) With edge reinforcements:		Separate reduction factors are to be applied for areas *P1* and *P2* using C_x for case ① or *Cy* for case ② in Table B.1.2 of Appendix B in this Chapter, with stress ratio: Ψ =1.0	Separate reduction factors are to be applied for areas *P1* and *P2* using case ⑮ in Table B.1.2 of Appendix B in this Chapter	Separate reduction factors are to be applied to areas *P1* and *P2* using case ⑮ in Table B.1.2 of Appendix B in this Chapter with: $\tau_{av} = \tau_{av}(web)h/(h-h_0)$
(c) Example of hole in web:		Panels *P1* and *P2* are to be evaluated in accordance with (a). Panel *P3* is to be evaluated in accordance with (b).		
	Note 1: Web panels to be considered for buckling in way of openings are shown shaded and numbered *P1*, *P2*, etc.			
	where: h : height, in m, of the web of the primary supporting member in way of the opening. h_0 : height in m, of the opening measured in the depth of the web. $\tau_{av}(web)$: weighted average shear stress, in N/mm^2, over the web height h of the primary supporting member in Table 4.3.3(4).			

4.3.4 Struts, pillars and cross ties

(1) Buckling utilization factor

The buckling utilisation factor, η, for axially compressed struts, pillars and cross ties is to be taken as:

$$\eta = \frac{\sigma_{av}}{\sigma_{cr}}$$

where: σ_{av}: average axial compressive stress in the member, in N/mm^2;

σ_{cr}: minimum critical buckling stress, in N/mm^2, taken as:

① $\sigma_{cr} = \sigma_E$, for $\sigma_E \leq 0.5R_{eH_S}$

② $\sigma_{cr} = \left(1 - \frac{R_{eH_S}}{4\sigma_E}\right)R_{eH_S}$, for $\sigma_E > 0.5R_{eH_S}$

σ_E: minimum elastic compressive buckling stress, in N/mm^2, according to 4.3.4(2) to (4);

R_{eH_S}: specified minimum yield stress of the considered member, in N/mm^2. For built up members, the lowest specified minimum yield stress is to be used.

(2) Elastic column buckling stress

The elastic compressive column buckling stress, σ_{EC} in N/mm^2 of members subject to axial compression is to be taken as:

$$\sigma_{EC} = \pi^2 E f_{end} \frac{I}{A\ell_{pill}^2} 10^{-4}$$

where: *I:* moment of inertia about the weakest axis of the cross section, in cm^4;

A: cross sectional area of the member, in cm^2;

ℓ_{pill} *:* length of the member, in m, taken as:

① for pillar and strut: unsupported length of the member;

② for cross tie:

a. in centre tank: distance between the flanges of longitudinal stiffeners on the starboard and port longitudinal bulkheads to which the cross tie's horizontal stringer is attached;

b. in wing tank: distance between the flanges of longitudinal stiffeners on the longitudinal bulkhead to which the cross tie's horizontal stringer is attached, and the inner hull plating;

f_{end} *:* end constraint factor, to be taken as:

① for pillar and strut:

f_{end} = 1.0 where both ends are simply supported;

f_{end} = 2.0 where one end is simply supported and the other end is fixed;

f_{end} = 4.0 where both ends are fixed;

② for cross tie:

f_{end} = 2.0.

A pillar end may be considered fixed when brackets of adequate size are fitted. Such brackets are to be supported by structural members with greater bending stiffness than the pillar.

(3) Elastic torsional buckling stress

The elastic torsional buckling stress, σ_{ET}, in N/mm^2, with respect to axial compression of members is to be taken as:

$$\sigma_{ET} = \frac{GI_{sv}}{I_{pol}} + \frac{\pi^2 f_{end} Ec_{warp}}{I_{pol} \ell_{pill}^2} 10^{-4}$$

where:

I_{sv} : St. Venant's moment of inertia, in cm^4, see Table 4.3.4 for examples of cross sections;

I_{pol} : polar moment of inertia about the shear centre of cross section, in cm^4:

$$I_{pol} = I_y + I_z + A\ (y_0^2 + z_0^2)$$

c_{warp} : warping constant, in cm^6, see Table 4.3.4 for examples of cross sections;

ℓ_{pill} : length of the member, in m as defined in 4.3.4(2);

y_0 : transverse position of shear centre relative to the cross sectional centroid, in cm, see Table 4.3.4 for examples of cross sections;

z_0 : vertical position of shear centre relative to the cross sectional centroid, in cm, see Table 4.3.4 for examples of cross sections;

A: cross sectional area, in cm^2, as defined in 4.3.4(2);

I_y : moment of inertia about y axis, in cm^4;

I_z : moment of inertia about z axis, in cm^4.

(4) Elastic torsional/column buckling stress

For cross sections where the centroid and the shear centre do not coincide, the interaction between the torsional and column buckling mode is to be examined. The elastic torsional/column buckling stress, σ_{ETF}, with respect to axial compression is to be taken as:

$$\sigma_{ETF} = \frac{1}{2\varsigma}\left[(\sigma_E + \sigma_{ET}) - \sqrt{(\sigma_E + \sigma_{ET})^2 - 4\varsigma\sigma_E\sigma_{ET}}\right]$$

where:

ζ : coefficient taken as:

$$\zeta = 1 - \frac{\left(y_0^2 + z_0^2\right)A}{I_{pol}}$$

y_0 : transverse position of shear centre relative to the cross sectional centroid, in cm, as defined in 4.3.4(3);

z_0 : vertical position of shear centre relative to the cross sectional centroid, in cm, as defined in 4.3.4(3);

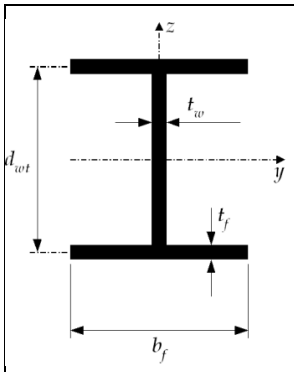
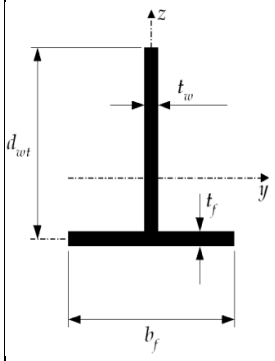
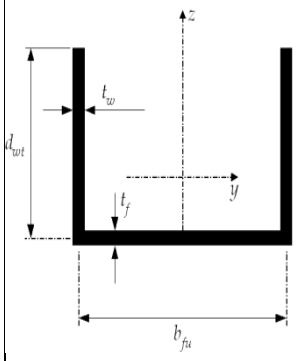
A: cross sectional area, in cm^2, as defined in 4.3.4(3);

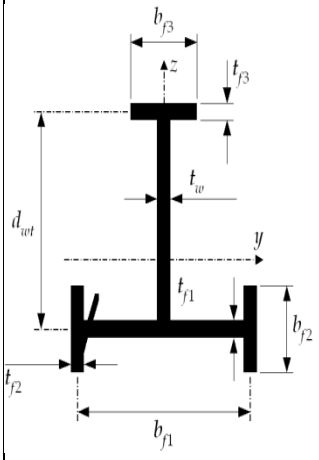
I_{pol} *:* polar moment of inertia about the shear centre of cross section, in cm^4 as defined in 4.3.4(3);

σ_{EC}*:* elastic column compressive buckling stress, as defined in 4.3.4(2);

σ_{ET}*:* elastic torsional buckling stress, as defined in 4.3.4(3).

Typical Cross Sectional Properties **Table 4.3.4**

	$I_{sv} = \frac{1}{3}\left(2b_f t_f^3 + d_{wt} t_w^3\right)10^{-4}$ cm^4
	$c_{warp} = \frac{d_{wt}^2 b_f^3 t_f}{24}10^{-6}$ cm^6
	$I_{sv} = \frac{1}{3}\left(b_f t_f^3 + d_{wt} t_w^3\right)10^{-4}$ cm^4
	$y_0 = 0$ cm $z_0 = -\frac{0.5 d_{wt}^2 t_w}{d_{wt} t_w + b_f t_f}10^{-1}$ cm $c_{warp} = \frac{b_f^3 t_f^3 + 4 d_{wt}^3 t_w^3}{144}10^{-6}$ cm^6
	$I_{sv-net50} = \frac{1}{3}\left(b_{fu} t_f^3 + 2 d_{wt} t_w^3\right)10^{-4}$ cm^4
	$y_0 = 0$ cm $z_0 = -\frac{d_{wt}^2 t_w 10^{-1}}{2 d_{wt} t_w + b_f t_f} - \frac{0.5 d_{wt}^2 t_w 10^{-1}}{d_{wt} t_w + b_{fu} t_f / 6}$ cm $c_{warp} = \frac{b_{fu}^2 d_{wt}^3 t_w \left(3 d_{wt} t_w + 2 b_{fu} t_f\right)}{12\left(6 d_{wt} t_w + b_{fu} t_f\right)}10^{-6}$ cm^6



$$I_{sv} = \frac{1}{3}\left(b_{f1}t_{f1}^3 + 2b_{f2}t_{f2}^3 + b_{f3}t_{f3}^3 + d_{wt}t_w^3\right)10^{-4} \quad \text{cm}^4$$

$y_0 = 0$ cm

$$z_o = z_s - \frac{(b_{f3}\, d_{wt}\, t_{f3} + 0.5 d_{wt}^2\, t_w)10^{-1}}{d_{wt}\, t_w + b_{f1}\, t_{f1} + 2b_{f2}\, t_{f2} + b_{f3}\, t_{f3}} \quad \text{cm}$$

$$c_{warp} = \left(I_{f1}\, z_s^2 + \frac{I_{f2}\, b_{f1}^2}{200} + I_{f3}\left(\frac{d_{wt}}{10} - z_s\right)^2\right) \quad \text{cm}^6$$

$$I_{f1} = \left(\frac{\left(b_{f1} - t_{f2}\right)^3 t_{f1}}{12} + \frac{b_{f2}\, t_{f2}\, b_{f1}^2}{2}\right)10^{-4} \quad \text{cm}^4$$

$$I_{f2} = \frac{b_{f2}^3\, t_{f2}}{12}10^{-4} \quad \text{cm}^4$$

$$I_{f3} = \frac{b_{f3}^3\, t_{f3}}{12}10^{-4} \quad \text{cm}^4$$

$$z_s = \frac{I_{f3}\, d_{wt}}{I_{f1} + I_{f3}}10^{-1} \quad \text{cm}$$

Note (1): All dimensions are in mm.

Note (2): Cross sectional properties are given for typical cross sections. Properties for other cross sections are to be determined by direct calculation.

4.3.5 Corrugation bulkhead

The buckling utilisation factor of flange and web of corrugation of corrugated bulkheads is based on the combination of in-plane stresses and shear stress.

The interaction curve of 4.3.3(2) is to be used with the following coefficients:

$$\alpha = 2$$

$$\psi_x = \psi_y = 1$$

4.4 Strength criteria

4.4.1 Allowable buckling utilization factor

The allowable buckling utilization factor, η_{all} of general structural members for hull structure is defined in Table 4.4.1.

Allowable Buckling Utilization Factor, η_{all} **Table 4.4.1**

Structural component	Allowable buckling utilisation factor, η_{all},
Plates and stiffeners	1.0

Stiffened and unstiffened panels Web plate in ways of openings	
Struts, pillars and cross ties	0.8

4.4.2 Stiffened/unstiffened panels

A structural member is considered to have an acceptable buckling strength if it satisfies the following criterion:

(1) UP-A method

The buckling strength of UP-A method is to satisfy the following criterion:

$$\eta_{UP-A} \leq \eta_{all} \tag{0.17}$$

where:

η_{UP-A} — maximum plate utilisation factor, calculated according to Method A as defined in 4.3.3(2) in this Chapter.

(2) UP-B method

The buckling strength of UP-B is to meet the following criterion:

$$\eta_{UP-B} \leq \eta_{all} \tag{0.18}$$

where:

η_{UP-B} — maximum plate buckling utilization factor, calculated according to Method B as defined in 4.3.3(2) in this Chapter.

(3) SP-A method

The buckling strength of SP-A method is to satisfy the following criterion:

$$\eta_{SP-A} \leq \eta_{all} \tag{0.19}$$

where:

η_{SP-A} — maximum stiffened panel buckling utilisation factor taken as the maximum of:

① The overall stiffened panel capacity as defined in 4.3.3(1) of this Chapter;

② The plate capacity calculated according to Method A as defined in 4.3.3(2) of this Chapter;

③ The stiffener buckling strength as defined in 4.3.3(3) of this Chapter considering separately the properties (thickness, dimensions), the pressures defined in 4.2.3(6) and the reference stresses of each EPP at both sides of the stiffener.

Note: The stiffener buckling capacity check can only be fulfilled when the overall stiffened panel capacity, as defined in 4.3.3(1), is satisfied.

(4) SP-B

The buckling strength of SP-B is to satisfy the following criterion:

$$\eta_{SP-B} \leq \eta_{all} \tag{0.20}$$

where:

η_{SP-B} : maximum stiffened panel utilisation factor taken as the maximum of:

① The overall stiffened panel capacity as defined in 4.3.3(1);

② The plate capacity calculated according to Method B as defined in 4.3.3(2);

③ The stiffener buckling strength as defined in 4.3.3(3) considering separately the properties (thickness, dimensions) and the reference stresses of each EPP at both sides of the stiffener.

Note: The stiffener buckling capacity check can only be fulfilled when the overall stiffened panel capacity, as defined in 4.3.3(1), is satisfied.

(5) Web plate in way of openings

The web plate of primary supporting members with openings is to satisfy the following criterion:

$$\eta_{opening} \leq \eta_{all} \qquad (0.21)$$

where:

$\eta_{opening}$: maximum web plate utilisation factor in way of openings, as defined in 4.3.3(4) and 4.1.4.

4.4.3 Struts, pillars and cross ties

The buckling strength of struts, pillars and cross ties is to satisfy the following criterion:

$$\eta_{Pillar} \leq \eta_{all}$$

where: η_{Pillar} maximum buckling utilisation factor of struts, pillars or cross ties, defined in 4.3.4(1) of this Chapter.

4.4.4 Corrugation bulkhead

(1) Overall column buckling

The overall buckling failure mode of corrugated bulkheads subjected to axial compression is to be checked for column buckling (e.g. horizontally corrugated bulkheads and vertically corrugated bulkheads subjected to local vertical forces).

Each corrugation unit within the extension of half flange, web and half flange (i.e. single corrugation as shown in grey in Figure 3.4.3) is to satisfy the following criterion:

$$\eta_{Overall} \leq \eta_{all}$$

where:

$\eta_{Overall}$ Maximum overall column utilisation factor, as defined in 4.3.4(1) and 4.3.4(2), considered as a pillar with a unsupported length taken as the length of the corrugation.

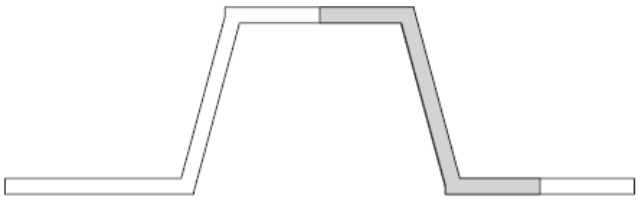


Figure 3.4.3 Diagram of Corrugation Element

End constraint factor, f_{end} corresponding to pinned ends is to be applied except for fixed end support to be used in way of stool with width exceeding twice the depth of the corrugation.

(2) Local buckling

The buckling strength of a unit flange and a unit web of corrugation bulkheads is to satisfy the

following criterion:

$$\eta_{Corr} \leq \eta_{all} \tag{0.22}$$

where:

η_{Corr} — maximum unit flange or unit web utilisation factor, as defined in 4.3.5 and 4.1.4 of this Chapter, two stress combinations are to be considered for the application of the above criterion:

① The maximum normal stress parallel to the corrugation, σ_x, combined with the stress perpendicular to the corrugation, σ_y, and with the shear stress, τ, at the location where the maximum normal stress parallel to the corrugation occurs;

② The shear stress, τ, combined with the normal stress parallel to the corrugation, σ_x, and with the stress perpendicular to the corrugation, σ_y, at the location where the maximum shear stress occurs.

The buckling assessment is to be performed for an aspect ratio α equal to 2, and for the thicknesses of the member where the maximum compressive/shear stress occurs, see 4.2.4(2)④.

Appendix A Stress Based Reference Stresses

A.1.1 General requirements

(1) Symbols

a : length, in mm, of the longer side of the plate panel as defined in 4.3.1 of this Chapter;

b : length, in mm, of the shorter side of the plate panel as defined in 4.3.1 of this Chapter;

A_i *:* area, in mm^2, of the *i*-th plate element of the buckling panel;

n : number of plate elements in the buckling panel;

σ_{xi}: actual stress, in N/mm^2, at the centroid of the *i*-th plate element in x direction, applied along the shorter edge of the buckling panel;

σ_{yi}: actual stress, in N/mm^2, at the centroid of the *i*-th plate element in y direction, applied along the longer edge of the buckling panel;

ψ: edge stress ratio as defined in 4.3.1 of this Chapter;

τ_i: actual membrane shear stress, in N/mm^2, at the centroid of the *i*-th plate element of the buckling panel.

A.1.2 Stress based method

(1) This section provides a method to determine stress distribution along edges of the considered buckling panel by 2nd order polynomial curve, by linear distribution using least square method and by weighted average approach. This method is called Stress based Method. The reference stress is the stress components at centre of plate element transferred into the local system of the considered buckling panel.

(2) Definition

A regular panel is a plate panel of rectangular shape. An irregular panel is plate panel which is not

regular, as detailed in 4.2.3(2) of this Chapter.

(3) Stress application

① Regular panel

The reference stresses are to be taken as defined in A.1.3(1) for a regular panel when the following conditions are satisfied:

a. At least, one plate element centre is located in each third part of the long edge *a* of a regular panel, and

b. This element centre is located at a distance in the panel local x direction not less than *a*/4 to at least one of the element centres in the adjacent third part of the panel.

Otherwise, the reference stresses are to be taken as defined in A.1.3(2) for an irregular panel.

② Irregular panel and curved panel

The reference stresses of an irregular panel or of a curved panel are to be taken as defined in A.1.4.

A.1.3 Reference stress

(1) Regular panel

① Longitudinal stress

The longitudinal stress σ_x applied on the shorter edge of the buckling panel is to be calculated as follows:

For plate buckling assessment, the distribution of $\sigma_{x(x)}$ is assumed as 2nd order polynomial curve as:

$$\sigma_x = Cx^2 + Dx + E$$

The best fitting curve $\sigma_{x(x)}$ is to be obtained by minimising the square error Π considering the area of each element as a weighting factor.

$$\Pi = \sum_{i=1}^{n} A_i \left[\sigma_{xi} - (Cx^2 + Dx + E) \right]^2$$

The unknown coefficients *C*, *D* and *E* must yield zero first derivatives, $\partial\Pi$ with respect to *C*,*D* and *E* respectively.

$$\frac{\partial \Pi}{\partial C} = 2\sum_{i=1}^{n} A_i x_i^2 \left[\sigma_{xi} - (Cx_i^2 + Dx_i + E) \right] = 0$$

$$\frac{\partial \Pi}{\partial D} = 2\sum_{i=1}^{n} A_i x_i \left[\sigma_{xi} - (Cx_i^2 + Dx_i + E) \right] = 0$$

$$\frac{\partial \Pi}{\partial E} = 2\sum_{i=1}^{n} A_i \left[\sigma_{xi} - (Cx_i^2 + Dx_i + E) \right] = 0$$

The unknown coefficients *C*, *D* and *E* can be obtained by solving the 3 above equations.

$$S_{X1} = \frac{1}{b}\int_0^b \sigma_x(x)dx = \frac{b^2}{3}C + \frac{b}{2}D + E$$

$$S_{X2} = \frac{1}{b}\int_{a-b}^{a} \sigma_x(x)dx = \left(a^2 - ab + \frac{b^2}{3}\right)C + \left(a - \frac{b}{2}\right)D + E$$

If $-D/2C < b/2$ or $-D/2C > a - b/2$, S_{X3} is to be ignored. Otherwise, S_{X3} is taken as:

$$S_{X3} = \frac{1}{b}\int_{x_{\min}}^{x_{\max}} \sigma_x(x)dx = \frac{b^2}{12}C - \frac{D^2}{4C} + E$$

where:

$$x_{\min} = -\frac{b}{2} - \frac{D}{2C}$$

$$x_{\max} = \frac{b}{2} - \frac{D}{2C}$$

The longitudinal stress is to be taken as:

$$\sigma_x = \max(S_{X1}; S_{X2}; S_{X3})$$

The edge stress ratio is to be taken as:

$$\psi_x = 1$$

For stiffener buckling assessment, $\sigma_x(x)$ applied on the shorter edge of the attached plate is to be taken as:

$$\sigma_x = \frac{\sum_1^n A_i \sigma_{xi}}{\sum_1^n A_i}$$

The edge stress ratio for the stress σ_x is equal to 1.0.

② Transverse stress

The transverse stress σ_y applied along the longer edges of the buckling panel is to be calculated by extrapolation of the transverse stresses of all elements up to the shorter edges of the considered buckling panel.

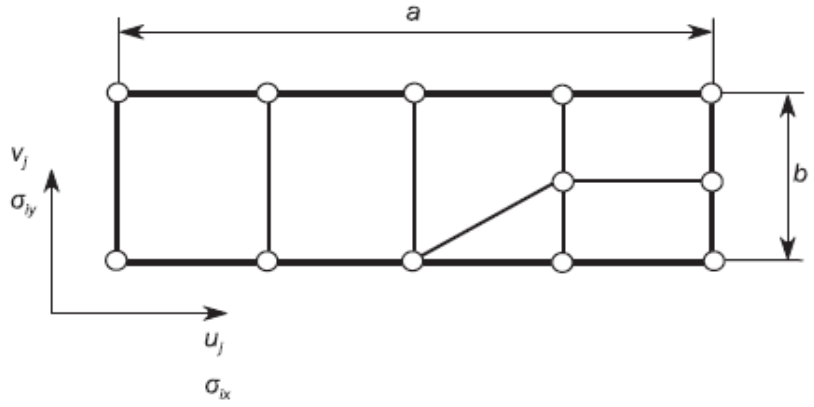


Figure A.1.3 Buckling Panel

The distribution of $\sigma_y(x)$ is assumed as straight line. Therefore:

$$\sigma_y(x) = A + Bx$$

The best fitting curve $\sigma_y(x)$ is to be obtained by the least square method minimising the square error Π considering area of each element as a weighting factor.

$$\Pi = \sum_{i=1}^{n} A_i \left[\sigma_{yi} - (A + Bx_i) \right]^2$$

The unknown coefficients *A* and *B* must yield zero first partial derivatives, $\partial\Pi$ with respect to *A* and *B*, respectively.

$$\frac{\partial \Pi}{\partial A} = 2\sum_{i=1}^{n} A_i \left[\sigma_{yi} - (A + Bx_i) \right] = 0$$

$$\frac{\partial \Pi}{\partial B} = 2\sum_{i=1}^{n} A_i x_i \left[\sigma_{yi} - (A + Bx_i) \right] = 0$$

The unknown coefficients *A* and *B* are obtained by solving the 2 above equations and are given as follow:

$$\begin{cases} A = \dfrac{\left(\sum_{i=1}^{n} A_i \sigma_{iy}\right)\left(\sum_{i=1}^{n} A_i x_i^2\right) - \left(\sum_{i=1}^{n} A_i x_i\right)\left(\sum_{i=1}^{n} A_i x_i \sigma_{iy}\right)}{\left(\sum_{i=1}^{n} A_i\right)\left(\sum_{i=1}^{n} A_i x_i^2\right) - \left(\sum_{i=1}^{n} A_i x_i\right)^2} \\ B = \dfrac{\left(\sum_{i=1}^{n} A_i\right)\left(\sum_{i=1}^{n} A_i x_i \sigma_{iy}\right) - \left(\sum_{i=1}^{n} A_i x_i\right)\left(\sum_{i=1}^{n} A_i \sigma_{iy}\right)}{\left(\sum_{i=1}^{n} A_i\right)\left(\sum_{i=1}^{n} A_i x_i^2\right) - \left(\sum_{i=1}^{n} A_i x_i\right)^2} \end{cases}$$

$$\sigma_y = \max(A, A + Ba)$$

$$\psi_y = \frac{\min(A, A + Ba)}{\max(A, A + Ba)} \quad \text{for} \quad \sigma_y \geq 0$$

$\psi_y = 1$ for $\sigma_y < 0$.

③ Shear stress

The shear stress τ is to be calculated using a weighted average approach, and is to be taken as:

$$\tau = \frac{\sum_{1}^{n} A_i \tau_i}{\sum_{1}^{n} A_i}$$

(2) Irregular panel and curved panel

The reference stress, including longitudinal, transverse and shear stresses are to be calculated using a weighted average approach. They are to be taken as:

$$\sigma_x = \frac{\sum_1^n A_i \sigma_{xi}}{\sum_1^n A_i}$$

$$\sigma_y = \frac{\sum_1^n A_i \sigma_{yi}}{\sum_1^n A_i}$$

$$\tau = \frac{\sum_1^n A_i \tau_i}{\sum_1^n A_i}$$

The edge stress ratios are to be taken as:

$$\psi_x = 1$$

$$\psi_y = 1$$

Appendix B Buckling Factors and Reduction Factors of Panels

B.1.1 Symbols

See the definitions in 4.3.1 of this Chapter.

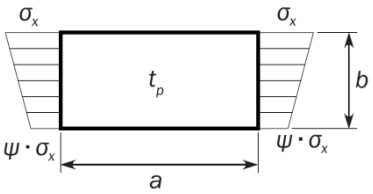
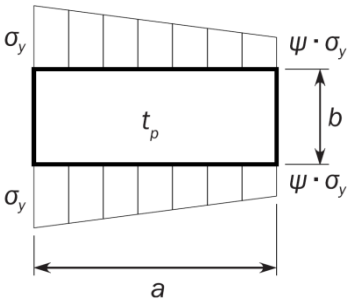
B.1.2 Plane Plate Panel

The buckling factor and reduction factor are to be calculated according to the equations in Table B.1.2.

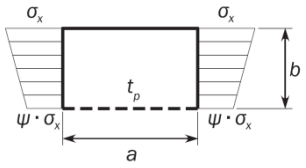
B.1.3 Curved Plate Panel

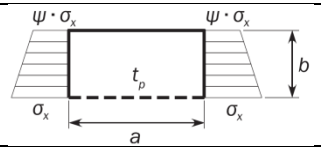
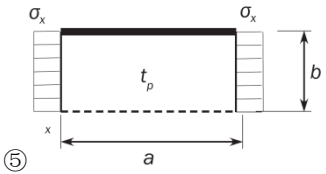
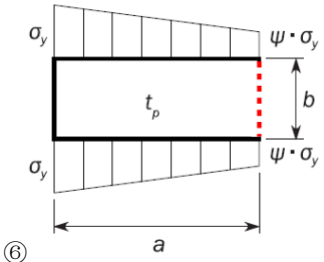
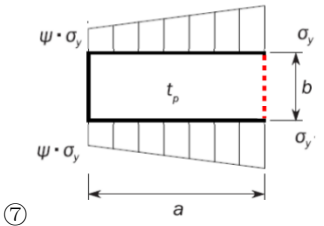
The bucking factor and reduction factor of curve plate panels which satisfy $R/t_p \leq 2500$ are to be calculated according to the equations in Table B.1.3.

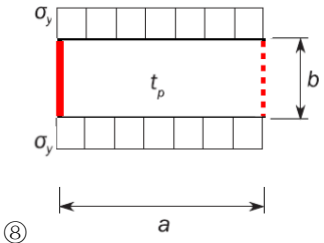
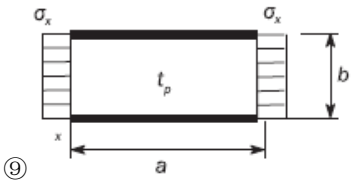
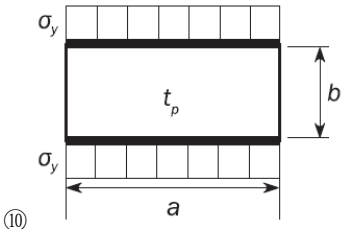
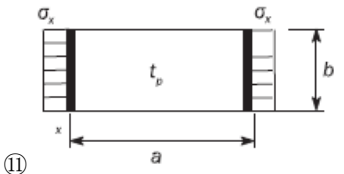
Buckling Factors and Reduction Factors of Plane Plate Panel **Table B.1.2**

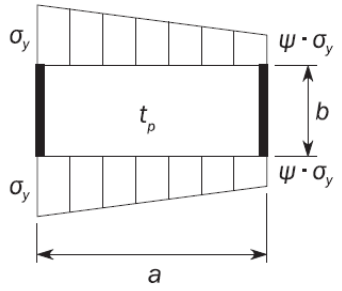
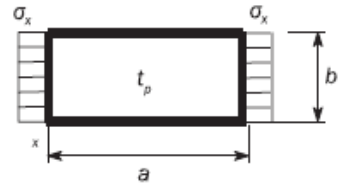
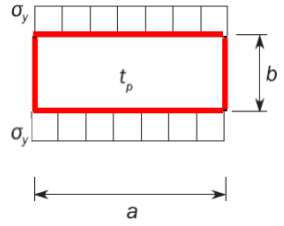
<table>
<tr><th>Case</th><th>Stress ratio ψ</th><th>Aspect ratio α</th><th>Buckling factor K</th><th>Reduction factor C</th></tr>
<tr><td rowspan="3">①

</td><td>$1 \ge \psi \ge 0$</td><td colspan="2">$K_x = F_{long} \dfrac{8.4}{\psi + 1.1}$</td><td rowspan="3">When $\sigma_x \le 0$, $C_x = 1$;
When $\sigma_x > 0$:
$C_x = 1$ for $\lambda \le \lambda_c$
$C_x = c\left(\dfrac{1}{\lambda} - \dfrac{0.22}{\lambda^2}\right)$ for $\lambda > \lambda_c$
where:
$c = (1.25 - 0.12\psi) \le 1.25$
$\lambda_c = \dfrac{c}{2}\left(1 + \sqrt{1 - \dfrac{0.88}{c}}\right)$</td></tr>
<tr><td>$0 > \psi > -1$</td><td colspan="2">$K_x = F_{long}\left[7.63 - \psi(6.26 - 10\psi)\right]$</td></tr>
<tr><td>$\psi \le -1$</td><td colspan="2">$K_x = F_{long}\left[5.975(1-\psi)^2\right]$</td></tr>
<tr><td rowspan="4">②

</td><td rowspan="3">$1 \ge \psi \ge 0$</td><td colspan="2">$K_y = F_{tran} \dfrac{2\left(1 + \frac{1}{\alpha^2}\right)^2}{1 + \psi + \frac{(1-\psi)}{100}\left(\frac{2.4}{\alpha^2} + 6.9 f_1\right)}$</td><td rowspan="4">When $\sigma_y \le 0$, $C_y = 1$;
When $\sigma_y > 0$,
$C_y = c\left(\dfrac{1}{\lambda} - \dfrac{R + F^2(H-R)}{\lambda^2}\right)$
where:
$c = (1.25 - 0.12\psi) \le 1.25$
$R = \lambda(1 - \lambda/c)$ for $\lambda < \lambda_c$
$R = 0.22$ for $\lambda \ge \lambda_c$</td></tr>
<tr><td>$\alpha \le 6$</td><td>$f_1 = (1-\psi)(\alpha - 1)$</td></tr>
<tr><td>$\alpha > 6$</td><td>$f_1 = 0.6(1 - \dfrac{6\psi}{\alpha})(\alpha + \dfrac{14}{\alpha})$
But not greater than $14.5 - \dfrac{0.35}{\alpha^2}$</td></tr>
<tr><td>$1 - \dfrac{4\alpha}{3} \le \psi < 0$</td><td colspan="2">$K_y = \dfrac{200 F_{tran}\left(1 + \beta^2\right)^2}{(1 - f_3)(100 + 2.4\beta^2 + 6.9 f_1 + 23 f_2)}$</td></tr>
</table>

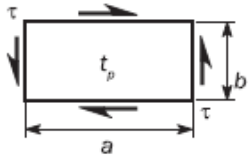
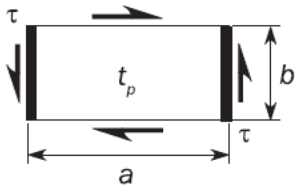
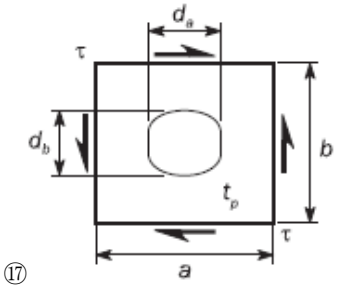
Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
		$\alpha > 6(1-\psi)$	$f_1 = 0.6(\frac{1}{\beta}+14\beta)$ But not greater than $14.5-0.35\beta^2$ $f_2 = f_3 = 0$	$\lambda_c = 0.5c(1+\sqrt{1-0.88/c})$ $F = \left(1-\left(\frac{K}{0.91}-1\right)\Big/\lambda_p^2\right)c_1 \geq 0$ $\lambda_p^2 = \lambda^2 - 0.5$ and $1 \leq \lambda_p^2 \leq 3$ $c_1 = 1$ is defined in 4.3.3(2)③. $H = \lambda - \frac{2\lambda}{c(T+\sqrt{T^2-4})} \geq R$ $T = \lambda + \frac{14}{15\lambda} + \frac{1}{3}$
		$3(1-\psi) \leq \alpha \leq 6(1-\psi)$	$f_1 = \frac{1}{\beta} - 1$ $f_2 = f_3 = 0$	
		$1.5(1-\psi) \leq \alpha < 3(1-\psi)$	$f_1 = \frac{1}{\beta} - (2-\omega\beta)^4 - 9(\omega\beta-1)(\frac{2}{3}-\beta)$ $f_2 = f_3 = 0$	
		$1-\psi \leq \alpha < 1.5(1-\psi)$	If $\alpha > 1.5$, $f_1 = 2\left(\frac{1}{\beta} - 16\left(1-\frac{\omega}{3}\right)^4\right)(\frac{1}{\beta}-1)$ $f_2 = 3\beta - 2$; $f_3 = 0$ If $\alpha \leq 1.5$, $f_1 = 2\left(\frac{1.5}{1-\psi}-1\right)\left(\frac{1}{\beta}-1\right)$ $f_2 = \frac{\psi(1-16f_4^2)}{1-\alpha}$ $f_3 = 0$; $f_4 = \left[1.5 - Min(1.5;\alpha)\right]^2$	
		$0.75(1-\psi) \leq \alpha < (1-\psi)$	$f_1 = 0$	

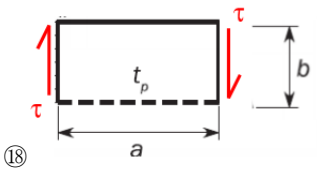
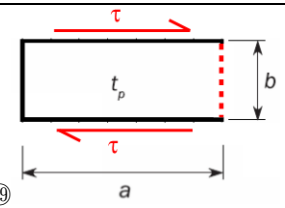
Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
			$f_2 = 1 + 2.31(\beta - 1) - 48\left(\frac{4}{3} - \beta\right) f_4^2$ $f_3 = 3 f_4 (\beta - 1)\left(\frac{f_4}{1.81} - \frac{\alpha - 1}{1.31}\right)$ $f_4 = \left[1.5 - Min(1.5; \alpha)\right]^2$	
	$\psi < 1 - \frac{4\alpha}{3}$	$K_y = 5.972 F_{tran} \frac{\beta^2}{1 - f_3}$ where: $f_3 = f_5\left(\frac{f_5}{1.81} + \frac{1 + 3\psi}{5.24}\right)$ $f_5 = \frac{9}{16}\left[1 + Max(-1; \psi)\right]^2$		
③ 	$1 \geq \psi \geq 0$	$K_x = \frac{4(0.425 + 1/\alpha^2)}{3\psi + 1}$		$C_x = 1$ for $\lambda \leq 0.7$
	$0 > \psi > -1$	$K_x = 4(0.425 + 1/\alpha^2)(1 + \psi) - 5\psi(1 - 3.42\psi)$		$C_x = \frac{1}{\lambda^2 + 0.51}$ for $\lambda > 0.7$

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
④ 	$1 \geq \psi \geq -1$	$K_x = \left(0.425 + \frac{1}{\alpha^2}\right)\frac{3-\psi}{2}$		
⑤ 	-	$\alpha \geq 1.64$	$K_x = 1.28$	
		$\alpha < 1.64$	$K_x = \frac{1}{\alpha^2} + 0.56 + 0.13\alpha^2$	
⑥ 	$1 \geq \psi \geq 0$	$K_y = \frac{4(0.425+\alpha^2)}{(3\psi+1)\alpha^2}$		$C_y = 1$ for $\lambda \leq 0.7$ $C_y = \frac{1}{\lambda^2 + 0.51}$ for $\lambda > 0.7$
	$0 > \psi \geq -1$	$K_y = 4\left(0.425+\alpha^2\right)(1+\psi)\frac{1}{\alpha^2} - 5\psi(1-3.42\psi)\frac{1}{\alpha^2}$		
⑦ 	$1 \geq \psi \geq -1$	$K_y = \left(0.425+\alpha^2\right)\frac{3-\psi}{2\alpha^2}$		

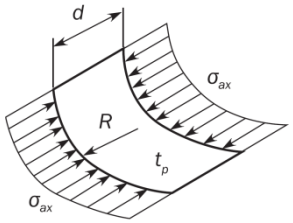
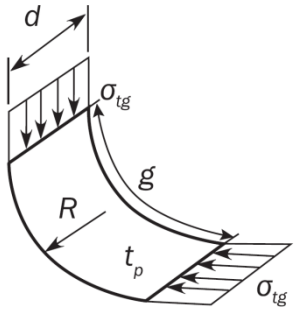
Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
⑧ 	--	$K_y = 1 + \frac{0.56}{\alpha^2} + \frac{0.13}{\alpha^4}$		
⑨ 	—	$K_x = 6.97$		$C_z = 1$ for $\lambda \le 0.83$ $C_z = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
⑩ 	—	$K_y = 4 + \frac{2.07}{\alpha^2} + \frac{0.67}{\alpha^4}$		$C_z = 1$ for $\lambda \le 0.83$ $C_z = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
⑪ 	—	$\alpha \ge 4$	$K_x = 4$	$C_z = 1$ for $\lambda \le 0.83$ $C_z = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
		$\alpha < 4$	$K_x = 4 + 2.74\left[\frac{4-\alpha}{3}\right]^4$	

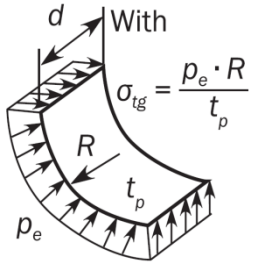
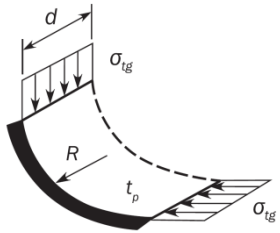
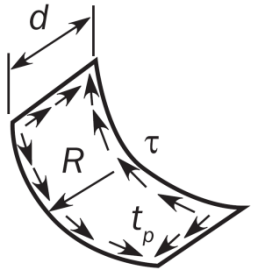
Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
⑫ 	-	K_y determined as per case②		If $\alpha<2$, $C_y=C_{y2}$; If $\alpha\geq 2$, $C_y=\left(1.06+\frac{1}{10\alpha}\right)C_{y2}$; Where: C_{y2} is equal to C_y calculated according to case ②
⑬ 	—	$\alpha\geq 4$	$K_x=6.97$	$C_x=1$ for $\lambda\leq 0.83$ $C_x=1.13\left(\frac{1}{\lambda}-\frac{0.22}{\lambda^2}\right)$ for $\lambda>0.83$
		$\alpha<4$	$K_x=6.97+3.1\left[\frac{4-\alpha}{3}\right]^4$	
⑭ 	—	$K_y=\frac{6.97}{\alpha^2}+\frac{3.1}{\alpha^4}\left(\frac{4-1/\alpha}{3}\right)^4$		$C_y=1$ for $\lambda\leq 0.83$ $C_y=1.13\left(\frac{1}{\lambda}-\frac{0.22}{\lambda^2}\right)$ for $\lambda>0.83$

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
⑮ 	–	$K_\tau = \sqrt{3}\left[5.34+\frac{4}{\alpha^2}\right]$		$C_\tau = 1$ for $\lambda \le 0.84$ $C_\tau = \frac{0.84}{\lambda}$ for $\lambda > 0.84$
⑯ 	–	$K_\tau = \sqrt{3}\left[5.34 + Max\left[\frac{4}{\alpha^2};\frac{7.15}{\alpha^{2.5}}\right]\right]$		
⑰ 	–	$K_\tau = K_{\tau case15} r$ $K_{\tau case15}$ is equal to K_τ calculated according to case ⑮ r = reduction factor of openings, to be taken as: $r = \left(1-\frac{d_a}{a}\right)\left(1-\frac{d_b}{b}\right)$ $\frac{d_a}{a} \le 0.7$ and $\frac{d_b}{b} \le 0.7$		

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
⑱ 	–	$K_\tau = \sqrt{3}\left(0.6+\frac{4}{\alpha^2}\right)$		$C_\tau = 1$ for $\lambda \le 0.84$
⑲ 	–	$K_\tau = 8$		$C_\tau = \frac{0.84}{\lambda}$ for $\lambda > 0.84$
Edge boundary conditions: - - - - - - - - - - - - Plate edge free. ———————— Plate edge simply supported. ▬▬▬▬▬▬ Plate edge clamped.				
Note (1): cases listed are general cases. Each stress component (σ_x, σ_y) is to be understood in local coordinates.				

Buckling and Reduction Factor for Curved Plate Panel With $R/t_p \le 2500$ **Table B.1.3**

Case	Aspect ratio	Buckling factor, K	Reduction factor, C
1  	$\frac{d}{R} \le 0.5\sqrt{\frac{R}{t_p}}$	$K = 1 + \frac{2}{3}\frac{d^2}{Rt_p}$	For general application: $C_{ax} = 1$ for $\lambda \le 0.25$ $C_{ax} = 1.233 - 0.933\lambda$ for $0.25 < \lambda \le 1$ $C_{ax} = 0.3/\lambda^2$ for $1 < \lambda \le 1.5$ $C_{ax} = 0.2/\lambda^2$ for $\lambda > 1.5$ For curved single fields, e.g. bilge strake, which are bounded by plane panels, $C_{ax} = \frac{0.65}{\lambda^2} \le 1.0$
	$\frac{d}{R} > 0.5\sqrt{\frac{R}{t_p}}$	$K = 0.267\frac{d^2}{Rt_p}\left[3 - \frac{d}{R}\sqrt{\frac{t_p}{R}}\right] \ge 0.4\frac{d^2}{Rt_p}$	
2a  	..	$K = \frac{d}{\sqrt{Rt_p}} + 3\frac{(Rt_p)^{0.175}}{d^{0.35}}$	For general application: $C_{tg} = 1$ for $\lambda \le 0.4$ $C_{tg} = 1.274 - 0.686\lambda$ for $0.4 < \lambda \le 1.2$ $C_{tg} = \frac{0.65}{\lambda^2}$ for $\lambda > 1.2$ For curved single fields, e.g. bilge strake, which are bounded by plane panels, $C_{tg} = \frac{0.8}{\lambda^2} \le 1.0$
	$\frac{d}{R} > 1.63\sqrt{\frac{R}{t_p}}$	$K = 0.3\frac{d^2}{R^2} + 2.25\left(\frac{R^2}{dt_p}\right)^2$	

Case	Aspect ratio	Buckling factor, K	Reduction factor, C
2b  p_e means external pressure,in N/mm^2.			
3  	$\frac{d}{R} \le \sqrt{\frac{R}{t_p}}$	..	As in load case 2a
	$\frac{d}{R} > \sqrt{\frac{R}{t_p}}$	$K = 0.3\frac{d^2}{R^2} + 0.291\left(\frac{R^2}{dt_p}\right)^2$	
4  	$\frac{d}{R} \le 8.7\sqrt{\frac{R}{t_p}}$	$K = \sqrt{3}\sqrt{28.3 + \frac{0.67d^3}{R^{1.5}t_p^{1.5}}}$	$C_\tau = 1$ for $\lambda \le 0.4$ $C_\tau = 1.274 - 0.686 \cdot \lambda$ for $0.4 < \lambda \le 1.2$ $C_\tau = \frac{0.65}{\lambda^2}$ for $\lambda > 1.2$
	$\frac{d}{R} > 8.7\sqrt{\frac{R}{t_p}}$	$K = \sqrt{3}\frac{0.28d^2}{R\sqrt{Rt_p}}$	
Explanations for boundary conditions: - - - - - - - - - - Plate edge free. ———————— Plate edge simply supported. ▬▬▬▬ Plate edge clamped.			

CHAPTER 5 GLOBAL FINITE ELEMENT STRENGTH ASSESSMENT FOR SHIP

5.1 General Requirements

5.1.1 For ore carriers of 350 m or over in length, direct calculation of global strength is to be carried out. For those of 300 m or over in length, strength assessment of primary structures in cargo hold area is in general to be carried out by means of direct calculation of global strength.

5.1.2 For ore carriers intended for overall strength (excluding torsional strength) assessment of primary members by means of direct calculation of global strength, the model, load cases and load calculation, strength criteria may be in accordance with the requirements of the Guidelines.

5.1.3 Right-handed Cartesian coordinate system is to be adopted in this Chapter, with the original point at the intersection of aft perpendicular with baseline in ship's longitudinal center plane:

- x — the longitudinal direction, positive forward;
- y — the transverse direction, positive to port from the center line;
- z — the vertical direction, positive upwards from the baseline.

5.1.4 The flow chart of FE direct calculation of global strength of ship is given in Figure 5.1.4.

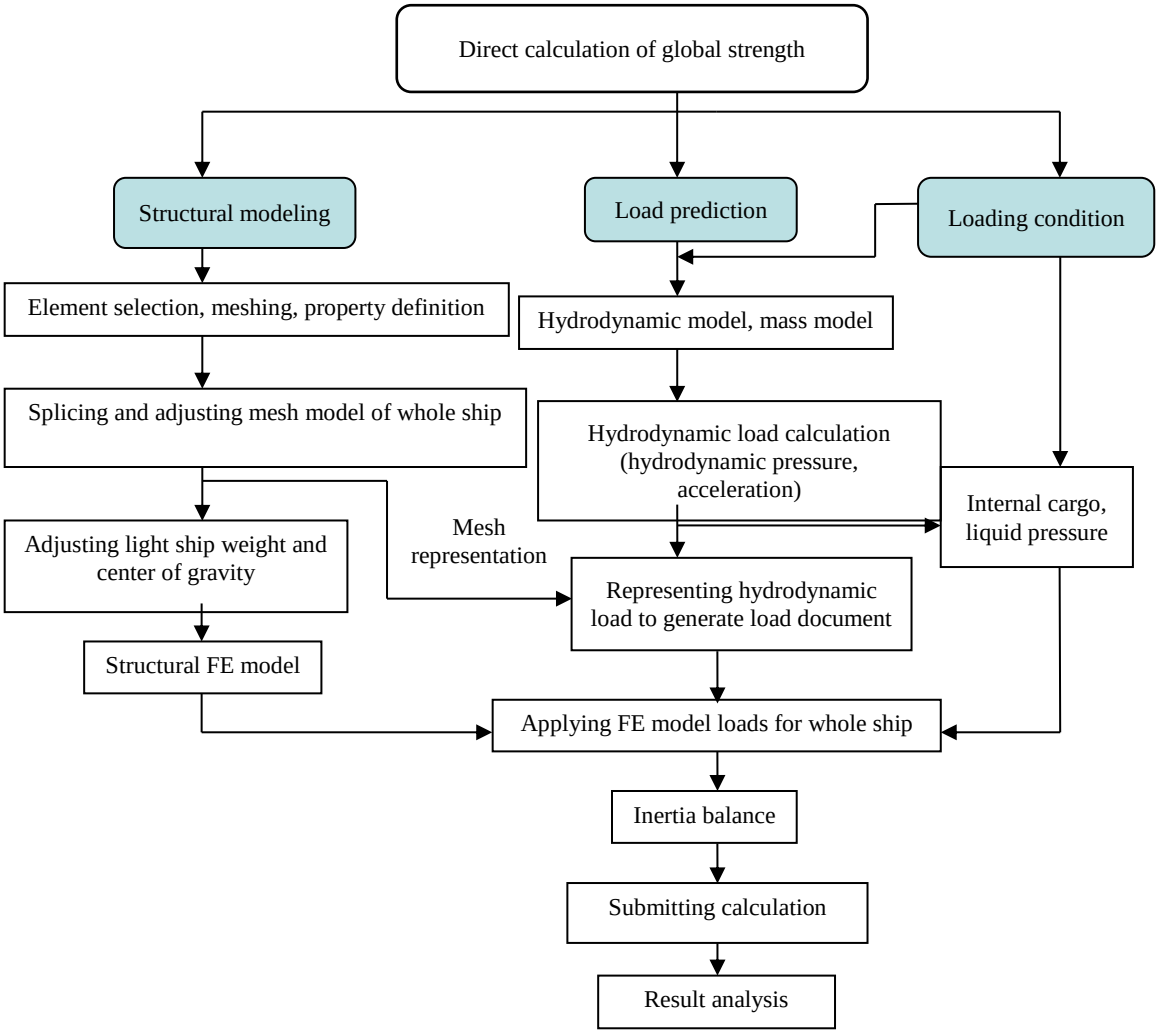


Figure 5.1.4 Flow Chart of Direct Calculation of Global Strength of Ship

5.2 Model Requirements

5.2.1 Hydrodynamic load calculation model

In addition to the geometric characteristics of hull, the hydrodynamic load calculation model is to reasonably reflect the hull mass and its distribution. Then the displacement, trim angle and bow and stern draughts of calculation model will be in consistent with those in loading manual through the adjustment of floating condition, and the error is to be controlled within ±1% of displacement and ±5 cm of trims both at bow and stern.

5.2.2 Extent of FE model

The global three-dimensional FE model is to cover hull structure within the whole ship's length and width, including all primary members, such as deck structure, side structure, double-bottom structure, transverse bulkhead, inner hull longitudinal bulkhead, bow and stern structures, etc. The main engine, superstructure, propeller shaft, etc., may be properly simplified, and smaller brackets, openings or holes may be neglected. The typical global FE model for ore carrier is given in Figure 5.2.2.

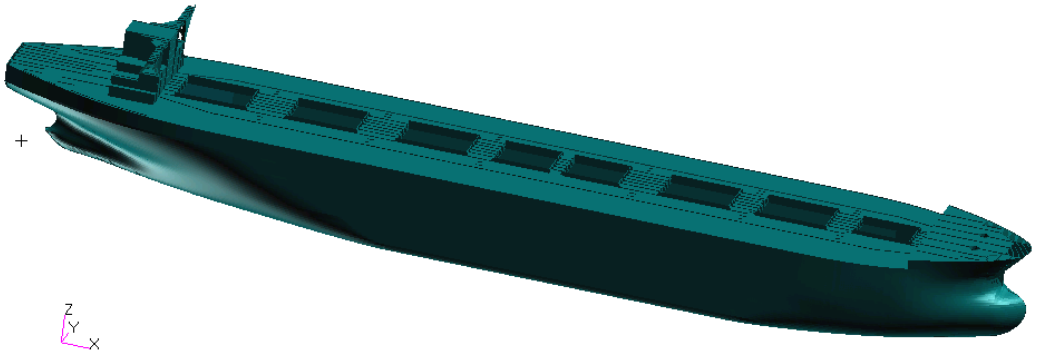


Figure 5.2.2 Typical Global FE Model for Ore Carriers

5.2.3 Finite element modeling

5.2.3.1 The element type is to be modeled in accordance with the requirement of 3.1.4 of the Guidelines. The main engine and large equipment may be modeled by mass concentration element. The pillar subjected to axial pull and compression may be modeled by rod element.

5.2.3.2 The FE meshing principles are to be in accordance with the requirement of 3.2.4 of the Guidelines. The structures other than cargo hold area are to comply with the following requirements:

(1) For areas other than cargo holds, where transverse framing deck, platform and shell plating are used, each adjacent two transverse frames is to be modeled as a mesh, with the width direction not more than the spacing of these two frames, and coordinated with the meshes of adjacent members. The meshing of plate element for other primary members may be referred to meshing methods of cargo hold area, based on the actual positions of framing and stiffeners, the member connection areas and the areas with larger linear variety may be properly adjusted locally.

(2) The forepeak tank, afterpeak tank and engine room are to be modeled by simplified or equivalent method in compliance with the precision requirements. In addition, where the maximum shearing force in shearing condition appears in the stem and stern areas, consideration is to be taken to ensure the mesh of this area have the same precision as that in cargo hold area.

5.2.4 Adjustment of weight and center of gravity of light ship

5.2.4.1 The property of the whole ship model is to be defined by cargo holds, to ensure that the mass distribution is matched with the ship's hydrostatic buoyancy. The error between the total weight and total buoyance is not to be more than 0.0001Δ, where Δ is the moulded displacement, in t, at the corresponding draught. The error of longitudinal coordinate for centers of mass and buoyancy is not to be more than 0.0025*L*, and the error of horizontal coordinate is not to be more than 0.001*B*.

5.2.4.2 Adjustment method

(1) The differences due to outfitting and modeling may be adjusted by correction of density of material.

(2) For large equipment, such as main engine, etc., adjustment may be made by simulation methods of beam element or mass concentration element.

5.2.5 Refined mesh model

5.2.5.1 Where the results of the following areas for the global FE calculation exceed 95% allowable stress as specified in 3.5.1, refined mesh is to be modeled for analysis:

(1) primary transverse supporting members in double-bottom and side tank;

(2) connection of the transverse bulkhead with lower stool and connection of the lower stool with inner bottom ;

(3) most stressed connection of the inner bottom with inner longitudinal bulkhead;

(4) deck plating in way of the hatch corners.

5.2.5.2 Two methods in 3.5.3.2 of the Guidelines may be adopted for refining model.

5.2.5.3 The refined meshing is to comply with the requirement of 3.5.3 in the Guidelines.

5.3 Hydrodynamic Load Calculation

5.3.1 Calculation condition

5.3.1.1 Each calculation condition consists of loading condition and wave load condition.

5.3.1.2 The maximum still water bending moment in hogging and sagging conditions under typical loading conditions and the condition under maximum still water shear force specified in loading manual are to be selected respectively. In general, the loading condition intended for calculation is given in Table 5.3.1.2, and the other most unfavorable load conditions in loading manual are also to be taken into consideration.

Loading Cases **Table 5.3.1.2**

Loading conditions	Cases
Full load	(1) sagging (2) maximum vertical still water bending moment (3) maximum, medium, minimum density of cargo
Normal ballast	(1) hogging (2) maximum vertical still water bending moment
Heavy ballast (if any)	(1) sagging (2) maximum vertical still water bending moment or shear force
Multi-port (if any)	(1) sagging or hogging (2) maximum vertical still water bending moment or shear force (3) maximum, medium, minimum density of cargo

5.3.1.3 The superimposition of corresponding wave loads are to be added in basis of the above loading conditions, the following dominant load parameters are to be taken into consideration in wave load case:

(1) vertical wave bending moment;

(2) vertical wave shear force (in way of the maximum still water shear force);
(3) bow vertical acceleration (calculation point is to be taken as the top end of intersection line between the fore bulkhead of No.1 cargo hold and longitudinal centerline section);
(4) bow transverse acceleration (calculation point is the same as (3));
(5) maximum heeling angle.

5.3.2 Loading condition combination

5.3.2.1 The loading condition combination, including loading condition and wave load condition are to be obtained according to 5.3.1.2 and 5.3.1.3 in this Chapter.

Calculation Conditions **Table 5.3.2.1**

Wave load parameter / Loading condition	Full load	Normal ballast	Heavy ballast (if any)	Multi-port (if any)
Vertical wave bending moment	Applicable	Applicable	Applicable	-
Vertical wave shear force	Applicable	Applicable	Applicable	Applicable
Bow vertical acceleration	Applicable	Applicable	Applicable	Applicable
Bow transverse acceleration	Applicable	Applicable	Applicable	Applicable
Maximum heeling angle	-	Applicable	-	Applicable

5.3.3 Hydrodynamic load analysis

5.3.3.1 The technical flow chart of wave load prediction is shown in Figure 5.3.3.1, mainly including hydrodynamic load calculation modeling, equivalent design wave determination, motion and load prediction.

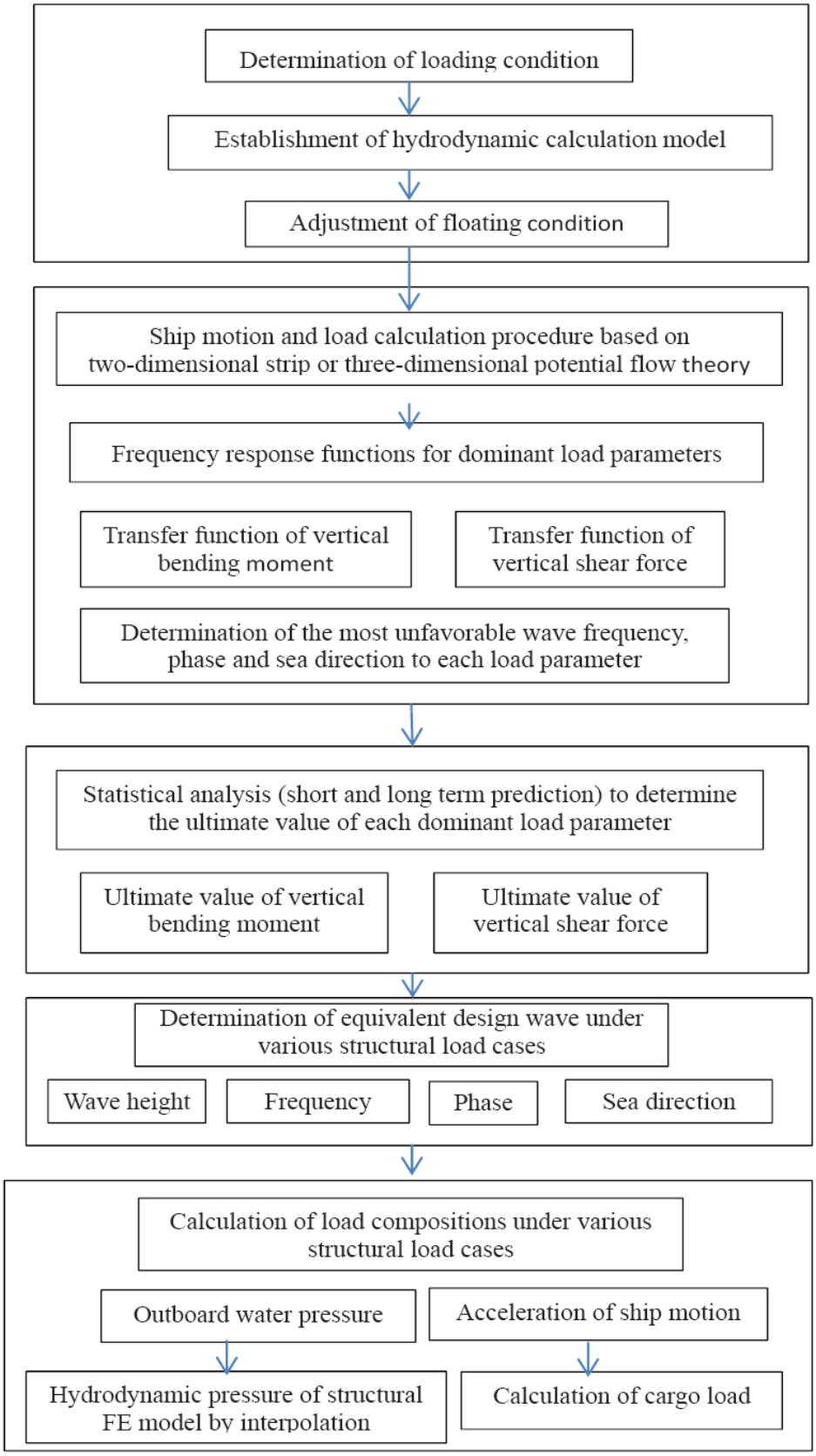


Figure 5.3.3.1 Technical Flow Chart for Wave Load Calculation of Ore Carriers

5.3.3.2 Transfer function of wave load

(1) The frequency response of dominant load parameter at various wave directions through three-dimensional ship motion, the inputs of wave direction, frequency and ship speed are to comply with the following.

- The angles of wave direction used for calculation are not to be less than 7, including 0°, 30°, 60°, 90°, 120°, 150° and 180°.
- The number of wave frequency is to be taken as 20~30 cases, the range taken as 0.2~1.2 rad/s, and the increments taken as 0.05 rad/s.
- The ship speed is taken as zero.

(2) In addition, the combined parameter of sea direction, frequency (i.e. wave length) and phase under the maximum frequency response function may be obtained according to the frequency response function curve of each dominant load parameter under various sea directions, for determination of the subsequent equivalent design wave.

5.3.3.3 Long-term predicted ultimate value

(1) For non-restriction navigation area, the wave scatter is the in the standard wave statistical data in North Atlantic provided by IACS Rec. No.34;

(2) In the short and long term prediction of wave load, PM wave spectrum is to be used, short crested wave spread function is to be obtained from square of the cosine function;

(3) The ultimate value of dominant load parameter is to be obtained from transfer function through long-term prediction, with the exceeding probability generally to be taken as 10^{-8};

(4) Considering practical navigating experience under extreme sea conditions, the exceeding probability for bow vertical acceleration and heeling angle predictions may be taken as $10^{-6.5}$.

5.3.3.4 Determination of equivalent design wave

The equivalent design eave is to be defined by sea direction, amplitude, wave length and phase.

(1) Sea direction

The sea direction of equivalent design wave means the sea direction with the maximum frequency response function of dominant load parameters.

(2) Amplitude calculation

The amplitude of equivalent design wave is to be determined by long-term predicted ultimate value of load parameter and frequency response function, to be calculated by the following equation:

$$a_W = \frac{L_j}{A_j}$$

where:

a_W — amplitude, in m;

L_j — long-term ultimate value of load parameter at the certain probability level;

A_j — the maximum value of frequency response function of dominant load parameter;

j — number of dominant load parameter.

(3) Wave length

The length of equivalent design wave is to be determined by the time instant when frequency response function achieves maximum, may be calculated by the following equation:

$$\lambda = (2\pi g) / \omega_a^2$$

where:

λ — length of design wave, in m;

g —acceleration of gravity;

ω_a — wave frequency corresponding to the maximum value of frequency response function of dominant load parameter, in rad/s.

(4) Phase

The time instant when dominant load parameter achieves maximum is to be determined by the phase when frequency response function reaches the maximum value, may be calculated by the following equation:

$$t_j = \frac{n\pi + \frac{\pi}{2} - \varepsilon_j}{\omega_a}$$

where:

ω_a — wave frequency corresponding to the maximum value of frequency response function of dominant load parameter, in rad/s;

ε_j — phase corresponding to the maximum value of frequency response function of dominant load parameter, in rad;

n — 0 or 1.

5.3.4 Motion and load prediction

According to the equivalent design wave, various load composition predictions, including acceleration of motion, outboard hydrodynamic pressure, are to be carried out.

5.3.4.1 Acceleration

The calculation of acceleration is normally in plural form, or represents by two real numbers, such as amplitude and phase. Due to the amplitude and phase, the acceleration at calculation point may be obtained by the following equation:

$$A_t = (a_i)(a_W)\sin(\omega_a t_j + \varepsilon_i)$$

where;

A_t — instantaneous acceleration at arbitrary calculation position of hull;

a_i — amplitude of frequency response function of acceleration;

a_W — amplitude of design wave;

ε_i — phase of frequency response function of acceleration;

t_j — time instant when dominant load parameter achieves maximum.

5.3.4.2 Hydrodynamic pressure calculation and loading

According to the equivalent design wave, the hydrodynamic pressure distribution when dominant load parameter achieves maximum (such as vertical bending moment) is to be calculated, and the hydrodynamic pressure distribution on the external surface of structural FE model is to be obtained by interpolation method, as shown in Figure 5.3.4.2.

The wave pressure under design wave is to be calculated by the following equation:

$$p_i = (A_i)(a_W)\sin(\omega_a t_j + \varepsilon_i)$$

where:

p_i — pressure at arbitrary calculation position of hull;

A_i — amplitude of frequency response function of wave pressure;

a_W — amplitude of design wave;

ε_i — phase of frequency response function of acceleration;

t_j — time instant when dominant load parameter achieves maximum.

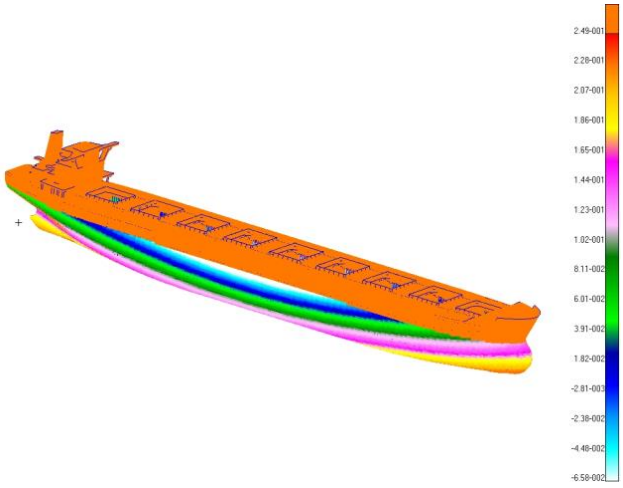


Figure 5.3.4.2 Diagram of Outboard Hydrodynamic Pressure

5.4 Global Ship Loads Applied and Inertia Balance

5.4.1 External water pressure

5.4.1.1 External water pressure includes external hydrostatic pressure and wave hydrodynamic pressure.

5.4.1.2 The external hydrostatic pressure acts, according to draught under the calculation condition, on external wet surface of hull, the equation is as following:

$$p_S = \rho_S g(T_{LC} - z)$$

where: ρ_S — density of sea water, to be taken as 1.025 t/m^3;

g — acceleration of gravity, to be taken as 9.81 m/s^2;

T_{LC} — draught under the loading condition taken into consideration, in m;

z — vertical coordinate of loading point, in m, but not to be greater than T_{LC}.

5.4.1.3 The hydrodynamic pressure is to be calculated by calculation method stipulated in 5.3.3 and applied on shell element of hull.

5.4.2 Internal load

5.4.2.1 The internal loads of ore carriers are to include cargo loads within cargo holds, internal load in tanks and inertial force of light ship.

5.4.2.2 The cargo load is to be calculated and applied in compliance with the requirements of 2.6 of Chapter 2 in the Guidelines, and the acceleration is to be calculated in compliance with the requirements of 5.3.4.1 of this Chapter.

5.4.2.3 The internal load in tank is to be calculated and applied in compliance with the

requirements of 2.6 of Chapter 2 in the Guidelines, and the acceleration is to be calculated in compliance with the requirements of 5.3.4.1 of this Chapter.

5.4.2.4 Inertial force of light ship means the one obtained by multiplying mass model only consisting of structural mass, excluding the mass of cargo, ballast water, etc., with acceleration of model motion.

5.4.3 Inertia balance for loads

5.4.3.1 The application of inertial force on each node and dynamic balance of external force of the global FE model may be achieved by loading and balance adjustment. The general flow chart of the whole ship's dynamic adjustment is shown in Figure 5.4.3.1.

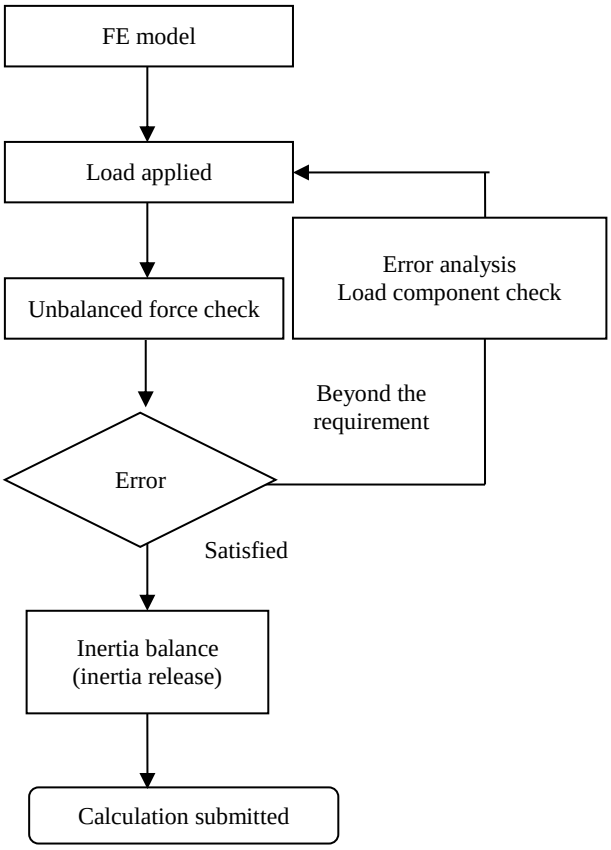


Figure 5.4.3.1 General Flow Chart of the Whole Ship's Dynamic Balance

5.4.3.2 For each load case, the unbalanced forces of model on axes x, y and z are to be calculated and checked upon the completion of global load application. In the case of a head sea condition, the unbalanced force on each direction is not to exceed 1% displacement of ship; in the case of a beam sea condition or oblique sea condition, the unbalanced force is not to exceed 2% displacement of ship.

5.4.4 Constraint condition

5.4.4.1 After the whole ship's dynamic balance is adjusted, the calculation model has been in a free dynamic balance, and in order to prevent rigid body motion, boundary constraint is to be applied to the model with six constraints for degree of freedom.

5.4.4.2 When inertia release function is used to carry out structural strength analysis, the boundary constraint may be carried out through reference points, shown in Figure 5.4.4.2. In general, the intersection of midship and longitudinal centerline section (Node 1) is to be selected

as virtual supporting.

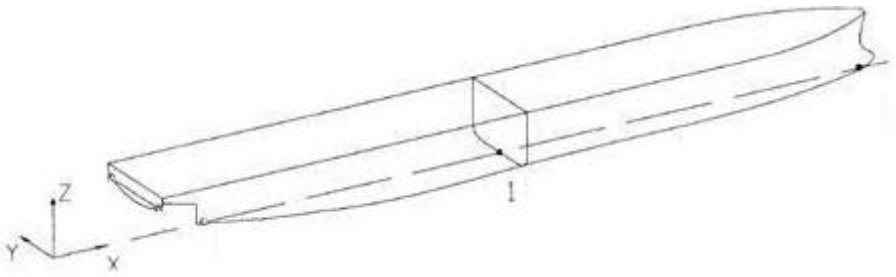


Figure 5.4.4.2 Diagram of Reference Point Position

5.5 Strength Assessment Criteria

5.5.1 Yield strength criteria

5.5.1.1 The yield strength criteria is as follows:

$$\sigma \le [\sigma]$$

where: σ — Von Mises corresponding stress of plate element center or axial stress of beam element for mesh area of spacing of frames, in N/mm^2;

$[\sigma]$ — allowable stress, in N/mm^2, to be calculated by:

$$[\sigma] = 220 / K \quad \text{N/mm}^2$$

K — material factor.

5.5.1.2 Where the refined mesh size is 50 mm × 50 mm, the stress criteria of refined mesh model is to be taken as 1.6 times of global FE allowable stress.

5.5.2 Buckling strength criteria

5.5.2.1 The buckling strength is to be checked by reference of the provisions on buckling strength assessment for hull structures in 4.1.6 in Chapter 4 of the Guidelines.

Appendix 1

Direct Strength Analysis of Engine Room Structures

1.1 General Requirements

1.1.1 Scope of application

1.1.1.1 This Appendix applies to direct strength analysis of engine room structures of very large ore carriers with the length of 350 m and above.

1.1.1.2 The direct strength analysis of engine room structures applies to strength assessment for the following structures:

1) longitudinal members of hull girders within engine room area;

2) transverse members within engine room area;

3) other primary supporting members within engine room area.

1.2 Structural Modeling

1.2.1 Extent of model

1.2.1.1 A three-cargo hold model is used in the direct strength analysis of engine room structures, generally including aft part, engine room and aftmost cargo hold adjacent to engine room, shown in Figure 1.2.1. For the ore carriers with specially arranged aftmost cargo holds, the extent of model is to be considered specially.

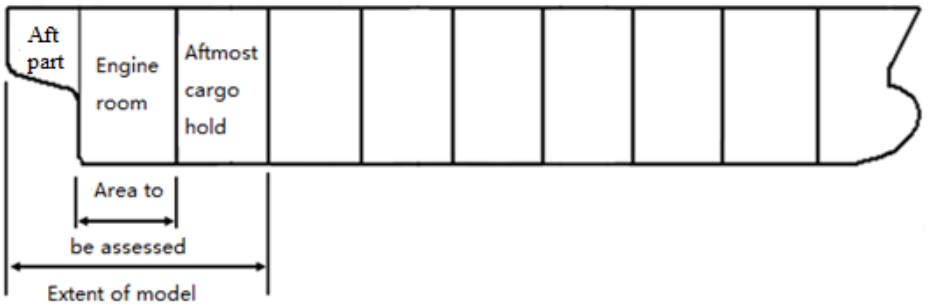


Figure 1.2.1 Extent of Model for Direct Strength Analysis of Engine Room Structure

1.2.2 Modeling requirements

1.2.2.1 The engine room is to be modelled according to actual hull structures. The superstructure, deckhouse, funnel, etc. located above the main deck may not be modelled, however, the effects of their weights on cargo hold model are to be taken into account.

1.2.2.2 The engine room is to be modelled by reference to structural modeling requirements for cargo hold areas specified in [3.2] of Chapter 3.

1) for the requirement for element size, see [3.2.2.2] of Chapter 3;

2) for the requirement for FE element type, see [3.2.4.1] of Chapter 3;

3) for FE modeling requirement, see [3.2.4.2] of Chapter 3;

4) for the requirement for structural scantlings, see [3.2.4.3] of Chapter 3.

1.2.3 Boundary conditions

1.2.3.1 The boundary conditions for direct strength analysis of engine room structures are

defined in Table 1.2.3.1.

Boundary Conditions of Engine Room Model Ends Table 1.2.3.1

Location		Translational			Rotational		
		δ_x	δ_y	δ_z	θ_x	θ_y	θ_z
Fore end of model: Nodes on longitudinal members		Fix	-	Fix	-	Fix	Fix
		End of beam (see [3.2.5.5] of Chapter 3)					
Aft end of model	Independent point (at the height of neutral axis of longitudinal centerline section	-	Fix	-	Fix	M_{T-end}	-
	Nodes on longitudinal members	Rigid link	Rigid link	Rigid link	-	-	-
Independent point (intersection of longitudinal centerline section and inner bottom in way of fore bulkhead of engine room)		-	Fix	-	-	-	-

Notes:

(1) [-] means no constraint applied (free).

(2) Rigid link means connecting the nodes of longitudinal member at model ends with the corresponding points.

(3) M_{T-end}, see [1.3.2.5].

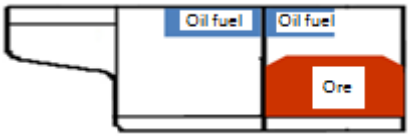
1.3 Loads

1.3.1 Load combinations

1.3.1.1 The load combinations specified in Table 1.3.1.1 are to be taken into consideration for direct strength analysis of engine room structures. If special compartment is arranged within engine room area or special load case is defined in loading manual, additional consideration is to be taken.

Load combinations for Direct Strength Analysis of Engine Room

Table 1.3.1.1

No.	Description	Loading pattern	Draught	Still water shear force C_{SF_LC}	Still water bending moment C_{BM_LC}	Designed wave (see [2.2.1] of Chapter 2)
1	Full load departure		T_{SC}	100%	100%	HSM-2 BSP-2P
2	Full load arrival		T_{SC}	100%	100%	HSM-2 BSP-2P
3	Ballast arrival		T_{BAL}	100%	100%	HSM-2 BSP-2P

1.3.1.2 In each load combination, the applicable loads are to include the followings:

1) sea pressure, see [2.5.1] of Chapter 2;

2) ore load, see [2.6.3] of Chapter 2;

3) ballast water, oil fuel and other internal loads of large tanks, see [2.6.1] of Chapter 2;

4) The pressure P_{dl}, in $\mathrm{kN/m^2}$, caused by homogeneously distributed loads on non-exposed deck and platform, is to be calculated by the following equation:

$$P_{dl} = \left(1 + f_\beta \frac{a_{z-env}}{g}\right) P_{dl-s}$$

where:

f_β: correction coefficient of wave direction, see [2.4] of Chapter 2;

a_{z-env}: envelope vertical acceleration, in $\mathrm{m/s^2}$, see [2.3.4.3] of Chapter 2;

P_{dl-s}: local static pressure, in $\mathrm{kN/m^2}$.

5) The concentrated load, F_U, in kN, caused by heavy machines within engine room is to be calculated by the following equation:

$$F_U = (1 + f_\beta * a_{z-env}) m_U$$

Where:

m_U:weight of machine, in t.

6) For hull and superstructure, only static loads are to be considered. If the superstructure, deckhouse, funnel, etc. above main deck are not modelled, their weights are to be applied on upper deck supporting members of these structures in the form of homogeneously distributed loads.

1.3.2 Adjustment of target hull girder loads

1.3.2.1 In each load combination, the hull girder vertical bending moment and shear force are to be adjusted to a target value. The procedure is to adjust the vertical shear force firstly, then to adjust the vertical bending moment.

1.3.2.2 The location of target hull girder shear force is to be in way of each main web frame of engine room area, including fore and aft bulkheads of engine room, and is to be extended two main web frames outside the engine room area. The target shear force, Q_{targ} in way of each main web frame is to be calculated by the following equation:

$$Q_{\mathrm{targ}} = C_{\mathrm{SF_LC}} * Q_{\mathrm{sw}} + f_{\beta} * C_{QW} * Q_{\mathrm{wv}}$$

where:

$C_{\mathrm{SF_LC}}$: coefficient of still water shear force, see Table 1.2;

Q_{sw}: allowable still water shear force, in kN, under sea-going condition;

C_{QW}: coefficient of combination of wave shear force, see [2.2.3] of Chapter 2;

Q_{wv}: wave shear force, in kN, under sea-going condition, see [2.4.3.2] of Chapter 2.

1.3.2.3 The target hull girder vertical bending moment is to be located in way of fore bulkhead of engine room, and the target bending moment $M_{\mathrm{v-targ}}$, is to be calculated by the following equation:

$$M_{\mathrm{v-targ}} = C_{\mathrm{BM_LC}} * M_{\mathrm{sw}} + f_{\beta} * C_{\mathrm{WV}} * M_{\mathrm{wv}}$$

Where:

C_{BM_LC}: coefficient of still water bending moment, see Table 1.2;

M_{sw}: allowable vertical bending moment, in kN.m, under sea-going condition;

C_{WV}: coefficient of combination of wave bending moment, see [2.2.3] of Chapter 2;

M_{wv}: wave bending moment, in kN.m, under sea-going condition, see [2.4.3.1] of Chapter 2.

1.3.2.4 In order to achieve the target value of hull girder shear force, the vertical shear force adjusted value, Q_{i}, is to be applied in way of main web frame defined in 1.3.2.2. Referring to [3.3.4.7] of Chapter 3, Q_{i} is to be applied on the corresponding transverse section through shear flow distribution method. The target shear force is to be adjusted according to Figure 1.3.2.1.

$$Q_1 = Q_{targ-1} - Q_{fem-1}$$

$$Q_{\mathrm{i}} = Q_{targ-i} - Q_{fem-i} - \sum_{j<i} Q_j$$

where:

Q_{i}: the adjusted shear force in kN, in way of i$^{\mathrm{th}}$ main web frame;

Q_{targ-i}: the target shear force, in kN, in way of i$^{\mathrm{th}}$ main web frame, see [1.3.2.2];

Q_{fem-i}: shear force, in kN, caused by local load in way of i$^{\mathrm{th}}$ main web frame.

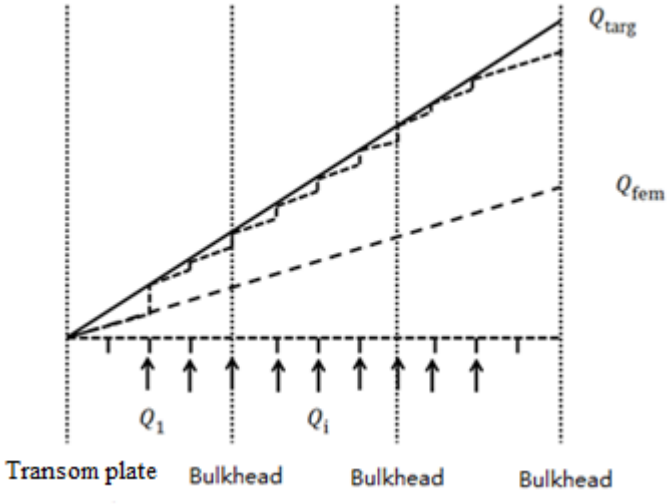


Figure 1.3.2.1 Adjustment of Target Hull Girder Shear Force

1.3.2.5 In order to achieve the target value of hull girder vertical bending moment in way of target location, the adjusted bending moment, M_{T-end}, is to be applied on the model ends. The target vertical bending moment is to be adjusted according to Figure 1.3.2.2.

$$M_{T-end} = M_{v-\text{targ}} - M_{\text{fem}} - \sum Q_{i*} l_i$$

where:

M_{T-end}: the adjusted vertical bending moment, in kN.m, at the model ends;

$M_{v-\text{targ}}$: the target vertical bending moment, in kN.m, see [1.3.2.3];

M_{fem}: the vertical bending moment, in kN.m, caused by local load in way of fore bulkhead of engine room;

Q_i: the adjusted shear force, in kN, in way of ith main web frame, see [1.3.2.4];

l_i: the distance, in m, between ith main web frame and aft end of model.

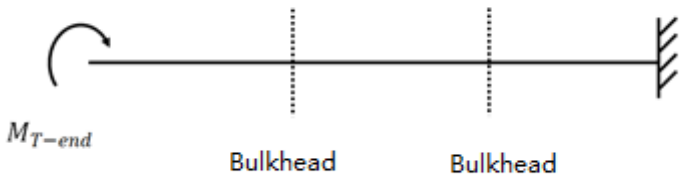


Figure 1.3.2.2 Adjustment of Target Hull Girder Bending Moment

1.4 Analysis Criteria

1.4.1 Extent of assessment

1.4.1.1 The extent of assessment is indicated in Figure 1.2.1.1. The primary members of engine room are to be carried out yield and buckling strength assessments in accordance with the requirements of [1.4.2] and [1.4.3].

1.4.2 Yield strength assessment

1.4.2.1 The yield strength assessment for primary members of engine room is to be carried out in accordance with the relevant requirements of [3.4.2] in Chapter 3.

1.4.3 Buckling strength assessment

1.4.3.1 The buckling strength assessment for primary members is to be carried out in accordance with the relevant requirements of Chapter 4.

Appendix 2

Requirements for Finite Element Calculation of Cargo Hold Carrying Ores Containing Moisture

2.1 General Requirements

2.1.1 Scope of application

2.1.1.1 The structural strength FE analysis for ore carriers carrying ores due to the change of moisture is to be carried out in accordance with the requirements of this Section.

2.1.1.2 FE yield strength and buckling strength analyses of cargo holds with the effects of moisture content are to be carried out for midship, foremost and aftmost cargo holds.

2.1.2 Applicable conditions

2.1.2.1 When the moisture content of ore is lower than TML, it may be regarded as a dry condition and FE direct analysis is to be carried out in accordance with the requirements of the Guidelines.

2.1.2.2 When the moisture content of ore is higher than TML, it may be regarned as a liquid condition and strength assessment is to be carried out in accordance with the requirements of the Guidelines.

2.2 Liquefied Ore Loads and Calculation Conditions

2.2.1 Loads

2.2.1.1 The loads considered for FE analysis of cargo holds under liquefied ore condition are to include hydrostatic and dynamic pressures of cargo, hydrostatic and dynamic pressures of ballast water and oil fuel, external hydrostatic and dynamic pressures and hull girder load.

2.2.1.2 The hydrostatic pressure of liquefied ore is to be calculated by the following equation:

$$P_{bs} = \rho_C g K_C \left(h_C - z \right)$$

where:

ρ_C — density of liquefied ore, not considered the effects of moisture content;

K_C — coefficient of load, to be taken as 1.0 for liquefied ore;

h_C — height of liquefied ore loaded, to be calculated by cargo surface level according to carrying capacity M under loading condition.

2.2.1.3 The dynamic pressure of liquefied ore is to be calculated by the following equation:

$$P_{bd} = \rho_C \left[a_X \left(x_G - x \right) + a_Y \left(y_G - y \right) + K_C a_Z \left(h_C - z \right) \right]$$

where:

ρ_C、K_C、h_C — to be taken by the above-mentioned equation for hydrostatic pressure;

x_G、y_G — center of gravity of hold, as defined in Section 2, Chapter 2 of the Guidelines;

a_X、a_Y、a_Z — acceleration in way of center of gravity of hold, as defined in Section 2, Chapter 2 of the Guidelines.

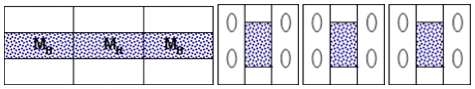
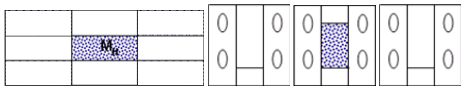
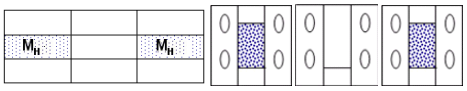
2.2.1.4 The external hydrostatic and dynamic pressures, hydrostatic and dynamic pressures of ballast water and oil fuel, as well as hull girder load are to be defined in accordance with the requirements of Chapter 2.

2.2.2 Loading conditions

2.2.2.1 The FE loading conditions of cargo holds under liquefied ore condition are given in Table 2.2.2.1. If other loading conditions of loading manual are more severe than those specified in Table 2.2.2.1, direct strength analysis is also to be carried out for such loading conditions.

Loading Conditions of Direct Strength Analysis for Liquefied Ore Holds

Table 2.2.2.1

No.	Description	Loading pattern	Draught	Still water bending moment	Wave condition
1	Homogeneously loaded — heavy cargo		T_{SC}	100% SAG	HSM-1 BSP-1P
2	Multiport -1		0.67 T_{SC}	100% SAG	HSM-1 FSM-1 BSP-1P
				100%(1) HOG	HSM-2 FSM-2
3	Multiport - 2		0.83 T_{SC}	100% SAG	HSM-1 FSM-1 BSP-1P
				100%(1) HOG	HSM-2 FSM-2

2.3 Finite Element Model

2.3.1 Extent of model

2.3.1.1 In line with the requirements of Section 2, Chapter 3 of the Guidelines, three-cargo holds model is to be adopted and the length of model is to cover the whole three holds.

2.3.2 Element meshing

2.3.2.1 According to the requirements of Section 2, Chapter 3 of the Guidelines.

2.3.3 Boundary conditions

2.3.3.1 According to the requirements of Section 2, Chapter 3 of the Guidelines.

2.4 Assessment Areas and Criteria

2.4.1 Assessment areas

2.4.1.1 For the structural strength assessment of cargo holds under liquefied cargo conditions, the following structural areas are to be focused on:

(1) web frame of ballast tanks;

(2) lower area of longitudinal bulkheads;
(3) corrugated bulkheads and lower stools;
(4) longitudinal girders.
2.4.2 Assessment criteria
2.4.2.1 The strength assessment criteria is to be in accordance with the requirements of Seciton 4, Chapter 3 in the Guidelines.

2.5 Buckling Strength Assessment

2.5.1 The hold based FE buckling strength assessment is to be carried out in accordance with the requirements of Chapter 4 in the Guidelines.

Appendix 3

Requirements for Hull Structural Fatigue Strength Assessment of Ore Carriers

3.1 General Requirements

3.1.1 This Appendix applies to hull structural fatigue strength assessment for ore carriers.

3.1.2 Those not covered by this Appendix are to be in accordance with the relevant requirements in CCS Guidelines for Fatigue Strength of Hull Structures.

3.1.3 In general, hull structural nodes in way of critical locations within cargo hold areas are selected to carry out fatigue strength assessment. For ore carriers, at least the following locations are to be checked:

(1) in way of connection of longitudinals (bottom, side, deck and inner hull) and transverse web frame;

(2) in way of connection of longitudinals (bottom, side, deck and inner hull) and transverse bulkheads;

(3) in way of connection of inner longitudinal bulkhead and inner bottom plating;

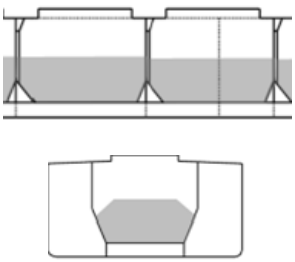
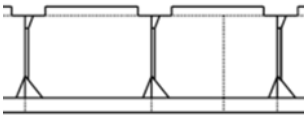
(4) in way of connection of inner bottom plating and lower stools;

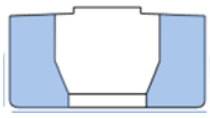
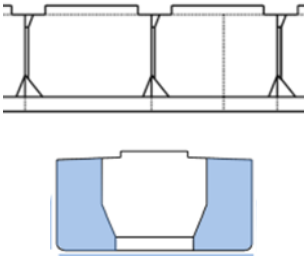
(5) in way of knuckle of inner longitudinal bulkhead (if any).

3.2 Loading Conditions and Loads

3.2.1 The loading conditions of fatigue assessment for ore carriers are to include homogeneously full load condition, normal ballast condition and maximum ballast condition (if any), with the detailed requirements given in Table 3.2.2.

Loading Conditions of Fatigue Assessment **Table 3.2.1**

Loading condition of fatigue assessment	Loading pattern	Draught	Correction coefficient of still water bending moment C_{SW}	Loading capacity of cargo hold M（t）	Density of dry cargo in bulk ρ_C（t/m^3）	Time distribution factor α
Homogeneously full load		Full loaded draught	0.8 (sagging)	M_H	Permissible maximum designed cargo density	0.5
Normal ballast		Light ballasted draught	0.6 (hogging)	—	—	0.35, if there is no extra data, 0.175 for

						normal ballast and maximum ballast, respectively
Maximum ballast (if any)		Maximum draught under ballast condition	0.65 (sagging)	—	—	

3.2.2 The fatigue loads of ore carriers are to be calculated in accordance with the relevant requirements of bulk carriers in Chapter 2 of CCS Guidelines for Fatigue Strength of Hull Structures. Unless provided in loading manual, k_r and *GM* which are adopted for motion calculation of fatigue assessment are to be taken in accordance with Table 3.2.2.

k_r and *GM* for Ore Carriers **Table 3.2.2**

Loading conditions of fatigue assessment	k_r	*GM*
Full load	*0.35 B*	*0.12 B*
Normal ballast	*0.45 B*	*0.33 B*
Maximum ballast	*0.40 B*	*0.25 B*

3.3 Simplified Stress Analysis

3.3.1 The simplified stress analysis method applies to fatigue strength assessment of connected nodes in way of ends of longitudinals for ore carriers. The simplified stress analysis is to be carried out in accordance with the relevant requirements of Chapter 4 of CCS Guidelines for Fatigue Strength of Hull Structures.

3.4 Finite Element Hot Spot Stress Analysis

3.4.1 Finite element hot spot stress analysis method applies to fatigue strength assessment of welded nodes and non-welded nodes for ore carriers. FE hog spot stress analysis of ore carriers is to be carried out in accordance with the relevant requirements of Chapter 5 of CCS Guidelines for Fatigue Strength of Hull Structures.

3.4.2 In the process of FE stress analysis, each calculation condition is to be divided into overall load case and local load case, and the hot spot stress is to be obtained by the combination of stresses under overall load case and local load case, and calculated according to the following equation:

$$\sigma_C = f_{ch}\sigma_{HG} + C_{VT}f_{cl}\sigma_L \quad \text{N/mm}^2$$

where: σ_{HG} — hot spot stress, in N/mm^2, under overall load case;

σ_L — hot spot stress, in N/mm^2, under local load case;

f_{ch}、f_{cl} — correction coefficient of corrosion, see 1.6.1 of Chapter 1 in CCS Guidelines for Fatigue Strength of Hull Structures;

C_{VT} — correction coefficient of ship type, for ore carriers, to be determined by the following requirements:

C_{VT}=0.6, for hot spot in way of connection of inner bottom plating and lower stool onboard ore carrier;

C_{VT}=0.9, for other hot spots onboard ore carrier.