Guidelines For Classification And Construction

Part 5 Offshore Technology

Volume 3

GUIDELINES FOR FLOATING PRODUCTION INSTALLATIONS

2021

Biro Klasifikasi Indonesia

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Amendments to the preceding Edition are marked by red color and expanded text.

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Foreword

These Guidelines provide new edition to the “Guidelines for Floating Production Installations (Pt.5, Vol. 3), 2013 Edition” along with the effective dates from which these changes are applicable.

These new edition gives amendments on design, construction, and survey after construction of the floating installation (including hull structure, equipment and marine machinery), the position mooring system and the hydrocarbon production facilities. Floating installations in this Guidelines covering ship types, column-stabilized types, tension leg platforms, and spar installations are included, as well as existing vessels converted to FPI. Requirements for optional notation for disconnectable floating installations, dynamic positioning systems, and import/export systems are also provided. This Guidelines will be used in conjunction with other BKI Rules and Guidelines, as defined herein.

The summary of current amendments for each section including the implementation date are indicated in *Guidelines Amendments Notice* pages.

These Guidelines is available to be downloaded at www.bki.co.id. Once downloaded, this Guidelines will be uncontrolled copy. Please check the latest version on the website.

Further queries or comments concerning this Rules are welcomed through communication to BKI Head Office.

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Guidelines Amendment Notice

These amendments will come into force for Floating Installations (e.g, Ship types, TLP, Columns Stabilized, Spar) contracted for construction* on or after **1st January 2022,** unless specified otherwise in the table.

Note:

**The "contracted for construction" date means the date on which the contract to build the ships is signed between the prospective owner and the shipbuilder. For further details regarding the date of "contract for construction", refer to IACS Procedural Requirement (PR) No. 29.*

Paragraph	Title/Subject	Status/Remark
Section 1 – Classification ** The requirements in Section 1.A.8 will come into force on 1st June 2022*		
1.A.	System Classification Boundaries, Symbols and Notations	
1.A.1	Classification Boundaries	
	The minimum scope of class is described throughout this section and covers the installation, the mooring system, and safety systems. Accommodations and deck appurtenances such as helideck, are considered within classification boundaries.	To clarify the classification bounderies
1.A.2	Class designation for Hull	Replaced with new requirements by changing the title and its contents. This subsection address about character class and class notation for hull.
1.A.3	Additional Class Notation for Hull	Change the title and add some new additional notations for hull.
1.A.4	Class design for Mechinery	Replaced with new requirements by changing the title and its contents. This subsection address about character class for machinery.
1.A.5	Additional Class Notation for Machinery	Change the title and to collect additional notations for machinery into one subsection.
1.A.6	Systems not Built Under Survey	Renumbering
1.A.7	Conversion of Existing Vessels or Floating Structures	Renumbering
1.A.8	Significant Change of Operating Conditions Affecting Safety of Unit or Personnel *	Add new requirements related affecting safety unit or personel due to significant change of operating.
1.C	Submission of Plans, Data and Calculations	
1.C.1	Design Plans and Data	Add a list of plan to be submitted
1.C.2	Position Mooring System Design Documentation	Add some list of design documentation to be submitted
1.C.3	Production Facilities and Production Support Facilities	Add requirement about data to be submitted
1.C.4	Marine Systems and Machinery Plans	Add requirements about data to be submitted
1.C.6.2	Procedures	Add a list of procedures to be submitted
Section 2 - Installation Types, Functions, Features and General Requirements		

Paragraph	Title/Subject	Status/Remark
2.A.	General Descriptions	
2.A.1.1	Purpose	
	Floating Production, Storage and Offloading: FPSO Floating Production (and Offloading): FPO Floating Storage and Offloading: FSO Floating Offshore Installation: FOI	Delete a word "unit" and make abbreviation of Class Notation of hull for FPI.
2.A.1.2	Major Element	
	Position Moooring System = Mandatory	To exclude the scope of hull notation (FPSO, FPO, FSO, FOI) related position mooring system from its notation elements. Position mooring system is mandatory for FPI with additional notation "POSMOSYS"
2.A.4.1	General	
	...Typical mooring system types include spread mooring, turret mooring, single point mooring and thruster assisted mooring.	To clarify the many kinds of mooring system type.
2.B	Design Basis and Environmental Loading	
2.B.3.1	Position Mooring System	
	Detailed requirements for the design environmental conditions, design operating conditions and disconnectable conditions are provided in Section 6.B.1.1.	Requirements related design environmental conditions (DEC, DOC, Disc) were moved into Section 6.B.1.1
2.B.3.2.4	Strength and Fatigue Life	
	When referred to elsewhere in these Guidelines, the safety factors for fatigue life are defined in Table 2.1 shown below.	Add requirements of Safety Factors for Fatigue Life.
2.B.4	Environmental Conditions	
2.B.4.1	General	Add a list of evironmental data are normally to be provided.
2.B.4.3	Current and Current Load	Change the title and to add some new requirements related current load.
2.B.4.4	Current and Wind Load under Oblique Environment	Add new requirement related current and wind load unader oblique environmental
2.B.4.6	Squall Load	Add new requirement related squall load.
2.B.4.7	Wave and wave load	Change the title and add requirements related wae drift load in 4.7.2
2.B.4.8	Wave-induced Motion of a Floating Unit	To change the title and renumbering
Table 2.5	Line Drag Coeffecient	Add New table related Line Drag Coeffecient.
2.C	General Requirements	
2.C.1.2	Lightweight Data	
	For specific requirements related to non-ship-type installations, refer to Section 5.A.3 or 5.B.2.	Add infromation about reference for spesific requirements.
2.C.1.3	Maximum Draft	Change the title and to add some new requirements.
2.C.1.4	Stability	Change the requirements .

Paragraph	Title/Subject	Status/Remark
2.C.1.9	Onboard Computers for Stability Calculations	Add information related the use of onboard computers for stability calculations.
2.C.1.10	Corrosion Protection of Steel	Add information releted corrosion protection of steel.
2.D	Installation, Hook-up, and Commissioning	
2.D.1.5	Hook-up of the Anchor Chain System	Add a list of procedure for hook-up of the anchor chain system.
2.D.4	Surveys During Installation, Hook-up and Commissioning	Change the requirements that are refer to Section 3.A.
Section 3 – Surveys *** ISIP will be come into force on 1st June 2022*		
3.A.	Surveys During Construction, Installation and Commissioning 1. General 2. Survey During Hook-Up 3. Surveys of the Mooring Systems 4. Surveys of the Import/Export Systems 5. Surveys of Disconnectable Systems 6. Surveys During Commisioning	Replaced with new requirements by changing the title and its contents. Changes were made to provide requirements more systematic for surveys during construction. In general, the contents of the requirements are developed from Section 2, D.
3.B.	Surveys After Construction 1. Conditions for Surveys After Construction 2. Surveys Interval 3. Survey Pre-Planning and In-Service Inspection Program (ISIP)** 4. Annual Surveys 5. Intermediate Surveys 6. Class Renewal Surveys 7. Drydocking Surveys or Equivalent 8. Tail Shaft and Tube Shaft Surveys 9. Boiler Surveys 10. Crew Habitability on Offshore Installations	Replaced with new requirements to provide requirements more systematic and in order to harmonize its pattern with other BKI Rules for surveys. In general, contain requirements are taken from requirements of Section 3 of the previous edition. Those requirements are distributed into each Sub-Section appropriately which are arranged based on the survey interval. There are some new requirements are introduced, i.e: Survey pre-planning and In-Service Inspection Plan (ISIP) and crew habitability on offshore installations. ISIP is applied in conjunction with Annex 10 Offshore Hull Monitoring Program to planning, identified and recorded critical area, delineates what information the shipyard is to include in the construction monitoring plan, and lays out the certification regime to be followed
Section 4 – Ship-Type Installations		
4.A.	Design Considerations	
4.A.1.	General	
4.A.1.1	Introduction	
	The relevant sections of design criteria are listed in Table 4.1 to Table 4.5 and Fig. 4.1 ……	Add information related to the list of applicable Sections corresponding to its design criteria.

Paragraph	Title/Subject	Status/Remark
	For a Ship-Type Installation with length in excess of 350 meters, the hull structure and critical structural details are to comply with the requirements for Dynamic Loading Approach (DYLA) and Spectral Fatigue Analysis (SFA). …….	To clarify the application of Guidelines for DYLA and SFA for each installation which have length > 350 m. All installation which comply with these guidelines will be assigned with **DYLA** and **SFA** notations respectively.
Table 4.1	**Design Considerations and General Requirements for Ship-Type Installations**	Add new table to provide a guide when using applicable section corresponding to its design criteria
Table 4.2	**Structural Design Requirements for New Build Installations within 0,4L For Ship-Type Installations ≥ 150 meters (Amidship)**	
Table 4.3	**Structural Design Requirements for New Build Installations Beyond 0,4L For Ship-Type Installations ≥ 150 meters**	
Table 4.4	**Structural Design Requirements for New Build Installations Within 0,4L For Ship-Type Installations <150 meters (Amidship)**	
Table 4.5	**Structural Design Requirements for New Build Installations Beyond 0,4L For Ship-Type Installations <150 meters**	
Fig. 4.1	**Ship Type Installations**	Add new figure to provide an illustration portion of ship type installations
4.A.1.4.4	**Strength Check for Impact Loads**	
	….. For Ship-Type Installations with spread mooring having significant overhanging sterns or relatively flat stern cross sections, structural strength against stern slamming load is additionally to be assessed. …..	Add new requirements on how to assessed slamming load due to significant overhanging stern for ship installation using spread mooring system.
4.A.2	**Longitudinal Strength**	
4.A.2.1	**Longitudinal hull girder strength**	
	Longitudinal strength is to be based on Rules for Hull (Pt.1, Vol. II) Sec. 5. The required hull girder section modulus for 0.4**L** amidships is to be the greater of the values obtained from the following equation or the minimum section modulus Wmin in the table below: …….	To clarify requirements for hull girder section modulus in 0,4 L.
4.A.2.1.1	**Wave Loads - Modified for Site-Specific Environmental Conditions**	Deleted (move to Section 4, C.2.3.2)
Fig. 4.1-4.4	-	Deleted and renumbering to be Fig. 4.9 -4.12
4.A.3	**Structural Design and Analysis of the Hull**	
4.A.3.1.2	**Superstructures and Deckhouses**	
	……. The design of buildings on top of the topside module is to be in accordance with the applicable requirements of the Rules for Facilities on Offshore Installations (Pt.5, Vol. XII).	To clarify requirements for design building on top of topside module.
4.A.3.1.7	**Materials and Welding**	
	For major hull interface structure as defined in 4.1, underdeck and hull interface plating or …..	Add new requirement releted specify of material on major hull interface and longitudinal.
4.A.3.1.10	**Bilge Keels**	

Paragraph	Title/Subject	Status/Remark
	For bilge keels 500 mm or less in depth, the requirements are given in Rules for Hull (Pt.1, Vol. II) Sec. 6, F. In addition to the requirements included in the above Rules for Hull (Pt.1, Vol. II), bilge keels greater than 500 mm in depth with single web or closed construction form are to be modelled ……..	Add requirements for structural design of bilge keel
4.A.3.2.2	Strength Analysis of the Hull Structure	
	For installations of 150 m in length and above, the required strength assessment of the hull structure is to be based on a three cargo length tank length finite element model amidships ……	To clarify requirements for strength analysis of the hull structure to be based on 3-cargo hold length FEM model.
4.A.3.2.3.1	Structural FE Model	
	For FPI conversions, as an alternative, a complete hull length or full cargo block length finite element model can be used in lieu of the three cargo tank length model.	To clarify alternative of 3 cargo tank length model in FPI conversion.
~~4.A.3.2.4~~	~~Alternative Approach - Cargo Block or Full Ship Length Model~~	Deleted (move to Section 3, B.1.3.4)
4.A.3.2.6	Renewal Scantlings	Add new requirements related to renewal criteria for both of new construction and conversion FPI
4.A.4.	Design and Analysis of Other Major Hull Structural Features	
	….. ~~Criteria applicable to the position mooring (e.g., turret) structure itself is given in Section 6, B.1, and~~ the above (or on) deck equipment or module structure is referred to in Section 7, A.7.	Deleted requirements of design analysis for position mooring section.
4.A.4.4.1	Yielding Checks	
	….. In no case is the plate element size required to be less than the plate thickness.	Add requirements of plate element size in yielding check using FE analysis.
Table 4.1	Safety Factors for Fatigue Life of Hull Interface Structures	Deleted (move to Section 2 to be Table 2.1)
4.A.5	Modules on Deck	
4.A.5.1	This section is applicable to ship-type installations which class topside production facilities or where the optional notation Topside Modules is requested. …… Fatigue analysis of the topside module/hull interface is required (see 4.4.3). Fatigue analysis of the modules on ship-type installations is optional, and where requested by the Owner.	Add new notation “Topside Modules” To clarify application fatigue analysis on topside module is optional.
4.A.6.	Other Systems	
4.A.6.1.2	Electrical Systems	
	……..For area classification requirements, refer to Section 7, A.9.	Add requirements to determined area classification.
4.A.6.1.5	Hydrocarbon Storage in Hull Tanks	
	If the ship-type installation to store hydrocarbons in hull tanks, …….	Corrigenda
4.B.	Additional Design Considerations for Conversions to FPI	

Paragraph	Title/Subject	Status/Remark
4.B.1.3.4	Alternative Structural Model Approach - Cargo Block or Full Ship Length Model	Add new requirements for alternative structural model approach of conversion FPI
4.B.1.5.1.2	Special Survey of Hull	
	A Class Renewal Survey of Hull, ……. ……. During the conversion of an existing vessel or reconversion of a unit, all tanks required to be coated by 1.5.1.3 are to be made available for examination by the BKI Surveyor after the cleaning and surface preparation has been done ……..	Editorial changes and add requirements for checking all tank to be hard coated.
4.B.1.5.1.3	Modifications	
	….. Additionally all ballast and void tanks are to be hard coated and the coating is to be in good condition. These coatings should follow Guidance for the Corrosion Protection and Coating Systems (Pt.1, Vol. G) or recognized standard.	Add requirements for coated all ballast tank and void tanks
4.B.3	Fatigue Consideration (Remaining Fatigue Life)	
4.B.3.2	Remaining Fatigue Life	
	$\frac{S_{priorConv}}{L_{P,PriorConv}} + L_{R,PostConv}$	Corrigenda formula
4.B.3.3	Remaining Fatigue Life for Longitudinal Stiffener Connections	Corrigenda formula
4.C.	Structural Design Requirements	
4.C.1.	General	
4.C.1.3.18	Produced Water Tanks	Add requirements for tank designated for produced water
4.C.2.	Loads	
Fig. 4.8C	Loading Pattern - Repair and Inspection Conditions for Double Hull and Double Side Single Bottom FPSO/FSO*	Add loading pattern for transit loading condition
Fig. 4.8D	Loading Pattern - Repair and Inspection Conditions for Single Hull FPSO/FSO	Add loading pattern for transit loading condition
4.C.2.3.2	Vertical Wave Bending Moment and Shear Force	Add formula to determined of vertical wave bending moment and shear forces.
Fig. 4.9	Sign Convention	New figure (old number Fig. 4.1)
Fig. 4.10	Distribution Factor M	New figure (old number Fig. 4.2)
Fig. 4.11	Distribution Factor F1	New figure (old number Fig. 4.3)
Fig. 4.12	Distribution Factor F2	New figure (old number Fig. 4.4)
Table 4.9A	Combined Load Cases*	Change coefficient in item pitch (c_{ϕ},)
Table 4.11	Design Pressure for Local and Supporting Members	Editorial changes
4.C.2.7	Impact Loads	
4.C.2.7.1	Impact Loads on Bow	
	γ_{ij} = local bow impact angle measured to the shell from the horizontal to the tangent line at the position considered, but is not to be less than 50°. Where this angle is not available, it can be taken as $\tan^{-1}(\tan \beta_{ij}/\cos \alpha_{ij})$	To clarify parameter values of local bow impact angle
4.C.3.	Initial Scantling Calculation (ISCal)	
Fig. 4.30	Scantling Requirement Reference by Subsection	Update reference

Paragraph	Title/Subject	Status/Remark
Fig. 4.31A Fig. 4.31B	Definitions of Spans (A) Definitions of Spans (B)	Add note that described of span between lower and upper end of the vertical web
4.C.3.2.1.3	Extent of Midship Scantlings	Add requirement to determined extent of midship scantlings
4.C.3.2.2	Hull Girder Moment of Inertia	Add formula to calculate hull girder moment of inertia
4.C.3.2.3	Hull Girder Ultimate Strength	Editorial changes
4.C.3.3	Shearing strength	
4.C.3.3.1	General	Editorial changes
4.C.3.4.1.4	Bilge Longitudinal	Editorial changes
Fig. 4.33	Bilge Longitudinal	Editorial changes and add title of figure
4.C.3.4.2	Bottom Shell and Inner Bottom Plating	
	…….. For transversely stiffened and unstiffened bilge shell plating, buckling strength is to be assessed in total strength assessment in accordance with the requirements in 4.5. ……	Add requirements for calculation buckling strength of curved panel
4.C.3.4.2.1	Bottom Shell Plating	Editorial changes and replaced ordinary steel to be normal steel
4.C.3.4.4	Bottom Girders/Floors	
	Notes: The minimum scantling requirements of t_1 for bottom girders/floors may be reduced for the conversion of an existing CSR tanker to a ship-type FPI, ……	Add new note that described requirement t_1 of conversion existing CSR tanker.
4.C.3.4.4.4	Bottom Girders under Longitudinal Bulkhead	
	$t_1 = (0.045 \cdot L + 3.5)\ R$ [mm]	Corrigenda formula
4.C.3.5.2	Deck Plating	
	…….. From these locations to the ends of the installation, the deck area may be gradually reduced in accordance with: – The deck sectional area at 0,15L from the ends may be one-half of the amidships deck area. …….	To clarify requirements of reduced deck area outside of 0,4 L midship.
4.C.3.6	Side Shell and Deck - Main Supporting Members	
4.C.3.6.1	General	
	The Section modulus and web sectional area of the deck transverse and deck girders are not to be less than loading pattern 1 as specified in 3.6.2. For a deck transverse and/or deck girder that is subjected to reactions (forces and moments) from the topside structure, ……	Editorial changes that provide new requirement for loading pattern 2 subjected to reaction forces from the topside structure
4.C.3.6.2	Deck Transverses and Deck Girder – Loading Pattern 1	Change title
4.C.3.6.3	Deck Transverses and Deck Girders – Loading Pattern 2	Add requirements for calculation deck transverse and girder due to topside structures.
~~4.C.3.6.4~~	~~Deck structure in forebody~~	Deleted (move to 5.4.3) Sub-Section 3.6.5-3.6.10 Renumbering to be 3.6.4 – 3.6.9
~~4.C.3.6.5-4.C.3.6.10~~	~~Renumbering to be:~~ ~~3.6.4 – 3.6.9~~	
4.C.3.8	Bulkheads - Main Supporting Members	
4.C.3.8.7	Nontight Bulkheads	

Paragraph	Title/Subject	Status/Remark
	….Openings in the nontight bulkhead are to have generous radii and their aggregate area is not to exceed 33%, nor to be less than 10% of the area of the nontight bulkhead, but it is recommended to be as close to 33% as practicable. The opening area is to be evenly distributed between 0,1 and 0,9 of the bulkhead depth. …	Add new requirements to determined minimum opening in nontight-bulkhead.
4.C.4.	Global Strength Assessments	
4.C.4.2.2	Structural Members and Elements	
	σ_i = stress intensity $= \sqrt{\sigma_L^2 + \sigma_T^2 - \sigma_L \cdot \sigma_T + 3 \cdot \tau_{LT}^2}$ [N/cm^2] ……	Changes symbol stress and shear stress to be "σ" and "τ" respectively
4.C.4.2.3	….. For transverse plating with vertical stiffeners at locations within 1,5 m of the horizontal girder, stringer or cruciform connections, the combined effects of the calculated stress components are to satisfy the following stress limit :	Deleted and changes symbol stress and shear stress to be "σ" and "τ" respectively
4.C.4.3.1.2	Buckling Control Concepts	
	…… g) Bracket plates, flanges of brackets and stiffeners of tripping brackets and main supporting members end brackets are proportioned such that local instability is prevented, see 4.4.5.6	Add new procedure for buckling control concepts in brackets, flange of brackets and stiffener tripping brackets, etc.
4.C.4.3.2.1 4.C.4.3.2.3 4.C.4.3.5.1 4.C.4.3.6.1	Buckling Limit State Ultimate Strength Buckling Criteria Local Plate Panels	Changes symbol stress and shear stress to be "σ" and "τ" respectively
4.C.4.3.7	Curved Plate Panels	Add new requirements of Buckling limit stated on curved panels
4.C.4.4.4.2	Corrugated Transverse Bulkheads	Corrigenda
4.C.4.4.5.6	Proportions of Unstiffened or Stiffened Brackets	Add new requirement of proportion of unstiffened and stiffened brackets
4.C.4.4.6	Curved Plates	Add new requirements of calculation critical bucking stress on curved plates
4.C.4.5.3.4	Generation of Stress Spectrum	
	….. Alternatively, for FPI conversions, in order to calculate the hot spot stress spectrum, load component spectral fatigue analysis (LC SFA) can be used provided the following are verified: ……	Add new alternative calculation of hot spot stress for FPI conversion
4.C.4.6.1	Calculation of Structural Responses	To clarify different method to calculation structural response between new build and conversion FPI.
Table 4.22	Allowable Stresses for Various Finite Element Fine Mesh Sizes	Editorial changes (changes mild steel = normal steel)
4.C.5.	Hull Structure Beyond 0,4 L Amidships	
4.C.5.2.3.1	Section Modulus	
	a) Longitudinally Framed Side Shell	Corrigenda
4.C.5.4.3	Forebody deck structure	New requirement (from Sub-Section 3.6.4)
4.C.6.	Application to Single Hull Ship-Type Installations	
4.C.6.2.1.1	Section Modulus of Bottom Transverses	

Paragraph	Title/Subject	Status/Remark
	$\alpha = \frac{\ell_g}{\ell_b} \cdot \sqrt[4]{\frac{I_b}{I_g} \cdot \frac{a_g}{a}} \leq 1,0$	Editorial changes
4.C.6.2.2.1	Section Modulus of Bottom Girders	
	$c = \alpha^2$ $\alpha = \left(\frac{\ell_b}{\ell_g}\right) \cdot \sqrt[4]{\frac{I_g}{I_b} \cdot \frac{a}{a_g}} \leq 1,0$	Change coefficient value "c" and σ_b
Table 4.23	Design Pressure for Local and Supporting Structures	
	5.*Deck Transverses with cross ties in wing tanks (Fig. 4.47)	Add new design pressure for deck transverse with cross ties
Fig. 4.51	Spans of Transverses and Girders	Add note that described of span between lower and upper end of the vertical web
4.C.6.2.4	Deck Transverses and Deck Girder – Loading Pattern 1	Change title
4.C.6.2.5	Deck Transverses and Deck Girders – Loading Pattern 2	Add new Sub-Section for calculation deck transverse and girder due to topside structures.
4.C.6.2.6	Longitudinal Bulkhead Vertical Webs	Sub-Section 6.2.5 renumbering to be 6.2.6
	ℓ_b = span of vertical web, [m], as indicated in Fig. 4.51. Where both lower and upper ends of the vertical web are fitted with a bracket of the same or larger size on the opposite side, the span □b may be taken between the toes of the effective lower and upper brackets	Add new requirements for determining span of vertical web.
4.C.6.2.7	Horizontal Girder on Transverse Bulkhead	Add new Sub-Section for calculation horizontal girder on transverse bulkhead
	Sub-Section 6.2.6 – 6.2.7 renumbering to be 6.2.8 – 6.2.9	
4.D	Ship -Type Installations Under 150 meters in Length	
4.D.1.	Introduction	
4.D.1.1.1	Classification	Editorial changes
4.D.1.1.2	Application	
	…….. In general, these Guidelines are valid for steel vessels not exceeding 150 m in length, L, and having a breadth, B, not exceeding one-fifth of the length, L, nor 2,5 (2,0 for steel vessels under 90 m) times the depth, Hs, to the strength deck.	To clarify application of Sub-Section D.
4.D.1.3.15	Testing	
	Requirements for testing are contained in Rules for Classification and Surveys (Pt.1, Vol.I) Annex A.2, E.1.8. This Rules are to be applied as far as applicable.	Update rules reference
4.D.2.	Hull Structures	
4.D.2.2.1.1	Bottom shell thickness	
	a) a = frame spacing [mm], but is not to be taken as less than: = min {864; (88% · (2,08 □ L + 438)} [mm]	To clarify value of **a**
	b) $t = 0,006 \cdot a \cdot \sqrt{0,7 \cdot T + 0,02 \cdot (L - 50)} + 2,5$	Editorial changes

Paragraph	Title/Subject	Status/Remark
	…….	
4.D.2.3.1	Amidships	
	…….. From these locations to the ends of the installation, the deck area may be gradually reduced in accordance with: – The deck sectional area at 0,15L from the ends may be one-half of the amidships deck area. …….	To clarify requirements of reduced deck area outside of 0,4 L midship.
4.D.2.7.2	Section Modulus	Editorial changes (changes mild steel = normal steel)
4.D.2.7.9	Struts	Editorial changes
4.D.2.9	Structure at Ends	Update rule references in order to harmonize with Rules for Hull (Pt.1, Vol.II)
Section 5 – Other Installation Types		
5.A.	Column-Stabilized Unit	
5.A.1.2	Definition	
	A column stabilized floating production installation consists of hull, topside deck and position mooring system. The hull may consist of pontoons, columns and bracing members. The tops of the columns are connected to a column top frame or a topside deck forming the global strength of the hull. For the hull with a column top frame, …….	Clarify the definition of column stabilized floating production installations.
5.A.4.4	Deck Clearance or Air Gap	Add title of sub section
	…… Guidance on air gap and horizontal wave impact analysis is provided in Rules for mobile offshore unit (Pt. 5, Vol. VI), Sec.5.B.2.6. ……	Add requirement related to air gap
5.A.2.	Structures	
5.A.2.1	Structural Design	
	The structural design criteria specified in this Section is presented in the Working Stress Design (WSD) format, also known as the Allowable Stress (or Strength) Design (ASD) format. For alternative structural design criteria, ….	To clarify that requirement in this sub-section are developed for Working Stress Design (WSD) criteria.
5.A.2.3.1	Hull, Integrated Deck and Top Column Frame	Change titles of sub-section and contain due to change of column stabilized installations
5.A.2.3.1.6	1) Material Yielding. For Hull, integrated deck and top column frame the yielding criteria based on the safety factors in Table 5.2 are to be used for bar and beam elements …..	To clarify acceptance criteria for Yielding and mesh size in design operating condition, loadout condition, damaged condition, etc.
5.A.2.3.2	Non Integrated Deck	Add new sub-section
	The design of non-integrated deck is to be based on applicable sections of the Rules for Facilities Offshore Installation (Pt. 5, Vol. XII) and B.3.3.2.	Add requirement related to calculation of non-integrated deck
5.A.2.5.2	Corrosion Protection and Control	
	…….. When reinforced coatings are installed (such as glass flake reinforced epoxy or thermally sprayed aluminium) which have satisfactory service experience ….	Add requirement related to how to handling reinforced coating.

Paragraph	Title/Subject	Status/Remark
5.A.3.	Stability	Change requirement related to transit voyage stability, onsite stability, lightweight and center of gravity, watertight and weathertight integrity and Penetrations based rules MOU (MODU Code)
5.B.	Tension Leg Platform	
5.B.2.	Stability	
5.B.2.1.1	Intact and Damaged Stability	
	Stability during wet tow to location is to comply with Coastal and Flag State requirements. If personnel will be on board during the tow, the stability is to meet the …….	Add requirement for stability during wet tow to location and during installation phase.
5.B.2.1.2	Weight Control	
	If integration of topsides takes place offshore, an alternative procedure may be applied using an inclining test or lightweight survey of the hull combined with weighing of the topside components to be installed. …….	Add requirement for weight control when integration topside take place offshore.
5.B.2.2.2	Watertight Integrity	
	All internal and external openings whose lower edges are below the levels to which watertight integrity is to be ensured, as shown by the diagrams submitted in accordance with C.2.2, are to be fitted with appliances to ensure watertight integrity……..	Add requirement related to how to ensure watertight integrity of all internal and external opening
5.B.2.2.3	Penetrations	Add requirement related to penetration on watertight bulkhead and flats.
5.B.3.	Hull and Primary Structures	
5.B.3.3.1	Hull, Integrated Deck and Top Column Frame	
5.B.3.3.1.6	Acceptance Criteria	
	1) Material Yielding. For the hull, integrated deck and column top frame, the yielding criteria indicated in Rules for Mobile Offshore Unit (Pt.5,Vol.VI), Sec.4.C is to be used. The safety factors are to be based on Table 5.3 are to be used for bar and beam elements. ……	To clarify acceptance criteria for Yielding and mesh size in design operating condition, loadout condition, damaged condition, etc.
	2) Buckling and Ultimate Strength For the hull, integrated deck and column top frame, the buckling criteria in API Bulletin 2V and 2U or other recognized standards are to be used. Alternatively, the criteria specified in the Guidance for Buckling and Ultimate Strength Assessment for Offshore Structures (Pt.5, Vol.C) or other recognized standards may be used	To clarify how to calculated Buckling and Ultimate strength.
5.C.	SPAR Installations	Add new Sub-Section for requirement of SPAR installations.
Section 6 – Position Mooring Systems		
	All	Change the title of this section and subsection followed by add new requirement related position mooring system in all subsection. Survey for mooring system was moved to Section 3.

Paragraph	Title/Subject	Status/Remark
6.A	General	Add new subsection for general requirements of position mooring system.
6.B	Mooring System Design B.1 Environmental Criteria B.2 Mooring System Design Requirement B.3 Mooring System Criteria B.4 Mooring Line Monitoring	Change the title of subsection and add requirements related mooring system design.
6.C	Mooring System Component C.1 General C.2 Mooring Line C.3 Anchore C.4 Chain Stopper C.5 Fairleads and Sheaves C.6 Winches and Windlass C.7 Quality Control C.8 Control Stations C.9 Single Point Mooring System	Add new subsection and to collect the requirements related mooring system component in this subsection.
6.D	Mooring System Analysis D.1 General D.2 Environmental Load D.3 Mooring System Analysis D.4 Fatigue Damage	Add new subsection and requirements of mooring system analysis.
Section 7 – Process and Import and Export Systems		
7.A	Hydrocarbon Production and Process Systems	
7.A.1.2	Installations Classed as FOI (Production Facilities not Classed)	
	…… For installations with the FOI classification symbol equipment certification is required for equipment in the above listed systems.	Change requirement of certification of production facilities to be mandatory.
7.A.1.4	Installations Classed as FSO without Production and process Facilities onboard	Add requirement related to FSO without production facilities on board.
7.A.4.	Subsea Equipment	
	…… For a unit that has the riser system classed by BKI, the riser installation winch needs to comply with the following: ……	Add requirement related to unit which classed with riser systems
7.B	Import and Export Systems	
7.B.1.	General This Subsection applies to import and export systems utilized in Floating Installations when the class notations specified in Section 1, A,3.3 are requested. ……	Editorial changes due to changing requirement in Section 1.
7.B.4.4	Export Vessel Transfer System	
	……. In complying with these standards, BKI requires the Owner to observe the guidelines as given in The OCIMF Guide to Manufacturing and Purchasing Hoses for Offshore Moorings and The OCIMF Tandem Mooring and Offloading Guidelines for Conventional Tankers at F(P)SO Facilities, as applicable. ……..	Add reference that requires observed by owner when requested to classing Export vessel transfer systems
Section 8 – Materials and Welding		

Paragraph	Title/Subject	Status/Remark
-	**Rules for Testing and Certification of Materials** Pt 1, Vol. V Rules for Material Pt.1, Vol. W Gidance for Approval and Type Approval of Material and Equipment for Marine Use **Rules for Welding and Fabrication** Pt.1, Vol. VI Rules for Welding	Update reference information
Annex 3 – Buckling Strength of Longitudinal Members Applied to Reassessed Scantling Determination (See 4.B.2/Fig 4.5)		
All	t_b = substantial thickness of plating	To clarify that thickness are used in buckling calculation of conversion FPI is substantial thickness.
A3.B.	Elastic Buckling Stresses	
A3.B.2.2	Torsional Buckling Mode	
	$10^{-4} \cdot \frac{\pi^2 \cdot E \cdot I_w}{I_p \cdot \ell^2} \left(m^2 + \frac{K}{m^2} \right) + 0{,}385 \cdot E \frac{I_t}{I_p}$	Editorial changes
Annex 4 – Determination of Environmental Severity Factors		
A4.A	General	
	ESF (α) factors are applied to longitudinal stiffener members in the ISCal fatigue analysis. ESF (β) factors are applied to the dynamic load components of the load formulations in the ISCal strength analysis and the GSA strength and fatigue analysis.	To clarify that ESF (α) and (β) are used in both of ISCal and GSA analysis.
A4.B	ESF's of the Beta (β) Type	
	Ls =most probable extreme value based on the intended site (100 years return pe-riod), transit (10 years return period), and repair/inspection (1 year return pe-riod) and fatigue (20 years return period) environments for the dynamic load parameters specified in Table A4.1	To clarify most probable extreme value in site also included fatigue for 20 years return period.
Annex 5 –Fatigue Strength Assessment of Ship- Type Installations Change titles that omitted "Guide"		
	All	Change symbol stress and shear stress to be "σ" and "τ" respectively
A5.A	General	Editorial Changes
A5.B	Connections to be Considered for the Fatigue Strength Assessment	
A5.B.2.1.	-	Editorial Changes
A5.B.2.3	-	Editorial Changes
Table A5.1	Fatigue Classification for Structural Detail	Add figure that illustrated doubler on face plate or flange in Class Designation G.
A5.C	Fatigue Strength Assessment	
A5.C.1.	Assumptions	Add reference information for developed a linear cumulative damage model.
A5.C.4.	Cumulative Fatigue Damage	

Paragraph	Title/Subject	Status/Remark
	$\sigma_{i,j-k}$ = heading probability for loading condition i, to be based on submitted actual information. …….	Change calculation of heading probability for loading condition based on submitted actual information
A5.K.	Combined Fatigue Damage	Corrigenda formula for total fatigue damage
A5.L	Fatigue Strength Assessment for Service as a Trading Vessel	
A5.L.1	Cumulative Fatigue Damage for Trading Vessels	Editorial change and corrigenda formula for cumulative fatigue damage for trading vessels
Annex 7–Finite Element Analysis for Ship-Type Installations Change titles that omitted "Guidelines"		
A7.A.	Objective	Editorial Changes
A7.E.1	Plate Elements	Editorial Changes due to change of figure reference
A7.F.	General Guidance for 3-D Global FE Modeling	Editorial change in item number 1) and 4)
A7.G.3	Target Hull Girder Vertical Bending Moment and Vertical Shear Force	Add title with term of "Target" to clarify of requirement.
A7.G.3.1	Hull Girder Vertical Bending Moment The hull girder vertical bending moment is to reach the following required value, $M_{v\text{-}targ}$, which is a combination of the rule-required still water bending moment and the wave-induced vertical bending moment,…….	Clarify that requirement of vertical bending moment is combination of rules required still water and wave bending moments
A7.G.3.2	Hull Girder Vertical Shear Force ……The target hull girder vertical shear force is a combination of the rule-required still water shear force and the wave-induced vertical shear force:	
A7.G.4	Target Hull Girder Horizontal Wave Bending Moment	Add title with term of "Target" to clarify of requirement.
A7.H	Procedure to Adjust Hull Girder Shear Force and Bending Moment	
A7.H.1	General	Add term of "Target" to clarify of general requirements.
A7.H.3	Procedure to Adjust Vertical Shear Force Distribution to Target Values	Add title with term of "to Target Values" to clarify of requirement.
A7.H.4	Procedure to Adjust Vertical and Horizontal Bending Moments to Target Values	Add title with term of "to Target Values" to clarify of requirement.
A7.H.4.3	Application of End Bending Moments to Achieve Target Values	Add title with term of "to Achieve Target Value" to clarify of requirement and editorial change in requirements.
Annex 8 – Guidelines for Hull Girder Shear Strength for Ship-Type Installations		
A8.A	Introduction	Editorial Changes or Corrigenda
A8.B	Allowable Still Water Shearing Force	Editorial Changes or Corrigenda
Annex 9 – Wave Impact Criteria		
A9.A	Application and Scope	Added new scope about SPAR vessels
A9.B	Impact Load	Added Hard Tank as item subject to impact load in SPAR vessel.

Paragraph	Title/Subject	Status/Remark
A9.D	Structural Strength	Editorial Changes or Corrigenda
Annex 10 – Offshore Hull Construction Monitoring Program *OHCM program will come into force on 1st June 2022*		
	All	New annex that to be applied to FPI and assigned with OHCM notation. This annex provided requirements to defines what is meant by critical areas, described how they are to be identified and recorded, delineates what information the shipyard is to include in the construction monitoring plan and lays out the certification regime to be followed.
Annex 11 – Mooring Chain Fatigue due to Bending		
	All	New annex that provide guidance on the assessment of Out of Plane Bending (OPB) fatigue calculation on mooring chains
Annex 12– Vortex Induced Motion (VIM)		
	All	New annex that provide guidelines on VIM design parameters, experience in model testing, full scale measurement, strength and fatigue analysis procedure and method to minimize VIM

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Table of Contents

Foreword iii

Guidelines Amendment Notice v

Table of Contents xxi

Section 1 Classification 1–1
A. System Classification Boundaries, Symbols and Notations 1–1
B. Rules and the Criteria Presented for Classification 1–14
C. Submission of Plans, Data and Calculations 1–15

Section 2 Installation Types, Functions, Features and General Requirements 2–1
A. General Descriptions 2–1
B. Design Basis and Environmental Loading 2–6
C. General Requirements 2–16
D. Installation, Hook-up, and Commissioning 2–18

Section 3 Surveys 3–1
A. Surveys During Construction, Installation and Commissioning 3–1
B Surveys After Construction 3–8

Section 4 Ship-Type Installations 4–1
A. Design Considerations 4–1
B. Additional Design Considerations for Conversions to FPI 4–23
C. Structural Design Requirements 4–42
D. Ship -Type Installations Under 150 meters in Length 4–226

Section 5 Other Installation Types 5–1
A. Column-Stabilized Installations 5–1
B. Tension Leg Platforms 5–18
C. Spar Installations 5–41

Section 6 Position Mooring Systems 6–1
A. General 6–1
B. Mooring Systems Design 6–1
C. Mooring System Component 6–21
D. Mooring System Analysis 6–29

Section 7 Process and Import/Export Systems 7–1
A. Hydrocarbon Production and Process Systems 7–1
B. Import and Export Systems 7–7

Section 8 Materials and Welding 8–1

Annex 1 Abbreviations and References 1–1
A. Abbreviations 1–1
B. References 1–1

Annex 2 Guidance for the Class Notation, Storage Service 2–1
A. Introduction 2–1

B. Application 2–1
C. Survey After Construction 2–2

Annex 3 Buckling Strength of Longitudinal Members Applied to Reassessed Scantling Determination (See 4.B.2/Fig 4.5) 3–1
A. Application 3–1
B. Elastic Buckling Stresses 3–1
C. Critical Buckling Stresses 3–4
D. Working Stress 3–5
E. Scantling Criteria 3–6

Annex 4 Determination of Environmental Severity Factors 4–1
A. General 4–1
B. ESFs of the Beta (β) Type 4–1
C. ESFs of the Alpha (α) Type 4–3

Annex 5 Fatigue Strength Assessment of Ship-Type Installations 5–1
A. General 5–1
B. Connections to be Considered for the Fatigue Strength Assessment 5–2
C. Fatigue Strength Assessment 5–6
D. Fatigue Inducing Loads and Determination of Total Stress Ranges 5–11
E. Resulting Stress Ranges 5–22
F. Determination of Stress Concentration Factors (SCFs) 5–23
G. Stress Concentration Factors Determined From Finite Element Analysis 5–29
H. Fatigue Assessment of Structures Considering Low Cycle Fatigue 5–33
I. Low Cycle Fatigue Damage 5–35
J. Combined Fatigue Damage 5–39
K. Fatigue Strength Assessment for Service as a Trading Vessel 5–39

Annex 6 Hull Girder Ultimate Strength 6–1
A. General 6–1
B. Plate Element 6–2
C. Stiffener Element 6–5
D. Corner Element 6–8

Annex 7 Finite Element Analysis for Ship-Type Installations 7–1
A. Objective 7–1
B. Scope of Application 7–1
C. Extent of the 3-D Global Finite Element Model 7–2
D. Coordinate System of the Model 7–2
E. Element Types 7–2
F. General Guidance for 3-D Global FE Modeling 7–6
G. Loading Conditions 7–6
H. Procedure to Adjust Hull Girder Shear Force and Bending Moment 7–8
I. Boundary Conditions 7–16
J. Validation of 3-D Global Response 7–18
K. Detailed Stress Assessment - Local FEA 7–19
L. Fatigue Assessment - Fatigue FEA 7–20

Annex 8 Hull Girder Shear Strength for Ship-Type Installation 8–1
A. Introduction 8–1
B. Allowable Still-water Shearing Force 8–1
C. Distribution Factors 8–3

Annex 9 Wave Impact Criteria 9–1
A. Application and Scope 9–1
B. Impact Load 9–1
C. Areas of Wave Impact 9–2
D. Structural Strength 9–3
E. Compactness and Detailing 9–6

Annex 10 Offshore Hull Construction Monitoring Program 10–1
A. Introduction 10–1
B. Application 10–1
C. Critical Area 10–1
D. Determination of Critical Areas 10–2
E. Construction Monitoring Plan 10–2
F. Surveys After Construction 10–3
G. Notation 10–3

Annex 11 Mooring Chain Fatigue Due to Bending 11–1
A. General 11–1
B. Interlink Stiffness and Sliding Threshold 11–1
C. Tension-Bending Fatigue Analysis Approach 11–2
D. Tension-Bending Fatigue Damage Calculation 11–3
E. Stress Concentration Factors (SCFs) 11–4
F. S-N Curve 11–4
G. Mitigation Method 11–5

Annex 12 Vortex Induce Motion (VIM) 12–1
A. General 12–1
B. VIM Design Parameters 12–1
C. Strength Design 12–3
D. Fatigue Analysis 12–4
E. Model Testing 12–6
F. Methods to Improve Mooring Design for VIM 12–7

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Section 1 Classification

A. System Classification Boundaries, Symbols and Notations 1–1
B. Rules and the Criteria Presented for Classification 1–14
C. Submission of Plans, Data and Calculations 1–15

The requirements for conditions of classification are contained in the separate, generic Rules for Classification and Survey (Pt.5, Vol.I).

Additional requirements specific to floating production installations are contained in the following Sections.

A. System Classification Boundaries, Symbols and Notations

The following classification boundaries, symbols and notations are specific to floating production installations.

1. Classification Boundaries

The classification of a Floating Production Installation (FPI) includes three major items: the installation, its position mooring system, and its production facilities. The minimum scope of class is described throughout this section and covers the installation, the mooring system, and safety systems. Accommodations and deck appurtenances such as helideck, are considered within classification boundaries.

Classification of additional equipment and systems may be offered if requested by the Owner. (See Section 2, A.1.2)

Where Import and or Export Risers provide substantial mooring restraint, the design, construction and classification of the Riser(s) providing restraint and their connection to the seabed will require special consideration.

2. Class designation for Hull

The construction symbol, ✠ , is assigned to Floating Production Installations for which the hull construction and/or the manufacture and installation of its components and any associated required testing, as applicable, and the on-site installation (for site specific FPIs) and commissioning tests and trials of the FPI is carried out by BKI. For FPIs constructed under survey of another recognized Classification Society or Authority, the symbol, ✠ , will be assigned to Floating Production Installations. General definition of construction symbol ✠ & ✠ see Guidance for Class Notation (Pt.0, Vol.B), Sec.1, Table.1.1

A100 is a class symbol that, together with the symbol, ✠, indicates compliance with the hull requirements of the BKI Rules, Guidelines, or their equivalent for service and survey by BKI during construction of the vessel. The symbols ✠ A100 may be followed by appropriate FPI type notation such as the notations shown in A.2.1. Definition of class symbol A100 see Guidance for Class Notation (Pt.0, Vol.B), Sec.1, Table.1.2

Temporary mooring equipment symbol ⓘ is defined in Guidance for Class Notation (Pt.0, Vol.B), Sec.1, Table.1.3 and will be placed after the symbols of classification to signify that the equipment for

temporary mooring of the floating installation complies with Rules for Hull (Pt.1, Vol.II) Sec.18. This symbol based on operational design of ship type installation.

2.1 New Construction

Systems that have been built, installed and commissioned to the requirements of the Guidelines and to the satisfaction of the BKI Surveyors, where approved by the BKI Head Office for service for the specified design environmental conditions, are to be classed and distinguished in the BKI Register by the symbol ✠ A100, followed by the appropriate notation for the intended service and hull type given below:

- Floating Production, Storage and Offloading : FPSO (hull type)
- Floating Production (and Offloading) : FPO (hull type)
- Floating Storage and Offloading : FSO (hull type)

The above class notations cover the following components:

1) Floating Production Installation, including its hull structure, applicable marine systems and associated equipment and machinery, safety systems and associated equipment, life saving appliances machinery under one of the above notations, subject to the requirements of these Guidelines.
2) Topside Production Facilities according to the requirements of the Rules for Facilities on Offshore Installations (Pt.5 Vol.XII) and these Guidelines.

The service notation will be appended by one of the following qualifier (Ship-Type), (Column-Stabilized), ,(TLP) or (Spar) to indicate the hull type. The hull structural configurations of these installations are described in Section 2, A.2.

Position Mooring System "POSMOSYS" as additional notation is mandatory for floating production installation, and will be assigned after FPI type notation, see 3.1.

Examples of notations for installations are:

- ✠ A100 FPSO (Ship-Type), POSMOSYS
- ✠ A100 FSO (Ship-Type), POSMOSYS
- ✠ A100 FPO (TLP), POSMOSYS
- ✠ A100 FOI (Column-Stabilized), POSMOSYS
- ✠ A100 FOI (Spar), POSMOSYS

2.2 Conversion to FPI

2.2.1 Conversion of Existing Vessel

An existing vessel is a vessel that has been issued a Certificate of Classification. When an existing vessel is converted to an FPI, and is classed under the provisions of Section 4, B.1, it will be distinguished in the BKI Register by the symbol A100, followed by the appropriate notation for the intended service, the qualifier (Ship-Type) and the additional notation CI. Examples of notations are:

- ✠ A100 FPSO (Ship-Type), POSMOSYS, CI
- ✠ A100 FOI (Ship-Type), POSMOSYS, CI

2.2.2 Conversion of Vessel Design or Vessel Under Construction

.1 A vessel's design that has been approved by BKI or another IACS member and is to be converted to an FPI, can either be classed under the provisions of A.2.2.1 and

Section 4, B.1 as an FPI conversion, or it can be classed as a new build FPI under the provisions of A.2.1.

.2 A vessel under construction that has not been issued a Certificate of Classification, and its design has been approved by BKI or another IACS member, can either be classed under the provisions of A.2.2.1 and Section 4, B.1 as an FPI conversion, or it can be classed as a new build FPI under the provisions of A.2.1.

2.3 Floating Offshore Installation (FOI)

Where an installation is fitted with production facilities, but the optional classification of the production facilities is not requested, the installation will be classed and distinguished in the BKI Register by the symbol ✠ **A100,** followed by the notation **FOI (Hull Type)** and additional notation **POSMOSYS**, provided the installation and position mooring system comply with the applicable requirements. On a Floating Offshore Installation (**FOI**), certain systems and equipment for the production facilities are to be in compliance with Section 7, A.1.2.

Where an installation is fitted with production facilities, but the optional classification of the topside production facilities is not requested, but the essential safety features of the production facilities in compliance with Section 7, A.1.3 are approved by BKI, the installation will be classed and distinguished in the BKI Register by the symbol ✠ **A100**, followed by the notation **FOI (hull type)** and additional notation **POSMOSYS**. "Production Facilities" will be indicated in the Register. Compliance with the applicable requirements for the installation and position mooring system, is required.

In either case, the scope of classification for an FOI includes the shipboard systems, including the electrical system circuit protection for the production facilities and production fire fighting equipment.

In addition, topside structures and modules of Column-Stabilized Installations, Tension Leg Platforms and SPAR installations are to comply with Section 5, A.2.3; Section 5, B.3.1.3; and Section 5, C.3.1.3 respectively.

For a Ship-Type Installation with FOI notation, topside modules are not within the scope of class. However, the hull interface structure is to comply with Section 4, A.4. See also Section 4, A.3.2.3. When requested by the Owner, an optional additional notation **Topside Modules** is available for a Ship-Type Installation when topside modules comply with Section 4, A.5. The notation for a Ship-Type FOI will be appended as follows:

– **FOI (Ship-Type), POSMOSYS, Topside Modules**

3. Additional Class Notation for Hull

3.1 Mooring System

A Floating Production Installation (FPI) is to be provided with mooring system designed to maintain the floating installation on station in all design conditions valid for its intended area of operation. The design mooring system are to comply with Section 6 as additional notations **POSMOSYS**.

3.2 Disconnectable System

A floating installation system that has a propulsion system (with character class, ✠ **SM**) and a means of disengaging the installation from its mooring and riser systems to allow the installation to ride out severe weather or seek refuge under its own power for a specified design environmental condition will be

classed the above designations and with additional notations **Disconnectable** at the end. One example of such class designation is:

- ✠ A100 FPSO (Ship-Type), POSMOSYS, Disconnectable
- ✠ SM

See 4. of this Section for ✠ SM notation.

3.3 Dynamic Loading Approach (DYLA)

Where the system's hull structure has been built to plans reviewed in accordance with the procedure and criteria in Guidelines for Dynamic Loading Approach (Pt.7, Vol.2) for calculating and evaluating the behaviour of hull structures under dynamic loading conditions, in addition to compliance with other requirements of the Guidelines the installation will be classed and distinguished in the Register by the additional notation **DYLA**. The **DYLA** notation will be placed after the appropriate hull classification notation. The application of the dynamic loading approach is optional.

The dynamic load components considered in the evaluation of the hull structure are to include the external hydrodynamic pressure loads, internal dynamic loads (fluids stored onboard, ballast, major equipment items, etc.) and inertial loads of the hull structure. The magnitude of the load components and their combinations are to be determined from appropriate ship motion response calculations for loading conditions that represent the envelope of maximum dynamically-induced stresses in the installation. The adequacy of the hull structure for all combinations of the dynamic loadings is to be evaluated using an acceptable finite element analysis method. In no case are the structural scantlings to be less than those obtained from other requirements in this Guidelines.

The basic additional notation **DYLA** is applied when the hydrodynamic loads have been determined using the wave environment of the North Atlantic as if the installation is a trading vessel with a 20-to 25-year service life. If the wave environment of the intended site is used during the analysis, the notation will include an **S** qualifier, followed by the design return period at the defined site. For example, if the 100-year return period was used, the following may apply: **DYLA (S100)**. Transit conditions to the intended site are also to be included in the **DYLA** evaluation.

3.4 Strength Criteria for Ship-Type Installations

Ship-type installations of 150 meters or more in length that are designed and built to the requirements of Section 4 will be identified in the Register by the notation as given in 2 of this Section.

The basic notation in 2. of this Section is applied when the dynamic loads have been determined using the wave environment representative of unrestricted service, i.e., for North Atlantic exposure as if the installation is a trading vessel with a 20-to 25-year service life. There are several additional notation, described in the following sub sections, covering site-specific wave environment, design return period, definition of the site and whether the installation has been converted from an existing vessel.

3.4.1 New Construction

For new-build ship-type installations where transit condition and site-specific environmental data have been used per this Guidelines in lieu of North Atlantic data, the basic notation will be followed by the additional notation **in *site***. This additional notation "**in**" will then be followed by the definition of the site. For example, **in NATUNA Field.**

3.4.2 Conversion of Existing Vessel to FPI

For a converted installation where the trading vessel and site-specific environmental data have been used per this Guidelines, the basic notation is followed by the additional notation **CI,** *site*. The **CI,** will be followed by the definition of the site. For example, **CI, NATUNA Field.**

3.4.3 Relocation of FPI

As site specific units, FPIs are designed and classed taking into consideration the location where they will operate and the intended period of operation. When the FPI is relocated to a new site, either within the same field or in a different operating area, or when the intended period of operation is extended, the strength of the unit is to be reassessed to satisfy that the unit will remain in compliance with applicable requirements as described below.

1) Relocation within the Same Field.

When an FPI is relocated within the same field or the same operating area, the environmental conditions are expected to remain identical to those considered during the original classification process for the current site.

If the environmental conditions for the field or operating area have been revised since the original approval due to new environmental data or changing environmental conditions, the Coastal State[1] may require the use of new environmental conditions for the relocation, in which case the same requirements as relocation to a different operating area will apply.

The expected operating life in the new location may be within the originally considered design life or otherwise, it may extend beyond the original design life period. In the latter case, in addition to the requirements for relocation, the requirements for life extension will apply.

It is expected that relocation within the same field will require at least a new position mooring and anchoring system for the new site and probably, modifications to the process facilities.

For the relocation within the same field, without exceeding the original design life of the unit, the following actions will to be required:

- Design review and surveys related to the new position mooring system and anchoring.
- Design review and surveys related to the modifications to the process facilities, if applicable.
- Design review and surveys related to any other modifications affecting class items.
- Drydocking survey, including gauging, with steel renewals as necessary to bring the unit to a satisfactory condition to complete the remaining design life at the specific site.

Structural strength analysis and fatigue life re-evaluation for the hull structure, turret, module structures, etc. will not to be required, unless structural modifications are performed or current environmental conditions are harsher than the environmental conditions considered in the original design.

[1] Coastal State Authority is the Authority responsible for the safety standards of units operating in or adjacent to their territorial waters.

For structures, systems or equipment not modified and maintained per original design, design review is to be based on the design codes used in the original design with current environmental data.

For added or modified structures, systems or equipment, design review is to be based on the design codes at the time of the contract for the relocation with current environmental data.

Surveys are to be based on the current guideline requirements, see Section 3.

2) Relocation to a Different Operating Area.

When an FPI is relocated to an operating area where the environmental conditions are different than those at the original site, the structural strength and fatigue life of the unit will need to be reassessed for the new conditions. However, if the new location has milder environmental conditions than the current site, the reassessment may not need to be performed provided that the unit is kept under the same structural condition as in the original site and the design fatigue life of the unit is not extended.

Relocation to a different operating area will require a new position mooring and anchoring system for the new site and most probably, extensive modifications to the process facilities.

For the relocation to a different operating area, the following actions will be required:

- Structural strength analysis and fatigue life re-evaluation for the hull structure, turret, module structures, etc. (except as noted above).
- Design review and surveys related to the new position mooring system and anchoring.
- Design review and surveys related to the modifications to the process facilities.
- Design review and surveys related to any other modifications affecting class items.
- Drydocking survey, including gauging, with steel renewals as necessary to bring the unit to a satisfactory condition to complete the remaining design life at the specific site.
- Design review and surveys are to be based on the current BKI requirements at the time of the contract for the relocation of the unit.

For structures, systems or equipment not modified and maintained per original design, design review is to be based on the design codes used in the original design with current environmental data.

For added or modified structures, systems or equipment, design review is to be based on the design codes at the time of the contract for the relocation with current environmental data.

Surveys are to be based on the current guideline requirements, see Section 3.

3.5 Strength Criteria for Other Installation Types

Installations (other than ship-type, see A.3.3 above) that are designed and built to the requirements of Section 5 will be identified in the Register by the notation as given in A.2 of these Section followed by additional notation, described in the following Subparagraphs, covering site-specific wave environment and definition of the site.

3.5.1 New Construction

Site-specific environmental data will be indicated by the **in *site*** additional notation following the basic notation of A.2. The additional notation will then to be followed by the definition of the site. For example, **✠ FOI (TLP), POSMOSYS, in NATUNA Filed.**

3.5.2 Relocation of FPI

As site specific units, FPIs are designed and classed taking into consideration the location where they will be operated and the intended period of operation. When the FPI is relocated to a new site, either within the same field or in a different operating area, or when the intended period of operation is extended, the strength of the unit is to be reassessed to satisfy that the unit will remain in compliance with applicable requirements.

3.6 Design Life and Design Fatigue Life

3.6.1 Design Life-New Construction

Floating installations designed and built to the requirements in these Guidelines and maintained in accordance with the applicable BKI requirements are intended to have a structural design life of not less than 20 years for a new build hull structure. Where the structural design life is greater than 20 years and the floating installation is designed for uninterrupted operation on-site without any drydocking, the nominal design corrosion values (NDCV) of the hull structure are to be increased in accordance with Section 4, C.1.1.4 for ship-type installations or an acceptable equivalent criteria for non-ship-type installations. When the design life is greater than 20 years (in 5-year increments) the increased life will be identified in the Register by the additional notation **HL (number of years)**. The (**number of years**) refers to a design life different than 20 years.

3.6.2 Design Fatigue Life – New Construction

Where a floating installation's design calls for a minimum design fatigue life of 20 years or more, the design fatigue life is to be verified to be in compliance with the fatigue criteria in these Guidelines. The "design fatigue life" refers to the target value set by the owner or designer, not the value calculated in the analysis.

The required fatigue strength analysis of critical details and welded joints in floating installations is to be in accordance with the criteria in Annex 5 for ship-type installations or an acceptable equivalent criterion for non-ship-type installations.

Design fatigue life value notation is to be assigned and published in the Register for the hull, hull interface structure, position mooring system and components. The hull interface structural requirements for ship-type installations are described in Section 4, A.4 and the position mooring system requirements in Section 6. When only the required fatigue analysis of Annex 5 for ship-type installations or Section 5, A.2.3; B.3.3; C.3.3 for non-ship-type installations is performed for either unrestricted service wave environment or the transit and site specific wave environment, the class notation **FL (number of years), Year** will be assigned to identify the design fatigue life in years and the year of maturation of fatigue life in define site. For example, **FL(30), 2049** for an FPI built in 2019 if the minimum design fatigue life specified is 30 years.

If spectral fatigue analysis (see Section 1, A.3.7) is requested by the owner or designer, only the design fatigue life notation, **SFA (number of years), Year** will be assigned and

published in the Register for the hull and hull interface structural system. Although only the **SFA** notation is assigned, and not the **FL** notation, the required fatigue analysis of Annex 5 for ship-type installations or Guidance for the Fatigue Assessment of Offshore Structure (Pt.5, Vol.B), Sec.6 for non-ship type installation is to be performed and the calculated fatigue life is to satisfy the design fatigue life.

Where different design fatigue life values are specified for structural elements (hull and hull interface structure) and position mooring system within the installation, the notation **FL** (**number of year**), **Year** will be followed by the notation **FLM**(**number of years**), **Year**, where (**number of years**) refers to the design fatigue life for the position mooring system and **Year** refers to the year of maturation associated with the position mooring system. In the case when spectral fatigue analysis is also applied the least of the fatigue life values calculated by the required fatigue strength analysis for the **FL** notation and the spectral fatigue analysis is to satisfy the design fatigue life. The "design fatigue life" refers to the target value set by the applicant, not the value calculated in the analysis.

For example if the design fatigue life is specified as 25 years, the fatigue calculations of hull structural components are to satisfy a fatigue life of 25 years. The fatigue calculations of the position mooring hull interface structures and hull mounted equipment interface structures, and position mooring system are to also satisfy fatigue lives of (25 x FDF) years, where FDF are the fatigue safety factors specified in Table 2.1 for hull interface structures and in Table 6.4 for mooring lines.

3.6.3 Conversion of Existing Vessel to FPSO, FPO or FSO

When an existing vessel is converted to an FPSO, FPO or FSO in the process referred to as an FPI vessel conversion, and the ship-shaped FPSO, FPO or FSO is classed under the provisions of Section 4, B.1, the expected minimum remaining fatigue life of the structure is to be assessed according to Section 4, B.3 and documented by recording its value in the Register. The **RFL** notation will be followed by the value of the expected minimum remaining fatigue life in years, and the year of maturation of fatigue life in the defined site location in accordance with 3.4.2. For example, **RFL (15), 2018** indicates that the expected minimum remaining fatigue life of the structure is 15 years, which will be reached in the year 2018. The **RFL (number of years)**, Year notation as applied to an FPI vessel conversion is mandatory.

Where different design fatigue life values are specified for structural elements (hull and hull interface structures) and the position mooring system within the installation, the notation **RFL**(**number of years**), **Year** will be followed by the notation **FLM**(**number of years**), **Year**, where (**number of years**) refers to the target value of the fatigue life for a new position mooring system and Year refers to the year of maturation associated with the new position mooring system. Where an existing mooring system is to be reused, the notation **RFLM**(**number of years**), **Year** referring to the remaining fatigue life of the existing position mooring system will apply.

When an existing vessel is converted to a FPSO, FPO or FSO and is intended to be used at marginal field and the unit will be drydocking every 5 years, the **RFL** notation may be omitted. A notation **MARGINAL FIELD in *site*** will be added after **CI** to indicate the intended use for 5 years for the site. For a marginal field FPI without **RFL** notation, the following actions will be required:

– Verification document of the existing vessel's original fatigue life that provided by owner/applicant. If the remaining fatigue life as unrestricted vessel is not less than 5 years and Alpha factors for the intended site is greater than 1, the fatigue analysis for the hull structure based on intended site is not mandatory. However, the hull interface structures for process modules, flare tower, mooring structure,

riser porch or balcony are to be evaluated for compliance with Section 4, A.4.2, based on FEM models and including fatigue analysis. The analysis is to apply the most critical combination of topsides or mooring loads and hull girder loads.

- If the document of remaining fatigue life as unrestricted vessel is less than 5 years, or if the Alpha factors for the intended site is not greater than 1, the fatigue analysis for the hull based on intended site is mandatory for a fatigue life of 10 years. The fatigue analysis of the hull structure is to comply with Section 4, B.1.3.6. The hull interface structures for process modules, flare tower, mooring structure, riser porch or balcony are to be evaluated for compliance with Section 4, A.4.2, based on FEM models and including fatigue analysis. The analysis is to apply the most critical combination of topsides or mooring loads and hull girder loads.
- Mooring system is to be designed for compliance with Section 6 for a fatigue life not less than 10 years.
- Survey of the FPI hull structure after conversion is to comply with Rules for Classification and Survey (Pt.1, Vol.I) Sec.4.I.B or C or D.
- If the FPI intends to be relocated to a new site or extend the life at current site after 5 years, the FPI is to be assessed in accordance with 3.6.4 and 3.6.5 with consideration of the above actions.

3.6.4 Relocation of FPI

When an FPI is relocated to a new site, either within the same field or in a different operating area, the fatigue life of the unit is to be reassessed to satisfy that the unit's remaining fatigue life for the new operating conditions is within the design fatigue life of the unit. The position mooring system including chain and other mooring components is also subject to reassessment if it is to be used at the new site.

3.6.5 Life Extension of FPI on the Same Site

When an FPI exceeds the design fatigue life specified in the **FL (number of years), Year** or **RFL (number of years), Year** notation for which it was classed, an evaluation is to be made and appropriate actions are to be taken to extend the fatigue life up to the new operating life of the unit under the site-specific environmental conditions.

For conversions, the design fatigue life will depend on the minimum remaining fatigue life expected from the time of the conversion, the remaining fatigue life is indicated with the **RFL** notation.

For both original build FPIs and conversions, the remaining fatigue life of the unit may be extended during the operating life of the FPI by renewals or modifications of those structural details with lower fatigue life.

For the life extension of the unit remaining in the same location, the following actions will be required:

- Verification from original fatigue analysis that the actual fatigue values of all the structural elements of the unit are still higher than the proposed extended fatigue life;

  or

  New fatigue analysis covering all the structural elements (hull, turret, hull interfaces, position mooring system) in accordance with **SFA, FL** or **RFL** requirements, as applicable. Risers (if classed) are also to be analyzed for the extended fatigue life.

- Identification of structural elements or details with a fatigue life below the new intended design fatigue life of the unit and proposed actions to increase the fatigue life of those elements or details.
- Design review and surveys of structural modifications proposed as a consequence of the fatigue analysis.
- Enhanced survey program to monitor those structural elements or details with lower fatigue life which cannot be modified or renewed on site.
- Special Periodical survey, including Underwater Inspection, to determine the structural condition of the unit at the time of the life extension.

For structures, systems or equipment not modified and maintained per original design, the new fatigue analysis and related design review, when necessary, is to be based on the design codes used in the original design with current environmental data.

For added or modified structures, systems or equipment, the new fatigue analysis and related design review are to be based on the design codes at the time of the life extension with current environmental data.

Surveys are to be based on the current Guidelines requirements, see Section 3.

Once the life extension is approved, the existing **SFA**, **FL** or **RFL** notation with year of maturation will is to be updated accordingly.

When a fatigue notation is requested, and where none of the above notations was previously assigned to the unit, the most appropriate fatigue notation for the unit is to be assigned.

For the first life extension up to 5 years, upon agreement with operator/owner, a new notation **LE** (**number of years**) **Year** can be granted instead of **RFL** or **FL** without performing new fatigue analysis as required in this section. To be granted **LE** Notation, the following conditions are to be satisfied:

- Any modifications to the structure have class approval.
- Critical areas of the original design have been re-examined using NDT techniques and verified to be satisfactory by BKI Surveyor.
- Additional items to be determined on a case-by-case basis during the life extension process have been resolved.

3.7 Spectral Fatigue Analysis

3.7.1 Design Fatigue Life – New Construction

Where more extensive use of Spectral Fatigue Analysis is performed in accordance with criteria established in Section 4, A for ship-type installation or the Guidance for the Fatigue Assessment of Offshore Structures (Pt.5, Vol.B), Sec.6 for non-ship-type installation, the installation is to be identified in the Register by the notation **SFA (number of years), Year**. The fatigue analysis is performed for either unrestricted service wave environment or the transit and site-specific wave environment in accordance with Section 1, A.3.5. The (**number of years**) refers to the design fatigue life equal to 20 years or more, as specified by the applicant. The **Year** is the year of maturation of fatigue. For example, **SFA (30), 2049** if the design fatigue life specified is 30 years, and the FPI is built in 2019. Only one minimum design fatigue life value is applied to the entire structural system. For a structural location required to have an additional factor applied to the minimum design fatigue life (say, due to safety critical function or

relative difficulty of inspection, see for example, Section 6, B.1.7), the required minimum fatigue life for such a location is the minimum design fatigue life being applied in the project multiplied by the additional factor. The 'design fatigue life' refers to the target value set by the designer and not the value calculated in the analysis. The calculated values are usually much higher than the target value specified for design. The application of spectral fatigue analysis is optional except for the ship-type installation over 350 meters in length as indicated in Section 4, A.1.1.

Where Spectral Fatigue Analysis is performed, **SFA** notation is assigned and different design fatigue life values are specified for structural elements (hull and hull interface structures) and the position mooring system within the installation, the notation **SFA(number of years), Year** will be followed by the notation **FLM(number of years), Year**, where (**number of years**) refers to the target value of the fatigue life for the position mooring system and components and **Year** refers to the year of maturation associated with the position mooring system.

3.7.2 Conversion of Existing Vessel to FPSO, FPO or FSO

When spectral fatigue analysis is applied to an existing vessel that is converted to an FPSO, FPO or FSO, the expected minimum remaining fatigue life of the structure is to be assessed according to Section 4, B.3.2 and documented by recording its value in the Register. The **SFA** notation will be followed by the value of the expected minimum remaining fatigue life in years preceded by the letter **R**, and the year of maturation of fatigue life in the defined site location in accordance with 3.5.2. For example, **SFA (R15), 2021** indicates that the expected minimum remaining fatigue life of the structure is 15 years, which will is to be reached in the year 2021 at the defined site location. The application of spectral fatigue analysis for FPI conversions is optional except for the ship-type installation over 350 meters in length as indicated in Section 4, A.1.1.

Where Spectral Fatigue Analysis is performed, **SFA** notation is assigned and different design fatigue life values are specified for structural elements (hull and hull interface structures) and the position mooring system within the installation, the notation **SFA (Rnumber of years), Year** will be followed by the notation **FLM (number of years), Year**, where **(number of years)** refers to the target value of the fatigue life for a new position mooring system and **Year** refers to the year of maturation associated with the new position mooring system. Where an existing mooring system is to be reused, the notation **RFLM (number of years), Year** referring to the remaining fatigue life of the existing position mooring system will apply.

3.8 Additional Corrosion Margin

Where the installation incorporates additional plate thicknesses above the required scantlings, the installation will be identified in the Register by the notation **ACM**, followed by the description of the major hull girder component(s) that has the additional thickness. This notation will also include a number to indicate the magnitude of the additional thickness (rounded down to the nearest 0,5 mm) that has been applied, i.e., **ACM (DK+0,5)**. In order to apply the notation **ACM**, the additional thickness must be applied to the complete structural element throughout the tank area of the installation. This notation documents major areas of the structure that have an additional "as-built" margin on thickness to address areas subject to significant corrosion or areas where it may be desirable to increase normal corrosion margins to extend a structural member's anticipated service life. This notation is optional and is only available to new construction FPIs.

The major structural components are defined as follows:

- DK Upper deck (including stringer plate)
- BS Bottom shell (including bilge)
- IB Inner-bottom
- SS Side shell (including shear strake)
- IS Inner skin (including "hopper" sloping plating)
- LB Longitudinal bulkheads other than the inner skin
- TB Transverse Bulkhead

3.9 Hull Construction Monitoring Program

Ship-type installations designed and reviewed to the FPI Guidelines are to comply with the requirements of the Offshore Hull Construction Monitoring Program in Annex 10 and have the notation **OHCM**.

4. Class designation for Machinery

The construction symbol, ✠ , is assigned to Floating Production Installations for which the installation of its machinery and components and/or the manufacture and any associated required testing, as applicable, and the on-site installation (for site specific FPIs) and commissioning tests and trials of the FPI is carried out by BKI. For FPIs constructed under survey of another recognized Classification Society or Authority, the symbol, ✠ , will be assigned to Floating Production Installations. General definition of construction symbol ✠ & ✠ see Guidance for Class Notation (Pt.0, Vol.B), Sec.1, Table.1.1.

4.1 Class symbol SM

SM is a class symbol that, together with the symbol,✠, indicates the machinery including electrical installations for self-propulsion comply with the BKI`s requirements of the BKI Rules, Guidelines, or their equivalent for service and survey by BKI during construction of the vessel. The symbols ✠**SM** may be followed by appropriate FPI class notation for Machinery such as the additional notations shown in 5. General definition of class symbol **SM** see Guidance for Class Notation (Pt.0, Vol.B), Sec.1, Table.1.2. This notation is mandatory for classification of self-propelled floating production installations.

4.2 Class symbol A-SM

A-SM is a class symbol that, together with the symbol, ✠, indicates the machinery including electrical installations for non self-propelled comply with the BKI`s requirements of the BKI Rules, Guidelines, or their equivalent for service and survey by BKI during construction of the vessel. The symbols ✠ **A-SM** may be followed by appropriate FPI class notation for Machinery such as the additional notations shown in 5. Definition of class symbol **A-SM** see Guidance for Class Notation (Pt.0, Vol.B), Sec.1, Table.1.2. This notation is mandatory for classification of non self-propelled floating production installations.

5. Additional Class Notation for Machinery

5.1 Automations and Monitoring Systems (OT-S or OT Notations)

For automations and monitoring systems of the machinery space, BKI will consider additional class notation with symbols **OT-S** or **OT**, as appropriate, provided that the applicable requirements of Rules for Automation (Pt.1, Vol.VII) are satisfied.

5.2 Dynamic Positioning Systems

Dynamic positioning systems installed for station keeping purposes, will be denoted by the notation **DP** (see Guidance for Class Notation Sec. 3, B.2). Any additional installation of dynamic positioning systems will be reviewed case by case basis.

5.3 Additional Equipment and Systems

Additional equipment and systems, such as the subsea template, Import (or Export) PLEMs and the Import (or Export) system may be considered at the Owner's request. Where the import and export systems are built in full compliance with the requirements of Section 7, B, the installation will be classed and distinguished in the Register by the notation **IMPT-EXPT**. The notations **IMPT** or **EXPT** will be applied to the installation when only the import system or the export system, respectively, is built in full compliance with the requirements of Section 7, B. These notations for import and export systems are optional.

6. Systems not Built Under Survey

Systems that have not been built under survey to BKI, but which are submitted for classification, will be subjected to a special classification survey. Where found satisfactory and thereafter approved by the BKI, they will be classed and distinguished in the Register by the symbols and special notations as described in 2 through 5 of this Guidelines, but the symbol ✠ will be omitted.

7. Conversion of Existing Vessels or Floating Structures

Modifications of existing vessels or floating structures intended for classification as Floating Installations are to be converted under BKI design review and survey.

8. Significant Change of Operating Conditions Affecting Safety of Unit or Personnel

In a few occasions, the operating conditions of the FPI initially considered during the classification of the unit change with time. For example, the composition of the oil coming from the well may turn sour (high concentration of hydrogen sulfide, H_2S). If these changes affect the safety of the unit or the personnel on board, the owner/operator needs to approach BKI as the changes may have an effect in the compliance with the applicable Rules and Guidelines and therefore, in the maintenance of class.

If it is confirmed that the changes are affecting the compliance with the applicable Rules and Guidelines, there are two options:

- To identify the Rule/Guidelines requirements that the unit has to comply with in order to maintain classification and to verify compliance by design review and survey, as applicable; or
- To perform a risk assessment with BKI participation in order to analyze the new hazards due to the changes and determine the mitigation actions required to

bring the unit to an equivalent level of safety to the applicable Rules and Guidelines.

B. Rules and the Criteria Presented for Classification

1. Application

1.1 General

The criteria in this document are applicable to Floating Production, Storage and Offloading installations (FPSOs), as defined in Section 2, A.1. The criteria are also applicable to Floating Production Unit (FPOs), as defined in Section 2, A.1.2, Floating Storage and Offloading systems (FSOs), as defined in Section 2, A.1.2, or Floating Offshore Installation (FOI), as defined in Section 2, A.1.2, with corresponding classification notation, as indicated in A.

The application of the criteria to systems other than the above will be considered on a case-by-case basis.

The criteria are applicable to those features that are permanent and can be verified by plan review, calculation, physical survey or other appropriate means. Any statement in the Rules and the criteria in this document regarding other features are to be considered as guidance to the designer, builder, Owner, etc

1.2 Application

The application of this Guidelines is, in general, based on the contract date for construction or conversion between the shipbuilder and the prospective owner (e.g., Guidelines which became effective on 1 July 2013 are not applicable to a floating production installation for which the contract for construction was signed on 30 June 2013).

In the case of conversions, structures other than hull structures (such as deckhouses), machinery equipment and/or marine systems which will remain unchanged or with minor modifications during the conversion will be considered on the basis of the original Rules used for the vessel construction as well as the safety features of the converted unit.

2. Reference Standards

Reference is made in this Guidelines to BKI Rules and other criteria issued by BKI and other organizations. Annex 1, B contains a listing of such Reference Standards.

3. Risk Evaluations for Alternative Arrangements and Novel Features

Risk assessment techniques may be used to demonstrate that alternatives and novel features provide acceptable levels of safety in line with current offshore and marine industry practice. The Guidance for Risk Evaluations for the Classification of Marine-Related Facilities (Pt.3, Vol.A) provides guidance to BKI clients on how to prepare a risk evaluation to demonstrate equivalency or acceptability for a proposed Floating Production Installation.

Risk evaluations for the justification of alternative arrangements or novel features may be applicable either to the installation as a whole, or to individual systems, subsystems or components. BKI will consider the application of risk evaluations for alternative arrangements and novel features in the design of the floating production installations, Verification Surveys during construction, and Surveys for Maintenance of Class.

Portions of the floating production installation or any of its components thereof not explicitly included in the risk evaluation submitted to BKI are to comply with any applicable part of the BKI Rules and Guidelines. If any proposed alternative arrangement or novel feature affects any applicable requirements of Flag and Coastal State, it is the responsibility of the Owner to discuss with the applicable authorities the acceptance of alternatives based on risk evaluations.

C. Submission of Plans, Data and Calculations

1. Design Plans and Data

Plans showing the scantlings, arrangements and details of the principal parts of the hull structure of each installation to be built under survey are to be submitted and approved before the work of construction has commenced. These plans are to clearly indicate the scantlings, joint details and welding, or other methods of connection. In general, plans are to be submitted that include the following, where applicable:

1) General Arrangement
2) Body Plan, lines, offsets, curves of form, inboard and outboard profile
3) Wind heeling moment curves of equivalent data
4) Arrangement plan of watertight compartmentation
5) Diagrams showing the extent to which the watertight and weathertight integrity is intended to be maintained, the location, type and disposition of watertight and weathertight closures
6) Capacity plan and tank sounding tables
7) Summary of distributions of weights (fixed, variable, ballast, etc.) for various conditions
8) Type, location and quantities of permanent ballast, if any
9) Loadings for all decks
10) Transverse section showing scantlings
11) Longitudinal sections showing scantlings
12) Decks, including helicopter deck
13) Framing, shell plating, watertight bulkheads and flats, structural bulkheads and flats, tank bulkheads and flats with location of overflows and air pipes
14) Pillars, girders, diagonals and struts
15) Stability columns, intermediate columns, hulls, pontoons, superstructure and deck houses
16) Arrangement and details of watertight doors and hatches
17) Foundations for anchoring equipment, industrial equipment, process, and process support modules, etc., where attached to hull structure, superstructures or deckhouses
18) Mooring turrets and yoke arms, including mechanical details
19) Corrosion control arrangements
20) Methods and locations for nondestructive testing
21) The plans listed in Section 5, A.1.4.6 for column-stabilized units
22) Plans and calculations/analyses for the module structures to support production facilities
23) Plans and calculations/analyses for module support structures
24) Construction Monitoring Plan
25) Structural critical inspection points (SCIPs) (see Section 3, B.1.2.15 and B.3)

2. Position Mooring System Design Documentation

The design documentation for the mooring system is to include the following, when applicable:

1) Mooring Arrangement or Pattern.
2) Details of winching equipment.
3) Details of anchoring system.
4) Details of mooring line segments.
5) Connections at anchors and between mooring line segments.
6) Details of in-line (spring) buoys.
7) Details of buoy for CALM system.
8) Details of SALM structures, if appropriate.
9) Details of Turret System to show turret structure, swivel, turntable and disconnecting device.
10) Details of yoke (hard or soft) connecting the installation and CALM/SALM structure.
11) Environmental Report.
12) Mooring Analysis describing method of load calculations and analysis of dynamic system to determine the mooring line design loads.
13) Mooring fatigue analysis report
14) Mooring installation/hook-up procedures
15) Model Test report when the design loads are based on model tests in a wave basin.
16) General arrangements of the thruster(s) installation, its location of installation, together with its supporting auxiliary machinery systems, fuel oil tanks, foundations, and watertight boundary fittings.
17) Thruster specifications and calculations of a system with dynamic positioning system for thruster forces and power to counteract environmental forces. (See Sections 2, B.3 and 2, B.4)
18) Details of arrangements and procedures for the crew to periodically verify that mooring lines have not failed. (See Section 6, A.1.8)
19) Operations manual for mooring system and for thruster assist system.

3. Production Facilities and Production Support Facilities

The following design documentation of a floating production and storage system is required to be submitted, as applicable:

1) General Arrangements showing arrangements and locations of storage tanks, machinery, equipment, living quarters, fire walls, emergency shutdown (ESD) stations, control stations, crude loading and discharge stations and the flare (see Section 7, A.7.2).
2) Hazardous Area Classification Plans, as defined in Section 2, A.3.4 herein.
3) Details of Storage Tank Venting and Inerting indicating arrangements for storage tank venting and inerting.
4) Arrangements for Use of Produced Gas as Fuel showing piping and control arrangements for use of produced gas as fuel showing details of double wall or ducting arrangements for the pipe runs in way of the safe space.
5) A design specification that is to include design parameters (environmental conditions, geographical location of the unit, external loads, pressures, temperatures, etc.), standards and codes adopted throughout the design, construction and testing stages and the process description.
6) A description of the field development plan, including well fluid properties, production rates, gas oil ratios, processing scheme, well shut-in pressures.

7) Process flow sheets showing major process equipment components, process piping, material balance, normal pressures and temperatures at the inlet and outlet of each major component.

8) Piping and Instrumentation Diagrams (P&IDs) indicating location of all sensing and controlling elements on the process and production support systems, sizing and material specification of piping and the associated components, maximum design pressure and temperature ratings, piping strength and flow calculations.

9) List of electrical equipment located in hazardous areas together with the certificates issued by an independent testing laboratory to show suitability of their use in the intended location.

10) Electrical one line diagram showing ratings of all generators, motors, transformers, type and size of wires and cables. Types and rating of circuit breakers with the setting, interrupting capacity of circuit breakers and fuses.

11) Short circuit current calculations and coordination data giving the maximum calculated short circuit current available at the main bus bars and at each point in the distribution system in order to determine the adequacy of the interrupting capacities of the protective device. A system coordination study is to be included.

12) Safety Analysis, including Safety Analysis Function Evaluation (S.A.F.E.) charts.

13) Emergency shutdown system (ESD) relating to all sensing devices, shutdown valves, shutdown devices and emergency support system to their functions and showing ESD logic for the complete process and the subsea valves system.

14) Emergency backup and uninterrupted power source, supply and the consumers.

15) Pressure vessel (fired and unfired) and heat exchangers, design dimensional drawings, design calculations, material specifications, pressure and temperature ratings, together with weld details and the details of their support.

16) Pressure relief and depressurization vent systems showing arrangements sizing of the lines, capacities of the relief valve, materials, design capacity, calculations for the relief valves, knock out drums, anticipated noise levels and gas dispersion analyses.

17) Complete details of flares, including pilots, igniters and water seal and design calculations, including stability and radiant heat analyses.

18) Schematic plans for the production support systems, including the size, wall thicknesses, maximum design working pressure and temperature and materials for all pipes and the type, size and material of valves and fittings.

19) Compressors, pumps selection and control arrangements, including specification data sheet.

20) Fire and gas detection system showing the location and detailed description of all power sources, sensors, annunciation and indication, set point for the alarm system.

21) Passive and active fire protection system indicating locations of fire walls, fire pumps and their capacities, main and backup power supply, fixed and portable fire extinguishing, and fire fighting systems and equipment. In this regard, supportive calculations are to be submitted to show the basis of capacities and quantities of fire extinguishing equipment.

22) Escape route plan showing escape routes to abandonment stations and survival embarkation areas.

23) Startup and commissioning procedures detailing sequence of events for inspection, testing and startup and commissioning of equipment and system.

24) Installation, Hook-up and Commissioning Procedures. (See Section 2, D)

Above items 1), 2), 9), 13), 20), 21), and 22), are required to be submitted for any type of a floating production installation that is classed with or without its topsides production facilities.

4. Marine Systems and Machinery Plans

Plans showing marine piping systems, electrical systems, fire fighting systems and equipment, and machinery and equipment not associated with the process facilities are to be submitted (see Section 4, A.6, Section 5, A.4, Section 5, B.6 or Section 5, C.6 depending on the type of installation).

Where applicable, machinery plans listed in Rules for Machinery Installations (Pt.1, Vol.III) or Rules for Machinery Installations (Pt.5, Vol.IV) are to be submitted. Machinery general arrangements, installation and equipment plans, are also to be submitted and approved before proceeding with the work.

5. Additional Plans

Submission of additional plans and calculations may be required when additional classification designations or certifications are requested:

- Additional classification designations under A.2 – A.7 or Section 7, B (See Section 7, B.2 for import/export system submission requirements).
- Certifications under A.2 – A.7.

6. Manuals and Procedures

6.1 Operations Manual

The Operations Manual is to be submitted, providing guidance information for operating personnel regarding the following, when applicable:

Subject	References in this Guidelines
– Loading Manual	Section 2, C.1.4, Section 5, A.1.3
– Trim and Stability	Section 2, C.1.5 and C.1.6, Section 5, A.3.1

6.2. Procedures

Procedures are to be submitted for the following:

Subject	References in this Guidelines
– Disconnecting Procedure, if applicable	Section 2, D.1.7
– Drydocking Procedure *	Section 3, B.7
– Hook Up Procedures	Section 2, D.2
– Import/Export System	Section 7, B.4.4, Section 2, D.1.6
– Installation Procedures	Section 2, D.1
– Installation Manual	Section 2, D.1.6
– Lay-up and Reactivation, if applicable *	Section 3, B.1.11
– Startup and Commissioning Procedures *	Section 2, D.3
– In-Service Inspection Program (ISIP)	Section 3, B.1.2.15 and B.3

* Submitted to attending Surveyor for review and agreement

Section 2 Installation Types, Functions, Features and General Requirements

A. General Descriptions 2–1
B. Design Basis and Environmental Loading 2–6
C. General Requirements 2–16
D. Installation, Hook-up, and Commissioning 2–18

A. General Descriptions

1. Basic Configurations

1.1 Purpose

A Floating Installation provides hydrocarbon processing and/or hydrocarbon storage and offloads hydrocarbons. Where discussion of the various component systems supporting hydrocarbon processing and/or storage may cause confusion with the total system, Floating Installation is used to generically identify the combination under discussion and refers to a site-specific installation.

The notations:

- Floating Production, Storage and Offloading: **FPSO**
- Floating Production (and Offloading): **FPO**
- Floating Storage and Offloading: **FSO**
- Floating Offshore Installation: **FOI**

Are based on accepted industry practice and were chosen to provide a clear description of the function of each configuration.

- **FPSO** - This installation processes, stores and offloads hydrocarbons.
- **FPO** - This installation processes and offloads hydrocarbons without storage capacity.
- **FSO** - This installation stores and offloads hydrocarbons without hydrocarbon processing facilities. An FSO receives oil from a nearby installation that contains processing equipment. FSOs should not connect directly to a well.
- **FOI** - This installation may process and offload hydrocarbons and may or may not have storage capacity, but the production facilities are not classed.

1.2 Major Elements

A Floating Installation consists of several of the following major elements that are addressed in this Guidelines:

- Installation
- Position mooring (or station keeping system)
- Production processing facilities
- Import/export system

Classification boundaries encompass the installation and position mooring system and may include the production facilities. Import/export systems may be classed, as well. See Section 1, A

A Floating Installation classed as an **FPSO, FPO, FSO** or **FOI** includes the following elements:

	Installation	Storage	Hydrocarbon Process System(s)	Import/Export System	Position Mooring System
FPSO	√	√	√	Optional	Mandatory
FPO	√	---	√	Optional	Mandatory
FSO	√	√	---	Optional	Mandatory
FOI (Production Facilities not classed)	√	Safety Feature Only See Section 7, A.1.2		Optional	Mandatory
FOI (with **Production Facilities** indicated in Column 4)	√	Safety Features Only See Section 7, A.1.3		Optional	Mandatory

2 Installation

2.1 General

Installation, as used in this Guidelines, refers to a floating structure and the machinery, equipment and systems necessary for safety, propulsion (if fitted) and auxiliary services. The structural configurations of these installations may be ship-shaped or barge-shaped (with or without propulsion), column stabilized or any other configuration of a purpose-built floating installation.

2.2 Ship-Type Installations

Ship-type installations are single displacement hulls, either ship-shaped or barge-shaped, which have been designed or converted to a floating production and/or storage system. They may have propulsion machinery and/or station keeping systems.

2.3 Column-Stabilized Installations

Column-stabilized installations consist of surface piercing columns, submerged pontoons and a deck supported at column tops. Buoyancy is provided by the submerged pontoons, surface piercing columns and braces, if any.

2.4 Tension Leg Platform Installations

Tension leg platform (TLP) installations are vertically moored, buoyant structural systems wherein the excess buoyancy of the platform maintains tension in the mooring system. The TLPs consist of buoyant pontoons and columns, a column top frame or a topside deck and a tendon system with its seafloor foundations.

2.5 Spar Installations

Spar installations are deep draft, vertical floating structures, usually of cylindrical shape, supporting a topside deck and moored to the seafloor. The hull can be divided into upper hull, mid-section and lower hull.

2.6 Other Types

Purpose-built and new configurations belong to this category.

3. Production Facilities

3.1 General

The production facilities typically consist of the processing, safety and control systems, production support systems and auxiliary equipment for processing hydrocarbon liquid and gas mixtures from wells or other sources. Generally, a production facility includes all elements located onboard the Floating Installation unit. These elements are located from (and including) the first inlet flange of the well fluid flow line above the water level inboard to (and including) the last onboard flange. Some important items related to production facilities are defined in the following paragraphs.

3.2 Production Support Systems

The production support systems include power generation and distribution, instrument and service air, potable water, fuel oil systems, HVAC (Heating, Ventilation and Air Conditioning), instrumentation, communication systems and firewater systems required to support hydrocarbon production and processing.

Production support systems may be in addition to or extensions of the normal marine utility systems found on MODUs, barges or ship-type installations. (See Section 7, A)

3.3 Manned Facility

A manned facility is one with permanent occupied living accommodations or one that requires the continuous presence of personnel for more than 12 hours in successive 24 hour periods.

3.4 Hazardous Areas: Classified Areas and Area Classification Plan

A classified area is an area in which flammable gases or vapours are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures. See Rules for Facilities on Offshore Installation (Pt.5, Vol.XII), Sec.3, F.8.

An area classification plan is a set of drawings indicating extent, boundaries and classification of all classified areas.

3.5 Piping and Instrumentation Diagrams (P&IDs)

P&IDs show the size, design and operating conditions of each major process component, piping and valve designation and size, sensing and control instrumentation, shutdown and pressure relief devices with set points, signal circuits, set points for controllers, continuity of all line pipes and boundaries of skid units and process packages.

3.6 Safety Analysis Function Evaluation (S.A.F.E.) Charts

The S.A.F.E. charts list all process components and emergency support systems with their required sensing devices and the functions to be performed by each device and relate all sensing devices, shutdown valves, shutdown devices and emergency support systems to their functions.

4. Position Mooring System

4.1 General

A Position Mooring System keeps the installation on station. The Position Mooring System includes mooring lines, connectors and hardware, winches, piles, anchors and thrusters. For a single point mooring system, the turret, turntable, disconnecting system, buoy, anchoring legs, etc., are also part of the system.

Typical mooring system types include spread mooring, turret mooring, single point mooring and thruster assisted mooring.

4.2 Spread Mooring

A spread mooring is a system with multiple catenary mooring lines anchored to piles or drag anchors at the sea bed. The other end of each line is individually attached to winches or stoppers on the installation through fairleads as necessary. A catenary mooring line may have one or more line segments, in-line buoy(s) (spring buoy) or sinker(s) (clumped weight) along the line.

4.3 Single Point Mooring (SPM)

A single point mooring allows the installation to weathervane. Three typical types of single point mooring systems that are commonly used are described below:

4.3.1 CALM (Catenary Anchor Leg Mooring)

A catenary anchor leg mooring system consists of a large buoy anchored by catenary mooring lines. The installation is moored to the buoy by soft hawser(s) or a rigid yoke structure.

4.3.2 SALM (Single Anchor Leg Mooring)

A single anchor leg mooring system consists of an anchoring structure with built-in buoyancy at or near the water surface and is itself anchored to the seabed by an articulated connection.

4.3.3 Turret Mooring

A turret mooring system consists of a number of mooring legs attached to a turret that is designed to act as part of the installation, allowing only angular relative movement of the installation to the turret, so that the installation may weathervane. The turret may be mounted internally within the installation or externally from the installation bow or stern. Typically, a spread mooring arrangement connects the turret to the seabed.

4.3.4 Yoke Arm

A yoke arm is a structure at the end of the installation that only allows angular relative movement between the installation and the mooring attachment to the seabed.

4.4 Dynamic Positioning and Thruster Assisted Systems

A dynamic positioning system is defined as all of the equipment necessary to provide a means of controlling the position and heading of a Floating Installation within predetermined limits by means of vectored thrust.

A thruster-assisted system provides controlled thrust to assist the main (usually static) mooring system and reduce component loading of the main mooring system.

5. Subsea System

5.1 General

A subsea system is a flexible/articulated piping system providing a conduit for the hydrocarbons from the subsea pipeline to the surface components. It includes subsea pipelines, subsea well system and risers.

The definitions in this Section describe the various aspects of the classification procedure in this Guidelines.

5.2 Floating Hose

A floating hose is a floating conduit used to export hydrocarbons from a point of storage/production, either an SPM or installation's manifold to a receiving installation's manifold for transport.

5.3 On Bottom Flexible Flow Lines

These lines are conduit used to connect one subsea location to another subsea location prior to a vertical conveyance by the riser system to the surface.

5.4 Pipe Line End Manifold (PLEM)

A PLEM is the assemblage of valves and components or equipment performing the equivalent function connecting the production facilities to the pipeline carrying product to or from the shore, an offloading system or to another facility.

5.4.1 Import PLEM

Import PLEM is the equipment connecting to the Import Riser and the import supply line or wellhead. (In some configurations, the wellhead may provide the function of the Import PLEM.)

5.4.2 Export PLEM

Export PLEM is the equipment connection between the Export Riser and the product discharge line.

5.5 Riser

A riser is a subsea rigid and/or flexible pipe that connects the surface facilities with the sea floor and is thus the conduit for fulfilling the desired function of conveying fluids, gas, electrical power, etc.

5.6 Riser System

The riser system includes the entire assemblage of components, control systems, safety systems and tensioning devices that ensure the integrity of the riser throughout its operation. Riser classification boundaries are defined in Section 7, B.1.

5.7 Riser Support

Riser support comprises any structural attachments, including buoyancy devices that are used to give structural integrity to the riser or transfer load to the supporting structure.

5.8 Submerged Jumper Hoses

Jumper hoses are flexible lines used in conjunction with rigid risers to accommodate the relative motion between the Floating Installation and the submerged top of the riser. Jumper hoses may also be used to connect the subsea manifold to the wellhead.

B. Design Basis and Environmental Loading

1. General Design Basis

The design basis of a Floating Installation identifies, among other items, the production rate, storage capacity and loading capabilities. Since the system operation is site-specific, the environmental conditions of the site directly influence the design of such a system.

The effects of prevailing winds are to be considered to minimize the risk of vented or flared hydrocarbons to personnel, living quarters and evacuation means. Generally, atmospheric vents, flare systems and emergency gas release vents are to be arranged in such a way so that prevailing winds will carry heat and/or unburned gases away from potential ignition sources on the installation. See API RP 14J.

The design environmental conditions are to include those for the operation, installation and transit portions of the Floating Installation's design life. This Section specifically covers the environmental design criteria for:

- Position Mooring System.
- Structural Strength and Fatigue Life Assessments.

2. Design Documentation

The design documentation submitted is to include reports, calculations, plans and other documentation necessary to verify the structural strength of the installation itself and adequacy of the mooring system, production and other utility facilities and riser system (if included in the classification) for the intended operations.

3. Design Conditions

The FPI is to be designed for load scenarios encountered during transit and site-specific conditions. Site-specific conditions are to include both the Design Environmental Condition and the Design Operating Condition.

3.1 Position Mooring System

The position mooring system of a Floating Installation is to be designed to survive in the Design Environmental Condition and operate in the Design Operating Condition. For a disconnectable mooring system, the limiting condition at which the mooring system is to be disconnected or reconnected is to be specified. Detailed requirements for the design environmental conditions, design operating conditions and disconnectable conditions are provided in Section 6, B.1.1.

3.2 Structural Strength and Fatigue Life

3.2.1 Project Site

The site-specific environmental conditions, including both 100-year return period environmental events and wave scatter diagram data of wave height/period joint occurrence distribution, are to be considered for the installation's hull strength and fatigue life assessment. Fatigue life assessment is also to include the effects of on-site operational loading and unloading cycles. A minimum return period of 100 years for the design response should be used for the DEC criteria per API RP 2T. A minimum return period of 50 years for the structural response may be specially considered, provided that it is accepted by the Coastal State. Different environmental conditions may induce different worst responses on various parts of the hull structure. The wave-induced maximum motion responses and maximum structural load effects may result from different wave periods. Therefore, the following two environmental conditions are to be considered

to derive the maximum motion responses and maximum structural load effects. The larger of the two values obtained from 1) and 2) is to be considered the maximum response:

1) 100-year return period waves characterized by a significant wave height with a range of associated peak wave periods. Both winter storms and tropical cyclones (hurricanes or typhoons), if any, need to be considered.
2) Wave scatter diagram data of wave height/period joint occurrence distribution. The length of time on which the data base for the wave scatter diagram data is constructed is long enough to be a reliable basis for design (preferably at least five years). The occurrence distribution is to be annualized with equal probability of occurrence for each data point. Each data point is to represent a sea state of approximately three hours in a continuous time duration of the database.

For both of the above environmental conditions the following are also to be considered:

3) Wave directions of head seas and other directions relative to the installation heading, including the effects of wind and current, with proper probability distribution are to be considered, irrespective of the type of mooring system utilized.
4) As appropriate, either long-crested seas or short-crested seas with spreading function are to be considered for various design issues.

3.2.2 Transit

The wind and wave conditions representing the environment for the transit route from the building or outfitting site (or the shipyard where the conversion modifications are made) to the project site and the time of the year are to be determined for the design of a floating installation. Except for floating installations that qualify for the DISCONNECTABLE classification notation, any other transit conditions occurring during the operational life of the floating installation are to be submitted for review. Prior to commencement of such a voyage, a BKI's Surveyor is to attend and survey the installation to assess its condition.

As a minimum, the wind speed and significant wave height of 10-year return period are to be considered, unless a weather routing plan is to be implemented for the voyage. Seasonal effects on the design environments as appropriate for the proposed transit duration can be considered.

In addition to the check on the installation's hull strength during transit, special attention is to be paid to items such as the flare boom, crane pedestal and process equipment supports that will be subject to motion- induced loading and/or effects of green water. Motion-induced loads during transit are to be calculated and the superstructures and their supports, which are included in the scope of classification, shall be verified against these loads.

If fitted with an internal turret, special consideration is to be given to bottom slamming to preclude damage to the turret supports and bearings.

3.2.3 Disconnectable Installations

For disconnectable floating installations that are disconnected from its mooring and riser systems due to the occurrence of a limiting extreme environmental condition, the structural strength of the installation shall comply with unrestricted service (North Atlantic) conditions. However, if the disconnectable floating installation is restricted to a specific service area in proximity to its operating site location, reduced design load parameters may be applied with an appropriate limited area of disconnected service notation DISCONNECTABLE-R (from site to designated port) or (from site to geographic area Lat. X1, Long. Y1; Lat. X2, Long. Y2; Lat. X3, Long. Y3; Lat. X4, Long. Y4), where permitted by local authorities or regulations.

3.2.4 Strength and Fatigue Life

Hull strength and fatigue life assessment are calculated according to Section 4 or Section 5 for a given project site and transit route.

When referred to elsewhere in these Guidelines, the safety factors for fatigue life are defined in Table 2.1 shown below.

Table 2.1 Safety Factors for Fatigue Life

Importance	Degree of accessibility for inspection and repair		
	Dry Access	Underwater Access	Not Accessible
Non-Critical	2(5)	3	5
Critical	3	5	10

Notes:

1. *"Critical" implies that failure of these structural items would result in the rapid loss of structural integrity and produce an event of unacceptable consequence.*
2. *"Access" refers to the possibility of a close inspection and repair operation.*
3. *Due to the structural redundancy and accessibility of inspection inherent in typical hull structures of ship-type installations, the applied safety factor is generally 1,0. The approach outlined in Section 4, A.3.2.5.2 and B.1.3.6.2 is to be followed.*
4. *In the event of a safety factor conflict due to different degrees of accessibility to a location, the more stringent safety factor is to be used.*
5. *BKI will consider a reduction in fatigue safety factor from 2. to 1. when the structural detail is readily visible, inspectable and repairable during normal operation.*

4. Environmental Conditions

4.1 General

The environmental conditions for various design conditions described in B.3 are to be submitted with adequate data for the specific site of operation. Statistical data and mathematical models that describe the range of pertinent expected variations of environmental conditions are to be employed. All data used are to be fully documented with the sources and estimated reliability of data noted.

An environmental report describing methods employed in developing available data into design criteria is to be submitted in accordance with Section 1, C.2. Probabilistic methods for short-term, long-term and extreme-value prediction are to employ statistical distributions appropriate to the environmental phenomena being considered, as evidenced by relevant statistical tests, confidence limits and other measures of statistical significance. Hind casting methods and models are to be fully documented.

Generally, data and analyses supplied by recognized consultants will be accepted as the basis of design. Published design standards and data, if available for the location of interest, may be cited as documentation.

Specifically, the following environmental data are normally to be provided:

1) Extreme events of 100-, 10- and 1-year return period data for wind speed, significant wave height and current. A range of associated wave periods is to be considered for each specified significant wave height. Both winter storms and tropical cyclones (hurricanes or typhoons), if any, need be considered.
2) Directional data and angular separation for extreme values of wind, waves and current.
3) Wave spectral shape formulation.
4) Current speed and directional variation through the water depth.
5) Wave height/period joint occurrence distribution (wave scatter diagram data with equal annual probability of occurrence for each data point).

6) Long-term wave statistics by direction.

7) Water depth and tidal variations, including wind and pressure effects of storms.

8) Air and sea temperature.

9) Ice, iceberg and snow, if any.

10) Time series of squalls with wind speeds and wind directions in the areas where the maximum mooring system responses are governed by squalls (refer to Section 6, B.1.1.2)

4.2 Environmental Loads

The design of a Floating Installation requires the establishment of environmental loads considering the following parameters:

- Air and sea temperatures
- Currents
- Ice and Snow
- Tides and storm surges
- Waves
- Wind

Other phenomena such as loop currents, tsunamis, submarine slides, seiche, abnormal composition of air and water, air humidity, salinity, ice drift and icebergs may require special considerations.

Wind tunnel and towing tank tests on the project-specific submerged hull and superstructures are preferred in determining current and wind loads. Alternatively, the following calculation procedures can also be applied.

4.3 Current and Current Load

The current forces on the submerged hull, mooring lines, risers or any other submerged objects associated with the system are to be calculated using a current profile established in accordance with 3.1. In areas where relatively high velocity currents occur, load amplification due to vortex shedding is to be considered.

Model tests can be used in determining current loads. Alternatively, the following calculation procedures can also be applied.

Current force, $F_{current}$, on the submerged part of any structure is calculated as the drag force by the following equation :

$$F_{current} = \frac{1}{2} \cdot \rho_{water} \cdot C_D \cdot A_{current} \cdot u_c |u_c| \quad [kN]$$

where

ρ_{water} = density of sea water, 1,025 [tonnes/m^3]

C_D = drag coefficient, in steady flow (dimensionless)

u_c = current velocity vector normal to the plane of projected area [m/s]

$A_{current}$ = projected area exposed to current [m^2]

Drag coefficients in steady flow vary considerably with section shape, Reynold's number and surface roughness and are to be based on reliable data obtained from literature, model or full scale tests.

For a Floating Installation using a ship-type configuration (e.g., tankers), current forces may be calculated (as appropriate) by using coefficients based on model test data as presented in Prediction of Wind and Current Loads on VLCCs, published by Oil Companies International Marine Forum (OCIMF). Drag

coefficients obtained using computational fluid dynamics (CFD) method may be acceptable if the application is well validated and documented.

Table 2.5 provides recommended drag coefficients for mooring lines and risers. Other coefficients can be used if well documented.

4.4 Current and Wind Load under Oblique Environment

For environments approaching from an oblique direction, the following equation can be used to evaluate wind and current forces if more accurate predictions are not available.

$$F_\phi = F_x\left[\frac{2\cos^2\phi}{1+\cos^2\phi}\right] + F_y\left[\frac{2\sin^2\phi}{1+\sin^2\phi}\right] \quad [kN]$$

where

F_ϕ = force due to oblique environment [kN]

F_x = force on the bow due to a bow environment [kN]

F_y = force on the beam due to a beam environment [kN]

ϕ = direction of approaching environment, in degrees off bow

4.5 Wind

The wind conditions for various design conditions are to be established from collected wind data and should be consistent with other environmental parameters assumed to occur simultaneously. In general, the wind speed is to be based on a recurrence period of 100 years.

The environmental report is to present wind statistics for the site of installation. The statistics are to be based on the analysis and interpretation of wind data by a recognized consultant. The report is to include a wind rose or table showing the frequency distributions of wind velocity and direction and a table or graph showing the recurrence period of extreme winds. The percentage of time for which the operational phase limiting wind velocity is expected to be exceeded during a year and during the worst month or season is to be identified.

4.5.1 Wind Load

The wind loading can be considered either as a steady wind force or as a combination of steady and time-varying load, as described below:

- When wind force is considered as a constant (steady) force, the wind velocity based on the 1-minute average velocity is to be used in calculating the wind load.
- Effect of the wind gust spectrum can be taken into account by considering wind loading as a combination of steady load and a time-varying component calculated from a suitable wind spectrum. For this approach, the wind velocity based on 1-hour average speed is to be used for steady wind load calculation. The first approach is preferred to this approach when the wind energy spectrum cannot be derived with confidence.

Wind pressure, P_{wind}, on a particular windage of a floating installation may be calculated as drag forces using the following equations:

$$P_{wind} = 0{,}610 \cdot C_s \cdot C_h \cdot V_{ref}^2 \quad [N/m^2] \quad V_{ref} \quad [m/s]$$

where

C_s = Shape Coefficient (dimensionless)

C_h = Height Coefficient (dimensionless)

The height coefficient, C_h, in the above formulation accounts for the wind velocity (V_{wind}) profile in the vertical plane. The height coefficient, C_h, is given by the following equation:

$$C_h = \left(\frac{V_z}{V_{ref}}\right)^2 \quad \text{or} \quad C_h = \left(\frac{z}{Z_{ref}}\right)^{2\beta} \quad \text{,but } C_h\ (\geq 1)$$

where the velocity of wind, V_z, at a height, z, is to be calculated as follows:

$$V_z = V_{ref}\left(\frac{z}{Z_{ref}}\right)^{\beta}$$

V_{ref} = velocity of wind at a reference elevation, Z_{ref}, of 10 m.

β = 0,09 – 0,16 for 1-minute average wind

= 0,125 for 1-hour average wind.

The corresponding wind force, F_{wind}, on the windage is :

$$F_{wind} = P_{wind} \cdot A_{wind}$$

where

A_{wind} = projected area of windage on a plane normal to the direction of the wind, in m^2

The total wind force is then obtained by summing up the wind forces on each windage.

Representative values of C_h are given in Table 2.3. Wind profiles for the specific site of the Floating Installation should be used.

The shape coefficients for typical structural shapes are presented in Table 2.2. To convert the wind velocity, V_t, at a reference of 10 m above sea level for a given time average, t, to velocity of another time average, the following relationship may be used :

$$V_t = f \cdot V_{(1\,hr)}$$

Example values of the factor f, based on API RP 2A, for U.S. waters are listed in Table 2.4. Values specific to the site of the Floating Installation are to be used.

Wind forces can be calculated for large ship-type installations with relatively small superstructure (e.g., tankers) using the coefficients presented in the document Prediction of Wind and Current Loads on VLCCs, OCIMF. Additional forces due to superstructures and equipment can be calculated by the above formula and added to these results.

Wind forces on Floating Installations other than ship-type are to be calculated by the summation of wind forces on individual areas using the above formulas.

If the 1-hour average wind speed is used, the wind's dynamic effect should be separately considered. The wind energy spectrum, as recommended in API RP 2A, may be used.

4.6 Squall Load

A squall is a strong transient wind event characterized by sudden rapid increases in wind speed and sudden shifts in wind direction. The concept of a wind spectrum is not applicable to squalls. A squall event is normally presented by time series of scalar mean wind speed and associated unit vector mean direction. Squall loading is to be calculated in time domain.

4.6.1 100-year Squalls

100-year squalls can be established by scaling the wind speeds of selected squall events as given in below. The maximum wind speed of a squall event is to be scaled to the wind speed associated with 100-year return period of a given metocean site.

$$V_{100}(t_i) = \frac{V_{100}}{V_{max}} V(t_i) \qquad [m/s]$$

where

$V_{100}(t_i)$ = wind speed at time i of scaled 100-year squall [m/s]

$V(t_i)$ = wind speed at time i of a squall record [m/s]

V_{100} = wind speed with 100-year return period [m/s]

V_{max} = maximum wind speed of a squall record [m/s]

4.6.2 Squall Direction

The wind direction of one-minute mean of a squall time record can be in any direction. The direction of a squall in these Guidelines is defined as the wind direction corresponding to the maximum wind speed in a squall time record.

Squall directions, as well as current and wave directions of site specific information can be used for the mooring analysis. If such information is not available, below guidelines can be followed.

For a spread mooring system, co-linear condition, namely, squall, current and waves are in same direction, can be considered. Mooring analysis should include following directions as minimum

1) Squall direction in each mooring line group
2) Squall direction is beam-on a moored FPSO

For a single point mooring, in addition to the co-linear condition, following additional conditions should also be considered.

1) Initial direction (wind direction at the initial time step of a squall) in stern, 30 degrees and 60 degrees from stern, respectively.
2) Current and waves are collinear and both at 30 degrees to squall.
3) Waves at 30 degrees to squall and current at 90 degrees to squall.

The squall direction will be varied depending on the case being considered. Therefore the initial squall direction for the analysis case considered is to be shifted accordingly as following.

$$\theta_i(t_0) = \theta(t_{max}) - \beta_i \qquad [degrees]$$

where

$\theta_i(t_0)$ = Initial squall direction for the analysis case i, degrees

$\theta(t_{max})$ = Squall direction defined as at the maximum wind speed of a squall, degrees

β_i = Specified direction for analysis case i, such as the direction of a mooring line group, etc.

4.7 Waves and Wave Load

Wave criteria are to be described in terms of wave energy spectra, significant wave height and associated period for the location at which the Floating Installation is to operate. Waves are to be considered as coming from any direction relative to the installation. Consideration is to be given to waves of less than the maximum height because the wave-induced motion responses at waves with certain periods may be larger in some cases due to the dynamic behavior of the system as a whole.

4.7.1 Wave Forces

The wave forces acting on a floating installation consist of three components :

- first order forces at wave frequencies,
- second order forces at frequencies lower than the wave frequencies and
- a steady component of the second order forces. This steady component of the wave force is called Mean Drift Force.

The calculation of wave loading is necessary for assessing the installation motion responses and the mooring system. It requires calculations of dynamic characteristics of the installation and the hydrodynamic loading on the installation for a given environmental condition.

For structures consisting of slender members that do not significantly alter the incident wave field, semi-empirical formulations, such as Morison's equation, may be used. For calculation of wave loads on structural configurations that significantly alter the incident wave field, appropriate methods which account for both the incident wave force (e.g., Froude-Krylov force) and the forces resulting from wave diffraction are to be used. In general, application of Morison's equation may be used for structures comprising slender members with diameters (or equivalent diameters giving the same cross-sectional areas parallel to the flow) less than 20 percent of the wave lengths.

For a column-stabilized type of installation consisting of large (columns and pontoons) and small (brace members) cylindrical members, a combination of diffraction and Morison's equation can be used for calculation of hydrodynamic characteristics and hydrodynamic loading. The designer may refer to Rules for Structure (Pt.5, Vol.II), Sec. 2. Alternatively, the suitable model test results or full scale measurements can be used.

Wave force calculations should account for shallow water effects which increase current due to blockage effects, change the system natural frequency due to nonlinear behavior of moorings and alter wave kinematics.

4.7.2 Wave Drift Load

The second order mean wave drift load and slowly varying wave drift load are to be calculated using appropriate motion analysis computer programs, model tests, or extrapolated from model test results of a similar vessel.

Wave-current interaction effects on wave drift forces are to be included. They can be assessed with simplified wave drift force correction methods, where current effect is included through the consideration of encounter frequency, heading, and relative speed, or direct numerical simulations where wave-current interaction is considered in numerical models. Empirical corrections for the current effect from model tests can be used if available. The method used is to be documented in the mooring analysis report where applicable.

4.8 Wave-induced Motion of a Floating Unit

The wave-induced response of an installation consists of three categories of response, i.e., first order (wave frequency) motions, low frequency or slowly varying motions and steady drift.

4.8.1 First Order Motions

These motions have six degrees of freedom (surge, sway, heave, roll, pitch and yaw) and are at wave frequencies that can be obtained from model tests in regular or random waves or by computer analysis in frequency or time domain.

4.8.2 Low Frequency Motions

These motions are induced by low frequency components of second order wave forces. The low frequency motions of surge, sway and yaw can be substantial, particularly at frequencies near the natural frequency of the system.

The low frequency motion-induced mooring line tension in most systems with a tanker-type installation is a dominating design load for the mooring system. The low frequency motions are to be calculated for any moored installation by using appropriate motion analysis software or by model test results of a similar vessel.

4.8.3 Steady (Mean) Drift

As mentioned above, an installation subjected to waves experiences a steady drift along with the first and second order motions. The mean wave drift force and yawing moment are induced by the steady component of the second order wave forces. Mean drift forces and yawing moments are to be calculated using appropriate motion analysis computer programs or extrapolated from model test results of a similar vessel.

4.9 Directionality

The directionality of environmental conditions can be considered if properly documented by a detailed environmental report.

4.10 Soil Conditions

Site investigation in general should be in accordance with Rules for Structures (Pt.5, Vol.II), Sec.7. Soil data should be taken in the vicinity of the foundation system site. An interpretation of such data is to be submitted by a recognized geotechnical consultant. To establish the soil characteristics of the site, the foundation system borings or probings are to be taken at all foundation locations to a suitable depth of at least the anticipated depth of any piles or anchor penetrations plus a consideration for the soil variability. As an alternative, sub-bottom profile runs may be taken and correlated with at least two borings or probings in the vicinity of anchor locations and an interpretation may be made by a recognized geotechnical consultant to adequately establish the soil profile at all anchoring locations.

Table 2.2 Shape Coefficients C_s for Windages

Shape	C_s
Sphere	0,40
Cylindrical Shapes	0,50
Hull above waterline	1,00
Deck House	1,00
Isolated structural shapes (Cranes, channels, beams, angles, etc.)	1,50
Under deck areas (smooth)	1,00
Under deck areas (exposed beams and girders)	1,30
Rig derrick	1,25

Table 2.3 Height Coefficients Ch for Windages

Height above Waterline		C_h	
Meters	Feet	1-min	1-hr
0,0 – 15,3	0 – 50	1,00	1,00
15,3 – 30,5	50 – 100	1,18	1,23
30,5 – 46,0	100 – 150	1,31	1,40
46,0 – 61,0	150 – 200	1,40	1,52
61,0 – 76,0	200 – 250	1,47	1,62
76,0 – 91,5	250 – 300	1,53	1,71
91,5 – 106,5	300 – 350	1,58	1,78

Table 2.4 Wind Velocity Conversion Factor*

Wind Duration	Factor "f"	
1	Hour	1,000
10	Min	1,060
1	Sec	1,260
15	Sec	1,310
5	Sec	1,310
3	Sec	1,330
* The values of “f” are most representative of Indonesia waters. Site-specific data should be used. See 4.4.1		

Table 2.5 Line Drag Coefficient

Component	C_D
Chain	2,40
Unsheathed spiral wire rope	1,60
Strand rope	1,80
Sheathed rope	1,20
Fiber rope	1,60
Pipe/riser	1,20

C. General Requirements

1. All Installations

1.1 General

This Chapter covers the requirements for installations (ship-type, column-stabilized, tension leg platform, and spar) as defined in A.2. Other types, as defined in A.2.4, will be considered on a case by case basis.

This Section covers the requirements for installations that are newly designed or are undergoing a major conversion that affects the principal dimensions of the floating installation, or an existing vessel that is undergoing conversion to a floating installation. The application of these requirements to existing vessels undergoing conversions will be considered by BKI based on the service history, age, condition of the existing floating installation, etc.

The designer is required to submit to BKI for review all applicable design documentation, such as reports, calculations, plans and other documentation necessary to verify the structural strength of the floating installation itself, see Section 1, C. The submitted design documentation is to include the design environmental conditions see B.4.

1.2 Lightweight Data

The lightweight and centre of gravity are to be determined for installations of all types. An inclining test will be required for the first floating installation of a series, when as near to completion as practical, to determine accurately the lightweight and position of center of gravity. An inclining test procedure is to be submitted for review prior to the test, which is to be witnessed by BKI Surveyor. For specific requirements related to non-ship-type installations, refer to Section 5, A.3, B.2 or C.2.

1.3 Maximum Draft

Every installation is to have marks that designate the maximum permissible draft to which the installation may be loaded. Such markings are to be placed at suitable visible locations on the hull or structure to the satisfaction of BKI. On column-stabilized installations, where practical, these marks are to be visible to the person in charge of liquid transfer operations.

Where a Load Line certificate, issued in accordance with the International Convention of Load Lines, 1966, as amended by the 1988 Protocol, is not required, marks shall be affixed to the hull that clearly show the maximum draft permitted.

Maximum draft marks are to be established under the terms of the International Convention of Load Lines, 1966. Only the summer freeboard should be applied, unless other freeboards are necessary for disconnectable ship-type units. Where minimum freeboards cannot be computed by the normal methods laid down by the convention, such as in the case of a column stabilized installation, they are to be determined on the basis of compliance with strength and stability criteria in the Rules and applicable statutory regulations.

The installation's arrangements are to comply with all applicable regulations of the International Convention on Load Lines. Where alternative method of establishing the maximum draft has been based on strength and stability calculations as described above, arrangements are to be consistent with watertight and weathertight integrity assumptions in those calculations.

1.4 Loading Manual (Operating Manual)

For a ship-type installation, a loading manual is to be prepared and submitted for review pertaining to the safe operation of the installation from a strength point of view. This loading manual is to be prepared for the guidance of and use by the personnel responsible for loading the installation. The manual is to include means for determining the effects of various loaded, transitional and ballasted conditions upon the hull girder bending moment and shear force and is to be furnished to the master of the installation for guidance. In addition, a loading instrument suitable for the intended service is to be installed on the installation. The check conditions for the loading instrument and other relevant data are to be submitted for review.

An operating manual is required for the marine operation of all Floating Installations, containing the information listed in Rules for Mobile Offshore Unit (Pt.5, Vol.VI), Sec.2, C.3.1 and Section 5, A.4.6, as applicable. The above mentioned loading manual may be included in the overall operating manual or issued as a separate document. The loading manual, if issued as a separate document, is to be referenced in the overall operating manual. Further, where **DISCONNECTABLE** is requested as an additional classification notation, the operating manual is to include procedures for disconnection and reconnection of the installation to its mooring and riser system. (See D.1.7 and D.7.2.)

See Section 4 and Section 5 and for additional requirements pertaining to each installation type.

1.5 Trim and Stability Booklet (Operating Manual)

In addition to the loading manual described in Section 2, C.1.4, a ship-type floating installation is to be provided with sufficient information to guide the master and other responsible personnel in the safe loading, transfer and discharge of cargo and ballast with respect to the hull's trim and stability. The information is to include various loaded, transitional and ballasted example conditions over the full range of operating drafts together with stability criteria to enable the responsible personnel to evaluate the intact and damage stability of any other proposed condition of loading.

This information may be prepared as a separate trim and stability booklet or may be included in the overall operating manual. If issued as a separate document, the trim and stability booklet is to be referenced in the overall operating manual. In addition to the booklet or section of the operating manual, the stability guidance information also may be incorporated as part of the loading instrument described in 1.4. (See B.1.4 and Rules for Mobile Offshore Unit (Pt.5, Vol.VI), Sec.2, C.3.1.14), Regulation 10 of the 1966 Load Line Convention, Regulation 27 and 28 of MARPOL 73/78 2012 Consolidated Edition.)

See Section 4 and Section 5 and for additional requirements pertaining to each installation type.

1.6 Stability

The intact and damage stability of the installation are to be evaluated in accordance with the requirements of the Flag and Coastal State. Ship-type installations are to comply with the IMO Code on Intact Stability, the 1966 Load Line Convention, SOLAS Convention or IMO MODU Code as applicable, and MARPOL 73/78. Non-ship-type installations are to meet the requirements in Section 5, A.3, B.2 or C.2. For general requirements pertaining to the makeup and issuance of loading guidance with respect to stability, see 1.5.

1.7 Engineering Analysis

Documentation necessary to verify the adequacy of the hull structure is to be submitted for review. The needed extent and types of analyses and the sophistication of such analyses vary, depending on one or a combination of the following factors:

1) The design basis of the hull structure versus the conditions to be encountered at the site for the installation.

2) The relative lack of experience with the hull structure's arrangement, local details, loading patterns, failure mode sensitivities.

3) Potential deleterious interactions with other subsystems of the floating offshore installation.

The required structural analyses are to employ the loads associated with the environmental conditions determined in association with B. These conditions include those expected during the operational life of the Floating Installation on site and those expected during the transport of the structure to the site of the installation.

For sites with relatively mild environmental conditions, it may be possible, depending on the intended service of the structure, to reduce the structural analysis effort where it is demonstrated that the hull structure satisfies the unrestricted criteria of the pertinent BKI Rules applicable to the installation type being considered. However, it may still be deemed necessary to perform and submit for review specific analyses for such considerations as the interface between the position mooring system and the hull structure, or the effects of structural support reactions from deck mounted (or above-deck) equipment modules or both, potential sloshing load effects and fatigue strength assessments of hull components where the other applied BKI Rules do not address that consideration to the extent needed for a floating offshore installation. More specific information on required structural analyses is given in Section 4 and Section 5 for each type of hull structure covered by these criteria.

1.8 Mooring Systems and Equipment

Position mooring systems are to meet the requirements of Section 6. For temporary mooring equipment, see Section 1, A.6. and Section 4, A.3.1.6.

1.9 Onboard Computers for Stability Calculations

The use of onboard computers for stability calculations is not a requirement of class. However, if stability software is installed onboard floating installations contracted on or after 1 July 2005, it needs to cover all stability requirements applicable to the floating installation and is to be approved by for compliance with the requirements of Guidelines for Certification of Loading Computer System (Pt.4, Vol.1).

1.10 Corrosion Protection of Steel

Unless otherwise approved, all steel work is to be suitably protected by an efficient corrosion prevention system, such as hard protective coatings or equivalent. Reference can be made to IMO resolution MSC. 288(87), MSC. 289(87), MSC. 215(82) and MSC. 244(83).

D. Installation, Hook-up, and Commissioning

1. General

The requirements in this Chapter apply to the procedures to be submitted and the surveys to be performed for all BKI-classed Floating Installations.

Prior to carrying out the installation, the installation procedures are to be submitted for review. The installation procedures to be submitted are to include the following, where applicable.

1.1 General Description

General description of the entire layout of the mooring system and of the Floating Installation with risers, subsea pipelines and, as applicable, pipeline end manifolds (PLEMs).

1.2 Pre-installation Verification

Pre-installation verification procedures for the seabed condition in way of the installation site and contingency procedures for removing any obstacles found on site.

1.3 Pile or Anchor and Mooring Line Installation

Pile or anchor and mooring line installation procedures which are to include, but are not limited to, the following:

1) General preparations for installation.
2) Rigging arrangements for piles, chaser pile and driving hammers.
3) Work barge setup during the various phases of installation, taking into consideration the prevailing weather conditions.
4) Anticipated pile driving resistance.
5) Pile penetration acceptance criteria established by design and pile refusal and overdrive contingency procedures.
6) Procedure for positioning of the pile orientation toward the center of the Position Mooring System and the criteria for allowable deviations of position and orientation.
7) Procedure for installation of the mooring line and the precautions to be taken in order to prevent any twisting of the mooring chains during installation.
8) Procedure for installation of anchors, including piggyback anchors, if applicable, and procedure for determining the installed positions and orientations of the anchors. Criteria for allowable deviations in positioning and orientation are also to be included.

1.4 Tensioning and Proof Load Testing

Tensioning and proof load testing procedures of the anchor piles or anchors and chain system are to include the following:

1) Rigging arrangements for proof load tension testing of the mooring chains, anchor or pile system.
2) Work barge setup to perform the proof load testing of the chains and anchor or pile system.
3) Detailed tensioning procedure, including type of tensioning device to be utilized and tensioning operations.
4) Chain retrieval and abandonment procedures during tensioning.
5) Procedure for chain proof load tensioning by ballasting the Floating Installation, if applicable.

1.5 Hook-up of the Anchor Chain System

Procedure for hook-up of the anchor chain system to the Floating Installation, which is to include the following:

1) Rigging and towing procedures for positioning of the Floating Installation for hook-up to the mooring system.
2) Preferred ballast condition of the Floating Installation prior to the hook-up.
3) Procedure for sequential hook-up of the chains, repositioning of the Floating Installation and tensioning of the chains.

4) Method of determining the correct tension of the chains and the acceptable design tolerance.
5) Procedure for determining the positioning of the SPM system relative to the PLEM or wellhead and the acceptable design tolerance for the position of the SPM center relative to the PLEM or wellhead.
6) Method of securing the chain turntable from movement and the overall safety precautions for the entire hook-up installation.
7) Procedure for chain tensioning by ballasting the Floating Installation, if applicable.
8) Procedure for commissioning and testing the equipment (if fitted) required to be used for periodic verification of mooring line failure See Section 6, B.4 as applicable.

1.6 Import/Export System Installation

The Import/Export System Installation Procedure is to be submitted for review in conjunction with the design review so that it can be verified that all appropriate installation loadings have been considered. The manual is to describe procedures to be employed during the installation of the import/export systems. In addition, the manual is to include a list of allowable environmental limits under which system installation may proceed. Abandonment procedures, retrieval procedures and repair procedures are to be supplied, when deemed necessary.

1.6.1 Rigid and Flexible Risers

The procedure to hook-up the import/export risers to the Floating Installation is to include the following items, where applicable:

1) Handling and rigging of the rigid and flexible riser during installation.
2) Positioning of the work barge for the various phases of the installation.
3) Procedure for installation of the buoyancy tank and arch support and clump weight, if applicable, including steps to avoid riser interference and precautions against damaging the riser during installation.
4) Tie-in rigging technique for hook-up of both ends of the risers.
5) Procedure for hydrostatic testing of the risers. Hydrotest pressure and test duration are to be in accordance with API or other recognized code of practice.

1.6.2 Export Vessel Transfer System

The procedure for installing the export system is to include the following items, as applicable.

1) Rigging, handling and make-up of the export hose system and precautions against damage during installation.
2) Fitting of all the necessary accessory and navigational aids.
3) Procedure for paying out of the hose string into the sea.
4) Procedure for filling and testing the hose string. The required design and testing pressure and testing duration are to be provided.

1.7 Disconnecting Procedure

For disconnectable mooring systems, the procedures for the disconnecting and connecting of the Floating Installation's mooring system are to be submitted. These procedures are to include the abandonment and retrieval of the import and export systems. Also see Section 1, C.6 for Operating Manual requirements.

2. Hook-up Procedures Submittal

Any system component installation intentionally left incomplete to ease the installation of the Floating Installation at site is to be documented and a procedure for site hook-up and testing is to be submitted.

3. Start-up and Commissioning Procedures Submittal

Start-up and commissioning procedures for the production system are to be submitted for review per the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII).

4. Surveys During Installation, Hook-up and Commissioning

The following items are to be verified or witnessed, where applicable, in accordance with BKI reviewed procedures by the attending Surveyor in accordance with Section 3, A.

1) Pile or anchor and mooring line installation
2) Mooring system tensioning and proof load testing
3) Hook-up of mooring chain
4) Import and export system installation and hook-up when Classed
5) Disconnecting sequence
6) Start up and commissioning of all Classed systems and equipment

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Section 3 Surveys

A. Surveys During Construction, Installation and Commissioning 3–1
B Surveys After Construction 3–8

A. Surveys During Construction, Installation and Commissioning

1. General

1.1 General

The requirements in this Section apply to BKI approved procedures and the surveys to be performed on any type of Floating Production Installation (FPI).

Prior to carrying out the on-site installation, BKI approved installation procedures are to be made available to the Surveyor. Detail of the required procedures are given in Section 2, D.1.

1.2 Surveys During Construction or Modification

1.2.1 Ship-Type Installations

In general, surveys of ship-type installations are to follow Rules for Classification and Survey (Pt.1, Vol.I) and the requirements of Section 4 for the vessel's structure and machinery. In addition, Section 7, A.1 lists specific fire and safety systems that are covered in the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII). The Applicable Rules of Part 5 Offshore Technology are to be followed for topside structure.

.1 Topside Modules

For ship-type installations with **FOI** notation, topside modules are not within the scope of class. When notation **Topside Modules** is requested or when topside production facilities are requested for class, topside modules are to follow Applicable Rules of Part 5 Offshore Technology.

1.2.2 Other Installation Types

In general, surveys of other installation types are to follow the Rules for Classification and Survey (Pt.5, Vol.I) and the requirements of Section 5 for structure and machinery. In addition, Section 7, A.1 lists specific fire and safety system requirements included in the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII). The Applicable Rules of Part 5 Offshore Technology are to be followed for topside structure. Applicable Rules are to be followed as listed below as applicable to the equipment fitted on board. The specific requirements may be modified upon agreement from BKI Engineering and the applicable Assistant Chief Surveyor Office.

Survey	Rules Section
General	Applicable requirements of Rules for Classification and Survey (Pt.5, Vol.I)
Hull Structure and Outfitting	
Machinery, Piping, Pressure Vessels and Outfitting	
Mechanical and Piping Systems	
Electrical Cables and Equipment	
Electrical Systems	
Hazardous Areas	
Fire and Safety systems	Section 7, A.1
Stability and Commissioning	Applicable requirements of Rules for Classification and Survey (Pt.5, Vol.I)

Survey	Rules Section
Topsides Structure General	Rules for Structures (Pt.5, Vol.II), Sec.4 and 5
Topsides Structure Materials	Rules for Materials (Pt.1, Vol.V)
Topsides Structure Welding and Fabrication	Rules for Welding (Pt.1, Vol.VI)

1.3 Mooring System Construction

Items of equipment to be used in a mooring system are to be examined during the fabrication process, and testing is to be performed to the satisfaction of the attending Surveyor.

Components fabricated by welding are to meet the requirements of Rules for Welding (Pt.1, Vol.VI) and are to be to the Surveyor's satisfaction. Specifications to be used for chain, wire rope and connecting hardware are to be submitted for review. Physical testing, including break, pull, dimensional and non-destructive testing, is required to be performed in accordance with the submitted specifications to the satisfaction of the attending Surveyor.

2 Surveys During Hook-up

2.1 General

Survey during the hook-up onboard FPIs, whether classed as an FOI or not, is mandatory. Survey during hook-up is to be performed following reviewed procedures and is to include the following, where applicable.

2.2 Piping Systems

Piping hook-up is to be verified for compliance with the reviewed drawings and procedures. Welds are to be visually inspected and nondestructive testing (NDT) performed as required. Upon completion of hook-up, the affected sections are to be hydrostatically tested in accordance with Section 4 or Section 5, as applicable and proven tight.

2.3 Electrical Systems

Electrical hook-up is to be verified for compliance with the approved drawings and procedures. Proper support for cables and proper sealing of cable entries to equipment are to be verified. Upon completion of the hook-up, the affected sections of the equipment and cabling are to be insulation tested and proven in order. All grounding is also to be verified as being in order.

2.4 Instrumentation

Instrumentation hook-up is to be verified for compliance with the reviewed drawings and procedures. Tubing supports are to be verified. Upon completion, all systems are to be functionally tested and proven as being in order. The manufacturer's limits on bend radii for any component of the instrumentation system are to be observed.

2.5 Mechanical Equipment

Mechanical equipment hook-up is to be verified for compliance with the reviewed drawings and procedures, including the grounding of the equipment. Upon completion, all equipment is to be functionally tested and proven as being in order.

3 Surveys of the Mooring System

3.1 General

Survey of the mooring system of all type of FPIs, whether classed as an FOI or not, is mandatory. During installation of the FPI's mooring system, the requirements as contained in this Section are to be verified or witnessed, where applicable, by the attending Surveyor in accordance with procedures in Section 2, D.1.

3.2 Certification of Components and Transit Damage Survey

All applicable components required to be certified at the manufacturers' facilities have received certification.

All mooring components are to be examined for transit damages prior to installation. Any damages found are to be dealt with to the satisfaction of the attending Surveyor.

3.3 Survey of the Installation Site

The area at and in the vicinity of the mooring site is to be surveyed by divers or remotely operated vehicles (ROVs) to confirm that there are no obstructions or debris prior to installation.

3.4 Installation of Anchors/Piles and Mooring Lines

3.4.1 Anchors or Piles

During the installation of the anchors or anchor piles, the following are to be verified in order, where applicable:

1) Proper locking of all connecting shackles from chains to piles or anchors and chains to chains.
2) Sealing of all Kenter shackle locking pins.
3) All complements of anchor chains for correct sizes and lengths.
4) All anchor pile or anchors are installed in the designed positions and orientations and are within the allowable design tolerance.

3.4.2 Mooring Lines

.1 General

During the installation of the mooring lines, the following are to be verified in order, where applicable:

1) The paying out of the anchor chains after the installation of the piles is to be performed in accordance with the approved procedures.
2) Unless otherwise approved by the attending Surveyor, the first pair of anchor chains to be cross-tensioned is the first pair to be installed.
3) The cross-tensioning is to be verified to confirm all pretensioning loads are in accordance with the design and there is no movement or pullout of the anchor piles.
4) Upon successful completion of the pretensioning, the subsequent hooking up of all of the chain legs to the chain stoppers in the turntable is to be verified.
5) During tensioning of the chains for the position mooring system, the relative position of the mooring system's center to the PLEM is to be verified for compliance with the design specifications and tolerance.

6) Upon completion, the chain tension is to be verified by measuring the catenary angles of the chains for compliance with the design specifications and tolerance. Any excess length of chain above the chain stoppers is to be removed, unless it is designed to be retained in the chain well.

7) If the Mooring System design incorporates equipment which is to be used by the crew to periodically verify that the mooring lines have not failed/parted (See Section 6, A.1.8 then such equipment is to be commissioned and demonstrated to the Attending Surveyor.

.2 Fibre Rope Mooring Lines

In general, API RP 2SM Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Rope for Offshore Mooring should be followed to minimize damage during handling and installation.

1) Minimum Tension for Aramid Rope.

   The aramid rope should maintain a minimum tension of 2% Maximum Breaking Strength (MBS) if it is suspended by a buoy after pre-installation.

2) Preset Mooring.

   In general, contact of fiber rope with seabed should be minimized during deployment. However, in some instances, it is necessary for the mooring line to be preset prior to hook-up with the installation. Presetting of fiber rope on seabed is acceptable if the rope passes the test for particle ingress resistance as outlined in the API RP 2SM Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Rope for Offshore Mooring.

3) Dropped Rope during Deployment.

   A rope accidentally dropped on the seafloor during deployment can be reused under the following conditions:

   A) The rope passes the test for particle ingress resistance as outlined in the API RP 2SM Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Rope for Offshore Mooring, and

   B) The rope is retrieved quickly and inspected according to API RP 2I. There is no damage exceeding the API RP 2I discard criteria.

4) Preloading Operation.

   The preloading operation to remove as much permanent elongation as possible and to increase stiffness of the rope should be carefully planned before installation. The preload level and duration should be determined based on a number of considerations including amount of permanent elongation to be removed, limitation of preloading equipment, and time required to complete the preload operation. The preload duration should not be less than one hour. The preload level and duration achieved and rope elongation should be recorded for each step and compared with the expected values.

The pre-tension of fiber rope mooring lines are to be within the designer recommended limits. It is noted that the measurement of catenary angles may not be sufficient for TLMs (Taut Leg Moorings). Other means are to be used to determine the mooring line tensions to the satisfaction of the attending Surveyor. Reference may be made to the API RP 2SM Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Rope for Offshore Mooring for details of fiber rope construction, installation, and testing.

3.5 Field Test

After the mooring system is deployed, each mooring line will be required to be pull-tested. The test is to demonstrate adequacy of anchor holding capacity, eliminate slack in the grounded portion of the mooring lines, detect damage to the mooring components during installation, and demonstrate that the mooring line's inverse catenary is sufficiently formed to prevent unacceptable mooring line slacking due to additional inverse catenary cut-in during storm conditions. During the test, each mooring line will be pulled to the maximum design load determined by dynamic analysis for the intact design condition and held at

that load for 30 minutes. For certain high-efficiency drag anchors in soft clay, the test load may be reduced to not less than 80 percent of the maximum intact design load. For all types of anchors, the attainment of design-required minimum soil penetration depth is to be verified at the site.

BKI will determine the necessity of a maximum intact design tension pull test depending on the extent of the geotechnical investigation, the magnitude of loading, analytical methods used for the geotechnical design and the experience with the soils in the area of interest. For suction piles, BKI will also review the pile installation records to verify the agreement between the calculated suction pressures and the suction pressure used to install the suction piles. For conventional piles, BKI will review the pile installation records to verify the agreement between the calculated pile driving blow counts and the actual blow counts required to drive the piles to the design penetration. For plate anchors, BKI will check the keying loads so that sufficient anchor fluke rotation takes place without further loss of anchor penetration. If the calculated anchor rotation during keying differs from the anchor rotation in site, the anchor's structure should be checked for any resulting out-of-line loading so that its integrity is not compromised. For dynamically installed anchors, BKI will review if the final penetration depth and pile inclination angle are within the allowable ranges.

If the maximum intact design tension pull tests are waived, BKI will require preloading each anchor to a load that is necessary to develop the ultimate holding capacity of the anchor, but not less than the mean intact design tension, and to ensure the integrity and alignment of the mooring line.

For a disconnectable mooring system, the pull test load will be the greater of the following two values:

1) Maximum design load for "DISconnecting Environmental Condition (DISEC)" (i.e., the limiting extreme environmental condition at which the installation is to be disconnected).
2) Maximum design load of mooring line for the "Design Environmental Condition (DEC)" without the installation (i.e., the disconnected mooring system alone).

3.6 Post Installation Survey

The Owner should conduct within three months or as soon as practical after completion of initial hook-up of the mooring system with the floating vessel. If needed, additional surveys should be performed after subsequent installation activities (riser hookup, etc.) that may have significant impact on the mooring system.

The mooring line should be inspected for any external damage by Remotely Operated Vehicle (ROV) or diver. Twist can be verified at installation by ROV/diver monitoring of the marking that runs externally on the jacket. Particular attention should be made to the condition of fiber ropes terminations. Other design aspects which should be verified immediately following hook-up are the fiber rope near surface termination position and the preloading. Estimated elongation should be recorded for all lines during the preloading operation. The purpose of the survey is to establish the initial condition, which will be compared with future inspection results. The Owner is to advise BKI of any anomalies found, but Surveyor attendance is not required.

4 Surveys of the Import/Export System

4.1 General

Survey of the import/export system is required only if the system is to be classed with BKI and to be recommended with the optional classification notations explained in Section 1, A, Where the import/export system is to be classed, during installation of the system, the following items are to be witnessed by the Surveyor, as applicable.

4.2 Certification of Components and Transit Damage Survey

All applicable components required to be certified at the manufacturers' facilities have received certification.

The riser is to be examined for damage as it is being paid out, and sufficient tension is to be maintained to keep the riser free of deformations or buckles.

4.3 Buoyancy Tank and Arch Support

The buoyancy tank and arch support are to be verified as being installed in the correct position relative to the water surface end of the riser.

4.4 Installation of Riser Clamps and End Flanges

The installation of the riser clamps on the buoyancy tank and arch support are to be monitored to verify that the riser is adequately secured and not damaged due to excessive tightening of the clamps.

The installation of the end flanges of the riser is to be monitored for compliance with the approved procedures.

4.5 Underwater Examination

Upon completion of installation, the entire underwater complement of components is to be generally examined and verified by divers or ROVs for compliance with the reviewed design specifications and configurations. At a site with limited visibility, alternative means of verifying the installation are to be submitted for review and are to be performed to the satisfaction of the attending Surveyor.

4.6 Hydrostatic Testing

Hydro testing of the import/export system is to be performed in accordance with the approved procedure. The test pressure and duration of the hydro test are to follow the appropriate codes, such as ANSI/ASME B31.8, API RP 2RD and RP 17B.

4.7 Floating Hose String

The make-up of the export floating hose string is to be verified for compliance with the approved procedures. Suitable gaskets for the hose flanges, positioning of all navigational aids, correct location of the breakaway couplings and tightening of the flange bolts are also to be verified.

During the paying out of the hose string, verification is to be made that the hose string bend radii are not smaller than the manufacturer's recommended limits.

Upon completion of installation, the entire export hose string is to be hydrostatically tested in accordance with the approved procedure and codes, such as the *OCIMF Guidelines for the Handling, Storage, Inspection, and Testing of Hoses in the Field.*

4.8 Subsea Control System

Subsea controls, if installed, are to be satisfactorily tested.

4.9 Navigational Aids

All navigational aids are to be functionally tested and proven in working order.

5 Surveys of the Disconnectable System

5.1 General

Survey of the disconnectable mooring system is required only if the system is to be classed with BKI and to be recommended with the optional classification notations explained in Section 1, A, Where the disconnectable system is to be classed, the system together with system's capability to disconnect free from its mooring system is to be demonstrated to the satisfaction of the attending Surveyor, in accordance with approved test procedures.

5.2 Disconnecting Time

During the disconnect operation, the time taken to effectively free the Floating Installation from the mooring system is to be recorded in the operation manual.

6 Surveys During Commissioning

6.1 General

Survey of the start-up and commissioning of the production facilities is required only if the FPI's production facilities are to be classed with BKI and to be recommended with the optional classification notations explained in Section 1, A.

The start-up and commissioning of hydrocarbon production systems are to be verified by the attending Surveyor in accordance with the procedures reviewed and agreed by the attending Surveyor. The scope of the start-up and commissioning to be verified by the Surveyor is to include the following items:

6.2 Safety and Operational Readiness

Verify precautions for safety of personnel during commissioning, including checks of operational readiness of all lifesaving equipment, fire and gas detection systems, fire fighting equipment, emergency shutdown systems and unobstructed escape routes.

6.3 Communication Procedures

Verify establishment of communication procedures prior to the start of commissioning operations.

6.4 Emergency Procedures

Verify that emergency procedures are provided to deal with contingencies, such as spillage, fire and other hazards. Drills may have to be performed to demonstrate readiness to these procedures.

6.5 Start-up and Testing of Production Support Systems

Verify start-up and testing of all support utility systems, including main and auxiliary sources, for the process system prior to commissioning.

6.6 Hook-up and Testing

Verify proper hook-up and testing of the entire process system prior to commissioning, including the testing of entire system for leaks, the process control functions and emergency shutdown system.

6.7 Purging of the Production System

Verify purging of the entire production system of oxygen to an acceptable level prior to the introduction of hydrocarbons into the production system.

6.8 Introduction of Hydrocarbons and Control of Flow

Verify the introduction of hydrocarbon into the process system and the system's capability to control the flow of the well effluent in the system in a stabilized manner without undue control upsets.

6.9 Start-up of the Flare System (if applicable)

Verify the start-up of the flare system, if applicable, including the necessary precautions taken to eliminate the risk of explosion or fire. The functional capability of the flare system is to be verified.

6.10 Function of the Post Commissioned System

The post-commissioned process system is to be verified for operating satisfactorily for duration of at least 12 hours.

Equipment required verification but not used during initial start-up and commissioning is to be identified for verification at the next Annual Survey.

B Surveys After Construction

1. Conditions for Surveys After Construction

1.1 Application

Surveys After Construction is surveys for maintenance of class after constructions, installations, and commissioning have been completed. General requirements regarding conditions for survey after construction, including validity of class and terms of suspension are contained in the Rules for Classification and Survey (Pt.1, Vol.I) and Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.2, as applicable. Additional requirements specific to floating production installations are contained in this subsection.

Rules for Classification and Surveys (Pt.1, Vol.I) are applied to all existing vessels on the effective date of the Amandment Notice.

1.2 Definitions

1.2.1 Ballast Tank

A **Ballast Tank** is a tank which is used primarily for the carriage of salt water ballast. Salt water ballast tanks are coated with a corrosion resistant hard coating such as epoxy or zinc on all structural surfaces that may or may not be supplemented by anodes.

1.2.2 Corrosion

Active Corrosion means gradual chemical or electrochemical attack on a metal resulting from a reaction with its environment and producing loose scale.

Allowable Corrosion or **Wastage Limit** is the acceptable corrosion limit for the installation's structure in a given area. Also known as the **Allowable Limit**.

Excessive Corrosion is an extent of corrosion that exceeds the allowable limit.

Extensive Area of Corrosion is corrosion of hard and/or loose scale, including pitting, over 70% or more of the plating surface in question, accompanied by evidence of thinning.

Grooving Corrosion is a localized, linear corrosion which occurs at structural intersections where water collects or flows. This corrosion is sometimes referred to as "in line pitting attack" and can also occur on vertical members and flush sides of bulkheads in way of flexing.

Localized Corrosion is by name local in nature and may be caused by a local breakdown in coating from contact damage, insufficient preparation or at areas of stress concentration.

Overall Corrosion appears as an non-protective rust which can uniformly occur on tank internal surfaces that are uncoated, or where coating has totally deteriorated. The rust scale continues to break off, exposing fresh metal to corrosive attack. Thickness cannot be judged visually until excessive loss has occurred.

Pitting Corrosion is a localized corrosion of a metal surface that is confined to a small area and takes the form of cavities called pits.

Substantial Corrosion is an extent of corrosion such that assessment of corrosion pattern indicates wastage in excess of 75% of the allowable corrosion, but within the acceptable limits.

Weld Metal Corrosion is defined as preferential corrosion of weld deposit. The most likely reason for this attack is galvanic action with the base metal which may start as pitting and often occurs on hand welds as opposed to machine welds.

1.2.3 Corrosion Control System

Corrosion Control System may be achieved by application of hard protective coating (usually epoxy coating or equivalent), impressed current cathodic protection (ICCP) system, sacrificial anodes, etc., provided that they are applied and maintained in compliance with the manufacturer's specification.

Corrosion control system for salt water ballast tanks is to be a corrosion resistant hard coating such as epoxy or zinc on all structural surfaces that may or may not be supplemented by anodes. Where a long retention of salt water ballast is expected, special consideration may be given to the use of inhibitors or sacrificial anodes.

1.2.4 Critical Structural Areas

Critical Structural Areas are locations which have been identified from calculation to require monitoring or from the service history of the subject unit or from similar sister units to be sensitive to cracking, buckling or corrosion which would impair the structural integrity of the unit.

1.2.5 Girth Belt/Belt (Transverse Section)

A Girth Belt includes the following:

Surface-Type Units*:* Deck, bottom, side shell and longitudinal bulkhead plating and internal framing.

Column-Stabilized Units*:* Column and bracing plating and internals as deemed necessary. Deck sides and bottom of lower hulls between columns, including internal stiffeners as deemed necessary.

1.2.6 In-Service Inspection Program (ISIP)

In-Service Inspection Program (ISIP) is a comprehensive program that outlines the procedures to be followed and the inspection frequency of the hull and mooring system of a floating facility. All installations

are to be surveyed in accordance with an BKI approved ISIP plan. Risk Based Inspection for Plans complying with the Guidance for Survey Using Risk Based Inspection for Offshore Industry (Pt.5, Vol.A) may meet this requirement if they cover all components of the ISIP. For further details, see 3.

1.2.7 Lightering Service

Lightering Service is the side-by-side mooring of two installations, either while underway or stationary, for the purpose of transferring petroleum cargo, excluding bunkers, from a installation to be lightered to a service vessel. Both the lightered installation and the service vessel are to be considered in lightering service.

1.2.8 Panel

Panel is the area between adjacent main frames or girders from stiffener to stiffener.

1.2.9 Produced Water Management and Storage Plan

Each unit that stores produced water in the hull is required to develop and maintain a Produced Water Management and Storage Plan. The purpose of this plan is to identify the locations where produced water is stored and verify that the risks associated with corrosion from produced water are managed. The plan is to include the Owner's overall management strategies for the unit (or fleet) as well as the records for the individual unit.

The plan is to list and track at least the following items:

- Identification of tanks used to store produced water
- Amount of produced water stored in each tank
- Lengths of time produced water is stored in each tank

Note:

If produced water is stored for more than three months at a time in an unprotected area or tank, additional examination or mitigation will be required as sulfate reducing bacteria can increase on a logarithmic scale.

The plan is to consider the corrosive effects of produced water, and to have a mitigation strategy in place. The mitigation strategy may include one or more of the following items, and is to provide details as necessary:

- Protective coatings in locations where produced water will be stored
- Anodes in unprotected areas where produced water is stored
- More frequent examination and corrosion rate re-evaluation
- Corrosion study backed by test coupons and/or chemical analysis of the produced water
- Periodical analysis of the water, identifying such items as p_H, salts, and sulfate reducing bacteria
- Application of biocides
- Minimizing the amount of time that produced water is stored in the tank
- Submittal of expected corrosion rates to BKI Head Office
- Additional methods that have proven effective

The plan is to be developed and implemented by the Owner. The BKI Surveyor will verify the effectiveness of the plan at each survey.

1.2.10 Survey

Close-up Survey is a survey where the details of structural components are within close visual inspection range of the Surveyor (i.e., normally within hand reach). In the offshore industry, this may be referred as the Close Visual Inspection (CVI).

Overall Survey is a survey intended to report on the overall condition of the structure and to determine the extent of additional close-up surveys. In the offshore industry, this may be referred as the General Visual Inspection (GVI)

1.2.11 Representative Spaces/Tanks

Representative Spaces/Tanks are those which are expected to reflect the condition of other spaces of similar type and service and with similar corrosion preventive systems. When selecting representative spaces, account is to be taken of the service and repair history onboard and identifiable critical and/or Suspect Areas.

1.2.12 Spaces

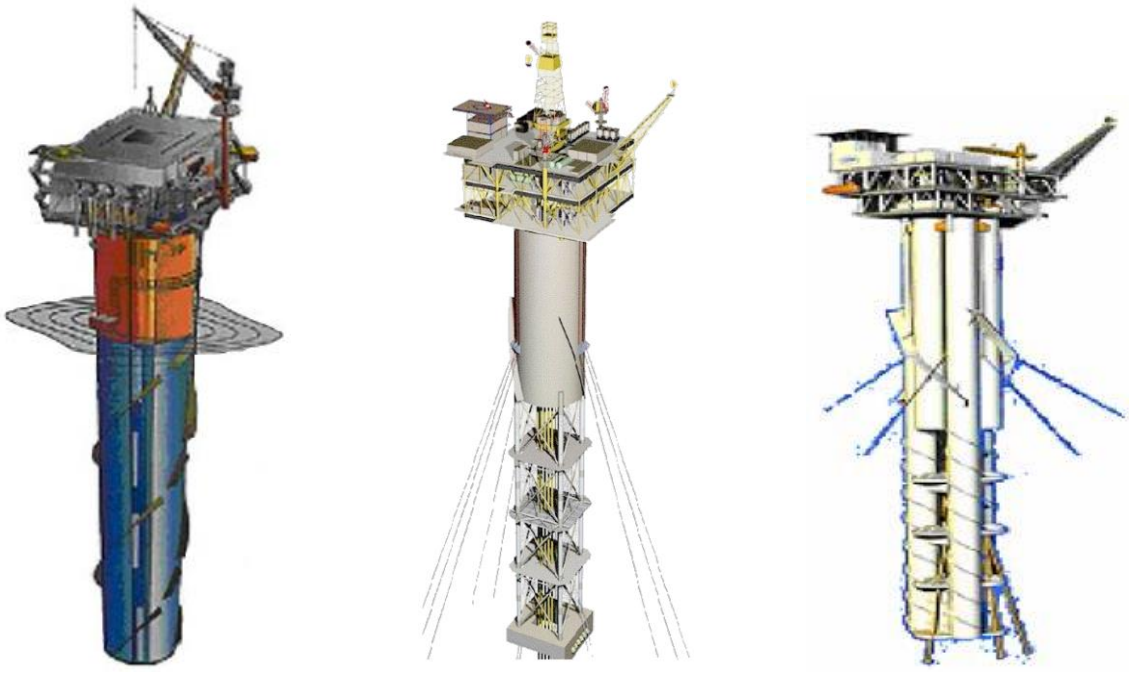
Spaces are separate compartments including tanks, cofferdams, machinery spaces, voids and other internal spaces.

1.2.13 Spar

Spar is a single column-stabilized production installation that is moored to the seabed with conventional catenary mooring system.

Typical Spar configurations (see, Fig.3.1) are:

- "Conventional" Spar which has one-piece cylindrical hull.
- "Truss" Spar where the midsection is composed of truss elements connecting the upper buoyant hull (hard tank) with the bottom soft tank containing permanent ballast.
- "Cell" Spar which is built from multiple vertical cylinders.



Conventional Spar Truss Spar Cell Spar

Fig. 3.1 Spar Configurations

1.2.14 Splash Zone

Splash Zone on a Tension Leg Platform (TLP) is defined as follows:

- Upper Limit of Splash Zone (above the operating draft) = U1 + U2
  - Where U1 = 65% of 1-year storm wave height
    U2 = motion of the installation
- Lower Limit of Splash Zone (below the operating draft) = L1 + L2
  - Where L1 = 35% of 1-year storm wave height
    L2 = motion of the installation

Splash Zone on a Column-Stabilized Unit (CSU) or a Spar is defined as follows:

"Splash Zone" means the external surfaces of the unit that are periodically in and out of the water when the unit is at its operating depth. In general, this zone is between 5 m above and 4 m below the waterline.

Splash zone of a floating offshore installation is to be defined and recorded for use during visual examinations and hull gauging required during periodical surveys carried out in accordance with these Rules.

1.2.15 Structural Critical Inspection Point (SCIP)

Structure Critical Inspection Point (SCIP) is a structural point defined in the ISIP (see 3.) plan as a critical inspection area as a result of structural assessment using applicable calculations and analysis.

In general, SCIPs are locations with higher stresses and estimated lower fatigue life. These locations are locations which have been identified from calculation to require monitoring or from the service history of the subject unit or from similar sister units to be sensitive to cracking, buckling or corrosion which would impair the structural integrity of the unit.

1.2.16 Suspect Areas

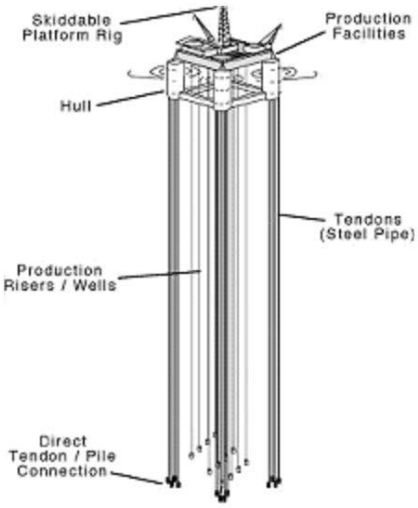
Suspect Areas are locations showing substantial and/or are considered by the Surveyor to be prone to rapid wastage.

1.2.17 Tension Leg Platform (TLP)

Tension Leg Platform (TLP) is a floating production installation tethered to the seabed with taut-catenary mooring system in a manner that eliminates most vertical movement of the structure.

Typical TLP configurations (see, Fig. 3.2) are:

- "Conventional" TLP which has four corner columns with a ring pontoon, and has three tendons per corner.
- "Sea-Star" TLP which has one central column with three tendon support structures, and two tendons per support structure. Its mooring system consists of six tendons, top connectors, bottom connectors, top transition joints, bottom transition joints and foundation piles.
- "Moses" TLP which has four inner columns with four tendon support structures, and two tendons per support structure.



Conventional TLP

Sea-Star TLP

Moses TLP

Fig. 3.2 TLP Configurations

1.2.18 Wind and Water Strakes

Wind and Water Strakes on a Column-Stabilized Unit (CSU), Spar and Barge- or Ship-Shaped Unit are the two (2) strakes or equivalent area located in the vicinity of the load waterline, operating draft or operating depth of the unit. For CSUs, this includes portions of columns and bracing members in the vicinity of the operating draft of the unit.

1.3 Notification and Availability for Survey

The Surveyors are to have access to classed floating production installations at all reasonable times. The Owners or their representatives are to notify the Surveyors on occasions when parts of the structure not ordinarily accessible can be examined.

The Surveyors are to undertake all surveys on classed installations upon request, with adequate notification, of the Owners or their representatives and are to report thereon to BKI. Where the Surveyors find occasion during any survey to recommend repairs or further examination, notification is to be given immediately to the Owners or their representatives in order that appropriate action may be taken. The Surveyors are to avail themselves of every convenient opportunity for performing periodical surveys in conjunction with surveys of damages and repairs in order to avoid duplication of work.

1.4 Damage, Failure, and Repair

1.4.1 Examination and Repair

Damage, failure, deterioration or repair to the floating production installation or its elements that affects or may affect classification is to be submitted by the Owners or their representatives for examination by the Surveyor at the first opportunity. All repairs found necessary by the Surveyor are to be completed to his satisfaction.

1.4.2 Repairs

Where repairs to the floating production installation or its elements that may affect classification are planned in advance, a complete repair procedure, including the extent of the proposed repair and the need for the Surveyor's attendance, is to be submitted to and agreed upon by the Surveyor reasonably in advance. Failure to notify BKI in advance of the repairs may result in suspension of the installation's

classification until such time as the repair is redone or evidence is submitted to satisfy the Surveyor that the repair was properly completed.

Note:

The above applies also to repairs during voyage.

The above is not intended to include maintenance and overhaul to hull, machinery and equipment in accordance with recommended manufacturer's procedures and established marine practice and that does not require BKI approval. Any repair as a result of such maintenance and overhauls that affects or may affect classification is to be noted in the ship's log and submitted to the Surveyors.

1.4.3 Representation

Nothing contained in this Section or in a rule or regulation of any government or other administration or the issuance of any report or certificate pursuant to this section or such a rule or regulation is to be deemed to enlarge upon the representations expressed in Rules for Classification and Surveys (Pt.5, Vol.I), Sec.1, A. The issuance and use of any such reports or certificates are to be governed in all respects by Rules for Classification and Surveys (Pt.5, Vol.I), Sec.1, A.

1.4.4 Application of Rules

The applicable BKI Rules to the floating production installation's classification is to be applied to any repair without changing the original design, carried out on the installation's structure, machinery or equipment that affects or may affect classification. Application of the most recent Rules will be specially considered at the Owner's request or otherwise mandated by the current Rules.

1.4.5 Prompt and Thorough Repairs

Notwithstanding 1.4.1 and 1.4.2 any damage in association with wastage over the allowable limits (including buckling, detachment or fracture), or extensive areas of wastage over the allowable limits, which affects or may affect the unit's structural, watertight or weathertight integrity, is to be promptly and thoroughly repaired. Areas to be considered include:

1) Side shell frames, their end attachments and adjacent shell plating
2) Deck structure and deck plating
3) Bottom structure and bottom plating
4) Inner bottom structure and inner bottom plating
5) Watertight and oil tight bulkheads
6) Hatch covers and hatch coamings, where fitted
7) Weld connection between air pipes and deck plating
8) Air pipe heads installed on the exposed decks
9) Ventilators including closing devices, if any
10) Bunker and vent piping systems
11) For double hull units the following additional areas are to be considered:
    - Side structure and side plating
    - Inner side structure and inner side plating
    - Longitudinal bulkhead(s) structure and longitudinal bulkhead(s) plating, where fitted
    - Transverse watertight or oil tight bulkheads structure and transverse watertight or oil tight bulkheads plating
12) For column-stabilized units, the following additional areas are to be considered:

- Columns
- Pontoons
- Bracing

13) For tension leg units, the following additional areas are to be considered:

- Tendons and tendon connections
- Columns
- Bracing

For instances where the unit is currently on location and producing, consideration may be given to allow the unit to carry out repairs on site. When this is allowed the Owner is to submit a repair plan that includes a time line for completion of the repairs and where necessary an Engineering Analysis and/or changes to the approved operating mode to justify continued operation.

Additionally, when a survey results in the identification of structural defects or corrosion, either of which, in the opinion of the Surveyor, will impair the unit's fitness for continued service, remedial measures are to be implemented before the unit continues in service.

Where damage found on structure is isolated and of a localized nature which does not affect the unit's structural integrity, consideration may be given by the Surveyor to allow an appropriate temporary repair to restore watertight or weather tight integrity and impose a Recommendation with a specific time limit.

1.5 Alterations / Modifications

No alteration or modification which affect or may affect classification or the assignment of load lines are to be made to the hull or systems of a classed floating production installation unless plans of the proposed alteration or modification are submitted and approved by an BKI Technical Office before the work is commenced, and such work, when approved, is to be performed to the satisfaction of the Surveyor. Nothing contained in this Section or in a rule or regulation of any government or other administration or the issuance of any report or certificate pursuant to this Section or such a rule or regulation is to be deemed to enlarge upon the representations expressed in Rules for Classification and Surveys (Pt.5, Vol.I), Sec.1, A. and the issuance and use of any such reports or certificates are to be governed in all respects by Rules for Classification and Surveys (Pt.5, Vol.I), Sec.1, A.

1.5.1 Application of Rules

The applicable BKI Rules to the floating production installation's classification are to be applied to minor alteration/modification carried out on the unit, including its structure, machinery or equipment, that affects or may affect classification. Application of the most recent Rules will be specially considered at the Owner's request or otherwise mandated by the current Rules.

The following cases may be considered as a major alteration or modification, and therefore require compliance with up-to-date Rules for the section being altered or modified:

- Changing configuration or material of structure that is defined as "Special Application Structure" or "Primary Application Structure" in accordance with these Rules.
- Changing a marine piping system (such as the ballast systems, bilge system, propulsion system, etc.) with all of its components (piping, valves, pumps, etc.).
- Changing a marine electrical system (such as the main power distribution, emergency power distribution, electrical propulsion system, etc.) with all of its components (cabling, electrical motors/pumps, panels, etc.).

– Changing layout and material used in the passive fire protection system, such as more than 10% of deck area alteration or modification to the footprint of the accommodation deckhouse/ superstructure or its material used for fire protection.

Note:

Adding another deck on top of an existing accommodation deckhouse is not considered to be a major modification of the entire deckhouse.

– Changing an active fire protection system (such as the fixed-firefighting system, fire and gas detection system, etc.) with all of its components (piping, pumps, hoses, panels, alarms, detectors, etc.).

1.6 Welding and Replacement of Materials

1.6.1 Normal and Higher Strength Structural Steels

Welding or other fabrication performed on the structural steels listed in Rules for Materials (Pt.1, Vol.V) Table 4.2 and 4.7 is to be in accordance with the requirements in Rules for Welding (Pt.1, Vol.VI), Sec.12.

1.6.2 Special Materials

Welding or other fabrication performed on other steels of special characteristics or repairs or renewals of such steel or adjacent to such steel is to be accomplished with procedures approved for the special materials involved. The procedures are to be in accordance with the information provided in Rules for Mobile Offshore Units (Pt.5, Vol. VI), Sec.2, C.3.2 and Rules for Welding (Pt.1, Vol.VI)

1.6.3 Substitutions and Alterations

Substitutions of steel differing from that originally installed, alteration of original structural configuration or change from bolted to welded joint is not to be made without approval by the BKI Head Office.

1.7 Corrosion Prevention System – Ballast Tanks

1.7.1 Corrosion Prevention System

Corrosion protection system for salt water ballast tanks is to be a corrosion resistant hard coating such as epoxy or zinc on all structural surfaces that may or may not be supplemented by anodes. Where a long retention of salt water ballast is expected, special consideration may be given to the use of inhibitors or sacrificial anodes.

1.7.2 Coating Conditions

Condition of hard coatings is defined as follows:

GOOD is a condition with only minor spot rusting.

FAIR is a condition with local breakdown at edges of stiffeners and weld connections and/or light rusting over 20 percent or more of areas under consideration, but less than as defined for POOR condition.

POOR is a condition with general breakdown of coating over 20 percent or hard scale at 10 percent or more of areas under consideration.

1.7.3 Salt Water Ballast Spaces

In salt water ballast spaces, other than double bottom tanks, where poor coating condition is found and Owners or their representatives elect not to restore the coating, where a soft coating has been applied or a protective coating has not been applied, the ballast tanks are to be internally examined at each subsequent Annual Survey.

Double bottom tanks for the purpose of this requirement are those double bottom tanks separate from topside tanks, side tanks or deep tanks.

1.8 Requirements for Internal Examinations

The following apply to all internal examinations of any spaces adjacent to shell plating, such as tanks, holds, voids or machinery spaces, and are applicable at Annual, Intermediate or Class Renewal Survey.

1.8.1 Safety

Precautions are to be taken for safety during inspection. Tanks are to be made safe for entry and work.

1.8.2 Preparation for Survey

In preparation for survey and to allow for a meaningful examination, all spaces are to be cleaned, including removal from surfaces of all loose accumulated corrosion scale. Spaces are to be sufficiently clean and illumination is to be provided to reveal corrosion, deformation, fracture, damages or other structural deterioration. For details see Rules for Classification and Survey (Pt.5, Vol.I), Sec.3.I.A.6.

1.8.3 Safe Access into Spaces with Soft Coatings

Where soft coatings are found, safe access is to be provided for the Surveyor to verify the effectiveness of the coatings and to perform an assessment of the conditions of internal structures that may include spot removal of the coating. Where the soft coatings are found no longer effective, the space shall be treated as an uncoated tank and sufficient cleaning, as required by 1.8.2, is to be performed prior to survey.

1.8.4 Extent of Overall Survey

Based on conditions found, thickness gauging and means of access to the upper part of the tank or space may be required. Where significant corrosion or structural damage is found, the extent of the overall examination may be expanded to other spaces. The requirements for Close-up Survey and thickness gauging, Rules for Classification and Survey (Pt. 1, Vol.I), Sec. 4.I.B and C will be applied to barge- and ship-shaped installations in some cases, as described in 6.2.1.8. Thickness gauging are to be taken by an BKI recognized specialist.

1.8.5 Examination of Plating and Framing

Casings, ceilings or linings, and loose insulation, where fitted, are to be removed as required by the Surveyor for examination of plating and framing.

1.8.6 Compositions on Plating

Compositions on plating are to be examined and sounded but need not be disturbed if found adhering satisfactorily to the plating.

1.9 Surveys Using Risk-Based Inspection (RBI) Techniques

A properly conducted Risk-Based Inspection (RBI) plan or Reliability Centered Maintenance (RCM) plan may be credited as satisfying requirements of Survey After Construction for the corresponding installation. The plan is to be in accordance with the Guidance for Surveys using Risk-Based Inspection for Floating Offshore Industry (Pt.5, Vol.A) or the Guidance for Surveys using Reliability-Cantered Maintenance (Pt.7, Vol.I)

The application of these Guides does not cover any statutory survey requirements that may apply to the installation being considered. Although BKI is authorized to perform statutory surveys on behalf of some authorities, BKI is not in a position to alter or waive them. The cognizant administration or regulatory body is the final determining body for statutory or regulatory requirements under their jurisdiction. The Owner is responsible in developing the inspection plan, to give due consideration to applicable requirements external to BKI.

1.10 Incomplete Surveys

When a survey is not completed, the Surveyor is to report immediately upon the work done in order that Owners and BKI may be advised of the parts still to be surveyed.

1.11 Lay-up and Reactivation

BKI is to be notified by the Owner that an installation has been laid-up. This status will be noted in the *Record*, and surveys falling due during lay-up may then be held in abeyance until the installation reactivates. Lay-up procedures and arrangements for maintenance of conditions during lay-up may be submitted to BKI for review and verification by survey.

In the case of installations that have been laid up for an extended period (i.e., six months or more), the requirements for surveys on reactivation are to be specially considered in each case, with due regard being given to the status of surveys at the time of the commencement of the lay-up period, the length of the period and the conditions under which the installation has been maintained during that period.

Where the lay-up preparations and procedures have been submitted to BKI for review and confirmed by Annual Lay-up Surveys, consideration may be given to deducting part or all of the time in lay-up from the progression of survey intervals.

For installations returning to active service, regardless of whether BKI has been informed previously that the installation has been in lay-up, a Reactivation Survey is required.

1.12 Onboard Documents and Records

The following documents are to be available onboard at all times.

Note:

This is applicable to all drilling units built under a contract, signed between the Builder and the Owner, on or after 1 January 2012.

1.12.1 BKI Reviewed and Stamped Documents

As a minimum, the following documents reviewed and stamped by BKI are to be available onboard the drilling unit for Surveyor's verification and reference during survey after construction:

1) Operating Manual
2) In Service Inspection Program (ISIP) Plan
3) Drawings indicating locations of all "Special", "Primary" and "Secondary" application structures as defined in these Rules

4) Drawings showing all watertight boundaries and access/closing devices for such boundaries
5) Drawings showing the Fire Protection Systems, clearly indicating all fire rated boundaries and access/closing arrangements for such boundaries, including location of fire dampers for 'A' class divisions
6) Drawings showing the Fire Extinguishing Systems, clearly indicating layout of all fixed and portable fire extinguishing systems. Minor changes to these drawings may be accepted and endorsed by the attending Surveyor, however the endorsed copy of the drawings are to be submitted to BKI engineering at earliest opportunity for record purposes.
7) Drawings showing layout of all Hazardous Areas, clearly indicating layout of different class hazardous divisions together with access/closing/ventilation arrangements for such division boundaries, the arrangement of ventilation shutdown and alarms, and a listing of Electrical Equipment in Hazardous Areas.
8) Drawings showing layout of the Emergency Shutdown Systems
9) Where the floating production installation is classed with a notation affecting its Automation System (such as **OT**, or **OT-S**), Automation System Operating Manual
10) Where the floating production installation is classed with a **DP** notation, the Dynamic Positioning System (DPS) Manual and the Failure Modes and Effects Analysis (FMEA)
11) Where the topside facilities of the floating production installation is also classed, drawings showing layout of the topside Production Facilities and associated Equipment, and a listing of all equipment and components of the Production, Process, and Support Systems
12) Where the floating production installation is classed with optional **HIMP** Notation, the Owner's Hull Inspection and Maintenance Program (HIMP) used for hull inspection and maintenance purposes is to be available onboard the installation

Minor changes to the drawings regarding fire protection systems, fire extinguishing systems, and listing of electrical equipment in hazardous areas, may be accepted by the attending Surveyor and revised documents endorsed to show Surveyor's verification, however the endorsed copy of the drawings are to be submitted to BKI engineering at earliest opportunity for record purposes.

1.12.2 BKI Surveyor Reviewed and Endorsed Documents

As a minimum, the following documents endorsed by an BKI Surveyor are to be available onboard the floating production installation for Surveyor's verification and reference during any survey after construction:

1) Construction Booklet.
2) BKI Certificates for temporary anchoring gear such as the anchors, chains and/or wires, and associated accessories (such as shackles, links, sockets, etc.) used for self-propelled installations units or installed on installations with the ① notation.
3) BKI Certificates for all mooring gear components such as the anchors, piles, chains and/or wires, and associated accessories (such as shackles, links, sockets, etc.), tendons, etc., used for station keeping of the installation at its operational site.
4) Record of all Non-destructive Testing (NDT) of critical structural areas carried out during each Drydocking Survey (or IW) or Class Renewal Survey – Hull.

1.12.3 Records

As a minimum, the following records are to be available onboard the floating production installation for Surveyor's verification and reference during any survey after construction:

1) All abnormalities found, including associated videos and photographic records

2) All repairs performed on any abnormalities found and any further repetitive abnormalities found subsequent to the repairs

3) All corrosion protection system maintenance, including records of all cathodic potential readings taken, records of depletion of all sacrificial anodes, impressed current maintenance records, such as voltage and current demands of the system, coating breaks and the monitoring records of the steel material wastage in way of the coating break areas

4) Any findings of abnormalities by the crew personnel onboard, including all leakages in bulkheads and piping

2. Survey Intervals

2.1 In-Service Inspection Program (ISIP) (see 3.)

All installations are to be surveyed in accordance with an BKI approved In-Service Inspection Program. Applicable class surveys of the floating installation's hull, structure and mooring system are to be carried out in accordance with the BKI approved ISIP.

All installations surveyed in accordance with an BKI approved ISIP, and are to be surveyed under Continuous Survey of the Hull and Mooring System. The due dates shown in BKI Survey Status are to be per the "Master Inspection Plan" mentioned in 3.2.2.2.2).

The Attending Surveyor is to review the ISIP for progression of the Class Renewal as part of the Annual Survey - Hull. This review is to verify that the ISIP is being maintained per the approved ISIP schedule and any adjustments thereto are to take into consideration completion of identified repairs (to the structure) before the due date of the Class Renewal.

2.2 Annual Surveys (see 4.)

Annual Surveys are to be carried out within three (3) months before or after each annual anniversary date of the crediting of the previous Class Renewal Survey – Hull or original construction date. For installations on Continuous Survey, all Continuous Survey requirements for those parts (items) due are generally to be completed each year. The Annual Survey will not be credited and the Certificate of Classification will not be endorsed unless Continuous Survey items which are due or overdue at the time of the Annual Survey are either completed or granted an extension.

2.3 Intermediate Surveys (see 5.)

Intermediate Surveys are to be carried out either at the second or third Annual Survey or between these surveys.

2.4 Class Renewal Surveys (see 6.)

A Class Renewal Survey is to be completed within five years after the date of build or after the crediting date of the previous Class Renewal Survey. The interval between Class Renewal Surveys may be reduced by BKI under certain circumstances. If a Class Renewal Survey is not completed at one time, it will be credited as of the completion date of the survey, but not later than five years from date of build or from the date recorded for the previous Class Renewal Survey. If the Class Renewal Survey is completed prematurely but within three months prior to the due date, the Class Renewal Survey will be credited to agree with the effective due date.

Special consideration may be given to Class Renewal Survey requirements in the case of floating production installations of unusual design, in lay-up or in unusual circumstances. BKI reserves the right to authorize extensions of Rule-required Class Renewal Surveys under extreme circumstances.

A Class Renewal Survey may be commenced at the fourth Annual Survey and be continued with a view to completion by the due date. In connection with the preparation for the Class Renewal Survey, thickness gauging, as required for the forthcoming Class Renewal Survey, are to be taken to the extent accessible and practical in connection with the fourth Annual Survey.

Where the Class Renewal Survey is commenced prior to the fourth Annual Survey, the entire survey is normally to be completed within 12 months if such work is to be credited to the Class Renewal Survey.

2.4.1 Continuous Surveys

At the request of the Owner, and upon approval of the proposed arrangements, a system of Continuous Survey may be undertaken whereby the Class Renewal Survey requirements are carried out in regular rotation to complete all requirements of the particular Class Renewal Survey within a five-year period. The completion date will be recorded to agree with the original due date of the cycle. If the Continuous Survey is completed prematurely but within three months prior to the due date, the Class Renewal Survey will be credited to agree with the effective due date.

BKI reserves the right to authorize extensions of Rule-required Special Continuous Surveys under extreme circumstances.

Each part (item) surveyed becomes due again for survey approximately five years from the date of the survey. For Continuous Surveys, a suitable notation will be entered in the *Record* and the date of completion of the cycle published. If any defects are found during the survey, they are to be dealt with to the satisfaction of the Surveyor.

2.4.2 In-line Surveys

All items required to undergo Class Renewal Surveys, including but not limited to hull, machinery, mooring, topside facilities, and automation, are to be carried out at the same time and interval in order that they are recorded with the same crediting date. In cases where damage has necessitated extensive repairs and examination, the survey thereon may, where approved by BKI, be accepted as equivalent to Class Renewal Survey.

2.5 Drydocking Surveys or Equivalent (see 7.)

For units operating in salt water, a minimum of two underwater examination are to be carried out two times in each five-year Class Renewal Survey period. One such examination is to be carried out in conjunction with the Class Renewal Survey – Hull. In all cases, the interval between any two underwater examinations is not to exceed thirty-six (36) months.

For units operating in fresh water the interval between Drydocking Surveys is not to exceed five years.

Consideration may be given to special circumstances which may justify an extension of the interval. An underwater inspection by a diver may be required for such extensions.

2.6 Tailshaft Surveys (see 8.)

2.6.1 Water-Lubricated Bearings in Fresh Water Exclusively

Survey interval is five (5) years.

2.6.2 Water-Lubricated Bearings in Fresh Water and Sea Water

1) **Single Screw** – Survey interval is three (3) years.
2) **Multiple Screw** – Survey interval is five (5) years.

3) **Continuous Liner or Equivalent** – Survey interval of five (5) years provided:

A) The tailshaft is protected by a continuous metallic liner, or continuous cladding of Rules for Machinery Installations (Pt.1, Vol.III), Sec.4, D.3.2 or fiberglass reinforced plastic coating between liners installed according to approved following procedure which effectively prevents seawater from contacting the steel shaft, or which have shafts of corrosion-resistant materials.

Glass reinforced plastic coating procedure:

Glass reinforced plastic coatings may be fitted on propulsion shafting when applied by a trained technician, utilizing a procedure that complies with a nationally recognized standard, such as ASTM D5162, to the satisfaction of the Surveyor. Such coatings are to consist of at least four plies of cross-woven glass tape impregnated with resin, or an equivalent process. Prior to coating, the shaft is to be cleaned with a suitable solvent and grit-blasted. The shaft is to be examined prior to coating and the first layer is to be applied in the presence of the Surveyor. Subsequent to coating, the finished shaft is to be subjected to a spark test or equivalent to verify freedom from porosity to the satisfaction of the Surveyor. In all cases where reinforced plastic coatings are employed, effective means are to be provided to prevent water gain access to the metal of the shaft. Provisions are to be made for over-lapping and adequately bonding the coating to fitted or clad liner.

B) In addition to the propeller hub details given in the Rules for Machinery Installations (Pt.1, Vol.III), Sec.6, E, the design includes other features that would further reduce stress concentration in the propeller assembly.

2.6.3 Oil-Lubricated Bearings

Survey interval is five (5) years.

2.6.4 Extensions – Water-Lubricated Bearings

1) *Extension up to Three (3) Months*. An extension up to three (3) months may be granted by the Surveyor, when requested by the Owner, provided a survey is carried out in accordance with Rules for Classification and Survey (Pt.1, Vol.I), Sec.3, B.1.4.2.A)

2) *Extension up to One (1) Year*. An extension up to one (1) year may be granted by the Surveyor, when requested by the Owner, provided a survey is carried out in accordance with Rules for Classification and Survey (Pt.1, Vol.I), Sec.3, B.1.4.2.B)

2.6.5 Extensions – Oil-Lubricated Bearings

1) *Extension up to Three (3) Months*. An extension up to three (3) months may be granted by the Surveyor, when requested by the Owner, provided a survey is carried out in accordance with Rules for Classification and Survey (Pt.1, Vol.I), Sec.3, B.1.4.2.2).C)

2) *Extension up to One (1) Year*. An extension up to one (1) year may be granted by the Surveyor, when requested by the Owner, provided a survey is carried out in accordance with Rules for Classification and Survey (Pt.1, Vol.I), Sec.3, B.1.4.2).B) An additional extension up to one (1) year may be considered, when requested by the Owner, provided a survey is carried out at the end of the first extension period, in accordance with Rules for Classification and Survey (Pt.1, Vol. I), Sec.3, B.1.4.2).B) No more than two (2) extensions may be granted.

3) *Extensions not Exceeding Five (5) Years.* an extension not exceeding five (5) years may be granted by the Surveyor, when requested by the Owner, provided a survey is carried out at the fifth year, in accordance with Rules for Classification and Survey (Pt.1, Vol.I), Sec.3, B.1.4.2).A) Consideration may be given to an additional extension not exceeding five (5) years when requested by the Owner, provided a survey is carried out at the fifth year after the first extension, in accordance with Rules

for Classification and Survey (Pt.1, Vol.I), Sec.3, B.1.4.2).A) No more than two (2) extensions may be granted.

2.7 Auxiliary Boiler Surveys (see 9.)

Waste-heat or fired auxiliary boilers intended for working pressures above 3,4 bar, a minimum of two surveys are to be carried out during each 5-year Class Renewal Survey period. One such survey is to be carried out in conjunction with the Class Renewal Survey. In all cases, the interval between any two such surveys is not to exceed 36 months.

An extension of the survey up to three (3) months may be granted by the Surveyor in exceptional circumstances*, provided a survey is carried out in accordance Rules for Classification and Survey (Pt.1, Vol.I), Sec.3, B.1.5.2.1).B)

In addition, annual examinations are to be carried out in accordance with Rules for Classification and Survey (Pt.1, Vol.I), Sec.3, B.1.5.2.2)

For units on Continuous Survey of Hull, the two surveys are to be carried out during each 5 year cycle and may be aligned with the Drydocking Survey dates as long as the interval between surveys does not exceed 36 months.

**** Note***

"Exceptional circumstances" means, e.g., unavailability of repair facilities, unavailability of essential materials, equipment or spare parts, or delays incurred by action taken to avoid severe weather conditions.

3. Survey Pre-Planning and In-Service Inspection Program (ISIP)

3.1 Survey Pre-Planning

Plans and procedures for a Class Renewal Survey, Drydocking Survey, and Underwater Inspection in Lieu of Drydocking (IW) are to be made available onboard for the purpose of carrying out an on-board survey pre-planning meeting with the attending Surveyor.

The planning document is intended to identify critical structural areas and to stipulate the minimum extent, location and means of close up inspection, extent and type of NDT, and thickness measurements with respect to the major structural components as well as to nominated areas.

The document is to be worked out by the Owner in co-operation with BKI and submitted for review well in advance of the survey.

The basis for nomination of the critical structural areas is an assessment in consideration of possible deterioration and designated fatigue prone areas where the following elements on a particular unit are taken into account:

- Design feature with relatively low fatigue life.
- Former history available at Owner's or BKI offices with respect to corrosion, cracking, buckling, indents and repairs for the particular installation as well as similar installations
- Installation's service history since last survey (e.g., area of operation, environmental data, water depth, length of time at each location etc.)

3.1.1 Planning Document

The degree of criticality is to be judged and decided on the basis of the installation's structural and fatigue analyses and recognized principles and practice. The planning document is required to contain the following items:

1) Main particulars
2) Plans to include details of major brace and column connections on column-stabilized units
3) Detailed information on NDT methods and locations
4) List of tanks with information on use, protection and condition of coating
5) Corrosion risk of tank and other major structural members
6) Design risk nomination of major structure
7) Nomination of areas for close up surveys and NDT
8) Nomination of areas of structure for thickness measurement
9) List of acceptable corrosion allowance of different structures
10) Method and extent of cleaning inspection points

3.1.2 In-Service Inspection Program (ISIP)

Where the installation is surveyed under an ISIP, the approved ISIP plan is to be used for the purpose of carrying out an on-board survey pre-planning meeting with the attending Surveyor.

All installations are to be surveyed in accordance with an BKI approved In-Service Inspection Program. Applicable class surveys of the floating installation's hull structure and mooring system are to be carried out in accordance with the BKI approved ISIP plan.

3.2 In-Service Inspection Program (ISIP)

In-Service Inspection Program (ISIP) is a comprehensive program that outlines the procedures to be followed and the inspection frequency of the hull and mooring system of a Floating Production Installation (FPI).

All installations classed by BKI are to be surveyed in accordance with an BKI-approved ISIP. A Risk Based Inspection (RBI) plan approved in accordance with the Guidance for Risk-Based Inspection for Floating Offshore Industry (Pt.5, Vol.A) may be considered the ISIP so long as it includes all components of the ISIP.

An ISIP is mandatory for BKI class surveys on all installations.

3.2.1 Coastal State Regulations

Compliance with an ISIP may be required by any Coastal State Authority. For example, for installations operating within the United States OCS, the United States Coast Guard (USCG) requires the installations to be inspected in accordance with an ISIP approved by the USCG (refer to the USCG D8(m) Policy Letter 03-2004 dated 03-May-2004). An ISIP plan in compliance with the BKI Rules will provide the basis for the owner's ISIP plan to be submitted to the USCG.

3.2.2 Contents of an ISIP Plan

Owner's ISIP plan is expected to at least cover the following items of .1 through .4 below. Additional documents such as tables, checklists, and procedural lists may be included as an Appendix to the plan.

.1 Introduction and General Information

1) Description of the installation, together with its dimensions, main particulars, and the arrangement of ballast tanks and other spaces.
2) Description of the installation's hull and special features. This is to include brief explanation of hull scantlings and locations with high stress.

3) Description of special application structures and Structural Critical Inspection Points (SCIPs). The ISIP plan is to include a copy of the BKI review letter agreeing to the defined Structural Critical Inspection Points. The ISIP plan is also to include a listing of special application structures.

4) Description and listing of primary and secondary application structures.

5) Description of the corrosion control system used throughout the installation, internally and externally, together with sacrificial anodes and the Impressed Current Cathodic Protection (ICCP) system, as applicable.

6) Description of the "splash zone" or "wind-and-water strakes" as applicable. The ISIP plan is to include a copy of the BKI review letter agreeing to the defined "splash zone" or "wind-and-water strakes" of the installation.

7) Arrangement and description of sea chest openings and sea valves.

8) Arrangement and listing of accessible and inaccessible spaces throughout the installation.

9) Supplementary drawings or sketches associated with above listed items (to be included in the ISIP plan as an Appendix).

.2 Operational Procedures and Requirements

1) Following inspection procedures are to be included in the ISIP plan:

   a) Description of underwater body inspections and internal structural inspection. The plan for IW is to be in accordance with applicable BKI Rules, and the ISIP plan is to briefly explain dive operations, safety standards and interaction with diving personnel and NDT specialists.

   b) Detailed scope of individual inspections such as;

      – Hull thickness gauging
      – Examination by Remotely Operated Vehicle (ROV)
      – Tank and space entry
      – General Visual Inspection (GVI) and Close Visual Inspection (CVI)
      – Non-Destructive Testing (NDT)

      Special inspection techniques, interval and procedures for the SCIPs are to be included.

2) An outline of the installation inspection schedule and frequency of all its hull structure and mooring system components are to be included in the ISIP plan. In general, this outline may be called the "Master Inspection Plan" and cover the entire life-cycle of the installation.

3) Facility component identification

4) Reporting and documentation, such as;

   A) General record keeping procedures for reports and surveys (company policy).

   B) Notification and report delivery procedures involving BKI.

   C) Specific record-keeping procedures and report contents for each component category identified under 3) above.

   D) Record-keeping for dive conducted during inspections of the underwater hull.

   E) A repair booklet is to be available for the surveyor to verify. The booklet is to indicate all the repairs carried out including but not limited to, the material replacement due to wastage, steel replacements, repaired fractures, additional reinforcements, substantial corrosion, etc. in the unit structural drawings. Also, the booklet is to indicate any scantling reassessments performed during the repair stage.

5) Damage assessment and repair procedures, such as:

   A) Discussion of categories of damage and company procedures to mitigate.

B) Casualty notification procedures following to facility relating to underwater body and hull structure.

C) Specific procedures and methods to investigate damage or potential damage to the hull or internal structures.

D) Procedures to submit proposed methods, for repair of both underwater defects and damage, to BKI.

.3 Structural Critical Inspection Points (SCIPs)

1) Details of structurally critical locations on the hull of the facility. This section is to at least include a listing, details, inspections cycles, and general inspection procedures of SCIPs.

2) Drawing detailing the crucial or high stress inspection points as determined by BKI.

.4 Post-Hurricane Structural Inspection

Timely and cost effective inspection of an offshore structure following a hurricane (or similar weather conditions such as a cyclone, typhoon, etc.) is critical before the operator safely re-man the unit/facility and brings production back on-line. In areas of the world where hurricane or equivalent weather events are common, an ISIP plan is required to contain owner's above-water and underwater inspection procedures before re-manning the unit/facility.

The API Bulletin "API BULL 2HINS: Guidance for Post-Hurricane Structural Inspection of Offshore Structures" published on 01-May-2009 is applicable to permanent fixed and floating structures in the Gulf of Mexico. In this bulletin, inspection refers to structural inspections only and does not include inspections of production equipment, process piping, electrical and instrumentation or other systems and components of the platform, unless noted otherwise. It provides necessary guidance regarding how a post-hurricane structural inspection needs to be carried out.

3.2.3 Structural Critical Inspection Point (SCIP)

SCIP is a structural point defined in the ISIP plan as a critical inspection area which has resulted from structural assessment using applicable calculations and analysis. In general, SCIPs are locations with higher stresses and estimated lower fatigue life. For the criteria, refer to Annex 10, D. SCIPs are locations which have been identified from calculation to require monitoring, or from the service history of the subject unit or from similar sister units to be sensitive to cracking, buckling or corrosion which would impair the structural integrity of the unit. A tabular listing of the SCIPs, indicating the stress and fatigue life of each location is recommended to be included in the ISIP plan submitted to BKI Head Office. Tables 3.1, 3.2 and 3.3 provide a list of typical structural areas/joints that are considered to be most critical and very critical.

Table 3.1 Critical Structures of a CSU

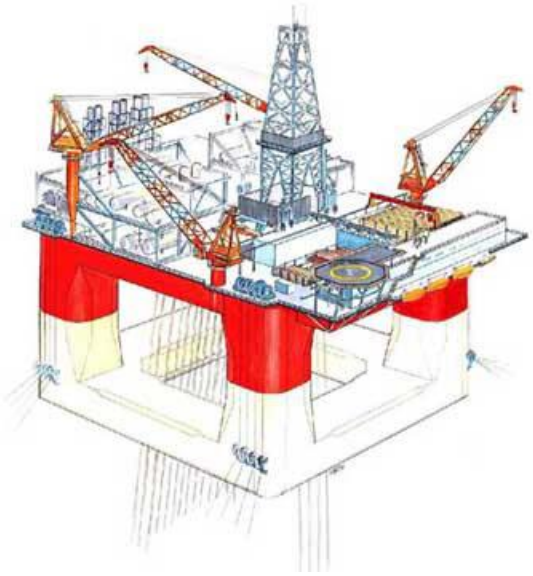
Special Application Structures (Most Critical) – Structure in way of main intersections of lower hulls, columns, braces, deck boxes, column top frames and (integrated) deck structures – Global strength members or portions of integrated deck structure which receive major concentrated loads – Intersection of column top frame members – Chain Jack & Fairlead foundations – Riser porches	
Primary Application Structures (Very Critical) – Lower hull shell and bulkheads – Column shell and bulkheads – Braces – Deck box bulkheads which form “box” or “I” beam type structures that contribute to global strength – Column top frame members – Integrated deck main truss members and nodes – Bulkheads, flats and framing which provide local reinforcement or continuity of structure in way of main intersections where not considered special	

Table 3.2 Critical Structures of a Spar

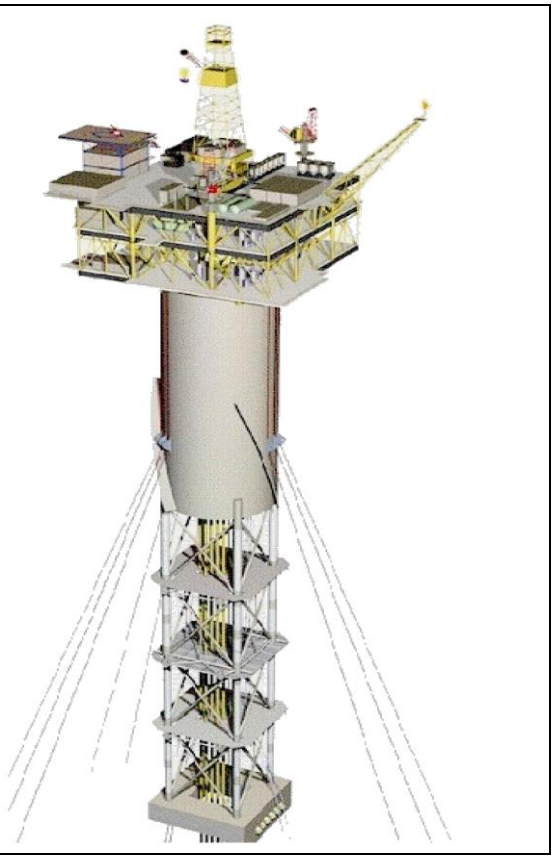
Special Application Structures (Most Critical) – Hard tank – Topside deck leg connection – Hard tank – Truss connection – Truss – Soft tank connection – Heave plate – Truss connection – Truss tubular joint cans – Chain jack & fairlead foundations – Riser guide – Hull connection – Riser porches	
Primary Application Structures (Very Critical) – All inner and outer hull shell plating – Hull top and bottom decks (incl. main girders) – All radial hull bulkheads – All hull ring frames and longitudinal girders – All truss chords and braces – Heave plate plating and girders – Soft tank plating and girders – All struts	

Table 3.3 Critical Structures of a TLP

Special Application Structures (Most Critical) – Structure in way of main intersections of lower hulls, columns, column top frames and (integrated) deck structures – Global strength members or portions of integrated deck structure which receive major concentrated loads – Intersection of column top frame members – Tendon porches – Riser porches	
Primary Application Structures (Very Critical) – Lower hull shell and bulkheads – Column shell and bulkheads – Column top frame members – Integrated deck main truss members and nodes – Bulkheads, flats and framing which provide local reinforcement or continuity of structure in way of main intersections where not considered special	

4. Annual Surveys

4.1 General

The documents and records referenced in 1.12, as applicable, are to be sighted onboard during Annual Surveys, and the survey is to include the following items of this Section, as applicable.

4.2 Hull

4.2.1 Ship-Type Floating Production Installations

For ship-type installations, the weather decks, hull plating and their closing appliances together with watertight penetrations are to be generally examined as far as practicable and placed in satisfactory condition, and the following items are to be verified.

.1 Structure

A) Main structure above waterline.

B) Interface structure between main hull and topside structures, including associated stools and elastomeric bearings, as fitted.

C) Topside Structure

Topside main module structures supporting production facilities and supporting systems under the following condition:

– when topside production facilities are within the scope of class or

– when optional notation Topside Modules is requested.

.2 Protection of Openings

A) Hatchways, manholes and scuttles in freeboard and superstructure decks.

B) Machinery casings, fiddley covers, funnel annular spaces, skylights, companionways and deckhouses protecting openings in freeboard or enclosed superstructure decks.

C) Portlights together with deadcovers, cargo ports, bow or stern access, chutes and similar openings in installation's sides or ends below the freeboard deck or in way of enclosed superstructures.

D) Ventilators including closing devices where fitted, air pipes together with flame screens and weld connections to deck plating. All air pipe "closure devices" installed on the exposed decks are to be externally examined, randomly opened out and their condition verified. Scuppers, inlets and overboard discharges are to be externally examined as accessible including their attachment to shell and valves.

E) Watertight bulkheads, bulkhead penetrations, end bulkheads of enclosed superstructures and the operation of any doors in same.

F) Weathertight doors and closing appliances for all of the above including stiffening, dogs, hinges and gaskets. Proper operation of weathertight doors and closing appliances to be confirmed.

.3 Freeing Ports

Freeing ports, together with bars, shutters and hinges.

.4 Protection of Crew

Guard rails, lifelines, gangways and deckhouses accommodating crew.

.5 Loading and Stability Information

Confirmation of loading guidance, stability data and damage control plans, as applicable.

Loading instruments accepted for classification or approved stability computers installed to supplement the Trim and Stability booklet are to be confirmed in working order by use of the approved check conditions, as applicable. The user's instruction manual for the loading instrument or the stability computer is to be confirmed onboard.

.6 Load Line

Confirmation is required that no alterations have been made to the hull or superstructures which would affect the calculation determining the position of the load lines. Record of Conditions of Assignment is to be available onboard for reference. The Load Line marks are to be sighted, found plainly visible, and re-cut and/or painted, as required.

4.2.2 Column Stabilized Floating Production Installations

For column-stabilized floating production installations, including Spars and TLPs, the exposed parts of the hull, the deck, deck houses, structures attached to the deck, derrick substructure, including supporting structure, accessible internal spaces and their closing appliances together with watertight penetrations are to be generally examined as far as practicable and placed in satisfactory condition, and the following items are to be verified.

.1 Structure

1) Main structure above waterline.
2) Structures attached to the deck, derrick substructure, including supporting structure,
3) Topside main module structures supporting production facilities and supporting systems.

.2 Protection of Openings

1) Hatchways, manholes and scuttles in freeboard and superstructure decks.
2) Machinery casings, fiddley covers, funnel annular spaces, skylights, companionways and deckhouses protecting openings in freeboard or enclosed superstructure decks.
3) Portlights together with deadcovers, cargo ports, bow or stern access, chutes and similar openings in installation's sides or ends below the freeboard deck or in way of enclosed superstructures.
4) Ventilators including closing devices where fitted, air pipes together with flame screens and weld connections to deck plating. All air pipe "closure devices" installed on the exposed decks are to be externally examined, randomly opened out and their condition verified. Scuppers, inlets and overboard discharges are to be externally examined as accessible including their attachment to shell and valves.
5) Watertight bulkheads, bulkhead penetrations, end bulkheads of enclosed superstructures and the operation of any doors in same.
6) Weathertight doors and closing appliances for all of the above including stiffening, dogs, hinges and gaskets. Proper operation of weathertight doors and closing appliances to be confirmed.

3 Upper Hull Support Structure above Waterline

Columns, diagonals and other parts of the upper hull supporting structure as accessible above the waterline.

.4 Protection of Crew

Guard rails, lifelines, gangways and deckhouses accommodating crew.

.5 Loading and Stability Information

Confirmation of loading guidance, stability data and damage control plans, as applicable.

Loading instruments accepted for classification or approved stability computers installed to supplement the Trim and Stability booklet are to be confirmed in working order by use of the approved check conditions, as applicable. The user's instruction manual for the loading instrument or the stability computer is to be confirmed onboard.

.6 Load Line (where assigned by BKI)

Where Load Line is assigned, confirmation that no alterations have been made to the hull or superstructures which would affect the calculation determining the position of the load lines. Record of Conditions of Assignment is to be available onboard for reference. The Load Line marks are to be sighted, found plainly visible, and recut and/or painted, as required.

4.2.3 Suspect Areas

Suspect areas of the hull are to be overall examined, including an overall and Close-up Survey of those suspect areas which were identified at the previous surveys.

Areas of substantial corrosion identified at previous surveys are to have thickness measurements taken.

Where extensive areas of corrosion are found or when considered necessary by the Surveyor, thickness measurements are to be carried out and renewals and/or repairs made when wastage exceeds allowable margins.

Where substantial corrosion is found, additional thickness measurements in accordance with Rules for Classification and Survey (Pt.1, Vol.I), Table 3.2 and Annex B.5 are to be taken to confirm the extent of substantial corrosion. These extended thickness measurements are to be carried out before the survey is credited as completed.

Where reduced scantlings on the basis of effective corrosion control have been adopted, the results of any measurements are to be evaluated based on the scantlings before reduction.

4.2.4 Cargo Tanks, Void Tanks, Ballast Tanks and Combined Cargo/Ballast Tanks

.1 Installations Over 5 Years of Age

Examination of the following tanks is to be carried out.

1) Ballast tanks and combined cargo/ballast tanks other than double bottom tanks, where the following conditions have been identified at previous surveys.
   - A hard protective coating was found in POOR condition, or
   - A soft coating has been applied, or
   - A hard protective coating has not been applied from the time of construction.
2) Double bottom ballast tanks, where substantial corrosion was found within the tank, and the following conditions have been identified at previous surveys.
   - A hard protective coating was found in POOR condition, or
   - A soft coating has been applied, or
   - A hard protective coating has not been applied from the time of construction.

.2 Installations Over 15 Years of Age

In addition to the requirements of 4.2.4.1, the following tanks are also to be examined.

1) Ballast tanks and combined cargo/ballast tanks other than double bottom tanks in way of spaces designated for the carriage of cargo, where FAIR coating conditions were identified at previous surveys, a minimum of three (3) so identified tanks (i.e., one (1) forward, one (1) midship and one (1) aft).
2) Peak tanks, where FAIR coating conditions were identified at previous surveys.
3) Void tanks that have been used for seawater ballast or produced water storage, where FAIR or POOR coating conditions were identified at previous surveys.
4) Cargo tanks, where substantial corrosion has been identified previously and no hard coating has been applied.

Note:

The internal examination by 4.2.4.2.4) is not necessary if the calculated corrosion rate will not require renewal prior to the next Class Renewal. The corrosion rate to be applied is the actual corrosion rate while in operation or the nominal designed corrosion rate values (NDVC), as defined in Section 4.C.1, whichever is greater.

Where extensive areas of corrosion are found or when considered necessary by the Surveyor, thickness measurements are to be carried out and renewals and/or repairs made when wastage exceeds allowable margins.

Where substantial corrosion is found, additional thickness measurements in accordance with Rules for Classification and Survey (Pt.1, Vol.I), Table 3.2 and Annex B.5 are to be taken to confirm the extent of substantial corrosion. These extended thickness measurements are to be carried out before the survey is credited as completed.

Where reduced scantlings on the basis of effective corrosion control have been adopted, the results of any measurements are to be evaluated based on the scantlings before reduction.

.3 Produced Water Management and Storage Plan

The Surveyor is to verify that the unit has a Produced Water Management and Storage Plan and that the plan overview is captured in the unit's BKI records. The Surveyor is to verify that the Owner's plan has been followed. If evidence is found that the mitigation strategy has not been followed or is ineffective based on the results of tank examinations, additional examinations of compartments where produced water has been stored will be necessary. This should include examination of tanks with a history similar to the ones experiencing corrosion, or tanks that have had produced water stored outside of areas protected by coatings or anodes.

Note:

Examples of evidence of an ineffective mitigation strategy would include holes in tank boundaries from pitting or large areas of wastage that were not noted during previous thickness measurements or visual examinations.

.4 Cargo Tanks Used for Produced Water Storage

Tanks that have had produced water stored with no mitigation strategy are to be opened for examination. Refer to 1.2.9 for a list of mitigation strategies.

4.2.5 Helicopter Deck

Where areas of the installation are designated for helicopter operations, the helicopter deck, deck supporting structure, deck surface, deck drainage, tie downs, markings, lighting, wind indicator, securing arrangements where fitted safety netting or equivalent, access arrangements including emergency escape, and access for fire fighting and rescue personnel, are to be examined.

4.2.6 Floating Production Installations with Fenders

In addition to the applicable requirements of 4.1, the Annual Survey is also to include an external examination of hull structures where fenders have been located. Where extensive areas of wastage are found, or when considered necessary by the Surveyor, thickness measurements and internal examination, including Close-up Survey, may be required.

4.2.7 Non Self Propelled Floating Production Installations

Machinery items installed consistent with the services of the installation are subject to a general examination and are to be placed in satisfactory condition.

4.2.8 Cargo Tanks Fittings

Cargo tank openings including gaskets, covers and coamings.

Pressure/vacuum relief valves, flame arrestors and flame screens. Tank vent protective devices are to be examined externally for proper assembly and installation, damage, deterioration or traces of carryover at the outlet. Where deemed suspect, the tank protective device is to be opened for examination.

4.2.9 Cargo Pump Room

Examination of pump room bulkheads for signs of leakage or fractures and, in particular, the sealing arrangement of all penetrations of bulkheads.

Confirmation that there are no potential sources of ignition in or near the cargo pump room and cargo area and that pump room access ladders are in good condition.

Pump room ventilation system including ducting, dampers and screens.

4.3 Mooring System

Annual Surveys of the mooring system is mandatory for all types of floating production installations, and are to comply with following requirements of 4.3.1 or 4.3.2, as applicable.

4.3.1 Spread Mooring System

At each Annual Survey, the spread mooring system is to be generally examined so far as can be seen and placed in satisfactory condition as necessary. In addition, the following above water items are to be examined, placed in satisfactory condition and reported upon, where applicable:

1) The anchor chain stopper structural arrangements are to be visually examined, including the structural foundations of all of the stoppers or holders. Tensioning equipment is to be generally examined.
2) The anchor chain catenary angles are to be measured to verify that the anchor chain tensions are within the design allowable tolerances. Where anchor cables are used, their tensions are to be verified to be within the allowable tensions.
3) The anchor chains or anchor cables above the water are to be visually examined for wear and tear.
4) Review onboard records and verify that the Crew are periodically checking the Mooring Lines for failure (See Section 1, C.6.2). If the method for checking mooring failure includes equipment then (See Section 6, B.4) then such equipment is to be demonstrated to the Attending Surveyor.

4.3.2 Single Point Mooring (SPM) Systems

At each Annual Survey, the single point mooring system is to be generally examined insofar as can be seen above water and placed in satisfactory condition as necessary. In addition, the following above water items are to be examined, placed in satisfactory condition and reported upon, where applicable:

1) The anchor chain stopper structural arrangements are to be visually examined, including the structural foundations of all of the stoppers.
2) The anchor chain's catenary angles are to be measured to verify that the anchor chain tensions are within the design allowable tolerances. Where anchor cables are used, their tensions are to be verified to be within the allowable tensions.
3) The anchor chains or anchor cables above the water are to be visually examined for wear and tear.
4) The condition of the bearings is to be verified for continued effectiveness of the lubrication system.
5) The entire assembly of the single point mooring structure above water is to be generally examined for damage, coating breaks and excessive signs of corrosion. This survey is to include all turret wall structures, accessible turret well structures, mooring arms, all structures supporting the disconnectable operations of the mooring system, etc., whichever are applicable.

4.3.3 Fibre Rope Mooring Systems

Particular attention is to be given to the examination of the following for fibre ropes during Annual Surveys:

1) The Surveyor is to review the records of anchor leg re-tensioning caused by creep, and confirm with designer that adequate chain/wire segments are available for further re-tensioning due to creep such that the fibre rope does not come into contact with the chain stoppers, fairleads, etc., and stays below the water surface. Refer to the vessel's drawings for determination of lengths of chain/wire segments.
2) The Surveyor is to verify that recorded values of creep are in accordance with the anticipated design values. Any deviance from design values are to be justified by the designer, and appropriate remedial action should be taken accordingly.
3) The pre-tension of mooring lines are to be within the designer recommended limits. It is noted that the measurement of catenary angles may not be sufficient for TLMs (Taut Leg Moorings). Other means are to be used to determine the mooring line tensions to the satisfaction of the attending Surveyor.

Reference may be made to the API RP 2SM Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring for details of fibre rope construction, installation, and testing.

4.3.4 Tendon Mooring System

When available, tendon tension monitoring records are to be reviewed and verified to be within design limits.

4.4 Fire and Safety Systems

Annual Survey of the entire fire and safety systems installed throughout the floating production installation is mandatory for all types of floating production installations.

Following systems are to be verified to confirm no significant changes have been made to any of the systems and that they remain in satisfactory condition.

4.4.1 Passive Fire Protection Systems

Passive fire protection systems, including the following items are to be generally examined and function tested as necessary:

1) Examination of structural fire protection as well as protection of accommodation spaces, service spaces and control stations, as accessible
2) Examination and function testing of fire doors
3) Examination and testing of ventilation fire-dampers
4) Examination and testing of ventilation system closures and stoppage of power ventilation
5) Examination and testing of shutters or water curtains (where fitted)

4.4.2 Active Fire Protection – Fixed Systems

Active fire protection fixed systems, including the following items are to be generally examined and function tested as necessary:

1) Examination of all items shown on the fire control plan, and confirmation that no alteration has been made to the BKI endorsed plan
2) Examination and testing of all fire pumps. Other pumps used for active fire protection are also to be examined. This is to include confirmatory testing of the fire pump capacity, and where installed, testing of relief valves of the fixed fire main system.
3) Examination and function testing of the fire main system
4) Examination and function testing of fire main isolation valves

5) Examination of all hydrants, hoses, nozzles, and shore connections, and testing of these as necessary

4.4.3 Active Fire Protection – Additional Fixed Systems

Where installed, active fire protection additional fixed systems, including the following items are to be generally examined and function tested as necessary:

1) Examination and testing of the gas smothering system, including confirmatory examination of the storage of the gas medium, gas alarms, and examination and testing of manual controls
2) Examination of the high or low expansion foam systems
3) Examination and function testing of fixed water spraying systems
4) Protection of helicopter decks with or without refuelling capacity
5) Examination of paint and flammable liquid lockers

4.4.4 Active Fire Protection – Portable Systems

All portable fire-fighting equipment fitted onboard, are to be in accordance with BKI approved plans. In addition, the following items are to be generally examined:

1) Examination of all portable and semi-portable extinguishers
2) Examination and testing of the firefighter's outfit, as necessary

4.4.5 Fire Detection and Alarm Systems

Fire detection and alarm systems, as installed, are to be examined and tested as necessary.

4.4.6 Gas Detection and Alarm Systems

Gas detection and alarm systems, as installed, are to be examined and tested as necessary.

4.4.7 Outfitting

Outfitting arrangements, including the following items are to be examined and tested as necessary:

1) All escape routes from accommodation spaces, service spaces and control stations, from Category 'A' machinery spaces, from other machinery spaces, deckhouses, together with stairway or ladders in way of any escape route, and the accessibility and access through the routes
2) Lighting and gratings in way of all escape routes
3) Guards and rails along floor deck areas and openings, and helicopter landing deck
4) Contact makers for general alarm system, communication system installed in all emergency control stations
5) Fire precautions taken in all machinery spaces

4.4.8 Emergency Shutdown Arrangements

1) Emergency shutdown arrangements provided to disconnect or shutdown, either selectively or simultaneously, of the electrical equipment as outlined in the floating production installation's operating manual, are to be examined and tested.
2) Services such as the emergency lighting, general alarm system, public address system, distress and safety radio system, that are required to be operable after an emergency shutdown of the installation, are to be verified for their proper operation.
3) All equipment in exterior locations w*h*ich is capable of operation after an emergency shutdown is to be verified as being suitable for installation in Zone 2 locations.

4.5 Machinery and Electrical Systems (Marine & Safety Systems)

Annual Survey of machinery and electrical systems servicing the marine and safety systems is mandatory for all types of floating production installations.

4.5.1 Machinery and Electrical Parts to be Examined

Surveys for ship- or barge-type installations are to comply with applicable requirements of Rules for Classification and Survey (Pt.1, Vol.I), Sec.3, B.1.1.2.2)

Surveys for column-stabilized installations are to comply with applicable requirements of Rules for Classification and Survey (Pt.5, Vol.I), Sec.3, B.I.2.2.3.

4.5.2 Self Propelled Installations – Main Propulsion Apparatus

Surveys of self-propelled installations is to comply with applicable requirements of Rules for Classification and Surveys (Pt.1, Vol.I), Sec.3, B.1.1.2.2)

.1 Thrusters (where installed)

Thruster surveys are to comply with the requirements of Rules for Classification and Surveys (Pt.1, Vol.I), Sec.3, B.1.1.2.2)

4.5.3 Preventative Maintenance Techniques

Surveys of machinery that has been accepted for surveys based on preventative maintenance techniques are to comply with the requirements of Rules for Classification and Surveys (Pt.1, Vol.I), Sec.3, B.1.3.4. and Guidance for Planned Maintenance Program (Pt.7, Vol.E).

4.5.4 Hazardous Areas

Surveys of hazardous areas and electrical equipment installed in hazardous areas are to comply with applicable requirements of the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII)

4.6 Inert Gas Systems (where installed)

Applicable requirements of Rules for Classification and Surveys (Pt.1, Vol.I), Sec.3, B.1.1.2.9) are to be complied with.

4.7 Liquefied Gas Installations (where installed)

The Annual Survey, except First Annual Survey, is to be carried out during a loading or discharging operation, as far as practicable.

In addition to the applicable requirements of 4.2.8 and 4.2.9, the Annual Survey is to include the following:

4.7.1 First Annual Survey

1) **Cargo Containment System**. An Overall Survey is to be made of the cargo containment system including the supporting and positioning arrangements, hatches, access arrangements and penetrations, the secondary barrier where fitted, adjacent hull structure and the insulation, insofar as possible without removing fixed insulation or structural members unless deemed necessary by the attending Surveyor.
2) **Secondary Barriers**. The secondary barrier is to be checked for its effectiveness by means of a pressure/vacuum test, a visual inspection or some other acceptable method.

3) **Other Items**. See 1.7.2 for additional items to be included in the first Annual Survey.

4.7.2 All Annual Surveys

1) **General**. The logbooks are to be examined with regard to correct functioning of the cargo containment and cargo handling systems. The hours per day of the reliquefaction plants or the boil-off rate is to be considered.

2) **Interbarrier Space Venting System**. The venting system or other arrangements provided for the emergency removal of gas from the interbarrier spaces (i.e., between the primary and secondary barriers) is to be confirmed in satisfactory condition.

3) **Cargo Tank Venting System**. The venting system for the cargo tanks and hold spaces is to be confirmed in satisfactory operating condition. The vent line drainage arrangement is to be examined.

4) **Instrumentation and Safety Systems**. Gas leakage detection equipment, including indicators and alarms, is to be confirmed in satisfactory operating conditions. Systems for temperature, pressure and liquid level indication of the cargo, cargo tank, insulation, the hull adjacent to the cargo containment system, and cargo refrigerating installations where fitted, including alarms, are to be confirmed in satisfactory operating condition. The piping of the gas detection system is to be visually examined for corrosion and damage and the integrity of the line between suction points and analyzing units is to be confirmed as far as possible.

   The logbooks are to be examined for confirmation that the emergency shutdown system has been tested.

5) **Environmental Control of Hold Spaces**. Inert gas and dry air systems, including indicators and alarms, are to be confirmed in satisfactory operating condition. Means for prevention of backflow of cargo vapor into gas-safe spaces is to be confirmed in satisfactory operating condition. For membrane containment systems, normal operation of the nitrogen control system for insulation and interbarrier spaces shall be confirmed.

6) **Cargo Handling Piping and Machinery**. All piping, cargo hoses, emergency shut-down valves, remote operating valves, machinery and equipment for loading, unloading, venting, compressing, refrigerating, liquefying, heating or otherwise handling the liquefied gas or vapor is to be examined, as far as possible. Records of stopping of the cargo pumps and compressors upon emergency shut-down of the system is to be verified/confirmed.

   Cargo hoses are to be verified, where appropriate, type-approved or marked with date of testing.

7) **Cargo Tank Tightness**. The tightness of cargo tanks is to be confirmed. For this purpose, the installation's gas leak detectors, micro-flow meters, etc. may be utilized providing that they are first proved to be in good order. The installation's logbooks are also to be reviewed to confirm the tightness of the cargo tanks.

8) **Heating Coils**. Heating coils and other heating systems which are essential to keep the temperature of the hull structure from falling below the minimum allowable value for the material used are to be proven in satisfactory operating condition.

9) **Ventilating System**. Examination of the ventilation system is to be made for all gas dangerous spaces and zones, including air locks, cargo pump rooms, cargo compressor rooms, cargo control rooms and spaces used for cargo handling operations. All portable ventilating equipment required for use in the gas dangerous spaces is to be examined. Provision of spares for mechanical ventilation fans for gas dangerous spaces and zones, recommended by manufacturer is to be confirmed.

10) **Spaces in Cargo Areas**. Air locks, cargo pump rooms, cargo compressor rooms, rooms containing electric motors for driving cargo pumps or compressors, cargo control rooms and spaces used for cargo handling operations are to be examined. All accessible gas-tight bulkhead penetrations including gas-tight shaft seals are to be examined. The means for accomplishing gas tightness of the wheelhouse doors and windows is to be examined.

The closing devices for all air intakes and openings into accommodation spaces, service spaces, machinery spaces, control stations and openings in superstructures and deckhouses facing the cargo area or bow and stern loading/unloading arrangements are to be examined.

All windows and sidescuttles within the area required to be of the fixed type (nonopening) are to be examined for gas tightness.

11) **Drip Trays**. Portable and fixed drip trays and insulation for the protection of the deck in the event of cargo leakage are to be examined.

12) **Gas Burning Installations**. Gas burning installations, including instrumentation and safety systems, are to be examined and confirmed in satisfactory operating condition. See also 4.7.2.4).

13) **Sealing Arrangements**. Sealing arrangements on the weather deck in way of openings for the cargo containment system are to be examined.

14) **Fire Protection and Fire Extinguishing Equipment**. The fire water main equipment, water spray equipment, dry chemical powder fire extinguishing systems in the cargo area, and fixed inerting and fixed smothering installations in gas-dangerous spaces are to be examined and operationally tested, as far as practicable.

15) **Electrical Equipment**. Electrical equipment in gas-dangerous spaces or zones is to be examined as far as practicable with particular respect to the following:

- Protective earthing
- Physical condition of electrical cables and supports
- Integrity of enclosures
- Intrinsically safe, explosion proof, or increased safety features of electrical equipment
- Functional testing of pressurized equipment and associated alarms
- Testing systems for de-energizing electrical equipment which is not certified safe for use in gas-hazardous areas but which is located in spaces protected by air-locks (e.g., electrical motor rooms or cargo control rooms)
- Insulation resistance readings of circuits. Where a proper record of testing is maintained, consideration may be given to accepting recent readings.

Note:

See also IACS Recommendation No.35 – Inspection and maintenance of electrical equipment installed in hazardous areas.

16) **Personnel Protection**. Firemen's outfits, protective clothing, and respiratory protection equipment are to be examined. Decontamination showers and eye wash are to be examined and operationally tested, as far as practicable.

17) **Tightness of Hull**. Means for detecting leakage into the hold space through the ship's structure forming the boundary of the hold space are to be examined.

18) **Operating Instructions**. Instructions and information material, such as cargo handling plans, loading manual, filling limit information, cooling-down procedure, are to be confirmed as being aboard the installation.

19) **Relief Valves**. All relief valves in the cargo containment and venting system are to be examined, including protective screens and flame screens, if provided, and seals confirmed intact. Records of opening and closing pressures of relief valves are to be confirmed onboard.

4.8 Dynamic Positioning Systems (if classed)

Dynamic Positioning Systems are to comply with the requirements of Rules for Dynamics Positioning Systems (Pt.4, Vol.II), Sec.3

4.9 Automatic and Remote-Control Systems (if classed)

For Shipboard Automatic and Remote-Control System, applicable requirements of Rules for Automation (Pt.1, Vol.VII) are to be complied with.

4.10 Production Facilities (if classed)

Where the floating production installation's production facilities are classed, applicable requirements of the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII) are to be complied with.

Maintenance records are to be kept and made available for review by the attending Surveyor. The maintenance records will be reviewed to establish the scope and content of the required Annual and Class Renewal Surveys. During the service life of the facilities, maintenance records are to be updated on a continuing basis. The operator is to inform BKI of any changes to the maintenance procedures and frequencies, as may be caused, for example, by changes or additions to the original equipment. The Surveyor may determine during the periodic survey if the changes are sufficient to warrant review by BKI' technical staff.

4.11 Import and Export Systems (if classed)

Where the floating production installation's import-export systems are classed, the import and export systems are to be examined as far as can be seen and placed in satisfactory condition as necessary. In addition, the following items are to be examined, placed in satisfactory condition and reported upon where applicable:

1) A general examination is to be performed on all electrical and fluid swivels, flexible risers, floating hoses, cargo piping and valves associated with the import and export systems, expansion joints, seals, etc.
2) The fluid swivels are to be examined for signs of leaks through their "tell-tale" apertures.
3) Records of maintenance are to be reviewed, including records of hose hydrostatic testing.
4) Navigational aids for all floating hoses are to be examined and functionally tested.
5) Riser tensioning arrangements are to be examined for proper functioning order.
6) All electrical equipment, fitted in hazardous location is to be examined for integrity and suitability for the continued service.

5. Intermediate Surveys

5.1 General

The documents and records referenced in 1.12, as applicable, are to be sighted onboard during Annual Surveys, and the survey is to include the following items of this Section, as applicable.

The Intermediate Survey requirements are in addition to the Annual Survey requirements stated in 4.

5.2 Hull

5.2.1 Ship-Type Floating Production Installations

Intermediate Surveys of self-propelled barge- or ship-type installations are to comply with the applicable requirements of Rules for Classification and Surveys (Pt.1, Vol.I), Sec.3, B.1.2

The scope of the second or third Annual Survey is to be extended to include the following.

.1 Survey Planning Meeting

A survey planning meeting is to be held prior to the commencement of the survey.

.2 Survey of Ballast Tanks

1) For Installations 5 < Age ≤ 10 years

Overall Survey of a minimum of three (3) representative ballast tanks selected by the Surveyor is to be carried out. Where a hard protective coating is found in POOR condition, where soft coating has been applied or where a hard protective coating has not been applied from time of construction, the examination is to be extended to other ballast tanks of the same type.

2) For Installations Age > 10 years

Overall Survey of a minimum of three (3) representative ballast tanks selected by the Surveyor to be carried out. Where a hard protective coating is found in FAIR or POOR condition, where soft coating has been applied or where a hard protective coating has not been applied from time of construction, the examination is to be extended to other ballast tanks of the same type.

.3 Survey of Ballast Tanks and Combined Cargo/Ballast Tanks Other than Double Bottom Tanks

Where provided, the condition of corrosion prevention system of ballast tanks and combined cargo/ballast tanks is to be examined.

Ballast tanks and combined cargo/ballast tanks, other than double bottom tanks, where a hard protective coating is found in POOR condition and Owners or their representatives elect not to restore the coating, where a soft coating has been applied or where a hard protective coating has not been applied from time of construction, the tanks in question are to be internally examined at each subsequent Annual Survey. Thickness measurements are to be carried out as considered necessary by the Surveyor.

.4 Survey of Ballast Tanks in way of Double Bottom

Double bottom ballast tanks, where a hard protective coating is found in POOR condition and Owners or their representatives elect not to restore the coating, where a soft coating has been applied or where a hard protective coating has not been applied from time of construction, the tanks in question are to be internally examined at each subsequent Annual Survey where substantial corrosion is documented. Thickness measurements are to be carried out as required.

.5 Survey of Cargo Tanks

At each Intermediate Survey after Class Renewal Survey No. 2, at least three (3) cargo tanks of integral type: one (1) center, one (1) port wing and one (1) starboard wing tank, are to be examined internally.

5.2.2 Floating Production Installations with Fender

In addition to the applicable requirements of 5.2.1, 5.2.3, and 5.2.4, the Intermediate Survey is to include an external examination and internal Close-up Survey of hull structures, including thickness measurements, where fenders for lightering operation have been located.

5.2.3 Hull Thickness Measurement

When extensive areas of wastage are found, thickness measurements are to be carried out and renewals made where wastage exceeds the allowable margin. Where reduced scantlings on the basis of effective corrosion control have been adopted, the results of any measurements are to be evaluated based on scantlings before reduction.

5.2.4 Tank Testing

Pressure testing of cargo and ballast tanks is not required unless deemed necessary by the attending Surveyor.

5.3 Liquefied Gas Installations (where installed)

The Intermediate Survey is preferably to be carried out with the installation in a gas free condition. The extent of the testing required for the Intermediate Survey will normally be such that the survey cannot be carried out during a loading or discharging operation.

In addition to the applicable requirements of Rules for Classification and Survey (Pt.1, Vol.I), Sec.3, B.1.1.2.11), the Intermediate Survey is also to include the following.

5.3.1 Instrumentation and Safety Systems

1) The instrumentation of the cargo installation with regard to pressure, temperature and liquid level is to be visually examined and to be tested by changing the pressure, temperature and level, as applicable, and comparing with test instruments. Simulated testing may be accepted for sensors which are not accessible or for sensors located within cargo tanks or inerted hold spaces. The testing is to include testing of the alarm and safety functions.
2) Gas detectors are to be calibrated or verified with sample gases.
3) The emergency shutdown system is to be tested, without flow in the pipe lines, to verify that the system will cause the cargo pumps and compressors to stop.

5.3.2 Gas Burning Installations

The instrumentation and safety systems for gas burning installations are to be examined and tested in accordance with the requirements of 5.3.1.1).

6. Class Renewal Surveys (CRS)

6.1 General

The documents and records referenced in 1.12, as applicable, are to be sighted onboard during Annual Surveys, and the survey is to include the following items of this Section, as applicable.

The Class Renewal Survey requirements are in addition to the Annual Survey and Intermediate Survey requirements stated in 4. and 5.

6.2 Hull

6.2.1 Ship-Type Floating Production Installations

In addition to the requirements of the Annual Survey – Hull, the CRS – Hull is to include sufficient examination, tests and checks carried out by the Surveyors to satisfy themselves that the hull and its outfitting are in or are placed in satisfactory condition and are fit for the intended purpose for the new period of class of five (5) years to be assigned, subject to proper maintenance and operation and to periodic surveys being carried out at the due dates. Class Renewal Survey is to include the following:

.1 Survey Planning Meeting

A survey planning meeting is to be held prior to the commencement of the survey.

.2 Drydocking Survey (or IW)

Drydocking survey is to be carried out in accordance with 7.

.3 Rudder

When the steering gear is maintained operational the rudder is to be examined and, when required, lifted and the gudgeons rebushed. The condition of carrier and steadiment/rudder stock bearings and the effectiveness of stuffing boxes are to be ascertained when the rudder is lifted.

.4 Shell Openings and Their Closures

All openings in the shell including overboard discharges are to be examined.

.5 Decks, Bulkheads and Shell Plating

All decks, watertight bulkheads, and internal and external surfaces of shell plating are to be examined. Plating in way of side shell or superstructure portlights is to be especially examined.

.6 Overall Survey Requirements

1) Spaces.

An Overall Survey of all spaces including holds and their tween decks, where fitted; double bottom, deep, ballast, peak and cargo tanks; pump rooms, pipe tunnels, duct keels, machinery spaces, dry spaces, cofferdams and voids, including the plating and framing, bilges and drain wells, sounding, venting, pumping and drainage arrangements.

Internal examination of fuel oil, lube oil and fresh water tanks is to be carried out in accordance with 5).

Where sounding pipes are fitted, the Surveyor is to confirm that a thick steel plate is securely fixed below the sounding pipe for the rod to strike upon.

This examination is to be supplemented by thickness measurement and testing as required to confirm that the structural integrity remains effective. The aim of the examination is to discover substantial corrosion, significant deformation, fractures, damages or other structural deterioration, that may be present.

2) Engine Room Spaces.

Engine room structure is to be examined. Particular attention is to be given to tank tops, shell plating in way of tank tops, brackets connecting side shell frames and tank tops, and engine room bulkheads in way of tank top and bilge wells. Particular attention is to be given to the sea suction, seawater cooling pipes and overboard discharge valves and their connection to the side shell plating. Where extensive areas of wastage are found, thickness measurements are to be carried out, and renewals and/or repairs made where wastage exceeds allowable margins.

3) Ballast Tanks and Combined Cargo/Ballast Tanks.

Where provided, the condition of corrosion prevention system of ballast tanks and combined cargo/ballast tanks is to be examined.

Ballast tanks and combined cargo/ballast tanks other than double bottom tanks, where a hard protective coating is found in POOR condition and Owners or their representatives elect not to restore the coating, where soft coating has been applied or where a hard protective coating has not been applied from time of construction, the tanks in question are to be internally examined at each subsequent Annual Survey. Thickness measurements are to be carried out as deemed necessary by the Surveyor.

When such breakdown of hard protective coating is found in double bottom ballast tanks and Owners or their representatives elect not to restore the coating, where a soft coating has been applied, or where a hard protective coating has not been applied from time of construction, the

tanks in question are to be internally examined at each subsequent Annual Survey where substantial corrosion is documented. Thickness measurements are to be carried out as required.

4) Cargo Tanks

Prior to entry into a cargo tank, the tank's history is to be reviewed to determine if produced water has been stored in the tank. The amount of produced water (height) and the length of time the produced water has been stored in the tank is to be reviewed. If excessive corrosion is found that can be attributed to produced water, additional tanks with similar histories are to be evaluated, and may require examination of those tanks at intervals of less than 5 years.

5) Fuel Oil, Lube Oil, Freshwater and Permanent Ballast Tanks.

Internal examination requirements will be specially considered for tanks used exclusively for permanent ballast which are fitted with an effective means of corrosion control.

Where tanks of integral structural type, except for peak tanks, are used primarily for heavy fuel oil or exclusively for light oils or fresh water, the internal examination may be specially considered, provided a general external examination and the following internal examinations are carried out.

Minimum requirements for internal examination of fuel oil, lube oil and fresh water tanks at Class Renewal Surveys are as follows.

A) Class Renewal Survey No. 1 (Age ≤ 5 Years)
   - None

B) Class Renewal Survey No. 2 (5 < Age ≤ 10 Years)
   - One (1) fuel oil tank in the Cargo length area. For installations without a defined cargo area a minimum of one (1) fuel oil tank.
   - One (1) freshwater tank

C) Class Renewal Survey No. 3 (10 < Age ≤ 15 Years)
   - One (1) fuel oil tank in way of the engine room
   - Two (2) fuel oil tanks in the Cargo length area. For installations without a defined cargo area a minimum of two (2) fuel oil tanks. One (1) deep tank is to be included, if fitted
   - All freshwater tanks

D) Class renewal Survey No. 4 and Subsequent Class Renewal Surveys (Age > 15 Years)
   - One (1) fuel oil tank in way of the engine room
   - Half of all fuel oil tanks in the Cargo length area, minimum two (2). For installations without a defined cargo area, half of all fuel oil tanks, a minimum of two (2). One (1) deep tank is to be included, if fitted
   - One (1) lube oil tank
   - All freshwater tanks

Note:

If a selection of tanks is accepted for examination, then different tanks are to be examined at each Class Renewal Survey on a rotational basis.

Independent oil tanks in machinery spaces are to be externally examined and, if deemed necessary, tested under a head of liquid.

.7 Protection of Other Openings

1) Tank Protective Devices

A) All tank protective devices, where fitted, are to be examined externally for proper assembly and installation, damage, deterioration or traces of carryover at the outlets.

B) All pressure-vacuum valves and pressure relief valves are to be opened out, pressure and vacuum valve discs checked for good contact with their respective seats and/or proved by testing.

2) Air Pipes.

All air pipes are to be opened out and closing arrangements and flame screens, if fitted, are to be examined both externally and internally. For designs where the inner parts cannot be properly examined from outside, this is to include removal of the head from the air pipe. Particular attention is to be paid to the condition of the zinc coating in heads constructed from galvanized steel.

3) Watertight Bulkheads.

Watertight bulkheads, bulkhead penetrations, end bulkheads of enclosed superstructures are to be examined. In addition, watertight doors are to be operationally tested and effectiveness to maintain tightness is to be confirmed.

.8 Close-up Survey Requirements

The requirements for Close-up Survey and thickness gauging, per Rules for Classification and Surveys (Pt.1, Vol.I), Sec.3, B.1.3, 4.I.B.4 and 4.I.C.4, will be applied to ship- and barge-type installations in the following cases:

1) The ballast tanks are uncoated.
2) Tank coatings are in FAIR or POOR condition as defined by 1.7.2.
3) Soft coatings are found to be no longer effective, 1.8.3.
4) Substantial corrosion is present

Thickness Measurements are to be carried-out as per 6.2.1.10

.9 Tank Testing

Boundaries of double bottom, deep, ballast, peak and other tanks, including holds adapted for the carriage of salt water ballast, are to be tested with a head of liquid to the top of air pipes or to near the top of hatches for ballast/cargo holds, except that cargo tanks on ship-type installations of both single and double hull construction may be tested to the highest point that liquid will rise under service condition. Boundaries of fuel oil, lube oil and fresh water tanks may be tested with a head of liquid to the highest point that liquid will rise under service condition. Tank testing of fuel oil, lube oil and fresh water tanks may be specially considered based on a satisfactory external examination of the tank boundaries, and a confirmation from the Master stating that the pressure testing has been carried out according to the requirements with satisfactory results, provided that representative tanks for fuel oil, lube oil and fresh water are tested.

The testing of double bottoms and other spaces not designed for the carriage of liquid may be omitted, provided a satisfactory internal examination together with an examination of the tank top is carried out.

Stagger testing of bulkheads is acceptable as alternative means of testing.

The Surveyor may require further tank testing, as deemed necessary.

.10 Hull Thickness Measurement (Gauging)

These requirements do not apply to independent cargo tanks.

1) Class Renewal Survey No. 1 (Age ≤ 5 Years)
   – Suspect areas throughout the installation.
2) Class Renewal Survey No. 2 (5 < Age ≤ 10 Years)
   – All main deck plates within the amidships 0,5 L or cargo tank section, whichever is longer.

- One (1) transverse section within the amidships 0,5 **L**.
- Plates in wind-and-water strakes outside the amidships 0,5 **L**.
- All complete transverse web frame rings in a ballast wing tank or ballast double hull tank, if any.
- One (1) deck transverse in each of the remaining ballast tanks, if any.
- Both transverse bulkheads including girder system in a ballast wing tank or ballast double hull tank, if any, or a cargo wing tank used primarily for water ballast.
- Lower part of transverse bulkhead including girder system in each remaining ballast tank, one (1) cargo wing tank and two (2) cargo center tanks.
- Internals in forepeak and afterpeak tanks.
- Suspect areas throughout the installation.

3) Class Renewal Survey No. 3 (10 < Age ≤ 15 Years)
- All main deck plates within the amidships 0,5 **L** or cargo tank, whichever is longer.
- Two (2) transverse sections within the amidships 0,5 **L**.
- Plates in wind-and-water strakes outside the amidships 0,5 **L**.
- All complete transverse web frame rings in all ballast tanks and in a cargo wing tank.
- A minimum of 30% of all complete transverse web frame rings in each remaining cargo wing tank. (In calculating the 30% minimum, the number of web frame rings is to be rounded up to the next whole integer.)
- A minimum of 30% of deck and bottom transverse in each cargo center tank. (In calculating the 30% minimum, the number of transverses is to be rounded up to the next whole integer.)
- All transverse bulkheads including girder and stiffener systems in all cargo and ballast tanks.
- Additional complete transverse web frame rings as considered necessary by the Surveyor.
- Internals in forepeak and afterpeak tanks including plating and stiffeners of forepeak and afterpeak tank bulkheads.
- Suspect areas throughout the installation.

4) Class Renewal Survey No. 4 and Subsequent Class Renewal Surveys (Age > 15 Years)
- All exposed main deck plates, full length. Also, exposed first-tier superstructure deck plates (poop bridge and forecastle decks).
- All keel plates full length. Also, additional bottom plates in way of cofferdams, machinery space and aft ends of tanks.
- A minimum of three (3) transverse sections within the amidships 0,5 **L**.
- All complete transverse web frame rings in all ballast tanks and in a cargo wing tank.
- A minimum of 30% of all complete transverse web frame rings in each remaining cargo wing tank. (In calculating the 30% minimum, the number of web frame rings is to be rounded up to the next whole integer.)
- A minimum of 30% of deck and bottom transverse in each cargo center tank. (In calculating the 30% minimum, the number of transverses is to be rounded up to the next whole integer.)
- All transverse bulkheads including girder and stiffener systems in all cargo and ballast tanks.
- Additional complete transverse web frame rings as considered necessary by the Surveyor.
- Any additional tanks and structure as considered necessary by the Surveyor.
- Internals in forepeak and afterpeak tanks including plating and stiffeners of forepeak and afterpeak tank bulkheads.
- All plates in two (2) wind-and-water strakes, port and starboard full length.
- Suspect areas throughout the installation.

– Plating of seachests. Shell plating in way of overboard discharges as considered necessary by the attending Surveyor.

Note:

Thickness measurements of any one entire girth belt(s) (transverse section(s)) shall be completed within 15 months from commencement of gaugings of a girth belt (transverse section.)

Thickness measurements review to be carried-out in accordance with Rules for Classification and Surveys (Pt.1, Vol.I), Sec.3, D

Individual plate and stiffener wastage allowances, Individual plate and stiffener wastage allowances for ship-type floating installations with design life of 20 years are to satisfy Rules for Classification and Surveys (Pt.1, Vol.I), Sec.3, D Local wastage allowable margins of plates and stiffeners for floating installations with design life longer than 20 years will remain the same as applied to the required 20 year life scantlings to determine minimum scantlings at which renewals are required. Accordingly, based on percent wastage allowance, renewals would be required when scantling were wasted to values as if the installation were a 20 year life installation. The allowable wastage is to be based on the smaller of the percent wastage allowance (see Table 4.7) or the allowable wastage based on local buckling strength.

.11 Application of Requirements for Close-Up Survey and Gauging per ESP Vessels

The requirements for close-up survey and thickness gauging, Rules for Classification and Surveys (Pt.1, Vol.I), Sec.3, B.1.3, 4.I.B.4 and 4.I.C.4 will be applied to ship- and barge-type installations in the following cases:

– The ballast tanks are uncoated.
– Tank coatings are in POOR condition as defined by 1.2.7.
– Soft coatings are found to be no longer effective 1.8.3
– Substantial corrosion is present.

6.2.2 Column Stabilized, Tension Leg Platform and Spar Floating Production Installations

For column-stabilized, Tension Leg Platform and Spar installations, the following are to be performed, as applicable, the parts examined, placed in satisfactory condition and reported upon:

.1 General Examination

The hull or platform structure, including tanks, watertight bulkheads and decks, cofferdams, void spaces, sponsons, chain locker, deck, keels, helicopter pad, machinery spaces, peak spaces, steering gear spaces and all other internal spaces are to be examined externally and internally for damage, fractures or excessive wastage.

.2 Examination of Tanks, Compartments and Free-Flooding Spaces

All tanks, compartments and free-flooding spaces throughout the installation are to be examined externally and internally. Internal examinations of lower hull are to be specially considered. Watertight integrity of tanks, bulkheads, hull, bulkhead deck and other compartments are to be verified by visual inspection. Suspect areas may be required to be tested for tightness, non-destructively tested or thickness gauged. Tanks and other normally closed compartments are to be ventilated, gas-freed and cleaned, as necessary, to expose damage and allow for a meaningful examination for excessive wastage. Internal examination and testing of void spaces, chain lockers and compartments filled with foam or corrosion inhibitors and tanks used only for lube oil, light fuel oil, diesel oil or other non-corrosive products may be specially considered, provided that, upon general examination, the Surveyor considers their condition to be satisfactory. External thickness gauging may be required to confirm corrosion control.

.3 Attachments of Anchor Racks, Fairleads, and Anchorlines

Attachments of anchor racks and anchor cable fairleads are to be examined. Foundations in way of selective anchor line fairlead support structures are to be cleaned and non-destructive examinations performed. Internal support structures in way of these foundations are to be closely examined.

.4 Other Structures

Applicable structures, such as pipe racks, process support structures, deck houses, superstructures, helicopter landing areas and their respective attachments to the deck or hull.

.5 Foundations

Foundations and supporting headers, brackets and stiffeners for process related apparatus, where attached to hull, deck, superstructure or deck house.

.6 Connections of Columns and Diagonals to Upper Hull, etc.

Connections of columns and diagonals to upper hull or platform and lower hull or pontoons. Joints of supporting structure, including diagonals, braces and horizontals, together with gussets and brackets. Internal continuation or back-up structure for the above. Non-destructive testing (NDT) may be required at suspect areas.

.7 Survey of Underwater Parts

Survey of parts of the installation that are underwater and inaccessible to the Surveyor may be accepted on the basis of an examination by a qualified diver, conducted in the presence of the Surveyor. Video or photo records, non-destructive testing and thickness gauging may be required in addition to the diver's report. Refer to Rules for Classification and Surveys (Pt.5, Vol.I), Sec.3.I.E.3

Where inspection of underwater joints is required, sufficient cleaning is to be performed in way, and water clarity to be adequate, to permit meaningful visual, video, camera or NDT, as required. Every effort is to be made to avoid cleaning damage to special coatings.

.8 Hull Thickness Measurement

At each Class Renewal Survey, hull thickness measurement (gauging) is to be performed where wastage is evident or suspected. At Class Renewal Survey No. 2 and subsequent Class Renewal Surveys, representative gauging's are required in accordance with Table 3.4 or Table 3.5 Special attention is to be given to the splash zones on hulls, columns and ballast tanks, free-flooded spaces and the bottom hulls. The thickness gauging requirements indicated in the table may be reduced or increased, as deemed necessary or appropriate by the Surveyor, in accordance with Notes 2 and 3 of Table 3.4 or Table 3.5.

6.2.3 Floating Production Installations with Fender

In addition to the applicable requirements 6.2.1, the Class Renewal Survey is also to include an external examination and internal Close-up Survey of hull structures, including thickness measurements, where fenders have been located.

Table 3.4 Thickness Gauging Requirements for Spars

Class Renewal Survey Number 1	Class Renewal Survey Number 2	Class Renewal Survey Number 3	Subsequent Class Renewal Survey
1) Suspect areas throughout the unit. 2) Columns and bracings where wastage is evident in Splash Zone.	1) Suspect areas throughout the unit. 2) Representative gaugings of columns and bracings in Splash Zone together with internals in way as deemed necessary. 3) Special and primary application structure where wastage is evident.	1) Suspect areas throughout the unit. 2) Representative gaugings, throughout, of special and primary application structures. 3) 1 girth belt of hull in Splash Zone together with internals in way. 4) Chain locker plating as deemed necessary. 5) Hulls in way of mooring fairleads where wastage is evident. 6) 1 girth belt of soft tank plating where wastage or failure of cathodic protection system is evident.	1) Suspect areas throughout the unit. 2) Comprehensive gaugings, throughout, of special and primary application structures, including deck to spar attachments, primary deck truss structure, hull truss structure, and hull plating. 3) 1 girth belt of hull in Splash Zone and internals in way. 4) Chain locker plating as deemed necessary and internals where accessible. 5) Hull in way of mooring fairleads and other attachments where wastage is evident. 6) 1 girth belt of soft tank plating where wastage or failure of cathodic protection system is evident 7) Representative gaugings of substructure of drilling derrick if fitted.

Notes:

1 *With reference to the ballasting history and arrangement and condition of coatings, tanks and specific thickness gauging locations should be selected which will provide the best representative sampling of areas likely to be most exposed to corrosion effect.*

2 *Gauging requirements noted may be modified as deemed necessary or appropriate by the Surveyor if the structure remains effectively protected against corrosion by a permanent type special coating or sufficient cathodic protection system.*

3 *In any case where excessive wastage is evident, additional gaugings may be required.*

4 *Structure application designations (special, primary, secondary) are defined in Section 5, A.2.5*

Table 3.5 Thickness Gauging Requirements for Column-Stabilized Units and Tension Leg Platforms

Class Renewal Survey Number 1	Class Renewal Survey Number 2	Class Renewal Survey Number 3	Subsequent Class Renewal Survey
1) Suspect areas throughout the unit. 2) Columns and bracings where wastage is evident in Splash Zone.	1) Suspect areas throughout the unit. 2) Representative gaugings of columns and bracings in Splash Zone together with internals in way as deemed necessary. 3) Special and primary application structure where wastage is evident.	1) Suspect areas throughout the unit. 2) Representative gaugings, throughout, of special and primary application structures. 3) 1 girth belt of each of 2 columns and 2 bracings in Splash Zone together with internals in way as deemed necessary. 4) Chain locker plating as deemed necessary. 5) Lower hulls in way of mooring attachments where wastage is evident. 6) 1 girth belt of each lower hull between one set of columns.	1) Suspect areas throughout the unit. 2) Comprehensive gaugings, throughout, of special and primary application structures. 3) 1 girth belt of each of one-half of the columns and bracings in Splash Zone and internals in way as deemed necessary (i.e., gauge half of the unit's columns and bracings in Splash Zone). 4) Chain locker internals as deemed necessary and internals where accessible. 5) Lower hulls in way of mooring fairleads and other attachments where wastage is evident. 6) 1 girth belt of each lower hull between one set of columns. 7) Representative gaugings of substructure of drilling derrick if fitted.

Notes:

1 *With reference to the ballasting history and arrangement and condition of coatings, tanks and specific thickness gauging locations should be selected which will provide the best representative sampling of areas likely to be most exposed to corrosion effect.*

2 *Gauging requirements noted may be modified as deemed necessary or appropriate by the Surveyor if the structure remains effectively protected against corrosion by a permanent type special coating.*

3 *In any case where excessive wastage is evident, additional gaugings may be required.*

4 *Structure application designations (special, primary, secondary) are defined in Section 5, A.2.5.*

6.3 Mooring System

Class Renewal Survey of the mooring system is mandatory for all types of floating production installations, and are to comply with following requirements of this Subsection, as applicable.

Since it is impractical to cover all types of mooring systems, the following are provided as guidance to show the basic intent of the requirements. Operators and designers may submit alternative survey requirements based either on service experience or manufacturer's recommendations. Upon BKI review and acceptance, these alternative survey procedures will form the basis for the Class Renewal Survey of the Mooring System.

Typically, the Class Renewal Survey – Mooring System is to include all items listed under the Annual Survey and, in addition, the following are to be performed, where applicable:

1) A Drydocking Survey or equivalent underwater inspection of the SPM system is to be performed. This survey is to include examination of the entire structure of the SPM, the protective coating, cathodic protection system, the chain stoppers and their locking devices.

   Any suspect areas where excessive corrosion is evident are to be thickness gauged. Gaugings are to be taken on the structures of the SPM when it has undergone service for 15 years or more.

2) An examination is to be made on all anchor chains for excessive corrosion and wastage. In particular, the areas to be specially examined are the areas having the most relative movement between the chain links. These areas are normally located in way of the seabed touchdown sections of the catenary part of the chains. The chains are to be inspected for looses studs and link elongations. Sufficient representative locations are to be gauged for wear and wastage. Areas susceptible to corrosion, such as the wind-and-water areas, are to be specially gauged, if considered necessary by the attending Surveyor.

3) A close examination is to be performed on all mooring components and accessible structural members that carry the mooring loads. These structures include the chain stoppers or cable holders, the structures in way of the chain stoppers or cable holders, structural bearing housing and turret/structural well annulus areas. These structures are to be thoroughly cleaned and examined and any suspect areas are to be non-destructively tested.

4) A general inspection is also to be carried out on the degree of scour or exposure in way of the anchor or anchor piles to ascertain that these components are not overexposed.

5) An examination is to be performed on the main bearing of the SPM system. This examination is to include visual inspection of bearing, if accessible, for water egress into the structural housing, corrosion, pitting and excessive wear. If the bearing is inaccessible, at least the weardown is to be ascertained and the condition of the bearing seals verified. If disassembled, the bearing rollers and the racer housings are to be examined.

6) For inaccessible structures, special alternative inspection procedures for inspection of these areas are to be submitted for approval.

7) The chain tensions are to be checked and where found not in compliance with the specifications are to be readjusted accordingly. Excessive loss of chain or tendon tensions is to be investigated.

8) Representative areas of the chains are to be examined and checked for excessive wastage. In particular, areas in way of the chain stoppers and the seabed touchdown areas are to be specially examined and measured for excessive wear.

9) For disconnectable type mooring systems, the disconnect and connect system for the mooring system is to be tested as considered necessary by the attending Surveyor. Alternatively, records of disconnect/connect operations between the credit date of the last Class Renewal Survey and the current due date of same may be reviewed, and if found satisfactory, it may be considered to have been in compliance with this requirement.

10) Examination of upper and lower tendon flex elements as accessible.

6.4 Fire and Safety Systems

Class Renewal Survey of the entire fire and safety systems installed throughout the floating production installation is mandatory for all types of floating production installations.

Class Renewal Survey – Fire and Safety Systems is to include compliance with the Annual Survey requirements and, in addition, the following requirements as listed below are to be carried out, as applicable, the parts examined, placed in satisfactory condition and reported upon.

Following systems are to be verified to confirm no significant changes have been made to any of the systems and that they remain in satisfactory condition.

6.4.1 Passive Fire Protection Systems

Passive fire protection systems, including the following items are to be tested:

1) Function testing of all fire doors
2) Function testing of all ventilation fire-dampers
3) Function testing of all ventilation system closures and stoppage of power ventilation
4) Function testing of all shutters or water curtains (where fitted)

6.4.2 Active Fire Protection – Fixed Systems

Active fire protection fixed systems, including the following items are to be tested:

1) Function testing of all fire pumps. Other pumps used for active fire protection are also to be tested. This is to include confirmatory testing of the fire pump capacity, and where installed, testing of relief valves of the fixed fire main system.
2) Hydrostatic testing of the fire main system
3) Hydrostatic testing of fire hoses, as necessary

6.4.3 Active Fire Protection – Additional Fixed Systems

Where installed, active fire protection additional fixed systems, including the following items are to be tested:

1) Gas smothering system, including confirmatory examination of the storage of the gas medium, gas alarms, and manual controls
2) Function testing of fixed water spraying systems.

6.4.4 Active Fire Protection – Portable Systems

All portable fire-fighting equipment fitted onboard, are to be in accordance with BKI approved plans. In addition, testing of the firefighter's outfit, as necessary.

6.4.5 Fire Detection and Alarm Systems

Fire detection and alarm systems, as installed, are to be tested.

6.4.6 Gas Detection and Alarm Systems

Gas detection and alarm systems, as installed, are to be tested.

6.4.7 Outfitting

Outfitting arrangements, including the following items are to be tested:

1) Lighting tings in way of all escape routes
2) Contact makers for general alarm system, communication system installed in all emergency control stations

6.4.8 Emergency Shutdown Arrangements

Emergency shutdown arrangements provided to disconnect or shutdown, either selectively or simultaneously, of the electrical equipment as outlined in the floating production installation's operating manual, are to be tested.

Services such as the emergency lighting, general alarm system, public address system, distress and safety radio system, that are required to be operable after an emergency shutdown of the installation, are to be verified for their proper operation.

6.5 Machinery and Electrical Systems (Marine & Safety Systems)

Class Renewal Survey – Machinery and Electrical Systems servicing the marine and safety systems is mandatory for all types of floating production installations.

Class Renewal Survey – Machinery is to include compliance with the Annual Survey requirements and, in addition, the following requirements as listed below are to be carried out, as applicable, the parts examined, placed in satisfactory condition and reported upon.

6.5.1 Correlation with Class Renewal Survey – Hull

Main and auxiliary engines of all types of installations are to undergo Class Renewal Survey at intervals similar to those for Class Renewal Survey – Hull in order that both may be recorded at approximately the same time. In cases where damage has involved extensive repairs and examination, the survey thereon may be considered as equivalent to a Class Renewal Survey.

6.5.2 Machinery Parts to be Examined

In addition to the requirements for Annual Survey, at each Class Renewal Survey, special attention is to be given to the following requirements, as applicable.

.1 Openings to the Sea and Fastenings

All openings to the sea, including sanitary and other overboard discharges together with the cocks and valves connected therewith, are to be examined internally and externally while the installation is in drydock or at the time of underwater examination in lieu of drydocking, and the fastenings to the shell plating are to be renewed when considered necessary by the Surveyor.

.2 Pumps and Pumping Arrangements

Pumps and pumping arrangements, including valves, cocks, pipes, and strainers, are to be examined.

.3 Non-metallic Expansion Pieces

Non-metallic flexible expansion pieces in the main salt-water circulating system are to be examined internally and externally.

.4 Bilge and Ballast System, and other Systems

The Surveyor is to be satisfied with the operation of the bilge and ballast systems. Other systems are to be tested as considered necessary.

.5 Machinery Foundations

The foundations of machinery, particularly those categorized as "Primary Application Structure" are to be examined.

.6 Pressure Vessels

Heat exchangers and other unfired pressure vessels (except those used solely for drilling operations and complying with a recognized standard) with design pressures over 0.7 bar are to be examined, opened out or thickness gauged and pressure tested as considered necessary, and associated relief valves proven operable. Evaporators that operate with a vacuum on the shell need not be opened, but may be accepted on the basis of satisfactory external examination and operational test or review of operating records.

6.5.3 Electrical Parts to be examined

.1 Main Switchboards and Distribution Panels

Fittings and connections on main switchboards and distribution panels are to be examined, and care is to be taken to see that no circuits are over fused.

.2 Cables

Cables are to be examined as far as practicable without undue disturbance of fixtures.

.3 Generator Run

All generators are to be run under load, either separately or in parallel; switches and circuit breakers are to be tested.

.4 Equipment and Circuits

All equipment and circuits are to be inspected for possible development of physical changes or deterioration. The insulation resistance of the circuits is to be measured between conductors and between conductors and ground and these values compared with those previously measured. Any large and abrupt decrease in insulation resistance is to be further investigated and either restored to normal or renewed as indicated by the conditions found.

.5 Electrical Auxiliaries, Generators and Motors

The specified electrical auxiliaries for vital purposes, generators and motors are to be examined and their prime movers opened for inspection. The insulation resistance of each generator and motor is to be measured.

.6 Accumulator Batteries

The accumulator batteries are to be examined, including their maintenance schedule and BKI reviewed procedure of maintenance.

.7 Bilge Alarm (if fitted)

Bilge alarm system, if fitted, is to be tested and proven satisfactory.

6.5.4 Hazardous Areas

Surveys of hazardous areas and electrical equipment installed in hazardous areas are to comply with applicable requirements of Rules for Facilities on Offshore Installations (Pt.5, Vol.XII)

6.5.5 Preventative Maintenance Techniques

Surveys of machinery that has been accepted for surveys based on preventative maintenance techniques are to comply with the requirements of Rules for Classification and Survey (Pt.1, Vol.I), Sec.3, B.1.3.4 and Guidance for Planned Maintenance Program (Pt.7, Vol.E)

6.5.6 Self Propelled Installations – Main Propulsion Apparatus

On self-propelled installations, in addition to the requirements for Annual Survey and the applicable requirements of 6.5.2, the main and auxiliary machinery, including pressure vessels, are to be surveyed in accordance with the requirements of the latest edition of Rules for Classification and Surveys, as applicable to self-propelled vessels.

Where the installation maintains the optional class symbol **SM**, the windings of generators and motors are to be thoroughly examined and found or made dry and clean. Particular attention is to be paid to the ends of the windings of stator and rotors. After the winding have been cleaned and found dry, they are to be varnished, if necessary, with a standard insulating varnish applied preferably by spraying.

.1 Thrusters (where installed)

Thruster surveys are to comply with the requirements of Rules for Dynamics Positioning System (Pt.4, Vol.II).

6.5.7 Major Repairs

On the occasion of major repairs, the coils repaired or renewed are to be subjected to a dielectric strain test, as specified under the applicable parts of Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.8 In addition, the circuits containing the repairs or renewals and coils which have been disturbed during repairs are to be subjected to dielectric strain tests for one minute by application of a potential of 125% of the maximum operating voltage of the circuits to which it is applied. The direct current fields of generators and motors are to be subjected for one minute to a test potential equal to 50% of the value specified under the applicable parts of Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.8 and the whole apparatus operated under full-load conditions.

6.6 Inert Gas Systems (where installed)

The following applicable requirements of the Inert Gas System are to be examined and placed in satisfactory condition:

1) General. All valves, including valves at boiler uptakes, air seal valves at uptakes, scrubber isolating valves, fans inlet and outlet isolating valves, main isolating valve, recirculating valve(if fitted),pressure/vacuum breaker and cargo tank isolating valves are to be examined.
   - Scrubber is to be examined.
   - Fans (blowers) including casing drain valves are to be examined.
   - Fan (blower) drives, either electric motor or steam turbine are to be examined.
   - Bellows expansions pieces are to be examined.
   - Sea water pumps, valves and strainers for scrubbers and water seals together with piping connections at the scrubber, water seals, shell plating and the remainder of the sea water piping are to be examined.
   - Stand pipe, where fitted, for purging in each cargo tank is to be examined.
   - Deck seals or double block and bleed assemblies, and non-return valves are to be examined externally and internally.
2) Separate Inert Gas Generator System. Surveys for separate inert gas generator systems are to comply with all applicable requirements for Class renewal Surveys given in this section of the Rules, together with the following:
   - Automatic combustion control system is to be examined and tested as necessary.
   - Combustion chamber and mountings are to be examined internally and externally.

– Forced draft fan is to be examined.
– Fuel oil service pumps are to be examined.

3) Gas Stored in Bottles System. Systems using inert gas stored in bottles are to comply with all applicable requirements for Class Renewal Surveys given in this section of the Rules together with the following:
   – Bottles are to be examined internally and externally. If they cannot be examined internally, they are to be thickness measured. When considered necessary by the Surveyor, they are to be hydrostatically tested. Relief valves are to be proven operable.
   – Where an alkali (or other) scrubber is fitted in the system the scrubber, circulating pump, valves and piping are to be examined internally and externally.

6.7 Liquefied Gas Installations (where installed)

In addition to the applicable requirements of 4.7 and 5.3, the Class Renewal Survey of Liquefied Gas Installations is to include the following:

6.7.1 Class Renewal Survey No. 1 and No. 2

1) An internal examination is to be made of all cargo tanks (primary containers), after being gas freed, including internal mountings and equipment.
2) For independent tanks, foundations, chocks, sway braces, keys, anti-flotation arrangements, the secondary barriers or hull plating or both are to be examined, with special attention being given to the cargo tanks and insulation in way of the above. See 6) for insulation removal. Framing adjacent to the cargo containment system is also to be examined.

   Where the arrangement is such that the insulation cannot be examined, the surrounding structures in the wing tanks, double bottom tanks and cofferdams are to be examined for cold spots while the cargo tank is in cold condition, unless sufficient evidence of the integrity of the insulation is available from the voyage records.
3) Venting systems, relief valves or other arrangements provided for emergency removal of gas from the interbarrier spaces and hold spaces are to be opened, inspected, tested and readjusted as necessary.
4) Relief valves, liquid-level indicators and venting systems for the primary cargo containment system are to be examined. All relief valves are to be opened, inspected, tested and readjusted as necessary. If the cargo tanks are equipped with relief valves with non-metallic membranes in the main or pilot valves, such non-metallic membranes are to be replaced. Liquid-level indicators and alarms are to be proven satisfactory. Where a proper record of continuous overhaul and retesting of individually identifiable relief valves is maintained, consideration will be given to acceptance on the basis of opening, internal examination and testing of a representative sampling of valves including each size of each type of liquefied gas or vapour relief valve in use, provided there is logbook evidence that the remaining valves have been overhauled and tested since the crediting of the previous Class Renewal Survey. The testing and setting of relief valves may be carried out in place or after removal.
5) All piping, machinery and equipment for loading, unloading, venting, compressing, refrigerating, liquefying, heating or otherwise handling the liquefied gas or vapour and liquid nitrogen, and gas burning installations is to be examined including removal of insulation and opening for examination, as deemed necessary. Where deemed suspect, a hydrostatic test to 1,25 times the Maximum Allowable Relief Valve Setting (MARVS) for the pipeline is to be carried out. After reassembly, the complete piping is to be tested for leaks. Where water cannot be tolerated and the piping cannot be dried prior to putting the system into service, the Surveyor may accept alternative testing fluids or alternative means of testing. All emergency shut-down valves and remote operating valves in the cargo piping systems are to be inspected and proven operable. The pressure relief valves are to be function-tested. A random selection of valves is to be opened for examination and adjusted.

6) Insulation is to be removed in way of any distorted or otherwise suspect insulation or structural part of the cargo tanks or elsewhere to carry out any of the examinations as required by the Surveyor.

7) Where there is evidence of corrosion, or where one side of the cargo tank is exposed to possible corrosive atmosphere, the plating of the cargo tanks is to be gauged by non-destructive means to determine the thickness.

8) All cargo pump tower structures are to be examined including stiffeners, bracings, fasteners and locking devices, spray nozzles, wiring with associated conduits and pipe connections. Where deemed necessary by the Surveyor, dimensional measurements and/or non-destructive testing may be required. See also 10).

9) The secondary barrier is to be checked for its effectiveness by means of a pressure/vacuum test, a visual inspection or other acceptable method.

10) Non-destructive Testing is to be carried out as follows:

A) Non-destructive testing is to supplement cargo tank inspection with special attention to be given to the integrity of the main structural members, tank shell and highly stressed areas, including welded connections as deemed necessary by the Surveyor. The following items are, inter alia, considered as highly stressed areas:

- Cargo tank supports and anti-rolling/anti pitching devices
- Web frames or stiffening rings
- Y-connections between tank shell and a longitudinal bulkhead of bilobe tanks
- Swash bulkhead boundaries
- Dome and sump connections to the tank shell
- Foundations for pumps, towers, ladders, etc.
- Pipe connections

B) For independent tanks type C, in addition to the requirements of A) above, at alternate Class Renewal Surveys, at least 10% of the length of the welded connections in each highly stressed area is to be tested. This testing is to be carried out internally and externally, as applicable. Insulation is to be removed, as necessary, for the required non-destructive testing.

C) For independent tanks type B, the extent of the non-destructive testing is to be in accordance with a planned program specially prepared and approved for the cargo tank design.

11) Where non-destructive testing, or other evidence such as leakage or distortion, raises doubts as to the structural integrity of a cargo tank, a hydrostatic or hydro pneumatic pressure test is to be carried out. For integral tanks and independent tanks type A and B, the test pressure is to be at least MARVS at the top of the tank. For independent tanks type C and pressurized tanks B with MARVS 2,06 bar and over, the test pressure is to be 1,25 times MARVS.

12) Electrical bonding arrangements, including bonding straps where fitted, of the piping systems located within cargo tanks, ballast tanks, pipe tunnels, cofferdams and void spaces bounding cargo tanks are to be examined.

13) Systems for removing water or cargo from interbarrier spaces and holds are to be examined and tested as deemed necessary.

14) For membrane and semi-membrane tanks systems, inspection and testing are to be carried out in accordance with programs specially prepared in accordance with an approved method for the actual tank system.

15) All gas-tight bulkheads are to be examined. The effectiveness of gas-tight shaft sealing is to be verified.

16) The hoses and spool pieces used for segregation of piping systems for cargo, inert gas and bilge are to be examined.

6.7.2 Class Renewal Survey No. 3 and Subsequent Class Renewal Surveys

In addition to all of the requirements of Class Renewal Survey No. 1 or 2, the following requirements are to be complied with for Class Renewal Survey No. 3 and all subsequent Class Renewal Surveys.

1) The plating of at least one (1) cargo tank, including membrane tanks and pressure vessels is to be gauged by non-destructive means to determine the thickness. Where only cargoes of a non-corrosive nature are carried, modifications to the extent of thickness measurements may be specially considered.
2) The plating of metallic secondary barriers which are structural supports for the primary barrier is to be gauged by non-destructive means to determine the thickness.

6.8 Dynamic Positioning Systems (if classed)

Dynamic Positioning Systems are to comply with the requirements of Rules for Dynamics Positioning Systems (Pt.4, Vol.II).

6.9 Automatic and Remote-Control Systems (if classed)

For Shipboard Automatic and Remote-Control System, applicable requirements of the Rules for Automation (Pt.1, Vol.VII) are to be complied with.

6.10 Production Facilities (if classed)

Where the floating production installation's production facilities are classed, applicable requirements of the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII) are to be complied with.

Maintenance records are to be kept and made available for review by the attending Surveyor. The maintenance records will be reviewed to establish the scope and content of the required Annual and Class Renewal Surveys. During the service life of the facilities, maintenance records are to be updated on a continuing basis. The operator is to inform BKI of any changes to the maintenance procedures and frequencies, as may be caused, for example, by changes or additions to the original equipment. The Surveyor may determine during the periodic survey if the changes are sufficient to warrant review by BKI' technical staff.

6.11 Import and Export Systems (if classed)

Since it is impractical to cover all types of import and export systems, the following are provided as guidance to show the basic intent of the requirements. Operators and designers may submit alternative survey requirements based either on service experience or manufacturer's recommendations. Upon review and if found acceptable, these alternative survey procedures will form the basis for the Class Renewal Survey of the Import and Export System.

Typically, the Class Renewal Survey is to include all items listed under the Annual Survey and, in addition, the following are to be performed:

1) Fluid and electrical swivels are to be disassembled, if considered necessary, and examined for wear and tear. The seals are to be examined. Upon completion of the reconditioning, the fluid swivels are to be hydrostatically tested. Similarly, the electrical swivels are to be insulation tested upon reassembly.
2) During underwater inspection of the SPM system, flexible risers are to be examined, including all arch support buoyancy tanks. Risers are to be inspected for damage in high stress areas, such as areas in way of the end flanges, areas in way of the arch support clamps and the bottom of all looped areas. Spreader bars, if fitted to separate one riser string from another, are to be inspected for wear

and tear. Hydrostatic tests may be required to be conducted on the risers, as deemed necessary by the attending Surveyor.

3) For deep sea applications, riser suspension or support systems are to be examined for deterioration and loss of tension. Support areas in way of the riser are to be closely examined for fretting corrosion, wear, kinks, creases, etc.

4) Floating export hoses are to be examined for kinks, surface cracks, chafing damages, etc. Hydrostatic and vacuum tests may be required to be conducted on the floating hose string, as deemed necessary by the attending Surveyor.

5) All piping systems are to be opened up for examination. Non-destructive and hydrostatic tests may be required, where considered necessary by the attending Surveyor.

6) For disconnectable type mooring systems, the disconnect and connect arrangements for the import and export systems are to be tested, as considered necessary by the attending Surveyor. Alternatively, records of disconnect/connect operations between the credit date of the last Class Renewal Survey and the current due date of same may be reviewed, and if found satisfactory, it may be considered to have complied with this requirement.

7) Hoses designed and manufactured based on OCIMF standards are to be tested in accordance with the OCIMF *Guide for the Handling, Storage, Inspection, and Testing of Hoses in the Field*.

7. Drydocking Surveys or Equivalent

7.1 Underwater Inspection in Lieu of Drydocking Survey (IW)

For site-specific floating production installations, IW by a diver and a remotely operated vehicle may be considered equivalent to a Drydocking Survey, provided the IW is carried out in accordance with Rules for Classification and Surveys (Pt.5, Vol.I), Sec.3.I.E and BKI approved ISIP. Prior to commencement of the IW, a plan is to be provided to the Surveyor for their acceptance. The plan for the IW is to contain the items listed below:

1) Scope of inspection that is not to be less than as noted in 7.2.

2) Procedure for divers to identify the exact location at which they are conducting their inspection.

3) Procedure for cleaning the marine growth for inspection purposes that is to include the extent and location of the underwater cleaning.

4) Procedure and extent for measuring the cathodic potential readings in way of the structures.

5) Procedure and extent for taking thickness gaugings of the structures and NDT of critical joints.

6) Certificates for External Specialists conducting the underwater inspection and thickness gauging.

7) Certification of personnel conducting NDE.

8) The type of underwater video and photography, including means of communication, monitoring and recording.

9) For Underwater Inspections in lieu of Drydocking Surveys (IW) associated with Class Renewal Surveys, means are to be provided to permit the opening up of all sea valves and overboard discharges for internal examination. In addition, all Class Renewal Survey items related to the underwater portion of the hull or structure, including the gauging requirements are to be dealt with during the underwater survey.

7.2 Parts to be Examined

7.2.1 Ship-type and Barge-type Floating Production Installations

For ship-type and barge-type installations, the following items are to be examined, as applicable:

The keel, stem, stern frame, rudder, propeller, and outside of side and bottom plating are to be cleaned as necessary and examined, together with bilge keels, thrusters, exposed parts of the stern bearing and seal assembly, sea chest, rudder pintles and gudgeons, together with their respective securing arrangements. All sea connections and overboard discharge valves and cocks, including their attachments to the hull or sea chests, are to be externally examined. All nonmetallic expansion pieces in the sea-water cooling and circulating systems are to be examined both externally and internally. The stern bearing clearance or weardown and rudder bearing clearances are to be ascertained and reported on.

7.2.2 Column Stabilized, Tension Leg Platform and Spar Floating Production Installations

For column-stabilized, tension leg platform and spar installations, the Structural Critical Inspection Points (SCIPs) identified in the In Service Inspection Program (ISIP) plan are to be examined. In addition, the following are also to be examined:

1) External surfaces of the upper hull or platform, footings, pontoons or lower hulls, underwater areas of columns, bracing and their connections, as applicable, are to be selectively cleaned and examined. These areas include joints of critical structural members, areas susceptible to damage from supply installations, anchor chains, dropped equipment, corrosion and erosion from loss of coating, or sand scouring and areas of progressed and accumulated wear-and-tear.
2) Non-destructive testing may be required of areas found to be suspect. Joints of different configurations of major structural members are to be selected, cleaned and magnetic particle inspected. The selection of these joints is to be such that all joints underwater are to be inspected every five years.
3) Sea chests and strainers are to be cleaned and examined.
4) External portions of propulsion units are to be examined, if applicable.
5) The type, location and extent of corrosion control (coatings, cathodic protection systems, etc.), as well as effectiveness, and repairs or renewals to same are to be reported in each survey. Particular attention is to be given to corrosion control systems in ballast tanks, free-flooding areas and other locations subjected to sea water from both sides.
6) All tanks and voids that are to be internally examined are to be thoroughly ventilated and gas freed prior to being entered and are to be carefully monitored for pocketing or emissions of hazardous gases during examination.
7) For vessels that are not on Continuous Hull Surveys using BKI approved ISIP, in conjunction with Drydocking Surveys (or equivalent), the following ballast spaces are to be internally examined, and the effectiveness of coatings or corrosion control arrangements are to be verified either visually by indicator strips or by thickness gauging (as considered necessary), placed in satisfactory condition, as found necessary, and reported upon:
   A) Representative ballast tanks in footings, lower hulls or free-flooding compartments, as accessible
   B) At least two ballast tanks in columns or upper hull, if applicable
8) Flooded member detection is to be performed above the watertight bulkheads on all buoyant tendons.

7.3 Corrosion Protection System – Underwater Body

In addition to the above requirements, the following are to be to be performed during all of the Drydocking (or equivalent) Surveys:

1) Cathodic potential readings are to be taken from representative positions on the entire underwater body and evaluated to confirm that the cathodic protection system is operating within design limits.

2) Sacrificial anodes are to be examined for depletion and placed in satisfactory condition, as considered necessary.
3) Impressed current system anodes and cathodes are to be checked for damage, fouling by marine growth and carbonate deposits. The current and voltage demands of the system are also to be checked to confirm the system is functioning properly.
4) Additional examinations are to be performed on the wind and water areas of the structures where coating breaks are evident. Thickness measurements in these areas may be required if found necessary by the attending Surveyor.

7.4 Mooring System

In addition to the above requirements, the following items of the mooring system are to be cleaned and examined, where applicable:

1) The mooring anchor chain or cable tensions are to be measured and the end connections of these components are to be examined. All mooring system components (chains, ropes, shackles, etc.) are to be generally examined for their entire lengths. Sufficient representative chain links, on each mooring leg, are to be cleaned of marine growth so that they can be examined and measured. These cleaned links are to be examined for all possible degradation mechanisms (i.e., corrosion, abrasion, fractures).
2) Anchors, cables and their respective handling means are to be examined.
3) The buoyancy tanks are to be cleaned and examined, if applicable.
4) Chain and stopper assemblies are to be cleaned, examined and NDT performed, as considered necessary by the attending Surveyor.
5) Areas of high stress or low fatigue life are to be preselected, cleaned and NDT performed, if considered necessary.
6) Scour in way of anchors or anchor piles is to be examined.
7) Cathodic potential readings are to be taken from representative positions on the entire underwater structure of the mooring system to confirm that the cathodic protection system is operating within design limits.
8) Highly stressed, high wear and tear areas of the mooring chain are to be closely examined and nondestructively tested, if found necessary by the attending Surveyor. These include areas in way of the stoppers and sea bed touchdown areas.

7.4.1 Fibre Rope

Particular attention is to be given to the examination of the following for fiber ropes during IW:

1) Records of anchor leg re-tensioning caused by non-recoverable elongation are to be reviewed, and confirmed with the designer that adequate lengths of chain/wire segments are available for further re-tensioning due to non-recoverable elongation such that the fiber rope does not come into contact with the fairlead and stays below the water surface.
2) The pretensions of mooring lines are within the designer's recommended limits. The measurement of catenary angles may not necessarily be very accurate for taut leg moorings. Thus other means are to be used to determine the mooring line tensions.
3) Conditions of the terminations are to be checked.
4) Foreign particles in way of rope body and crevices are to be examined and removed if possible.
5) Marine growth, if affecting the condition of the rope, is to be removed if possible, by a method which will not damage the rope.

Reference may be made to the API RP 2SM Design for details of fibre rope construction, installation, and testing.

.1 Fibre Rope Test Inserts

Placement and retrieval of test inserts are not required by BKI. However, the designer should be aware of the coastal state requirements on test insert.

7.5 Import and Export Systems (if classed)

7.5.1 Import System

For import systems, the following are to be cleaned and examined, where applicable:

1) The entire riser system.
2) The arch support buoyancy tanks, their structures and the clamping devices.
3) The flexible riser, including all end flanges and bolting arrangements and spreader bars, if applicable.

Hoses designed and manufactured based on OCIMF standards are to be tested in accordance with the OCIMF Guide for the Handling, Storage, Inspection, and Testing of Hoses in the Field.

7.5.2 Export System

For export systems, the following are to be cleaned and examined, where applicable:

1) The entire export flexible system is to be examined for damage due to chafing and fatigue fractures.
2) Hoses designed and manufactured based on OCIMF standards are to be tested in accordance with the OCIMF *Guide for the Handling, Storage, Inspection, and Testing of Hoses in the Field*.
3) All navigation aids are to be examined and functionally tested.

8. Tail Shaft and Tube Shaft Surveys

8.1 Tail Shaft and Tube Shaft Surveys

For Tail Shaft Surveys of self-propelled floating production installations, applicable requirements of Rules for Classification and Survey (Pt.1, Vol.I) Sec.3, B.1.4 are to be complied with. However, due to low running hours on tail shafts of installations, the interval between tail shaft surveys may be extended based on the following being performed to the satisfaction of the attending Surveyor:

8.1.1 Parts to be examined

Following items are to be carried out:

1) Diver's external examination of stern bearing and outboard seal area, including weardown check as far as is possible.
2) Examination of the shaft area (inboard seals) in propulsion room(s).
3) Confirmation of lubricating oil records (satisfactory oil loss rate, no evidence of unacceptable contamination).
4) Shaft seal elements are to be examined/replaced in accordance with seal manufacturer's recommendations.

9. Boiler Surveys

Boiler Surveys are to comply with the requirements of Rules for Classification and Survey (Pt.1, Vol.I), Sec.3, B.1.5.2.

10. Crew Habitability on Offshore Installations

10.1 Annual Surveys

The following information is to be reviewed by the attending BKI Surveyor for issues that could affect the offshore installation Habitability notation (**HBT** or **HBT+**).

1) Maintenance and Operations logs since the previous Initial, Annual or Class Renewal Survey, if any
2) Fire, repair and damage reports since the previous Initial, Annual or Class Renewal Survey, if any
3) A list of all structural or mechanical modifications to the offshore installation since the previous Initial, Annual or Class Renewal Survey, if any
4) Verification that equipment and facilities continue to be fit for purpose and are operating in accordance with accommodation area criteria stated within the Guidance for Crew Habitability on Offshore Installations (Pt.7, Vol.C) (referred to as "the Guide" hereinafter)

During the attending BKI Surveyor's review of the submitted information, a determination will be made as to whether changes or alterations have taken place that could affect the offshore installation Habitability notation. As a result, the offshore installation may be subject to the review, ambient environmental testing, and inspection requirements of the Guide.

10.2 Class Renewal Surveys

10.2.1 Survey Requirements

The Survey is to be comprised of BKI Engineering reviews, BKI Surveyor accommodation verifications, and witnessing of ambient environmental testing. The Survey will cover all applicable habitability aspects.

The following is to be submitted to BKI three (3) months prior to carrying out the ambient environmental testing:

1) Fire, repair or damage reports since previous Annual Survey, if any
2) A list of all structural or mechanical modifications to the offshore installation since previous Annual Survey that may have the potential to affect crew habitability, if any
3) Drawings/arrangements of personnel spaces, HVAC, electrical, etc., affected by alterations, if any
4) Copies of the approved Initial Test Plans and Test Reports
5) Copies of Test Plans and Test Reports resulting from Annual Surveys, if any
6) Previous Class Renewal Survey Test Plans and Reports
7) Proposed Class Renewal Survey Test Plans for the current survey.

The Class renewal Survey data submittal serves three purposes. The first is to perform an BKI Engineering review of personnel spaces against any alterations to the offshore installation related to the criteria in Annex 3 of the Guide since the Initial Survey, with measurements verified by an BKI Surveyor. The second purpose is to provide a history of ambient environmental testing, as well as the Class Renewal Survey ambient environmental Test Plans for review and approval by BKI Engineer. The third is to allow scheduling of measurement verifications and ambient environmental testing by BKI Surveyor.

A Class renewal Survey Test Plan for each ambient environmental aspect of Habitability is to be submitted in accordance with the criteria stated below. The approved Initial Test Plans should be used as a basis for creating the Class renewal Survey Test Plans.

For creation of the Class Renewal Survey Test Plans, Subsection E, "Test Plan", and Subsection F, "Test Requirements", of Section 3 through 6 of the Guide specify the requirements for each ambient environmental aspect (i.e., Section 3,E, Section 3,F, Section 4,E, Section 4,F, etc.). For specifying

measurement locations for the Class Renewal Survey Test Plans, the following changes to F.4.1, "Selection of Spaces where Measurements are to be Conducted", of each ambient environmental aspect of Habitability is to be followed:

1) Measurements are to be taken in all areas affected by the offshore installation alterations, if any. Measurements are limited to the ambient environmental aspect affected by the alteration. For example, structural changes require both whole-body vibration and noise measurements. Structural changes do not necessarily require indoor climate or lighting measurements. Changes to luminaires require lighting measurements but not whole-body vibration, noise, or indoor climate measurements.
2) For all ambient environmental aspects, measurements are to be taken in all worst case or problem area locations based on the requirements set forth in F.4.1, "Selection of Spaces where Measurements are to be Conducted", of the appropriate Section of the Guide. [For example, worst case for whole-body vibration is described in Section 3, F.4.1.)].
3) For whole-body vibration, measurements are to be taken in personnel cabins throughout the offshore installation. For offshore installations with less than thirty (30) cabins in the accommodation areas, twenty (20) percent is to be selected for measurement. For offshore installations with thirty or more cabins on board, fifteen (15) percent of cabins is to be measured. Attention must be given to selecting a variety of locations throughout the accommodation areas. The worst case locations can be considered part of the representative sample for crew cabins, if applicable.
4) For all ambient environmental aspects (except whole-body vibration), measurements are to be taken in twenty-five (25) percent of personnel cabins identified in the initial Test Plans. Any worst case locations can be considered part of the representative sample for personnel cabins, if applicable.
5) For all ambient environmental aspects, measurements are to be taken where a single instance of one (1) type of a manned space exists on board an installation (e.g., control room, radio room, mess, gymnasium, library, etc.). The worst case locations can be considered part of the single instance representative sample, if applicable.
6) Where multiple instances of the same type space exist, a representative sample of at least twenty-five (25) percent of each type is to be selected for measurement for all ambient environmental aspects. The worst case locations are to be considered part of the representative sample, if applicable.

For all ambient environmental conditions, visual/walk-through inspections are to be conducted in accordance with F.4.2 of the appropriate Section of the Guide.

10.3 Requirements for Offshore Installation Alterations

No alterations which affect or may affect the offshore installation's Habitability notation awarded (**HBT** or **HBT+**), including alterations to the structure, machinery, electrical systems, piping, furnishings or lighting systems, are to be made to the offshore installation unless plans of the proposed alterations are submitted to and approved by BKI before the work of alteration is commenced. If BKI determines that the alteration will affect the offshore installation's Habitability notation, the altered installation is to be subject to the review, verification, and ambient environmental testing requirements of the Guide.

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Section 4 Ship-Type Installations

A. Design Considerations 4–1
B. Additional Design Considerations for Conversions to FPI 4–23
C. Structural Design Requirements 4–42
D. Ship -Type Installations Under 150 meters in Length 4–226

A. Design Considerations

1. General

1.1 Introduction

The design and construction of the hull, superstructure and deckhouses of ship-type installations that are new builds or conversions are to be based on the applicable requirements of this Section and where referenced in the Part 1 Seagoing Ships. This section reflects the different structural performance and demands expected for an installation transiting and being positioned at a particular site on a long-term basis compared to that of a vessel engaged in unrestricted seagoing service.

The design criteria for new build or conversions of ship-type installations are located in A and C, with additional design criteria for ship-type conversions in B, which are applicable to installations of 150 meters or more in length. The relevant sections of design criteria are listed in Table 4.1 to Table 4.5 and Fig. 4.1. In D applies to installations under 150 meters in length. In addition, the applicable criteria contained in the Load Line, SOLAS and MARPOL Conventions issued by the International Maritime Organization are to be considered. It is further suggested that the local authorities having jurisdiction where the installation is to operate be contacted to obtain any further criteria that are applicable to the floating installations.

Note:

*This Guidelines is applicable to installations not exceeding 500 m in length, **L**, having breadths not exceeding one-fifth of the length nor 2,5 times the depth to the strength deck. Installations beyond these proportions will be reviewed on a case-by-case basis.*

The design criteria contained in C are applied in two phases. The first phase provides the basic hull design to reflect overall hull girder and local structural component strength, including fatigue strength. This is referred to as the Initial Scantling Evaluation (or ISCal) phase. For ship-type conversions, the reassessed and renewal scantlings are calculated in the IsCal phase, as described in B.2. The reassessed scantlings are the required scantlings for the site-specific location and transit condition, and are used to establish the minimum renewal scantlings of an FPI conversion. The second phase requires the performance of finite element structural analyses using either a three cargo tank-length model or cargo block-length model to validate the selected scantlings from the first phase. This is referred to as the Global Strength Assessment (or GSA) phase. For ship-type conversions, the GSA phase is used to validate the reassessed scantlings obtained in the IsCal phase.

Performance of additional structural analyses can lead to the granting of the optional **DYLA** classification notation, which signifies that the design meets the Dynamic Load Approach criteria. Also, the optional **SFA** classification notation can be granted, which signifies that the design satisfies fatigue strength criteria based on Spectral Fatigue Analysis.

For a Ship-Type Installation with length in excess of 350 meters, the hull structure and critical structural details are to comply with the requirements for Dynamic Loading Approach (DYLA) and Spectral Fatigue Analysis (SFA). The vessel will be identified in the

Register by the notations **DYLA** and **SFA**. For analysis using the Dynamic Loading Approach, acceptance of an equivalent method in lieu of the Dynamic Loading Approach may be considered by BKI.

The application of the design criteria in C to reflect the site-dependent nature of the floating offshore installation is accomplished through the introduction of a series of Environmental Severity Factors (ESFs). Reference is to be made to 2.1.1 and C.2 for the applicable structural design and analysis criteria that have been modified to reflect site-specific service conditions.

Table 4.1 Design Considerations and General Requirements for Ship-Type Installations

Ship Length	150 meters or more	Under 150 meters
Topic	Section	Section
General	A.1	D.1.1
Longitudinal Strength	A.2	
Design and Analysis of the Hull	A.3	
Design and Analysis of Other Major Hull Structures Features	A.4	
Modules on Deck	A.5	
Other Systems	A.6	
General Requirements	C.1.1	
Special Requirements for Deep Loading	C.1.2	D.1.2
Arrangement	C.1.3	D.1.3
Loads	C.2	

Table 4.2 Structural Design Requirements for New Build Installations within 0,4L For Ship-Type Installations ≥ 150 meters (Amidship)

Topic	Double Hull	Single Hull
	Section	Section
Initial Scantling Calculation (ISCal)		
Hull Girder Strength	C.3.2	
Shearing Strength	C.3.3	
Double Bottom Structures	C.3.4	
Side Shell and Deck	C.3.5, C.4.6	
Longitudinal and Transverse Bulkheads	C.3.7, C.3.8, C.3.9	
General		C.6.1
Main Supporting Structures		C.6.2
Global Strength Assessment (GSA)		
Yielding	C.4.2	
Buckling and Ultimate Strength	C.4.3, C.4.4	
Fatigue	C.4.5, C.4.6	
Critical Areas	C.4.7	
Strength Assessment		C.6.3
Additional Design Considerations for Conversions for Conversions to FPI within 0.4L		
Topic	Section	
General	B.1	
Steel Renewal Assessment	B.2	
Fatigue Consideration	B.3	

Table 4.3 Structural Design Requirements for New Build Installations Beyond 0,4L For Ship-Type Installations ≥ 150 meters

Topic	Section
Structure at Ends	A.3.9, C.5.1 and D.2.9
Forebody Side Shell Structure	C.5.2
Transition Zone	C.5.3
Forebody Strengthening for Slamming	C.5.4
Forebody Deck Structures	C.5.5
Additional Design Considerations for Conversions to FPI Beyond 0,4L	
Topic	**Section**
General	B.1
Steel Renewal Assessment	B.2
Fatigue Consideration	B.3

Table 4.4 Structural Design Requirements for New Build Installations Within 0,4L For Ship-Type Installations < 150 meters (Amidship)

Topic	Section
Hull Girder Strength	D.2.1
Shell Plating	D.2.2
Deck plating	D.2.3
Bulkhead Plating	D.2.4
Long or Wide tanks	D.2.5
Double Bottom Structures	D.2.6
Deep Supporting Members	D.2.7
Frames, Beams and Bulkhead Stiffeners	D.2.8

Table 4.5 Structural Design Requirements for New Build Installations Beyond 0,4L For Ship-Type Installations < 150 meters

Topic	Section
Structure at Ends within Cargo Spaces	D.2.1, D.2.2.5, D.2.3.1, D.2.4, D.2.5, D.2.6, D.2.7, D.2.8
Structure at Ends beyond Cargo Spaces	D.2.9

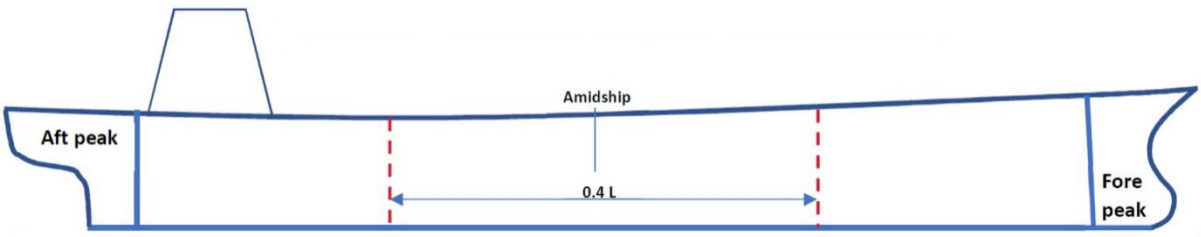


Fig. 4.1 Ship Type Installations

1.2 Definitions

1.2.1 Ship-type Installation

See Section 2, A.2 for the description of a ship-type installation. For installations that are considered ship-type, the definitions of primary characteristics of the installation can be found in Rules for Hull (Pt.1, Vol.II), Sec,2 and Rules for Machinery Installation (Pt.1, Vol.III).

1.2.2 Environmental Severity Factor

Environmental Severity Factors are adjustment factors for the dynamic components of loads and the expected fatigue damage that account for site-specific conditions as compared to North Atlantic unrestricted service conditions. See C.2 and Annex 4 for description of the concept, application and determination of Environmental Severity Factors.

1.2.3 Hull Interface Structure

The interface between the position mooring system and the hull structure, and between deck-mounted equipment modules and the hull structure, is the hull interface structure. The interface structure is defined as the attachment zone of load transmission between the main hull structure and hull-mounted equipment. See 4 for additional information on hull interface structure.

1.3 Structural Arrangement

The general arrangement and subdivision of the installation are to comply with applicable requirements of Rules for Hull (Pt.1, Vol.II), Sec.11 and 36 and Sub-Section C. Reference should also be made to the 1966 Load Line Convention and MARPOL 73/78.

1.4 Limit States

1.4.1 General

The structural strength assessments indicated in Table 4.6 are covered by the requirements of this Guidelines. In the case of installations sited at locations where the environmental conditions are less than that used for unrestricted service conditions, adjustments to the loadings and load effects produced by the site-specific long-term environment at the installation site can be applied to the assessment of hull strength and fatigue life. This is done by incorporating the Environmental Severity Factors (ESFs) for a given project site and the proposed transit route.

1.4.2 Limit States

The verification that the structural design is in compliance with these Guidelines requires that the design be checked against a set of limit states beyond which the installation's hull structure and mooring system are no longer considered adequate.

.1 Serviceability Limit State

Serviceability limit state, which addresses the structure's performance during its normal use, includes:

- Local damage which may reduce the working life of the structure or affect the efficiency of structural members
- Unacceptable deformations which affect the efficient use of structural members or the functioning of equipment
- Motions or accelerations that can exceed the range of effective functionality of topside equipment

.2 Ultimate Limit State

Ultimate limit state, which corresponds to the maximum load-carrying capacity, or in some cases, the maximum applicable strain or deformation, includes:

- Attainment of the maximum resistance capacity of sections, members or connections by rupture or excessive deformations
- Instability of the whole structure or of a significant part of it.

.3 Fatigue Limit State

Fatigue limit state relates to the possibility of failure due to cyclic loads.

.4 Accidental Limit State

Accidental limit state considers the flooding of any one cargo tank without progression of the flooding to the other compartments.

Table 4.6 Structural Strength Assessment

		Yielding Check	Buckling Check	Ultimate Strength Check	Fatigue Check
Local Structures	Plating	✓	✓	✓(1)	
	Stiffeners	✓	✓	✓(2)	✓(3)
Primary supporting members		✓	✓	✓	✓(3)
Hull girder		✓	✓(4)	✓	
Hull interface structures		✓	✓(5)	✓(6)	✓(7)

Notes:

✓indicates that the structural assessment is to be carried out.

1 *The ultimate strength check of plating is included as part of the buckling check of plating.*

2 *The ultimate strength check of stiffener is included as part of the buckling check of stiffeners.*

3 *The fatigue check of longitudinal stiffeners and primary supporting members is the fatigue check of connection details of these members.*

4 *The buckling check of stiffeners and plating included in hull girder strength is performed against stress due to hull girder bending moment and hull girder shear force.*

5 *The buckling check is to follow the Guidelines for Buckling and Ultimate Strength Assessment of for Offshore Structures (Pt.5, Vol.C).*

6 *The ultimate strength check of plating and stiffeners is included as part of the buckling check of plating and stiffeners, in accordance with the Guideline for Buckling and Ultimate Strength Assessment of for Offshore Structures (Pt.5, Vol.C).*

7 *The fatigue check is to follow the Guidelines for Fatigue Assessment for of Offshore Structures (Pt.5, Vol.B).*

1.4.3 Strength Criteria

.1 Serviceability Limit State

For the serviceability limit state design check in accordance with the partial factor design format, all partial safety factors are equal to unity C.4.2 and C.4.3.

- For the yielding check of the hull girder, the stress corresponds to a load at 10^{-8} probability level.

– For the yielding check and buckling check of plating constituting a primary supporting member, the stress corresponds to a load at 10^{-8} probability level.
– For the yielding and buckling check of stiffeners, the stress corresponds to a load at 10^{-8} probability level

.2 Ultimate Limit State

For the ultimate limit state design check of the strength of the hull girder in accordance with the partial factor design format, the ultimate strength of the hull girder is to withstand the maximum total still-water and wave sagging and hogging vertical bending moments obtained by multiplying a partial safety factor on the maximum still water sag and hog bending moments and a partial safety factor on the maximum sag and hog vertical wave bending moments as specified in C.3.2.3.

– The ultimate strength of the plating between ordinary stiffeners and primary supporting members is to withstand the loads due to the maximum total bending moment.
– The ultimate strength of the ordinary stiffener is to withstand the loads due to the maximum total bending moment.

.3 Fatigue Limit State

For the fatigue limit state design check in accordance with the partial factor design format, all partial safety factors are equal to unity. The fatigue life of representative structural details, such as connections of ordinary stiffeners and primary supporting members, is obtained from reference pressures at 10^{-4} probability level. See C.4.5 and Annex 5.

.4 Accidental Limit State

Longitudinal strength of hull girder in cargo tank flooded condition is to be assessed in accordance with B.1.3.3.2.

1.4.4 Strength Check for Impact Loads

Structural strength shall be assessed against impact loads such as forward bottom slamming, bow impact, green water on deck and sloshing loads in cargo or ballast tanks.

For Ship-Type Installations with spread mooring having significant overhanging sterns or relatively flat stern cross sections, structural strength against stern slamming load is additionally to be assessed. Reference can be made to applicable requirements of Rules for Hull (Pt.1, Vol.II), Sec.4, 6 through 10.

2. Longitudinal Strength

2.1 Longitudinal Hull Girder Strength

Longitudinal strength is to be based on Rules for Hull (Pt.1, Vol.II), Sec.5. The required hull girder section modulus for 0,4**L** amidships is to be the greater of the values obtained from the following equation or the minimum section modulus W_{min} in the table below:

$$W_{min} = \frac{M_t}{\sigma_p} \quad [cm^2\text{-}m]$$

where

M_t = total bending moment, as described below

σ_p = permissible longitudinal bending stress $[kN/cm^2]$

= 17,5 $[kN/cm^2]$

The total bending moment, M_t is to be considered as the maximum algebraic sum of the maximum still water bending moment (M_{SW}) for operation on site or in transit combined with the corresponding wave-induced bending moment (M_{WV}) expected on-site and during transit to the installation site. Due account is to be given to the influence of mooring loads and riser weights in calculating the vertical still water bending moments and shear forces.

In lieu of directly calculated wave-induced hull girder vertical bending moments and shear forces, recourse can be made to the use of the Environmental Severity Factor (ESF) approach described in C.2.1.1 and Annex 4, which can be applied to modify the Rules for Hull (Pt.1, Vol.II) wave-induced hull girder bending moment and shear force formulas (see C.2 2.3)

Depending on the value of the Environmental Severity Factor, β_{vbm}, for vertical wave-induced hull girder bending moment (see Annex 4, B), the minimum hull girder section modulus, W_{min}, of the FPI as specified in Rules for Hull (Pt.1, Vol.II), Sec.5, C.2.1 with multiplied by 10^4 to converting the unit into cm^2-m ($W_{min-ship}$), may vary in accordance with the following:

β_{vbm}	W_{min}
< 0,7	0,85 · $W_{min-ship}$
0,7 to 1,0	(0,5 + β_{vbm}/2) · $W_{min-ship}$
> 1,0	$W_{min-ship}$

2.2 Hull Girder Ultimate Strength

The hull girder ultimate longitudinal bending capacities for either hogging or sagging conditions are to be evaluated in accordance with Annex 6. The hull girder ultimate bending capacity for the design environmental condition (DEC) is to satisfy the limit state specified in C.3.2.3.

3. Structural Design and Analysis of the Hull

3.1 Structural Design of the Hull

The design of the hull is to be based on the applicable requirements of C or D, depending on the hull length and where referenced the Part 1 Seagoing Ships. For ship-type installations over 150 meters in length, C is the primary reference. Where the conditions at the installation site are less demanding than those for unrestricted service that are the basis of the Part 1 Seagoing Ships, the design criteria for various components of the hull structure may be reduced, subject to the limitations indicated below to reflect these differences. However, when the site conditions produce demands that are more severe, it is mandatory that the design criteria are to be increased appropriately.

C.2.1.1 presents an explanation of the Environmental Severity Factor (ESF) concept, which is used to adjust the unrestricted service criteria of the Rules for Hull (Pt.1, Vol.II).

In the application of the modified criteria, no minimum required value of any net scantling is to be less than 85% of the value obtained had all the ESF Beta values been set equal to 1,0 (which is the unrestricted service condition). In view of this, for an FPSO converted from a vessel, where the total bending moment for unrestricted service conditions is used for determination of the minimum required value of any net scantling, the total bending moment should consist of the maximum still water bending moment of the existing vessel and the wave-induced bending moment with all the beta values set equal to 1,0.

The loads arising from the static tank testing condition are also to be directly considered in the design. In some instances, such conditions might control the design, especially when the overflow heights are greater than normally encountered in oil transport service, or the severity of environmentally-induced load components and cargo specific gravity are less than usual.

3.1.1 Hull Design for Additional Loads and Load Effects

The loads addressed in this Subsection are those required in the design of an installation in C or D, depending on the length of the installation. Specifically, these loads are those arising from liquid sloshing in hydrocarbon storage or ballast tanks, green water on deck, bow impact due to wave group action above the waterline, bowflare slamming during vertical entry of the bow structure into the water, bottom slamming and deck loads due to on-deck production facilities. All of these can be treated directly by reference to C or D. However, when it is permitted to design for these loads and load effects on a site-specific basis, the formulations given in C.2 reflect the introduction of the Environmental Severity Factors (ESFs-Beta-type) into the Rule criteria. The paragraphs below give the location in C.2 where the adjusted load formulations are presented.

.1 Sloshing of Produced or Ballast Liquids

For ship-type installations, it is typical that the tanks may be subjected to partial filling levels. For tanks where partial filling is intended, sloshing analyses are to be performed. Firstly, the sloshing analysis is to determine if the sloshing natural periods of the anticipated filling levels in each tank are close to the installation's pitch and roll motion periods. It is recommended that the periods of the fluid motions in each tank for each anticipated filling level are at least 20 percent greater or smaller than those of the relevant installation's motion. This range of installation natural periods constitutes the "critical" range. If the natural periods of the tanks and installation are sufficiently separated, then no further analyses are required. However, when the tanks are to be loaded within "critical" filling levels, then additional analyses are to be performed in order to determine the adequacy of the structure for the internal pressures due to sloshing.

The extent of sloshing analyses is indicated in C.2.6. Reference can be made to C.2 on adjustments that could be used to modify the amplitudes of the ocean-based sloshing criteria. However, it should be borne in mind that the sloshing assessment criteria of C.2 are derived considering an unrestrained freely floating hull subjected to wave energy spectra representing the open ocean. Mooring restraints, potential hull weathervaning and different wave energy characterizations (e.g., energy spectra for ocean swells, tropical cyclonic storms and water depth effects) may need to be additionally considered by the designer when establishing the installation's motions for sloshing-induced loading analysis.

.2 Green Water Loads on Deck

When it is permitted to base the design on a site-specific modification of the Rules for Hull (Pt.1, Vol.II), reference is to be made to C.2.7.4.

.3 Bow Impact

When it is permitted to base the design on a site-specific modification of the Rules for Hull (Pt.1, Vol.II), reference is to be made to C.2.7.1.

.4 Slamming

When it is permitted to base the design on a site-specific modification of the Rules for Hull (Pt.1, Vol.II), reference is to be made to C.2.7.2 and C.2.7.3.

.5 Deck Loads

Deck loads due to on-deck production facilities for on-site and transit conditions are referenced in C.2.8.

3.1.2 Superstructures and Deckhouses

The designs of superstructures and deckhouses are to comply with the requirements of Rules for Hull (Pt.1, Vol.II), Sec.16. The structural arrangements of Rules for Hull (Pt.1, Vol.II), Sec.16 for forecastle decks are to be satisfied.

The design of buildings on top of the topside module is to be in accordance with the applicable requirements of the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII).

3.1.3 Helicopter Decks

The design of the helicopter deck structure is to comply with the requirements of Guidance for The Class Notation Helicopter Deck and Facilities (Helil & Helil (SRF) (Pt.7, Vol.A). In addition to the required loadings defined in Guidance for The Class Notation Helicopter Deck and Facilities (Helil & Helil(SRF) (Pt.7, Vol.A), the structural strength of the helicopter deck and its supporting structures are to be evaluated considering the DOC and DEC environments, if applicable.

3.1.4 Protection of Deck Openings

The machinery casings, all deck openings, hatch covers and companionway sills are to comply with C.1.2 and D.1.2.

3.1.5 Bulwarks, Rails, Freeing Ports, Ventilators and Portlights

Bulwarks, rails, freeing ports, portlights and ventilators are to meet the requirements of Rules for Hull (Pt.1, Vol.II), Sec.21.

3.1.6 Equipment

The provision of equipment on the installation is optional, except as noted below. For guidance on the requirements for temporary mooring equipment (anchor, chains, windlasses or winches, hawse pipe, etc.), refer to Rules for Hull (Pt.1, Vol.II), Sec.18.

Self-propelled disconnectable installations are to comply with Rules for Hull (Pt.1, Vol.II), Sec.18. Consideration may be given to arrangement with a single anchor subject to satisfactory submittal of a risk analysis to address conditions under which the installation may proceed toward shore, and with the agreement of the flag and coastal states. Any vessel entering piloted, restricted, or congested waters with only one anchor will require a tug escort regardless of the risk assessment findings, and this will be noted as an operating restriction on the Class certificate.

3.1.7 Materials and Welding

For a minimum design service temperature of 0°C and above, ship-type installations are to be constructed from steel selected in accordance with Rules for Hull (Pt.1, Vol.II), Sec.2. For a minimum design service temperature lower than 0°C, ship-type installations are to be constructed from steel selected in accordance with Rules for Structures (Pt.5, Vol. II), Sec.4 with the provision that the steel selection is not to be less conservative than that of Rules for Hull (Pt.1, Vol.II), Sec.2. The structural application categories defined in Rules for Hull (Pt.1, Vol.II), Sec.2 are to be used with the steel selection criteria in Rules for Structures (Pt.5, Vol.II), Sec.4 by applying the following correlations:

1) Class I correlates with Secondary
2) Class II correlates with Primary
3) Class III correlates with Special

The steel selection criteria of Rules for Hull (Pt.1, Vol.II), Sec.2 are to be implemented, as appropriate, and are to supplant less severe steel selection criteria of Rules for Structures (Pt.5, Vol. II), Sec.4 for equivalent structure.

For major hull interface structure as defined in 4.1, longitudinal underdeck and hull interface plating or bracket structures attached to the deck or hull should have the same or compatible material grade as the deck or hull structure, respectively.

The topside facilities (production deck) are to be constructed from steel selected in accordance with the Rules for Structures (Pt.5, Vol. II), Sec.4.

Turret and SPM buoy mooring systems are to be constructed from steel selected in accordance with the Rules for Structures (Pt.5, Vol. II), Sec.8.

Tower mooring systems are to be constructed from steel selected in accordance with the Rules for Structures (Pt.5, Vol. II), Sec.4.

All fabrication and welding are to comply with the requirements in Rules for Materials (Pt.1, Vol.V) and Rules for Welding (Pt.1, Vol.VI). The weld type and sizing are to be shown on the scantling drawings or in the form of a welding schedule and are to comply with the requirements that govern the steel selection.

3.1.8 Machinery and Equipment Foundations

Foundations for equipment subjected to high cyclic loading, such as mooring winches, chain stoppers and foundations for rotating process equipment, are to be analyzed to verify they provide satisfactory strength and fatigue resistance. Calculations and drawings showing weld details are to be submitted to the BKI for review.

3.1.9 Additional Considerations for Disconnectable Systems

.1 Machinery Space and Tunnel

Requirements for machinery spaces with regard to engine foundations, tunnels and tunnel recesses are given in Rules for Hull (Pt.1, Vol.II), Sec.8, C, as modified by C.1.3.17 and C.1.3.16.

.2 Keels, Stems, Stern Frames and Rudder Horns

Requirements for stems, stern frames, shoe pieces, rudder horns and gudgeons are given in Rules for Hull (Pt.1, Vol.II), Sec.13 and 14. Additional requirements for ice strengthening are given in Rules for Hull (Pt.1, Vol.II), Sec.15.

.3 Rudders and Steering Gears

For installations with steering capabilities, the requirements for rudder stocks, couplings, pintles, plating, steering gears, etc., are given in Rules for Hull (Pt.1, Vol.II), Sec.14. Ice-strengthened installations are to comply with Rules for Hull (Pt.1, Vol.II), Sec.15, as applicable.

3.1.10 Bilge Keels

For bilge keels 500 mm or less in depth, the requirements are given in Rules for Hull (Pt.1, Vol.II), Sec.6, F.

In addition to the requirements included in the above Rules for Hull (Pt.1, Vol.II), bilge keels greater than 500 mm in depth with single web or closed construction form are to be modeled in the cargo tank model described in 3.2 applying net scantlings based on a nominal design corrosion value of 1,0 mm. Strength of the structure in yielding and buckling are to be assessed against the criteria given in C.4.4.2 and C.4.4.3. As an alternative, buckling assessment may be carried out using eigenvalue analysis method with appropriate edge constraints. If the predicted buckling stress exceeds the proportional linear elastic limits, which may be taken as $0,6 \cdot R_{eH}$ for steel, plasticity correction is to be made. Locations on the bilge keel where stress concentrations occur are to be examined using fine mesh analyses applying procedures and criteria given in C.4.4.6. Locations to be analyzed are to include, but not limited to, areas where abrupt changes in geometry occur, end details of the bilge keel, toes of transverse support

brackets, and terminations of the bilge keel ground bar. Fatigue analysis of the aforementioned locations is to be carried out in accordance with Annex 5. A safety factor of 3 against the design fatigue life is to be applied. Additionally, the bilge keel and supporting structures are to be assessed for hydrodynamic drag loads due to wave dynamics and hull motion. These loads may be calculated either by model experiments or numerical simulation using three-dimensional flow analysis for the transit condition and site-specific operating condition, The methodology and test procedures and measurements or analysis methods are to be fully documented and submitted for review.

3.1.11 Sea Chests

Structural requirements for sea chests are given in Rules for Hull (Pt.1, Vol.II), Sec.8, B.5.4

3.2 Engineering Analyses of the Hull Structure

3.2.1 General

The criteria in this Subsection relate to the analyses required to verify the scantlings selected in the hull design in 3.1. Depending on the specific features of the offshore installation, additional analyses to verify and help design other portions of the hull structure will be required. Such additional analyses include those for the deck structural components supporting deck-mounted equipment and the hull structure interface with the position mooring system. Analysis criteria for these two situations are given in 4.

3.2.2 Strength Analysis of the Hull Structure

For installations of 150 m in length and above, the required strength assessment of the hull structure is to be based on a three cargo tank length finite element model amidships where the strength assessment is focused on the results obtained from structures in the middle tank. For FPI conversions, as an alternative, a complete hull length or full cargo block length finite element model can be used in lieu of the three cargo tank length model as described in B.1.3.4. Details of the required Finite Element Method (FEM) strength analysis are indicated in C.4.6 and Annex 7. The net scantlings used in the strength analysis of new build FPI and conversions to FPI differ as follows:

1) For new build FPI, the finite element strength analysis is performed using the new build net scantlings obtained by deducting the nominal design corrosion values in Table 4.8 from the new build design scantlings.
2) For FPI conversions, the finite element strength analysis is performed using the reassessed net scantlings obtained by deducting the nominal design corrosion values in Table 4.8 from the reassessed scantlings as determined in B.2.

When mooring and riser structures are located within the extent of the FE model, the static mass of the mooring lines and risers may be represented by a mass for which gravity and dynamic accelerations can be calculated and added to the FE model. The resulting dynamic loads shall be compared to the mooring and riser analysis results to ensure that the dynamic effects are conservatively assessed in the hull FE analysis.

For installations less than 150 m in length, it is recommended that a Finite Element Method (FEM) analysis be performed if the installation is of double hull construction or of unusual design (see D.1.1.2.3). When the design is permitted to be based on site-specific environmental conditions, the load components to be used in the strength analyses can be determined using 2.1, 3.1 and C.2.

Generally, the strength analysis is performed to determine the stress distribution in the structure. To determine the local stress distribution in major supporting structures, particularly at intersections of two or more members, fine mesh FEM models are to be analyzed using the boundary displacements and load

from the 3D FEM model. To examine stress concentrations, such as at intersections of longitudinal stiffeners with transverses and at cut outs, fine mesh 3D FEM models are to be analyzed.

The accidental load condition, where a cargo tank is flooded, is to be assessed for longitudinal strength of the hull girder consistent with load cases used in damage stability calculations.

3.2.3 Three Cargo Tank Length Model

.1 Structural FE Model

The three cargo tank length FE model is considered representative of cargo and ballast tanks within the 0,4**L** amidships. The same FE model may be used for hull structures beyond 0,4**L** amidships with modifications to the hull geometry, plate and stiffener properties and the applied loads, provided that the structural configurations are considered as representative of the location under consideration. Where the tanks in the 0,4**L** amidships are of different lengths, the middle tank of the FE model is to represent the cargo tank of the greatest length.

The assessment of the hull structure to resist hull girder vertical shear loads in the forward and aft cargo block regions may be based on the midship cargo tank finite element model with modifications to the structural properties, where appropriate. The strength assessment is calculated according to C.4 for the load cases described in 3.2.3.3.

For FPI conversions, reassessed net scantlings are to be used in the finite element model, and are obtained by deducting the nominal design corrosion margins from the reassessed scantlings of the structure. For FPI conversions, as an alternative, a complete hull length or full cargo block length finite element model can be used in lieu of the three cargo tank length model.

Details of the modeling, mesh size, element types used and boundary conditions are described in Annex 7. Detailed local stress assessment using fine mesh models to evaluate highly stressed critical areas are to be in accordance with Annex 7, K.

.2 Load Conditions

In the strength analyses of the three cargo tank length model, the following loading conditions are to be used:

General Loading Patterns. The FEM analysis is to be performed in accordance with the loading patterns specified in C.2. The loading patterns included in C.2 are intended to represent the envelope of worst case loading patterns for local load structural design purposes and may not necessarily represent the actual operating loading patterns of the FPI. The actual loading patterns for the installation are to be reviewed to verify that there are no other patterns producing more severe loading. If any worse governing loading patterns than those specified in C.2 exist, these loading patterns are to be included in the analyses. The structural responses for the still water conditions are to be calculated separately to establish reference points for assessing the wave-induced responses. Topside loads are also to be included in the load cases.

Loading patterns to be used for double hull, double side with single bottom and single hull installations are specified in C.2. In addition to the specified loading patterns and cargo densities, inspection and repair, transit, and static conditions representing tank testing, inspection and repair, and transit are also to be investigated.

Static Loading Conditions for New Construction. The tank loading patterns of Load Cases No. 9 and 10 specified in C are to be analyzed considering static conditions and seawater (Specific Gravity = 1,025) at minimum draft. The tanks are to be loaded considering the actual height of the overflow pipe, which is not to be taken less than 2,44 m above the deck at side. The external drafts for these load cases are to be taken as 25 percent of the scantling draft. However, Notes (1) and (2) below are applicable.

Notes:

1) *Where the actual minimum static condition with the tank loading pattern as the center row of tanks results in a draft less than specified, the actual loading condition draft is to be used.*

2) *For an installation with two outer longitudinal bulkheads only (inner skin), i.e., one tank across between the inner skin bulkheads, the minimum actual loading condition draft is to be used.*

Static Loading Conditions for FPI Conversions. The tank loading patterns of Load Cases No. 9 and 10 specified C are to be analyzed considering static conditions and seawater (Specific Gravity = 1,025) at minimum draft. The tanks are to be loaded to the top of access hatches for cargo tanks, or 760 mm above deck for ballast tanks. If the actual tank condition results in a static pressure head higher than specified, the actual pressure head is to be used. The external drafts for these load cases are to be taken as 30 percent of the scantling draft. However, Notes (1) and (2) of the above paragraph are applicable.

Inspection and Repair Conditions. Loading patterns representing inspection and repair conditions are also to be investigated. Inspection and repair conditions are to be analyzed using a minimum 1-year return period design operating condition load and a minimum specific gravity of cargo fluid of 0,9. Other aspects of the loading pattern, modeling, acceptance criteria, etc., indicated in C are to be followed.

Transit Conditions. The transit condition is to be analyzed using the actual tank loading patterns or loading patterns as defined in C.2.2.1. in association with the anticipated environmental conditions based on a minimum 10-year return period to be encountered during the voyage (see Section 2, B.3.2.2).

.3 Load Cases

The tank loading patterns as described above and specified in C.2 are to be applied. These loading patterns are intended to represent the envelope of worst case loading patterns for local load structural design purposes and may not necessarily represent the actual operating loading patterns of the FPI. The structural responses for the still water conditions are to be calculated separately to establish reference points for assessing the wave-induced responses. Additional loading patterns may be required for special or unusual operational conditions or conditions that are not covered by the loading patterns specified in C.2. Topside loads are also to be included in the load cases.

3.2.4 Fatigue Analysis

For all installations of 150 m and above, the extent of fatigue analysis required is indicated in C.4.5. For installations of less than 150 m, the requirements are indicated in D.1.1.3.

For the three cargo tank length model, the fatigue assessment is to be performed applying Annex 5 of these Guidelines.

For the cargo block model, the fatigue assessment is to be performed based on spectral fatigue analysis applying the latest edition of the Guidelines for Spectral-Based Fatigue Analysis (Pt.7, Vol.3).

The fatigue strength of welded joints and details at terminations located in highly stressed areas and in fatigue prone locations are to be assessed, especially where higher strength steel is used. These fatigue and/or fracture mechanics analyses, based on the combined effect of loading, material properties, and flaw characteristics are performed to predict the service life of the structure and determine the most effective inspection plan. Special attention is to be given to structural notches, cutouts, bracket toes, and abrupt changes of structural sections.

Consideration is also to be given to the following analyses:

1) The cumulated fatigue damage during the transit voyage from the fabrication or previous site for an existing FPI to the operation site is to be included in the overall fatigue damage assessment.

2) The stress range due to loading and unloading cycles is to be accounted for in the overall fatigue damage assessment. See Annex 5, 8

3.2.5 Acceptance Criteria

The total assessment of the structure is to be performed against the failure modes of material yielding, buckling, ultimate strength and fatigue. The reference acceptance criteria of each mode are given as follows:

.1 Material Yielding

For installation lengths of 150 m and above, the criteria are indicated in C.4.2.

For installation lengths of less than 150 m, the criteria are indicated in D.2.7.2 and D.2.7.4

.2 Buckling and Ultimate Strength of Plate Panels, Stiffeners and Longitudinals

For installation lengths of 150 m and above, the criteria is indicated in C.4.3.

For installation lengths of less than 150 m, the criteria are indicated in Rules for Hull (Pt.1, Vol.II), Sec.3, F. and Annex 3.

.3 Fatigue

The required target fatigue life as indicated in Section 1, A.3.6 and Annex 5 is 20 years. Annex 5 is also referred to for installations with lengths less than 150 m. Direct application of the Annex will result in the evaluation of members for stress ranges of an unrestricted trading service vessel. In the absence of more detailed environmental data, stress ranges are to be obtained in consideration of the unrestricted service environment. When the site-specific wave environment is used and produces less severe fatigue demand than the unrestricted service environment, credit can be given to the less severe environment by increasing the expected fatigue life. For site-specific environmental conditions producing more severe fatigue demand than the unrestricted service environment, the site-specific environmental data are to be used, and the calculated fatigue life is to be not less than 20 years.

Due to the structural redundancy and relative ease of inspection inherent in typical hull structures of ship-type installations, there is generally no further need to apply additional factors of safety above what is already built into the fatigue classification curves cited in Annex 5. Thus, for noncritical and inspectable structures, the fatigue safety factor is generally 1,0. However, for areas of the structure which are non-inspectable or "critical," such as in way of the connections to the mooring or production systems (see 4.), additional factors of safety should be considered in accordance with Section 2, B.3.3.4.

For existing installations that are employed in floating installation service, the estimated remaining fatigue lives of the critical structural details are to be assessed and the supporting calculations submitted for review. Special consideration is to be given to the effects of corrosion and wastage on the remaining fatigue life of existing structures.

Any areas determined to be critical to the structure are to be free of cracks. The effects of stress risers should be determined and minimized. Critical areas may require special analysis and survey.

3.2.6 Renewal Scantlings

.1 New Construction

Future steel renewals are to be based on the FPI required new build scantlings considering the wastage allowance as determined by the smaller of the % wastage allowance Table 4.7 or the allowable wastage based on buckling strength (see Annex 3).

.2 Conversion of Existing Vessel to FPI

Future steel renewals for FPI conversions are to be based on the FPI required scantlings, regardless of the original design renewal scheme. The process of determining the

required and renewal scantlings, as described in B.2 for an FPI vessel conversion, requires a reassessment of the vessel's scantlings based on transit condition and the specific site of the installation.

4. Design and Analysis of Other Major Hull Structural Features

4.1 General

The design and analysis criteria to be applied to the other pertinent features of the hull structural design are to conform to this Guidelines or to recognized practices acceptable to the Bureau. For many ship-type installations, the hull design will need to consider the interface between the position mooring system and the hull structure or the effects of structural support reactions from deck-mounted (or above-deck) equipment modules, or both. The interface structure is defined as the attachment zone of load transmission between the main hull structure and hull mounted equipment, such as topside module stools, crane pedestals and foundations, riser porches, flare boom foundation, gantry foundation, mooring and offloading, etc. The zone includes components of the hull underdeck structures in way of module support stools and foundations, such as deck transverse web frames, deck longitudinals and upper parts of longitudinal and transverse bulkhead structures, as well as foundations of the hull-mounted equipment. These components of the interface structure should comply with the criteria indicated in 4.4.

The criteria to be applied for the interface structures are presented below. When it is permitted to base the design of the ship-type offshore installation on site-specific environmental conditions, reference is to be made to 3.1, 2.1 and C.2 of this Guidelines regarding how load components can be adjusted.

The above (or on) deck equipment or module structure is referred to in Section 7, A.7.

4.2 Hull Interface Structure

The basic scantlings in way of the hull interface structure is to be designed based on the first principle approach and meet the requirements of Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.4, B strength criteria, Guidance for Buckling and Ultimate Strength Assessment for Offshore Structures (Pt.5, Vol.C) and Guidance for Fatigue Assessment for of Offshore Structures (Pt.5, Vol.B), or equivalent national industry standards recognized and accepted by BKI, such as API Standards. Welding design of hull interface structure connections is to be developed based on Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.3, C or a direct calculation approach. Material grades for the above- deck interface structure are to be selected as per Rules for Structures (Pt.5, Vol.II) requirements. The material grades for the hull structure components, such as deck and frame structures, are to be selected as per Rules for Hull (Pt.1, Vol.II), Sec.2.

The verification of the hull interface structure as defined above is to be performed using direct calculation of local 3-D hull interface finite element models, developed using gross scantlings and analyzed with load conditions and load cases described in the following sections.

4.2.1 Position Mooring/Hull Interface Modeling

A FEM analysis is to be performed and submitted for review:

.1 Turret or SPM Type Mooring System, External to the Installation's Hull

If the mooring system is of the turret or SPM type, external to the installation's hull, the following applies:

1) **Fore end mooring**. The minimum extent of the model is from the fore end of the installation, including the turret structure and its attachment to the hull, to a transverse plane after the aft end of the foremost cargo oil tank in the installation. The model can be considered fixed at the aft end of the model. The loads modeled are to correspond to the worst-case tank loads, seakeeping loads as determined for both the transit condition and the on-site design environmental condition (DEC),

ancillary structure loads, and mooring and riser loads for the on-site DEC, where applicable. The design operating condition (DOC) may also need to be considered for conditions which may govern.

2) **Aft end mooring**. The minimum extent of the model is from the aft end of the installation, including the turret structure and its attachment to the hull structure, to a transverse plane forward of the fore end of the aft most cargo oil tank in the hull. The model can be considered fixed at the fore end of the model. The loads modeled are to correspond to the worst-case tank loads, seakeeping loads as determined for both the transit condition and the on-site design environmental condition (DEC), ancillary structure loads, and mooring and riser loads for the on-site DEC, where applicable.

.2 Mooring System Internal to the Installation Hull (Turret Moored)

If the mooring arrangement is internal to the installation hull (turret-moored), the following applies:

1) **Fore end turret**. The model is to extend from the fore end of the installation to the after end of the cargo tank or hold aft of the one containing the turret. The model can be considered fixed at the aft end of the model. The loads modeled are to correspond to the worst-case tank loads, seakeeping loads as determined for either the transit condition or the on-site design environmental condition (DEC), ancillary structure loads, and mooring and riser loads for the on-site DEC, where applicable. The design operating condition (DOC) may also need to be considered for conditions which may govern.

2) **Midship turret**. The model can be a 3-tank model similar to that described in C.4.6 where the turret is located in the center tank of the model. Hull girder loads are to be applied to the ends of the model. The loads modeled are to correspond to the worst-case tank loads, seakeeping loads as determined for either the transit condition or the on-site design environmental condition (DEC), ancillary structure loads, and mooring and riser loads for the on-site DEC, where applicable. The design operating condition (DOC) may also need to be considered for conditions which may govern.

3) As a minimum, the following two cargo loading patterns that result in the worst load effects on the hull structure are to be considered:

   – Maximum internal pressure for fully filled tanks adjacent to the hold containing the turret, with the other tanks empty and minimum external pressure, where applicable. (See Fig. 4.2)

   – Empty tanks adjacent to the hold containing the turret, with the other tanks full and maximum external pressure, where applicable. (See Fig. 4.3)

   The interface structure is to be assessed for yielding, buckling and fatigue strength, and should include all structural members and critical connections within the hold containing the turret as well as the hold boundaries and their attachments.

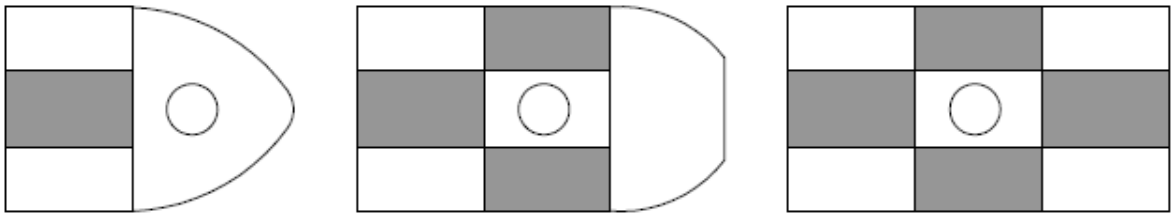


Fig. 4.2 Loading Pattern 1 with 2/3 Scantling Draft

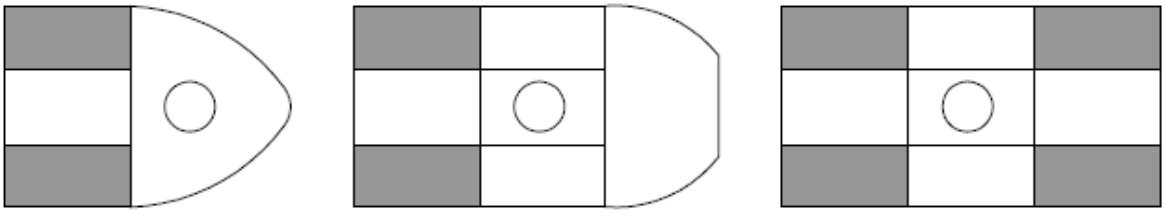


Fig. 4.3 Loading Pattern 2 with Scantling Draft

.3 Spread Moored Installations

The local foundation structure and installation structure are to be checked for the given mooring loads and hull structure loads, where applicable, using an appropriate FEM analysis. The mooring loads to be used in the analysis are to be based on the on-site design environmental condition (DEC) for hull structure, and the mooring loads for the on-site DEC and breaking strength of the mooring lines. The design operating condition (DOC) may also need to be considered for conditions which may govern.

4.2.2 Hull Mounted Equipment Interface Modeling

.1 Topside Module Support Stools and Hull Underdeck Structures

The topside module support stools and hull underdeck structures in way of module support stools, such as deck transverse webs, deck longitudinals, longitudinal and transverse bulkheads, are to be assessed for the most unfavorable load combinations of topside stool reactions and hull structure loads, where applicable, using an appropriate FEM analysis. The load combinations of topside stool reactions and hull structure loads are to be consistent with those assumed in the module analysis (refer to 5.). The finite element model extent is to be sufficiently large to minimize the cut boundary effects. The openings in way of critical areas are to be incorporated into the FEM model to investigate their effects. The loads for the on-site design operating condition (DOC), on-site design environmental condition (DEC) and transit condition are to be taken into account. Topside production and support systems are to be empty in transit condition. Special attention is to be given to the cutouts in deck transverse webs in way of topside module stools. The strength analysis for the typical cutout with the maximum topside stool reactions using a local fine mesh FEM model is to be carried out and submitted for review.

.2 Other Hull Mounted Equipment Foundation Structures

Other hull mounted equipment foundations, such as crane pedestals and foundations, riser porches, flare boom foundations, gantry foundations, offloading equipment foundations, etc., and hull vessel structure in way of the foundations are to be checked for the given functional loads, environmental loads and hull structure loads, where applicable, using an appropriate FEM analysis. The finite element model extent is to be sufficiently large to minimize the cut boundary effects. Openings such as cutouts in way of critical areas are to be incorporated into the FEM model. The loads for the on-site design operating condition (DOC), on-site design environmental condition (DEC) and transit condition are to be taken into account in the analysis. All equipment is to be in the stowed position for the transit condition.

4.3 Loads

4.3.1 Load Conditions

For all conditions, the primary hull girder load effects are to be considered, where applicable.

.1 Site Design Environmental Condition (DEC)

For non-disconnectable FPSOs or FSOs:

- Site DEC with hull design return period, and severe storm functional dead and live loads, as applicable, with 1/3 stress increase allowable (i.e., $0,8 \cdot R_{eH}$)

For disconnectable FPSOs and FSOs:

- Site Disconnectable Environmental Condition (DISEC), Client-specified site year return loads (See Section 2, B.3.1.1), and severe storm functional, dead and live loads (i.e., excluding tropical cyclones), as applicable, with 1/3 stress increase allowable (i.e., $0,8 \cdot R_{eH}$)

For the DEC and DISEC load conditions, the following assumptions are applicable:

- Topside Production Facility modules are in wet condition for all site conditions and in dry conditions for unrestricted service and transit conditions.
- Cranes are in stowed position
- Mooring loads in the most severe hull loading condition are determined from the site mooring load analysis for the following conditions:
  - All lines are intact
  - One line is damaged
  - For each individual line and associated fairlead, chock, chain stopper etc., the strength is to be assessed under the breaking strength of the line/chain with a Utilization Factor, UF = 0,8 for component stress, 0,9 for Von Mises element stress and 0,8 for buckling stress, in the case that the mooring loads in the above two conditions are not available.

Note :

FE analysis requirements for the position mooring/hull interface described 4.2.1 are to be met. In addition for the internal turret, the longitudinal strength calculations (i.e., Hull Girder longitudinal bending & shear strength and IACS buckling strength checks (UR S11.5), as per 2.1 of this Guidelines and Rules for Hull (Pt.1, Vol.II), Sec.3 and 5, for the hull girder section in way of the internal turret), for all applicable conditions, are to be submitted for review and approval.

.2 Site Design Operating Condition (DOC)

Site DOC with maximum functional live loads under site operation without 1/3 stress increase allowable (i.e., $0,6 \cdot R_{eH}$). Special consideration should be given to the following:

- Limiting environmental condition, specified by designer/operator, that would require suspension of normal operations, is to be minimum 1-year return as per this Guidelines.
- Deck support stools for topside production facility modules are in wet condition.
- Crane functional loads are as per API RP 2A and API Spec 2C Practices.
- Position mooring hull interface

.3 Transit Condition

For transit (topside production facility in dry condition), it is the shipyard's and/or designer's responsibility to specify the design parameters for the transit condition. There are generally four approaches available:

- Specified maximum seasonal weather routing condition;
- Maximum 10-year return response based on the worst environmental conditions and associated wave scatter diagram along the transit route,
- Maximum 10-year return response based on a composite wave scatter diagram,
- North Atlantic service condition, with a minimum 10-year return period, using the IACS standard wave data where the transit route is not yet defined or finalized.

.4 Damage Condition

Damaged Conditions (as applicable) with static deadweight and functional loads only, for a minimum 1-year return period DOC caused by accidental flooding.

4.3.2 Inertial Load Cases

The long-term and short-term DLP (Dominant Load Parameter) values can be calculated either using direct seakeeping/hydrodynamic calculations using 3D diffraction radiation program. The DLP values are to be selected for the most unfavorable structural response. Maximum accelerations are to be calculated at the

center of gravity of the most forward and aft and midship topside production facility modules. The load cases are to be selected to maximize each of the following DLPs together with other associated DLP values.

- Max. Vertical Bending Moment
- Max. Shear Force
- Max. Vertical Acceleration
- Max. Lateral Acceleration
- Max. Roll

Alternatively, the number of load cases can be reduced by assuming that all maximum DLP values occur simultaneously, which is a conservative assumption.

4.3.3 Hull Girder Load Cases

As a minimum, the following two hull girder load cases are to be analyzed:

- Maximum hull girder sagging moment (i.e., generally full load condition)
- Maximum hull girder hogging moment (i.e., generally ballast, tank inspection or partial loading condition)

4.4 Acceptance Criteria

4.4.1 Yielding Checks

.1 For DEC 100-Years Return Periods, Transit 10-Year Return Period and/or North Atlantic Loads:

1) For one-stiffener spacing element size FE analysis:
   - σ_e (Von Mises) < 0,9 R_{eH} plate membrane stresses at element centroids
   - σ_{1x} (axial stress) < 0,8 R_{eH} bar and beam elements
   - τ_{xy} (shear) < 0,53 R_{eH}
2) The effects of notches, stress risers and local stress concentrations are to be taken into account when considering load carrying elements. When stress concentrations are considered to be of high intensity in certain elements, the acceptable stress levels will be subject to special consideration. The following guidance may be used in such circumstances.

   For local detail FE model analyses (localized highly stressed area, 50 × 50 mm approximate element size. In no case is the plate element size required to be less than the plate thickness):
   - σ_e small area < 1,25 · S_m · R_{eH}
   - σ_{1x} element stress < 1,25 · S_m · R_{eH}

.2 For DOC (Deadweight + Maximum Functional Loads), with 1-Year Minimum Return Period Loads:

1) For one-stiffener spacing element size FE analysis:
   - σ_e < 0,7 · R_{eH} plate membrane stresses at element centroids
   - σ_{1x} < 0,6 · R_{eH} bar and beam elements
   - τ_{xy} < 0,4 · R_{eH}

   Note:

   These load cases often govern for benign environmental loads.
2) For local detail FE model analyses (localized highly stressed area, 50 × 50 mm approximate element size. In no case is the plate element size required to be less than the plate thickness.):

– σ_e small area < 0,97 · S_m · R_{eH}
– σ_{1x} element stress < 0,97 · S_m · R_{eH}

.3 For Damaged Condition:

Same as above for a minimum 1-year return period, except for the following, as applicable:

1) For one-stiffener spacing element size FE analysis:
   – $\sigma_v < 0.9 \cdot R_{eH}$ plate membrane stresses at element centroids
   – $\sigma_v < 0.8 \cdot R_{eH}$ bar and beam elements
   – $\tau_{xy} < 0.53 \cdot R_{eH}$
2) For local detail FE model analyses (localized highly stressed area, 50 × 50 mm approximate element size. In no case is the plate element size required to be less than the plate thickness):
   – σ_e small area < 1,25 · S_m · R_{eH}
   – σ_{1x} element stress < 1,25 · S_m · R_{eH}

where

R_{eH} = 1,0 for normal steel
= 0,95 for HT32 steel
= 0,908 for HT36 steel
= 0,875 for HT40 steel

For material grades other than the above, the allowable stresses will be specially considered.

4.4.2 Buckling Checks

BKI buckling criteria included in the latest edition of the Guidance for Buckling and Ultimate Strength Assessment for Offshore Structures (Pt.5, Vol.C) are to be used with the following:

– Buckling strength to be calculated using gross scantlings,
– Utilization Factor, UF :
  - UF = 0,8 or SF =1,25 for onsite DEC, transit condition and/or North Atlantic condition
  - UF = 0,6 or SF =1,67 for onsite DOC
  - UF = 0,8 or SF =1,25 for damage condition
  - UF determined on a case-by-case basis for other special conditions

4.4.3 Fatigue Calculations

.1 The fatigue damage/life calculations are to be carried out as per the latest edition of the Guidance for Fatigue Assessment of Offshore Structures (Pt.5, Vol.B). The fatigue calculations are to be carried out for the intended design operating life of the installation. Where the external interface connections are subjected to water immersion, the S-N curves in seawater with (CP) Cathodic Protection or (FC) Free Corrosion are to be used, as applicable. If the simplified fatigue calculation approach is to be used and the long-term Weibull distribution parameter is not available for the hull interface, then a Weibull parameter is to be developed for the specific location under consideration.

The safety factors for fatigue life for hull interface connections are to be in accordance with Table 2.1.

.2 Position Mooring Hull Interface

Structural members in way of the turret structure or other mooring structure are to be effectively connected to the adjacent structure in such a manner as to avoid hard spots, notches and other harmful stress concentrations.

Special attention is to be given to cutouts, bracket toes and abrupt changes of structural sections. These areas are considered to be critical to the vessel and are to be free of cracks. The effects of stress risers in these areas are to be determined and minimized.

The FE model used to perform the turret/hull integration strength analysis may also be used for the fatigue screening evaluation of the turret/hull interface structure to identify the critical fatigue details using the F or F2 Class S-N curves and appropriate safety factors. The refined stress analysis should be performed for the critical areas that fail to meet the screening, and the use of the hot spot approach as specified in the Guidance for Fatigue Assessment of Offshore Structures (Pt.5, Vol.B) is considered to be acceptable.

The fatigue cyclic loads are to correspond to the worst-case tank dynamic loads, seakeeping loads, inertia loads due to the vessel motion, and mooring and riser dynamic loads, where applicable. Different wave headings and vessel tank loading patterns should be considered and the fraction of the total time for each base wave heading and each tank loading pattern can be used directly.

The frequency difference between wave frequency stress response and low frequency stress response imposed by mooring lines and risers should be considered. Although the low frequency stress response has negligible effects on most hull structural details, it becomes significant and may have the dominant contribution to the fatigue damage of structural components in the mooring system, risers and their interface with the hull. When the wave frequency and low frequency stress responses are obtained separately, the method of simple summation of fatigue damages from the two frequency stress responses does not account for the coupling effects (i.e., the augmentation of the low frequency response by the wave frequency response is non-conservative and therefore should not be used).

There is an alternative method, which is both conservative and easy to use, that is known as the combined spectrum method. In this method, the stress spectra for the two frequency bands are combined. The RMS and the mean up-crossing frequency of the combined stress process are given, respectively, as follows:

$$\sigma_c = \sqrt{\sigma_w^2 + \sigma_\ell^2}$$

$$f_{0c} = \frac{\sqrt{f_w^2 \cdot \sigma_w^2 + f_{0\ell}^2 \cdot \sigma_\ell^2}}{\sigma_c}$$

where

σ_w = RMS of the wave-frequency stress component

σ_ℓ = RMS of the low-frequency stress component

f_{0w} = mean up-crossing frequency of the wave-frequency stress component

$f_{0\ell}$ = mean up-crossing frequency of the low-frequency stress component

However, if both frequency components of stress range are significant, the above-mentioned combination method may be too conservative since the wave frequency contribution is expected to dominate, thus controlling the mean up-crossing frequency of the combined stress process. To eliminate the conservatism, a correction factor given below can be applied to the calculated fatigue damage of the sea state:

$$\frac{f_{0p}}{f_{0c}}\left[\lambda_\ell^{(m/2)+1}\left(1 - \sqrt{\frac{\lambda_w}{\lambda_\ell}}\right) + \sqrt{\pi \cdot \lambda_\ell \cdot \lambda_w}\,\frac{m \cdot \Gamma\left(m/2 + \tfrac{1}{2}\right)}{\Gamma\left(m/2+1\right)}\right] + \left(\frac{f_{0w}}{f_{0c}}\right)\lambda_w^{m/2}$$

where

$\lambda_\ell = \frac{\sigma_\ell^2}{\sigma_c^2}$

$\lambda_w = \frac{\sigma_w^2}{\sigma_c^2}$

$f_{0p} = \sqrt{\lambda_\ell^2 \cdot f_{0c}^2 + \lambda_\ell \cdot \lambda_w \cdot f_{0c}^2 \cdot \delta_w^2}$ with $\delta_w = 0,1$

m = slope parameter of the S-N curve

Γ() = complete gamma function

.3 Hull-Mounted Equipment Interface

The procedure for the fatigue evaluation of the turret/hull integration structure can also be applied to deck-mounted equipment interface structures in which the wave-induced hull girder loads, external hydrodynamic pressure, and inertia loads due to the vessel motion as well as the specified equipment fatigue loads should be taken into account.

Special attention is to be given to the cutouts in deck transverse webs in way of topside module stools. Where applicable, the detail fatigue evaluation for the typical cutout with the maximum topside stool dynamic reactions is to be carried out and submitted for review.

5. Modules on Deck

5.1 General

This Sub-Section is applicable to ship-type installations which class topside production facilities or where the optional notation **Topside Modules** is requested.

The structural strength design of deck modules on ship-type installations is to be in accordance with Section 5, C.3.3.2.1 through 5, C.3.3.2.4 and 5, C.3.3.2.6, wherever applicable. The relative deformations among module supports (e.g., stools) and the rigidity of supports and ship-type installation hull/deck, as well as hull deformations, are to be included in the analysis if their effects on the module are significant.

The module structures above their supports are to be analyzed and shown explicitly on the drawings so that the construction of the module supports can be consistent with those assumed in the structural analysis. The module design reactions and conditions are to be assessed for the most unfavorable load combinations of topside stool reactions and hull structure loads. The design requirements for module supports are given in 3.1.1.3 and 4.3.

Fatigue analysis of the topside module/hull interface is required (see 4.4.3). Fatigue analysis of the modules on ship-type installations is optional, and where requested by the Owner.

6. Other Systems

6.1 Other Systems

Other systems are to comply with the applicable requirements as prescribed in the following Paragraphs.

6.1.1 Marine Piping Systems

Marine piping systems are those systems that are required to conduct marine operations and are not associated with the process facilities. These systems include, but are not limited to, bilge, ballast, tank

venting, sounding and fuel oil. Marine piping systems on ship-type installations are to be in accordance with the applicable requirements of Rules for Machinery Installation (Pt.1, Vol.III), Sec.11 and Rules for Building and Classing Facilities on Offshore Installations (Pt.5, Vol.XII), as applicable.

6.1.2 Electrical Systems

Electrical systems on ship-type installations are to comply with the applicable requirements of Rules for Electrical Installations (Pt.1, Vol.IV) and Rules for Building and Classing Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, F. For area classification requirements, refer to Section 7, A.9.

6.1.3 Fire Fighting Systems and Equipment

Fire fighting systems and equipment for service functions not associated with the process facilities are to be in accordance with the applicable requirements of Rules for Machinery Installation (Pt.1, Vol.III), Sec.12. Fire fighting systems and equipment for protection of hydrocarbon process and associated systems are to be in accordance with Rules for Building and Classing Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, H.

6.1.4 Machinery and Equipment

Machinery and equipment not associated with the process facilities are to be in accordance with the applicable requirements of Rules for Machinery Installation (Pt.1, Vol.III), Sec.2, 7 and 11. Machinery and equipment forming a part of the hydrocarbon processing facilities are to be in accordance with applicable requirements of the Facilities on Offshore Installations. Refer to Section 7, A regarding process-related machinery and equipment.

6.1.5 Hydrocarbon Storage in Hull Tanks

If the ship-type installation to store hydrocarbons in hull tanks, criteria for hull storage of hydrocarbons are to meet flag and coastal state requirements and applicable international requirements. The designs for scantlings and strength for such storage tanks are to be in accordance with C. Storage facility arrangement requirements see Rules for Building and Classing Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, E.3.5.

B. Additional Design Considerations for Conversions to FPI

1. General

1.1 Introduction

The conversion of an existing vessel to a ship-type FPI is referred to as an FPI Conversion.

The direct application of the criteria contained in Sections 2, C.1 and A. as the basis of acceptance of the hull structure of an existing vessel for FPI service will result in classification notations as described in Section 1, A.2.2, A.3 and 5. However, modified acceptance criteria, given in this Section, may be used for some aspects of the vessel's structural design as a conversion to FPI service. This Section applies to both the '*Change of Class Designation*' and '*Transfer of Class*' situations where the acceptance of the existing vessel's hull structure as an FPI conversion is pursued. '*Change of Class Designation*' refers to an existing vessel classed by BKI which is being converted to FPI service. 'Transfer of Class' refers to a vessel transferring into BKI classification from another IACS member Society.

Fig. 4.4 is a diagram depicting the conversion procedure given in this Section.

1.2 General

All applicable criteria contained in this FPI Guidelines are to be used in the classification of an FPI conversion, except that some criteria (primarily in Section 2, C.1 and A.) can be modified. Specific modifications are given below for the affected criteria.

The major criteria differences for the FPI conversion arise in the acceptance of the hull structure. The design of the hull structure relates to hull girder longitudinal strength and local scantling selection. Specific changes that will accommodate the use of the acceptance criteria for an FPI conversion are given in 1.3. The principal differences in the modified criteria are summarized as:

1) The hull girder strength and acceptability of local scantlings follow the Rule approach (it is noted that there are several valid bases to do this under the BKI's Rules and procedures, which are discussed in 1.4); and
2) The performance of strength analyses and stress checks, including finite element analyses are to be based on reassessed net scantlings. The determination of the reassessed scantlings is given in 2. and its purpose is to establish minimum renewal scantlings. The acceptance criteria for the hull structure are defined in 1.3.

The minimum fatigue life of the hull structure is also fundamentally different for a converted vessel. For a new-build, the minimum design service life for fatigue is 20 years; for an existing vessel to be converted to FPI service, the minimum intended on-site service life for fatigue can be less than 20 years (see 1.3.6.3).

1.3 Acceptance Criteria for the Hull Structure

1.3.1 General

For a vessel being converted to FPI service, the design and construction of the existing hull, superstructure and deckhouses are to meet either the applicable criteria of Rules for Hull (Pt.1, Vol.II) at the time of original build, or as applicable, the criteria presented in 1.4 below. In the case of the former approach in which the acceptance criteria is Rules for Hull (Pt.1, Vol.II) at the time of original build, the hull structure is also to satisfy the hull interface structure criteria, as applicable, and the remaining fatigue life requirements in 1.3.6. The second approach is based on criteria in 1.4, where Environmental Severity Factors (ESFs), as described in C.2.1.1 of this Guideline (which reflect expected conditions from the long-term mooring of the installation at an offshore site), are applied, and the required hull girder longitudinal strength in A.2 and strength assessment in C.3 and C.4 are satisfied. This results in revised values of required local scantlings that reflect the site-specific nature of the structural design. In the application of these criteria, no minimum required value of any scantling is to be less than 85 percent of the value obtained with all the Beta Values set equal to 1,0.

To be eligible to apply the second approach based on criteria in 1.4, it is to be demonstrated that the β type Environmental Severity Factors (ESFs) β_{VBM} and β_{WHT}, as defined in Annex 4, B, are 1,0 or less, and the required hull girder longitudinal strength as specified in A.2 is satisfied.

In addition, it is expected that the applicable and most recent versions of the criteria contained in the Load Line, SOLAS, MODU Code and MARPOL Conventions issued by the International Maritime Organization are to be considered. It is further suggested that flag state and the local authorities having jurisdiction where the installation is to operate be contacted to obtain any further applicable criteria. See also A.1.1

1.3.2 Structural Evaluation of the Hull

The hull structure that is to be converted is to satisfy renewal criteria that are to be established by a reassessment calculation. A reassessment calculation as described in 2. is first performed to establish the minimum renewal scantlings of individual plates and structural members below which renewals are required. For the uninterrupted operation of the installation on-site without any drydocking, the

anticipated corrosion predicted to occur over the proposed on-site life of the FPI is to be provided by the designer or owner and considered in the design. Estimation of anticipated corrosion rates are to be made, by taking into account any future corrosion protection measures to be used, previous service experience, the type and temperatures of stored fluids and the other variables significantly affecting the corrosion rate. In no case is this corrosion margin provided by the designer or owner for plates and structural members to be less than 0,5 mm, except for bottom, deck and side shell plating where it is not to be less than 1,0 mm.

For BKI classification of the FPI at the time of conversion, the rule required scantlings are the renewal scantlings as determined by the reassessment calculation plus the minimum corrosion margins stated above. However for surveys in service, if the gauged thickness is between the renewal thickness and the substantial corrosion thickness as defined in 2.2.1, either the affected areas are to be renewed or repaired, or alternatively, subsequent annual surveys of these affected areas are required.

1.3.3 Engineering Analyses of the Hull Structure

.1 General

This Sub-Section relates to the strength analyses required to verify the reassessed scantlings for the hull structure. Depending on the specific features of the offshore installation, additional analyses to verify and to help design other portions of the hull structure will be required. Such additional analyses include those for the hull interface structure such as the deck structural components supporting deck-mounted equipment and the hull structure interface with the position mooring system. Analysis criteria for these two situations are given in A.4.

Provided a scantling of the existing vessel is not below its renewal limit, or if it is to be renewed at the time of conversion, then it can be modeled in the structural analyses using the "reassessed net scantling," which is the "reassessed" value minus the "nominal design corrosion values" specified in Table 4.8.

Documentation necessary to verify the structural adequacy of the installation is to be submitted for review.

.2 Strength Analysis of the Hull Structure

When the design of the hull is accepted based on the criteria in 1.4 accounting for the on-site environmental effects, finite element structural analysis using the reassessed net scantlings is to be performed. The reassessed net scantlings are obtained by deducting the nominal design corrosion values in Table 4.8 from the reassessed scantlings as determined in 2.

A three cargo tank length model or full cargo block model as described in A.3.2.2 may be used for finite element analyses. Finite element analyses should also be performed in areas where structural configurations or novel features are present that affect the basic hull design.

The loading conditions to be analysed for the three cargo tank length model or full cargo block model are described in A.3.2.3 and 1.3.4, respectively.

The loads from the hull mounted top side production and support systems, and other equipment are to be included in the strength analysis. The accidental load condition, where a cargo tank is flooded, is to be assessed for longitudinal strength of the hull girder consistent with load cases used in damage stability calculations.

The additional loads and load effects of A.3.1.1 are also to be considered in the strength analysis.

1.3.4 Alternative Structural Model Approach - Cargo Block or Full Ship Length Model

.1 Structural FE Model

As an alternative to the three cargo tank length model in A.3.2.3, the finite element strength assessment can be based on a full length or cargo block length of the hull

structure, including all cargo and ballast tanks. All main longitudinal and transverse structural elements are to be modeled. These include outer shell, floors and girders, transverse and vertical web frames, stringers and transverse and longitudinal bulkhead structures. All plates and stiffeners on the structure, including web stiffeners, are to be modeled. Topside stools should also be incorporated in the model. The modeling mesh and element types used should follow the principles that are described in Annex 7, E and F.

An acceptable alternative to the full length hull structure model analysis is the DYLA analysis in accordance with the Guideline for Dynamic Loading Approach (Pt.7, Vol.2) provided that the loading conditions in 1.3.4.2 are used.

Boundary conditions should be applied at the ends of the cargo block model for dynamic equilibrium of the structure.

The strength assessment is calculated according to the loading conditions in 1.3.4.2 associated with each load case. The plates and stiffeners in the model are to be assessed against the yielding and buckling requirements of C.4.2 and C.4.3, respectively.

Detailed local stress assessment using fine mesh models to evaluate highly stressed critical areas are to be in accordance with Annex 7, L.

.2 Loading Conditions

In the strength analyses of the cargo block or full ship length model, the static on site FPI operating load cases are to be established to provide the most severe loading of the hull girder and the internal tank structures. The operating load cases found in the Loading Manual and Trim & Stability Booklet provide the most representative loading conditions to be considered for analysis. The static load cases should include as a minimum tank loading patterns resulting in the following conditions:

1) Ballast or minimum draft condition after offloading
2) Partial load condition (33% full)
3) Partial load condition (50% full)
4) Partial load condition (67% full)
5) Full load condition before offloading
6) Transit load condition
7) Inspection and repair conditions
8) Tank testing condition - during conversion and after construction (periodic survey)

The tank testing condition is to be considered as a still water condition. The static load cases 1) to 7) will be combined with environmental loading conditions to develop static plus dynamic load cases that realistically reflect the maximum loads for each component of the structure.

.3 Dynamic Loading

Hydrodynamic loading analysis of a full length model of the FPI hull in the static load conditions is to be carried out using a recognized vessel motions and loads hydrodynamic seakeeping software. In quantifying the dynamic loads, it is necessary to consider a range of wave environments and headings at the installation site, which produce the considered critical responses of the FPI structure. The maximum 100-year design response is to be determined based on the motion and structural load effects from Section 2, B.3.1 The static and dynamics of the position mooring and topside module loads contribution shall also be included.

Wave loads are to be determined based on an equivalent design wave approach where an equivalent design wave is defined as a regular wave that gives the same response level as the maximum design response for a specific response parameter. The equivalent design wave is characterized by wave amplitude, wave length, wave heading, and wave crest position referenced to amidships of the hull structure. This maximum design response parameter or Dominant Load Parameter (DLP) is to be determined for the site-specific environment with a 100-year return period, transit environment with a 10-year return period, and inspection and repair condition with a 1-year return period. In selecting a specific response parameter to be maximized, all of the simultaneously occurring dynamic loads induced by the wave are also derived. These simultaneous acting dynamic load components and static loads, in addition to the quasi-static equivalent wave loads, are applied to the cargo block model. The DLP essentially refer to the load effects, arising from vessel motions and wave loads, that yield the maximum structural response for critical structural members. Each set of DLP with equivalent wave and wave-induced loads represents a load case for structural FE analysis.

The wave amplitude of the equivalent design wave is to be determined from the maximum design response of a DLP under consideration divided by the maximum RAO amplitude of that DLP. RAOs will be calculated using a range of wave headings and periods. The maximum RAO occurs at a specific wave frequency and wave heading where the RAO has its own maximum value. The equivalent wave amplitude for a Dominant Load Parameter may be expressed by the following equation:

$$a_w = \frac{R_{max}}{RAO_{max}}$$

where

a_w = equivalent wave amplitude of the DLP

R_{max} = maximum response of the DLP

RAO_{max} = maximum RAO amplitude of the DLP

The DLPs of interest to develop the load cases are:

- Vertical bending moment-sag and hog
- Vertical shear force
- Horizontal bending moment
- Horizontal shear force
- Vertical acceleration
- Lateral acceleration
- Roll angle

Vertical bending moment and shear force are to be evaluated in way of an internally mounted mooring turret. Accelerations are to be determined at a sufficient number of process equipment locations to represent accurately the load effects arising from their motion. As appropriate, roll angle calculations may include simultaneous effects of waves and winds.

Other DLPs that may be deemed critical can also be considered in the analysis. The need to consider other DLPs or additional DLPs is to be determined in consultation with BKI.

.4 Load Cases

Load cases are derived based on the above static and dynamic loading conditions, and Dominant Load Parameters. For each load case, the applied loads to be developed for structural FE analysis are to include both the static and dynamic parts of each load component. The dynamic loads represent the combined effects of a dominant load and other accompanying loads acting simultaneously on the hull structure, including external wave pressures, internal tank pressures, deck loads and inertial loads on the structural components and equipment. For each load case, the developed loads are then used in the FE analysis to determine the resulting stresses and other load effects within the FPI hull structure.

1.3.5 Fatigue Analysis of the Hull Structure

Fatigue analysis is required considering the fatigue damage that has occurred during prior service as a trading vessel, during transit and during on-site operations including operational loading and unloading cycles. See A.3.2.5 and 3.

1.3.6 Acceptance Criteria

The total assessment of the structure is to be carried out against the failure modes of material yielding, buckling and ultimate strength, and fatigue. The reference acceptance criteria of each mode are given as follows.

.1 Material Yielding

See A.3.2.6.1.

.2 Buckling and Ultimate Strength

See A.3.2.6.2.

.3 Fatigue

For existing vessels that are employed in FPI service, the estimated remaining fatigue lives of the critical structural details are to be assessed and the supporting calculations submitted for review. Consideration is given to the effects of corrosion and wastage on the remaining fatigue life of existing structures by using net scantlings.

The minimum acceptable fatigue life for the FPI conversion is the greatest of: the on-site service life of the FPI, the time to the next Special Survey or five years. Whichever of these values controls, it is to be documented in accordance with Section 1, A.3.6.3 (the **RFL** classification notation) and used in the Survey Planning Document referred to in Section 1, C.6.2.

Annex 5 of this Guidelines is also referred to for ship-type installations with lengths less than 150 m. Application of the Annex will result in the evaluation of members for stress ranges of an unrestricted trading service vessel. In the absence of more detailed environmental data, stress ranges are to be obtained in consideration of the unrestricted service environment.

The fatigue strength is based on a cumulative damage theory, which infers that the structure is likely to experience a fatigue failure after a finite number of stress cycles occur. This is especially important when looking at FPI conversions. The installation has already experienced cycles of stress during the "ship" phase of its life and it will experience additional cycles during the "FPI" phase of its life. The basic concept is to keep the total number of cycles below the number that results in failure.

For FPI conversions, an analysis procedure accounting for the fatigue damage of the "ship" phase and FPI phase, including transit, is acceptable. First, the historical cumulative fatigue damage up to the time of conversion is to be calculated through realistic temporal weighting of wave environments experienced along the service routes during the service life of the vessel.

Second, the expected cumulative fatigue damage is to be calculated using site-specific wave environment and operational conditions, as well as transit condition. These will provide an estimate of the remaining fatigue life of the structural members at the time of conversion. See 3.

When the route and site-specific wave environments are used and they produce less severe fatigue demands than the unrestricted service environment of the Rules for Hull (Pt.1, Vol.II), credit can be given to the less severe environment by increasing the expected fatigue life. For site-specific environmental conditions producing more severe fatigue demand than the Rules for Hull (Pt.1, Vol.II) basis, the site-specific environmental data are to be used.

Due to the structural redundancy and relative ease of inspection inherent in typical hull structures of ship-type installations, there is no further need to apply additional factors of safety above what is already built into the fatigue classification curves cited in the above reference. However, for areas of the structure which are non-inspectable or "critical", such as in way of the connections to the mooring or production systems (see 1.3.7), additional factors of safety should be considered.

Any areas determined to be critical to the structure are to be free of cracks, and the effects of stress risers should be determined and minimized. Critical areas may require special analysis and survey.

For an existing classed vessel being converted to FPI service, the minimum fatigue lives of the structural components covered in 1.3.7 can be less than 20 years as mentioned above.

.4 Hull Girder Ultimate Strength

See A.2.2.

1.3.7 Analysis and Design of Other Major Structures

See Section A.4 for required analysis of hull interface structures. See also 1.3.6.3 for revised target minimum fatigue life for an existing vessel being accepted as an FPI conversion.

1.3.8 Turret Mooring

See Section 6, C.9.5 for required analysis of the turret mooring system.

See also 1.3.6.3 for revised target minimum fatigue life for as existing vessel being accepted as an FPI conversion.

1.4 Assessing the Design of the Hull Structure

1.4.1 General

The FPI conversion approach relies on a review of the hull's design. The review consists of an assessment of the hull girder strength and cargo region scantling review including main supporting members, local plating and stiffeners that directly contribute to the hull girder strength.

Two major purposes for this review are to assess the adequacy of the hull girder and local strength, and to "benchmark" the values upon which local scantling renewals are to be based for future in-service surveys. For this latter purpose, several approaches which can be applied are listed in 1.4.2.

An existing vessel can be sorted into one of three basic categories, as follows.

1) Vessel satisfies BKI Rules from its original classification [✠ in the classification symbol].
2) Vessel currently classed by an IACS member and recognized classification by BKI.
3) Vessel was never classed by an IACS member.

A vessel in category 1) or 2) can be considered for an FPI conversion. The acceptance criteria to be applied to a category 3) vessel will based on special consideration determined in consultation with the BKI.

1.4.2 Hull Design Review Acceptance Criteria

The review of the design of an existing hull structure, which is applicable to a vessel classed for unrestricted service, does not account for the increased or reduced local structural element strength requirements that could result from the long-term, moored operation of the installation at an offshore site. The approach to the design review also allows variations in the acceptance criteria that can be based on:

1) BKI's Rules from the year of build of the vessel with BKI's permissible corrosion limits for renewal; or
2) BKI's current Rules with BKI's permissible corrosion limits for renewal; or
3) The prior IACS member's approved scantlings (or as-built values) using that society's permissible corrosion limits for renewal. However the permissible corrosion limits for the longitudinal members are to be based on BKI's limits if the IACS member society's limits are greater.

When the acceptance criteria is based on 1), 2) or 3), the renewal scantlings for plates and stiffeners in the deck and bottom structure, within 0,15 Depth from deck and bottom, and for plates in side shell and longitudinal bulkheads must be established at the time of conversion. The allowable material diminution of these plates and stiffeners is to be based on the smaller of:

A) The wastage allowance based on 1), 2) and 3) or
B) The allowable wastage based on buckling strength is to apply to these plates and stiffeners subject to hull girder bending and shear stresses as required by Annex 3. When the acceptance criteria are based on 3), the IACS member's allowable wastage based on buckling considerations may be used.

The combination of the variety of ways to review local scantlings and the permissibility to account for site-dependent effects on global and local hull structural strength requirements can lead to a range of acceptable procedures.

If it is desired to account for the on-site environmental effects and how these affect the required scantlings, it will be necessary to establish the required renewal scantlings on this basis. This results in a reassessment of the hull structure design to establish the converted structure's renewal scantlings. The acceptance criteria for the hull structure are defined in 1.3.

1.5 Survey Requirements for a Conversion

A Floating Installation is expected to remain permanently moored on site, and it is therefore without the ready access to the repair and maintenance facilities used by a vessel. Considering these conditions, the following minimum Hull survey requirements for conversion of an existing vessel to FPI service are to be followed.

1.5.1 Conversion Survey Requirements

.1 Drydocking Survey

When the vessel is to be placed on drydock and surveyed, the requirements of Rules for Classification and Surveys (Pt.1, Vol.I), Sec.3, B.1.6.2 are to be followed..

.2 Class Renewal Survey of Hull

A Class Renewal Survey of Hull, appropriate to the age of the installation, is to be carried out in accordance with Rules for Classification and Surveys (Pt.1, Vol.I), Sec.4.I.B and C for non-Double Hull tankers and Double Hull tankers. All requirements for Close-up Survey and thickness measurements are to be applied.

During the conversion of an existing vessel or reconversion of a unit, all tanks required to be coated by 1.5.1.3 are to be made available for examination by the BKI Surveyor after the cleaning and surface preparation has been done to verify that the cleaning process has not exposed additional defects. This examination may be completed before or after a primer coat has been applied.

.3 Modifications

All modifications to the vessel are to be carried out in accordance with BKI-approved drawings and to the satisfaction of the attending Surveyor. In general, the IACS Rec. No. 47 for Shipbuilding and Repair Quality Standard (SARQS) requirements are to be followed unless a recognized shipyard or national standard is already established in the shipyard. Additionally all ballast and void tanks are to be hard coated and the coating is to be in good condition. These coatings should follow Guidance for the Corrosion Protection and Coating Systems (Pt.1, Vol.G) or recognized standard.

1.5.2 Structural Repairs/Steel Renewal

Renewed material should be replaced by steel of the same or higher grade and to the approved design scantling or greater. Workmanship is to be carried out in accordance with the IACS Rec. No. 47 for Shipbuilding and Repair Quality Standard (SARQS) requirements.

1.5.3 Bottom Plate Pitting Repair

The following repair recommendations apply to pitting found in both ballast and cargo tank bottom plating.

.1 Repair Recommendations

There are four main approaches used for dealing with severe bottom pitting.

1) **Partially Crop and Renew Affected Bottom Plating**. Partial cropping and renewal is primarily a matter of: proper welding technique, selection of an adequately sized plate insert and the appropriate nondestructive examination (NDE) of repaired areas.
2) **Clean Pitted Areas and Cover with Special Coating**. Cleaning out and covering with special coating without use of filler or weld build-up need only be limited by the maximum allowable depth of the pits (or allowable minimum remaining thickness of the bottom plating) permitted from a strength or pollution risk standpoint. The allowable loss of bottom cross-sectional area must also be considered.
3) **Clean Pitted Areas and Fill with Plastic Compound**. Use of plastic compound filler, such as epoxy, can be considered similar to 2) because no strength credit is given to the filler material.
4) **Fill by Welding**. Filling with welding warrants more serious consideration. Suggested welding practices for bottom plating are noted below.

.2 Pitting up to 15% of Bottom Plating Thickness (t)

No immediate remedial action is necessary. However, if the surrounding tank bottom is specially coated, corrosion progress in the pitted areas may be very rapid due to the area ratio effect of protected versus non-protected surfaces, therefore, as applicable, the coating is to be repaired.

.3 Scattered Pitting Up to 33% (1/3 t) of Bottom Plating Thickness

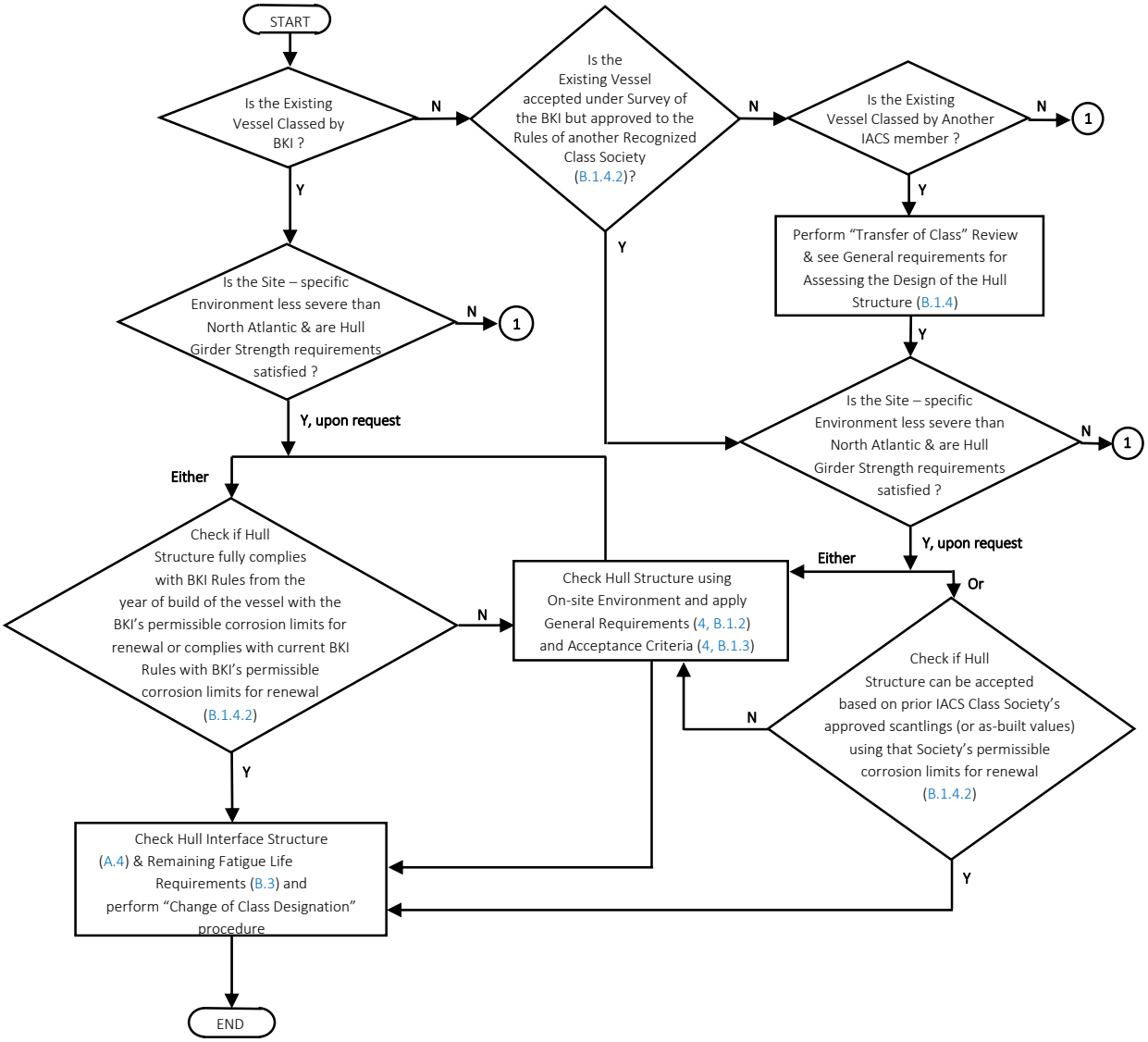
These pits may be filled with epoxy or other suitable protective compounds, provided the loss of area at any transverse section of the strake in question does not exceed 10%. Any areas that have been repaired by this method must be "mapped" and noted for close-up survey in the Survey and Inspection Plan required by Section 1, C.6.2.

.4 Pitting of Any Depth may be Welded, Provided:

Pitting may be welded, provided there is at least 6 mm remaining original plating thickness at the bottom of the cavity and there is at least 75 mm between adjacent pit welding areas. The maximum nominal diameter of any pit repaired by welding may not exceed 300 mm.

.5 Requirements for the Welding of Pits

1) **Pit Welding**. It is recommended that pit welding in bottom plating be built up at least 3 mm above the level of the surrounding plating and then ground flush. This is mandatory for: higher-strength steels grades D and E, for very small areas (less than 75 mm) in diameter and for such welding done afloat.
2) **Surface Preparation**. Pitted areas are to be thoroughly cleaned of rust, oil and cargo residues prior to welding.
3) **Filler Metal**. When welding, the filler metal grade appropriate to the pitted base metal and preheating, if applicable, are to be employed.
4) **Welding While Installation is Afloat**. For welding below the waterline of an installation afloat, properly dried low hydrogen electrodes are to be used. The pitted areas against water backing are to be preheated sufficiently to drive off any moisture that might be present. The preheat is to cover at least 102 mm of the material surrounding the welding or four times the material thickness, whichever is greater.
5) **Layer of Welding Metal**. A layer of weld metal is to be deposited along a spiral path to the bottom center of the pitted excavation. The slag is to be completely removed and the next successive layer is to be similarly deposited to build up the excavation at least 3 mm above the level of the surrounding plating.
6) **Extensive Pit Repairs**. For extensive pit repairs (i.e., greater than 20% intensity) of steel grades D, E and higher strength steel, welding against water backing is not recommended.
7) **Nondestructive Examination**. All welds to pitted areas in bottom plating are to be subject to nondestructive examination with particular attention to boundaries of the welded areas and at intersections of the welded areas and existing structural welding. Also, for welds of higher-strength steels, the NDE method is to be suitable for detecting sub-surface defects.
8) **Coating**. In order to reduce the likelihood of possible galvanic attack at the boundaries of built-up areas, coating over the area with a compound such as epoxy/glass flake should be considered. Also, where the pitting is in small areas of coating breakdown, it is essential to restore the coating intact in order to avoid the possible rapid corrosion of small bare areas in large protected areas (area ratio effect).
9) **Doublers**. Fitting of a doubler over pits is not considered a satisfactory repair.



LEGEND:

1 : Apply Section 2, C.1 & Section 4, A OR alternative criteria determined in consultation with BKI.
Y : Yes
N : No

Fig. 4.4 Procedure for Hull Structure Evaluation of Existing Vessel Converting to FPI

2. Steel Renewal Assessment

2.1 Introduction

Major aspects associated with a conversion include an existing vessel's original design and the basis of the design such as design criteria, vessel's classification, etc., its age, condition, maintenance and operational history as well as the design, survey and maintenance requirements for the converted structure.

The relative importance of these aspects are influenced by the structure's intended service, strength and fatigue requirements, and regulatory/certification requirements.

The minimum renewal values as described in 1.3 provide a baseline condition for the FPI installation as they are the minimum scantling requirements for classification. Also, based on the future anticipated corrosion expected to occur over the design life at the FPI site, the required minimum scantlings at the time of conversion can be determined.

2.2 Steel Renewal Assessment Procedure

The first step in determining the renewal scantlings for an FPI vessel conversion requires a reassessment of the vessel's scantlings based on the specific site of the installation. The reassessed scantlings determined in the Initial Scantling Calculation (ISCal) phase, which are used to establish the renewal scantlings, must also be confirmed by finite element analysis as part of the Global Strength Assessment (GSA).

2.2.1 Minimum Renewal Scantlings within 0,4 L

The Initial Scantling Calculation assesses the strength of the longitudinal scantlings for the FPI conversion. The strength evaluation is mainly applicable for the structure within the 0,4L midship region and consists of performing the following steps:

.1 Calculation of Environmental Severity Factor (ESFs) based on the environmental conditions as specified in Section 2, B.3.2.

.2 Determination of reassessed scantlings:

1) Assign initial input scantlings by reducing deck and bottom plating by 15%-20% of the as-built scantlings and using as-built scantlings for stiffeners.
2) Calculate the hull girder section modulus and individual stiffener section modulus.
3) Determine the hull girder and local strength requirements for the site specific offshore location.
4) Check if the input scantlings meet both hull girder and local strength requirements. If not, adjust input scantlings and go back to step 2).
5) As an option, the input scantlings can be further adjusted provided hull girder and local strength requirements are satisfied.
6) Determine the initial reassessed scantlings as the input scantlings.

.3 Establishing renewal scantlings:

1) Determine renewal scantlings of longitudinal structural members based on Rule permissible percentage wastage allowances in Table 4.7.
2) Check if renewal scantlings of longitudinal members (i.e. plating and longitudinals) satisfy local panel and stiffener buckling requirement. If not, adjust reassessed scantlings and go back to step .2.2).
3) Calculate substantial corrosion scantlings (scantlings corroded to 75% of allowable wastage).
4) Input anticipated corrosion wastage and then calculate yard renewal value.

.4 Verification of reassessed scantlings and renewal scantlings:

1) Check if reassessed scantlings meet hull girder bending strength requirement for inspection, repair, and transit condition.
2) Check if reassessed scantlings meet global hull girder and local scantling requirements.
3) Check if reassessed scantlings meet hull girder ultimate strength requirement as per C.3.2.3.
4) Check if reassessed scantlings meet hull girder shear strength requirement.
5) Check if reassessed scantlings meet the sloshing strength requirements for tank boundary members.

If any one of the above requirements of the ISCal phase is not met, adjust reassessed scantlings and go back to step .2.2).

.5 Output renewal table, where the following information are at least included:

1) Reassessed & renewal hull girder W for deck and bottom
2) Tabulate preliminary results of individual members as follows:

3) Member Identification, As-built Scantlings, Reassessed Scantlings (rounded to nearest 0,5 mm), Renewal Scantlings, Substantial Corrosion Scantlings, User-defined anticipated corrosion and Yard Required Scantlings.

4) Check reassessed scantlings by finite element analysis (GSA)

5) Determine final results of individual members as per 2)

The above procedure is an iterative procedure as it requires several strength and buckling requirements to be satisfied. The flow chart in Fig. 4.5 illustrates the iterative steps necessary to determine the reassessed and renewal scantlings within 0,4**L** amidships.

The procedure described above determines the reassessed and renewal scantlings within 0,4**L** amidships. The reassessed and renewal scantlings for the entire cargo block can also be determined using a similar procedure. To do so requires that the reassessed scantlings between 0,4**L** amidships and the ends of the cargo block be calculated using the same procedure as described above, except that the bending moments and local loads for scantling requirements at specific locations between 0,4**L** amidships and cargo block ends are applied in the procedure rather than the bending moments and local loads for scantling requirements required amidships. The reassessed scantlings in the cargo block region are to be verified by finite element analysis (GSA).

2.2.2 Minimal Renewal Scantlings at 0,125 L from the Ends

If 0,125 **L** from the ends is within the cargo block region, the reassessed and renewal scantlings at 0,125**L** can be determined either by taking the as-built scantlings at 0,125**L** from the ends as the reassessed scantlings at that location, or by applying the procedure described in 2.2.1. If however 0,125**L** is outside the cargo block region, then the as-built scantlings at 0,125**L** from the ends will be the reassessed scantlings at that location. The renewal scantlings will then be determined from the reassessed scantlings

If there is an increase or decrease in vessel length due to conversion the scantlings 0,125**L** from the ends should be assessed for the new length. Where an increase in length occurs it may be necessary to either modify the structure or consider early renewal for the scantlings at the ends.

2.2.3 Minimum Renewal Scantlings between 0,4L Amidships and 0,125L from the Ends

If the reassessed and renewal scantlings of the cargo block have been determined by the procedure described in 2.2.1, the reassessed and renewal scantlings have already been determined. If not, the continuous longitudinal members of the hull girder are to be maintained throughout 0,4**L** amidships, and then may be gradually tapered beyond 0,4**L** provided local strength and hull girder requirements are satisfied.

Where the scantlings are based on the still-water bending moment envelope curves, items included in the hull girder section modulus amidships are to be extended as necessary to meet the hull girder section modulus required at the location being considered.

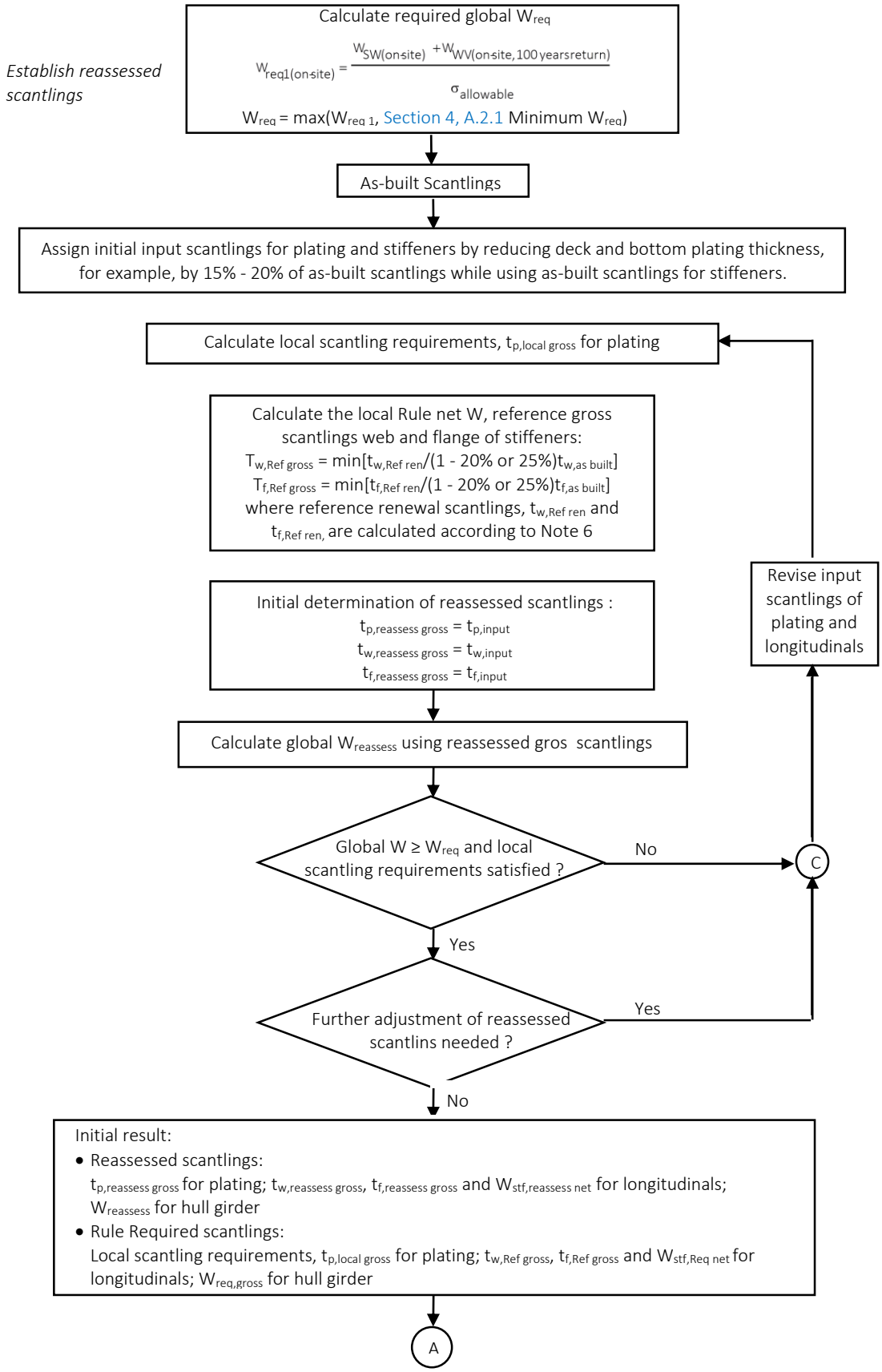


Fig. 4.5 Determination of Reassessed and Renewal Scantlings for Ship-Type FPI Conversions within 0,4 L Amidships - Flow Chart

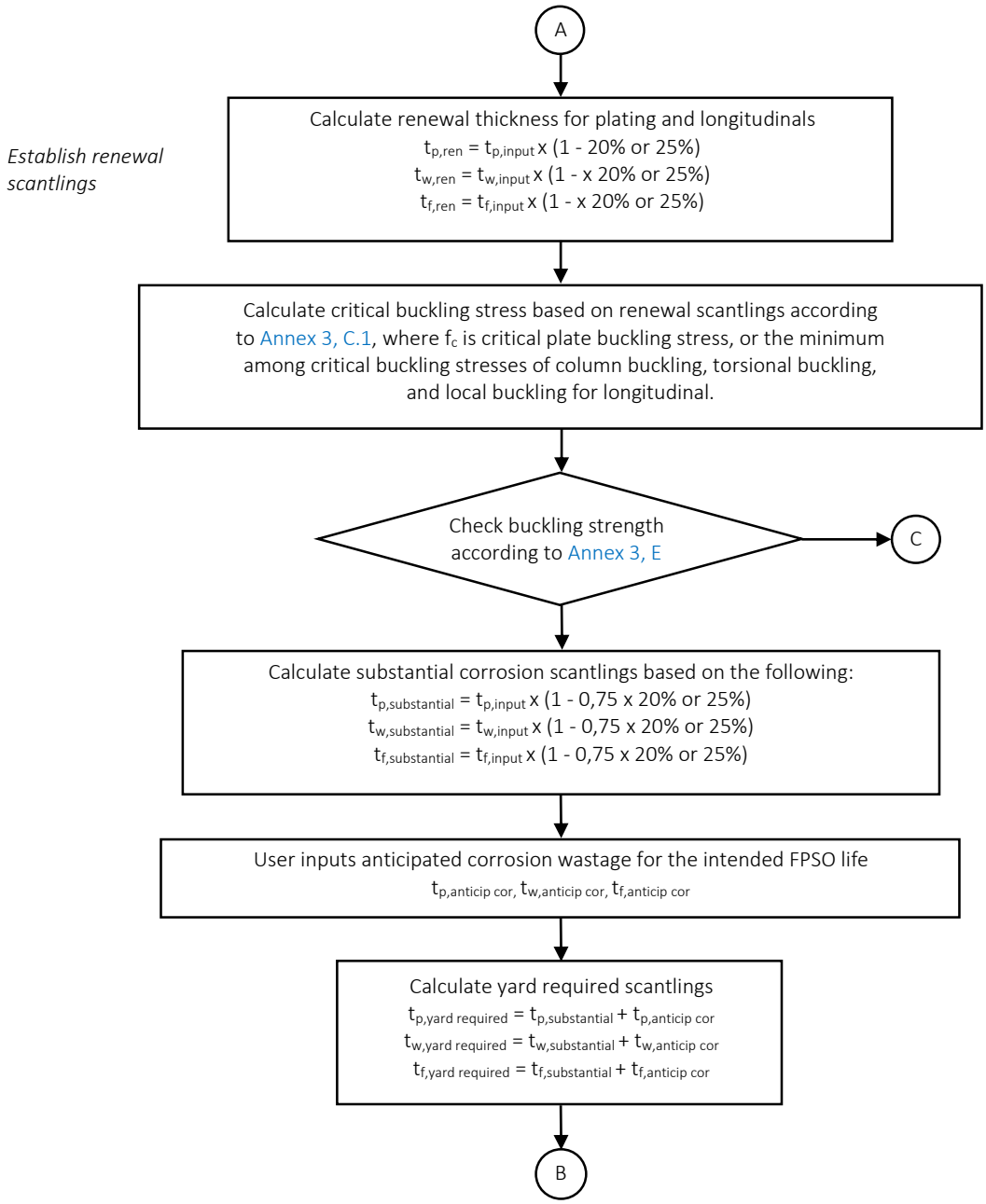
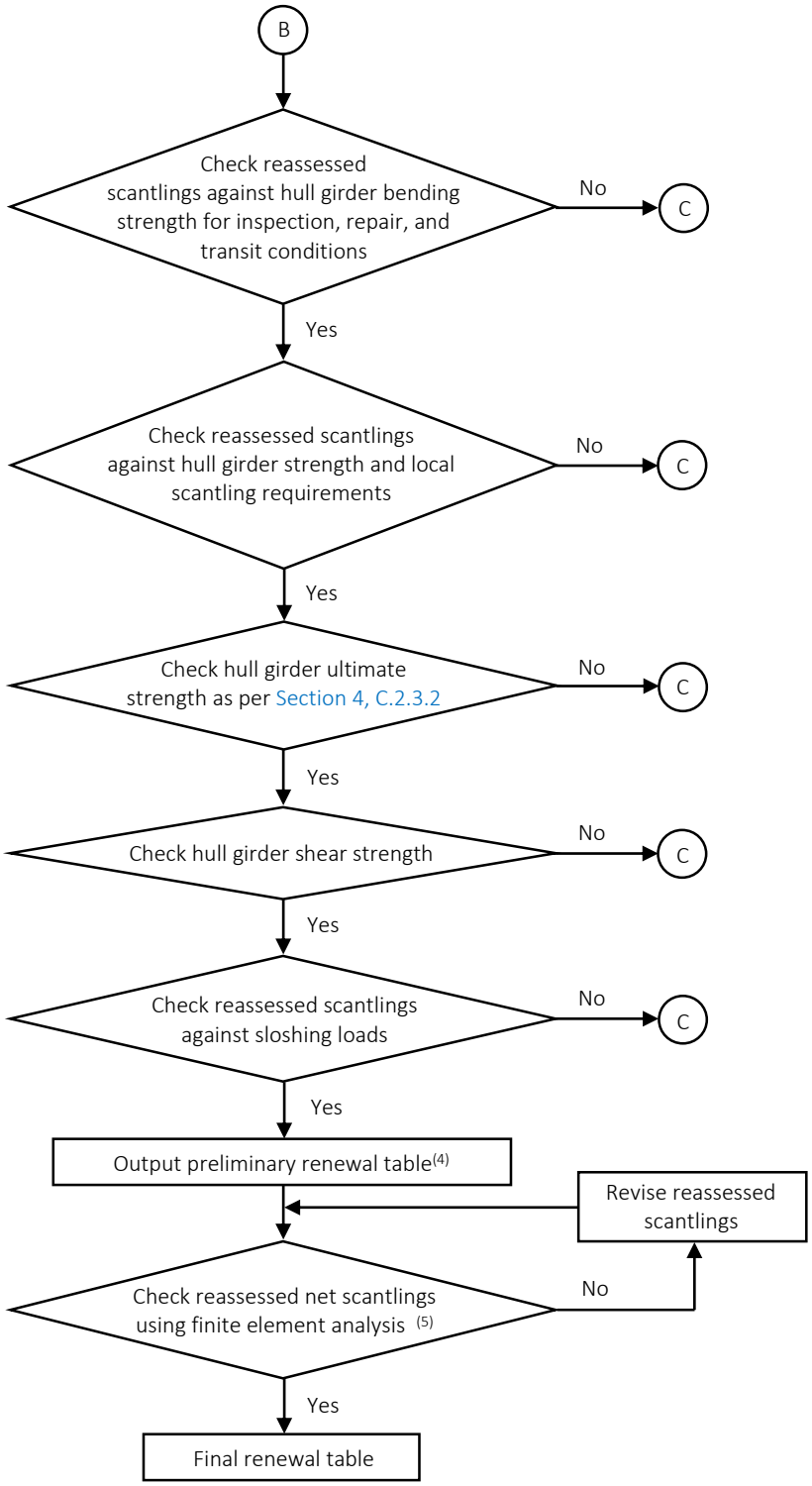


Fig. 4.5 Determination of Reassessed and Renewal Scantlings for Ship-Type FPI Conversions within 0,4 L Amidships - Flow Chart (*continued*)



Notes:

1. *See Table 4.7 for Individual Wastage Allowances*
2. *If the stiffener is bulb type, the reassessed scantling for flange of stiffeners is taken as the as-built scantling.*
3. *See Table 4.7*
4. *Renewal table should include at least reassessed and renewal hull girder W for deck and bottom as well as the following individual member information: Member Identification, As-built Scantlings, Reassessed Scantlings (rounded to the nearest 0,5 mm), Renewal Scantling Substantial Scantlings, User-defined Anticipated Corrosion, Yard Required Scantlings.*

Fig. 4.5 Determination of Reassessed and Renewal Scantlings for Ship-Type FPI Conversions within 0,4 L Amidships - Flow Chart (*continued*)

Notes: (continued)

5. *Reassessed net scantlings used in finite element analysis are the net scantlings of the minimum of the reassessed (round to the nearest 0,5 mm) and as-built scantlings.*
6. *Buckling Check of Longitudinal Stiffeners*

Stiffener Web Plate	*Material*	*Steel*			
		Normal	*HT32*	*HT36*	*HT40*
Angle and T Profile	$d_w/t_{w,Ref\,ren} \leq$	*70*	*65*	*60*	*55*
Bulb Profiles	$d_w/t_{w,Ref\,ren} \leq$	*36*	*34*	*31*	*28*
Flat bars	$d_w/t_{w,Ref\,ren} \leq$	*20*	*19*	*18*	*17*
Stiffener Flanges	$b_{flg\text{-}out}/t_{f,Ref\,ren} \leq$	*15*	*14*	*13*	*12*
where d_w = *depth of web plate [mm]* $b_{flg\text{-}out}$ = *breadth of larger flange outstands [mm]*					

Fig. 4.5 Determination of Reassessed and Renewal Scantlings for Ship-Type FPI Conversions within 0.4 L Amidships - Flow Chart (*continued*)

Table 4.7 Individual wastage allowances, vessels converted to FPI, 90 meters and over [1, 2, 3]

Ordinary and High Strength Steel	Converted 2009 or Later		Converted Before 2009	
	Double Bottom	Single Bottom with Single Side or Double Side	Double Bottom	Single Bottom with Single Side or Double Side
Strength Deck Plating	20%	20%	20%	20%
Continuous Long'l Hatch Coamings & Above Deck Box-Girders	20%	-----	20%	-----
Deck Plates within Line of Hatches and at Ends.	30%	30%	30%	30%
Forecastle, Poop and Bridge Deck Plates; Superstructure End Bulkheads	30%	30%	30%	30%
Tween Deck Plates	-----	-----	-----	-----
Sheer Strake Plates	20%	20%	20%	20%
Side Shell Plates	20%	25%	25%	25%
Bilge Strake Plates	20%	20%	25%	20%
Bottom Plates	20%	20%	25%	20%
Keel Plates[4]				
Outermost Strake of Inner Bottom	20%	-----	20%	-----
Other Plates of Inner Bottom	20%	-----	25%	-----
Top Strake of Longitudinal Bulkheads and Top Strake of Topside Tank Sloping Plating	20%	20%	20%	20%
Bottom Strake of Longitudinal Bulkheads	20%	20%	25%	20%
Other Plates of Longitudinal Bulkheads, Topside Tank Sloping Plating, Hopper Tank Sloping Plating and Transverse Bulkheads	20%	25%, 20% for transverse bulkheads only	25%	25%
Internals including Longitudinals, Girders, Transverses, Struts, Bulkhead Webs and Stringers, Brackets and Hatch Side Girders	20%	25%	25%	25%
Plates in way of Top of Tanks	25%	30%	30%	30%
Underdeck Box Girders (Long'l or Transverse)	20%	-----	20%	-----
Hatch Covers, Hatch coamings and brackets	30%	30%	30%	30%

Notes:

1 *The individual wastage allowances are acceptable, provided the W is not less than 90% of the greater W required: a) at the time of new construction or conversion or b) by A.2.1.*

2 *For tankers 130 m in length and above and over 10 years of age, sectional area calculations are to be carried out by BKI Techical Office.*

3 *For vessels built to other society rules, the Technical Office carrying out the initial plan review is to be contacted for wastage allowances.*

4 *Keel plates are to be renewed when they reach the minimum allowed thickness for adjacent bottom plating.*

3. Fatigue Consideration (Remaining Fatigue Life)

3.1 Introduction

An existing vessel structure will have accumulated some fatigue damage due to the prior service as well as steel wastage due to corrosion and wear. In order to account for the fatigue damage that has occurred and to determine the remaining fatigue life, a fatigue assessment of structural connection details shall be performed by the following steps :

- Determine the fatigue damage that has occurred due to the prior service as a trading vessel, and at a previous installation site, if applicable.
- Determine the fatigue damage that will occur during transit to the installation site.
- Calculate the total fatigue damage exerted by the connection details during the above service.
- Calculate the remaining fatigue life in the connection details of the longitudinal stiffeners for the site specific operation of the FPI.
- Develop renewal or reinforcement requirements for any stiffener connection that does not show adequate remaining fatigue life at the installation site.

3.2 Remaining Fatigue Life

Based on the application of the Palmgren-Miner cumulative damage rule when the cumulative fatigue damage ratio is equal to 1,0, the connection detail is assumed to fail. Considering fatigue damage ratios for the prior service to conversion and post conversion phases, this can be expressed as :

$$\frac{S_{priorConv}}{L_{P,PriorConv}} + L_{R,PostConv} = 1,$$

therefore

$$L_{R,PostConv} = L_{P,PostConv} \times \left(1 - \frac{S_{PriorConv}}{L_{P,PriorConv}}\right)$$

where

$L_{R,PostConv}$ = remaining fatigue life for on-site operation, post conversion

$L_{P,PostConv}$ = predicted (design) fatigue life for on-site operation, post conversion

$S_{PriorConv}$ = service years prior to conversion

$L_{P,PriorConv}$ = predicted (design) fatigue life prior to conversion

3.3 Remaining Fatigue Life for Longitudinal Stiffener Connections

For a vessel converted to an FPI, where historical trade routes and intended site have been specified, fatigue lives of both prior and post conversion phases can be calculated using Initial Scantling Calculation (ISCal) and Environmental Assessment software. The Initial Scantling Calculation Software is used to evaluate the fatigue response of longitudinal stiffener connections. The recognized software should calculate the environmental severity factors for fatigue (α factors) for the historical routes and intended site. When the α factor is greater than 1,0, it describes an increase in fatigue life due to reduced environmental conditions when compared to the North Atlantic environment (where α equals to 1,0). Once these factors have been established, the above equation can be modified to take into account environments other than the North Atlantic environment (unrestricted service) as follows :

$$L_{R,PostConv} = \frac{20}{DM_{comb}} \times \left[1 - \sum \frac{(S_{route\text{-}i}/\alpha_{Route\text{-}i})}{L_{P,Tanker}} - \sum \frac{(S_{His\ Site\text{-}i}/\alpha_{HisSite})}{L_{P,Site}} - \frac{(S_{Transit}/\alpha_{Transit})}{L_{P,Transit}}\right]$$

where

$L_{R,PostConv}$ = site specific post conversion remaining fatigue life of the unaltered connection

$S_{Route\text{-}i}$ = number of service years for the i-th historical route

$S_{His\ Site\text{-}i}$ = number of service years for the i-th historical site

$S_{Transit}$ = number of service years for the transit phase

$L_{P,Tanker}$ = predicted fatigue life for the tanker phase based on North Atlantic environment

$L_{P,Site}$ = predicted fatigue life for the historical site based on North Atlantic environment

$L_{P,Transit}$ = predicted fatigue life for the transit phase based on North Atlantic environment

$\alpha_{Route\text{-}i}$ = environmental severity factor for the i-th historical route, see Annex 4, C

$\alpha_{His\ Site\ i}$ = environmental severity factor for the i-th historical site, see Annex 4, C

$\alpha_{Transit}$ = environmental severity factor for the transit condition, see Annex 4, C

D_{MComb} = combined fatigue damage post conversion, see Annex 5, K

The expression $\Sigma(S_{Route\text{-}i}/\alpha_{Route\text{-}i})$ and $\Sigma(S_{His\ Site\text{-}i}/\alpha_{His\ Site\ i})$ are the weighted average for the various routes and historical sites for each longitudinal stiffener connection calculated by the recognized software.

The calculation of the remaining fatigue life is used only for the connection details that existed prior to conversion and were not modified in any way during the conversion. For connection details on new longitudinal members that are added or details that have been modified during the conversion, the predicted or design fatigue life calculated for the post conversion site specific environment will be applicable.

3.4 Remaining Fatigue Life for Connections of Transverses and Girders

Horizontal stringer or girder end connections on transverse bulkheads, bracket toes on side, bottom, deck and longitudinal bulkhead should be screened for fatigue strength using a finite element based fatigue assessment. For screening purposes the three tank length finite element model employed in the Global Strength Assessment (GSA) can be used to estimate the nominal stress in the connections. By applying the same nominal stress approach used for the fatigue evaluation of longitudinal stiffener connections, fatigue lives are estimated for transverse member connections. Where details are deemed critical as a result of this screening process, a more refined fatigue assessment based on the hot spot stress is performed using a fine mesh finite element analysis of the connection detail. The method used to account for prior service and remaining fatigue life is the same as described for longitudinal stiffener connections in 3.2.

The remaining fatigue life is calculated as :

$$L_{R,PostConv} = \frac{20}{DM_{comb}} \times \left[1 - \sum \left(\frac{S_{route\text{-}i}}{20} \times DM_{Route\text{-}I}\right) - \sum \left(\frac{S_{His\ Site\text{-}I}}{20} \times DM_{HisSite}\right) - \left(\frac{S_{Transit}}{20} \times DM_{Transit}\right)\right]$$

The expression $\Sigma((S_{Route\text{-}i}/20) \times DM_{Route\text{-}i})$ and $\Sigma((S_{His\ Site\text{-}i}/20) \times DM_{His\ Site\text{-}i})$ are the weighted average for the various routes and historical sites calculated based on weighted beta values from the Environmental Assessment software.

C. Structural Design Requirements

1. General

1.1 Design Considerations and General Requirements

1.1.1 General

The strength requirements specified in this Sub-Section are based on a "net" ship approach. In determining the required scantlings and performing structural analyses and strength assessments, the nominal design corrosion values given in Table 4.8 are to be deducted.

1.1.2 Initial Scantling Requirements

The initial requirements for plating, the section modulus of longitudinals/stiffeners, and the scantlings of the main supporting structures are to be determined in accordance with 3 for the "net" ship. These "net" ship values are to be used for further assessment as required in the following paragraph. The relevant nominal design corrosion values are then added to obtain the full scantling requirements.

1.1.3 Strength Assessment - Failure Modes

A global assessment of the structures, determined on the basis of the initial strength criteria in 3 is to be carried out against the following three failure modes.

.1 Material Yielding

The calculated stress intensities are not to be greater than the yielding limit state given in 4.2 for all load cases specified in 2.5.

.2 Buckling and Ultimate Strength

For each individual member, plate or stiffened panel, the buckling and ultimate strength is to be in compliance with the requirements specified in 4.3. In addition, the hull girder ultimate strength is to be in accordance with 3.2.3 and Annex 6.

.3 Fatigue

The fatigue strength of structural details and welded joints in highly stressed regions is to be analyzed in accordance with 4.5 and Annex 5.

1.1.4 Net Scantling and Nominal Design Corrosion Values (NDCV)

.1 General

The "net" thickness or scantlings correspond to the minimum strength in this section regardless of the design service life of the installation. In addition to the coating protection specified in the Rules for all ballast tanks, minimum corrosion values for plating and structural members as given in Table 4.8 and Fig. 4.6 are to be applied added to the net scantlings. These minimum corrosion values are intended for a design service life of 20 years. Where the design life is greater than 20 years, the minimum corrosion values of the hull structure are to be increased in accordance with 1.1.4.2. These minimum values are being introduced solely for the purpose of scantling requirements and strength criteria as indicated in 1.1.1, and are not to be interpreted as renewal standards.

In view of the anticipated higher corrosion rates for structural members in some regions, such as highly stressed areas, additional design margins should be considered for the primary and critical structural members to minimize repairs and maintenance costs. The beneficial effects of these design margins on

reduction of stresses and increase of the effective hull girder section modulus can be appropriately accounted for in the design evaluation.

.2 Nominal Design Corrosion Values for Design Life Greater than 20 Years

When the structural design life is greater than 20 years, the nominal design corrosion values (NDCV) of the hull structure are to be increased from those in Table 4.8 as follows:

1) For plating and structural members with 2,0 mm NDCV for 20-years design life, additional 0,1 mm per year for design life greater than 20-years. For example, 2,5 mm NDCV for 25-year design life.
2) For plating and structural members with 1,5 mm NDCV for 20-years design life, additional 0,075 mm per year for design life greater than 20-years. For example, 1,875 mm NDCV for 25-year design life.
3) For plating and structural members with 1,0 mm NDCV for 20-years design life, additional 0,05 mm per year for design life greater than 20-years. For example, 1,25 mm NDCV for 25-year design life.
4) For void spaces, no change in NDCV as it is considered independent of design life.

The NDCV values are to be considered minimum nominal design corrosion values. Actual corrosion could be more or less than the NDCV values. The designer or owner may specify additional design corrosion margins based on maintenance plans.

Note:

Local allowable wastage allowance of plates and stiffeners for floating installations designed for uninterrupted operation on-site without any dry docking and having a design life longer than 20 years is described in Section 3, B.6.2.1.10.

The rounding of the calculated thickness is to be the nearest half millimeter.

For example:

- For $10,75 \leq t_{calc} < 11,25$ mm, the required thickness is 11 mm
- For $11,25 \leq t_{calc} < 11,75$ mm, the required thickness is 11,5 mm

When the difference between the required net thickness and the offered net thickness is less than 0,25 mm, the offered net thickness is acceptable if the rounded required gross thickness is smaller or equal to the offered gross thickness.

1.1.5 Application

.1 Installation Size and Proportion

The requirements contained in this Section are applicable to double hull ship-type installations intended for unrestricted service, having lengths of 150 meters or more, and having parameters within the range as follows:

1) Proportions: $L/B < 5$, $B/H > 2,5$
2) Length: $L > 500$ m
3) Block Coefficient: $C_B < 0,6$
4) Large deck opening
5) Vessels with large flare
6) Carriage of heated cargoes
7) Unusual type or design

.2 Installation Types

The equations and formulae for determining design load and strength requirements, as specified in 2 and 3, are applicable to double hull ship-type installations. For single hull ship-type installations, the parameters used in the equations are to be adjusted according to the structural configurations and loading patterns outlined in 6. The strength assessment procedures and the failure criteria, as specified in 4, are applicable to all ship-type installations.

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

A Double side, single bottom ship-type installation is a monohull having full depth wing water ballast tanks or other non-cargo spaces and single bottom structure.

A Single hull ship-type installation is a monohull that does not have double side and double bottom spaces fitting the above definitions of Double hull ship-type installation.

.3 Direct Calculations

Direct calculations with respect to the determination of design loads and the establishment of alternative strength criteria based on first principles will be accepted for consideration, provided that all the supporting data, analysis procedures and calculated results are fully documented and submitted for review. In this regard, due consideration is to be given to the environmental conditions, probability of occurrence, uncertainties in load and response predictions and reliability of the structure in service.

Table 4.8 - Nominal Design Corrosion Values (NDCV)

Structural Element/Location		Nominal Design Corrosion Values (mm)		
		Cargo Tank	Ballast Tank Effectively Coated	Void
Deck Plating		1,0	2,0	1,0
Side Shell Plating		N.A.	1,5	1,0
Bottom Plating		N.A.	1,0	1,0
Inner Bottom Plating		1,5		
Longitudinal Bulkhead Plating	Between cargo tanks	1,0	N.A	1,0
	Other Plating	1,5		1,0
Transverse Bulkhead Plating	Between cargo tanks	1,0	N.A	1,0
	Other Plating	1,5		1,0
Transverse & Longitudinal Deck Supporting Members		1,5	2,0	1,0
Double Bottom Tanks Internals (Floors and Girders)		N.A	2,0	1,0[5]
Double Bottom Tanks Internals (Stiffeners)		N.A	2,0	1,0
Vertical Stiffeners and Supporting Members Elsewhere		1,0	1,0	1,0
Non-vertical Longitudinals/Stiffeners and Supporting Members Elsewhere		1,5	2,0	1,0

Notes:

1. *It is recognized that corrosion depends on many factors including coating properties, cargo composition, inert gas properties and temperature of carriage, and that actual wastage rates observed may be appreciably different from those given here.*
2. *Pitting and grooving are regarded as localized phenomena and are not covered in this table.*
3. *For nominal design corrosion values for single hull ship-type installations, see 6.*
4. *Side stringer plating in Void Space: Watertight adjacent to ballast tank 1,5 mm, Non-Tight: 1,0 mm.*
5. *Watertight bottom girder adjacent to ballast tank: 1,5 mm.*

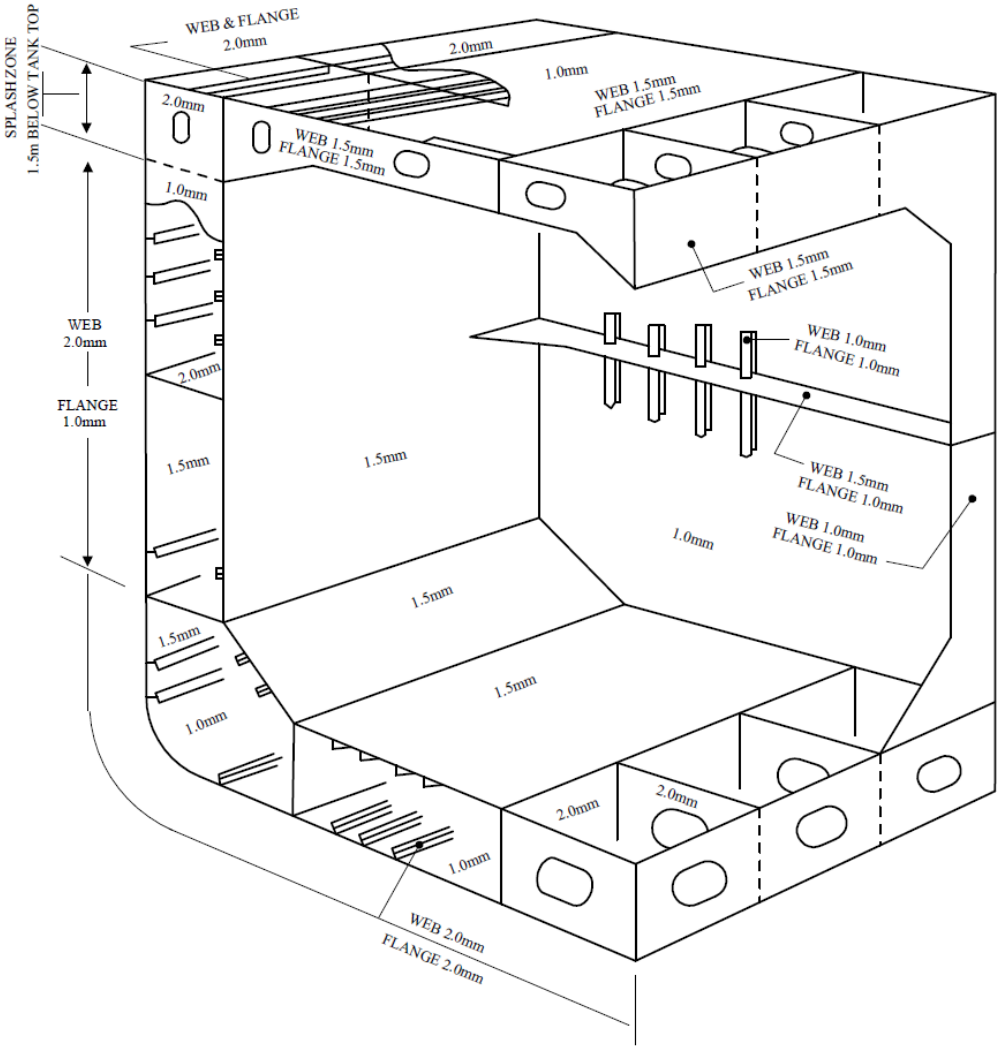


Fig. 4.6 Nominal Design Corrosion Values (NDCV)

1.1.6 Internal Members

.1 Section Properties of Structural Members

The geometric properties of structural members may be calculated directly from the dimensions of the section and the associated effective plating (see Fig. 4.35, as applicable). For structural member with angle θ (see Fig. 4.7) between web and associated plating not less than 75 degrees, the section modulus, web sectional area and moment of inertia of the "standard" (θ = 90 degrees) section may be used without modification. Where the angle θ is less than 75 degrees, the sectional properties are to be directly calculated about an axis parallel to the associated plating (see Fig. 4.7).

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

$$W = \alpha_\theta \cdot W_{90}$$

where

α_θ = $1,45 - 40,5/\theta$

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

The effective web section area may be obtained by the following equation:

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

where

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

The effective moment of inertia may be obtained by the following equation:

$$I = \alpha_\theta \cdot I_{90}$$

where

α_θ = 1,45 – 40,5/θ

I_{90} = effective moment of inertia at θ = 90 degrees

In the above equation, θ is in degrees.

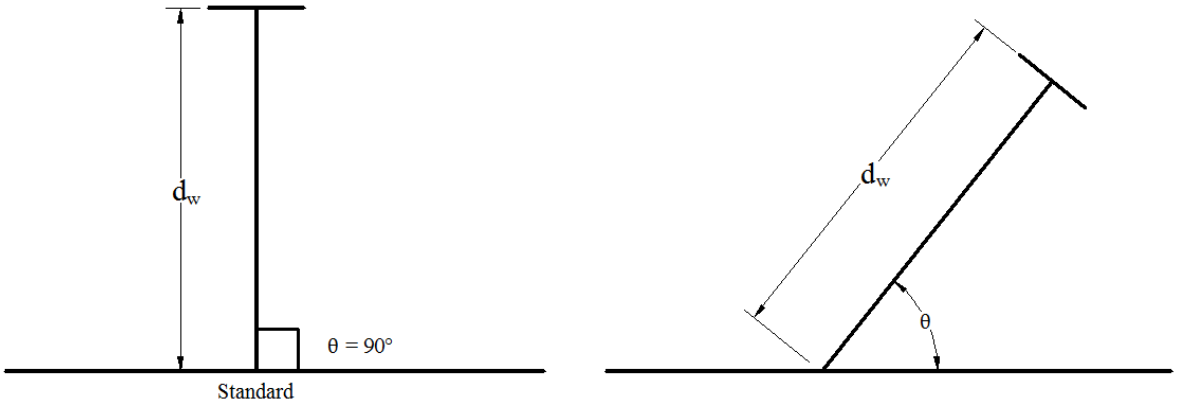


Fig. 4.7

.2 Detailed Design

The detailed design of internals is to follow the guidance given in Rules for Hull (Pt.1, Vol.II), Sec.3 and sub-section 3.1.3, see also Annex 5.

1.1.7 Breaks

Special care is to be taken to provide against local stresses at the ends of the cargo oil spaces, superstructures, etc., and throughout the structure in general. The main longitudinal bulkheads are to be suitably tapered at their ends, and effective longitudinal bulkheads in the poop are to be located such as to provide effective continuity between the structure in way of and beyond the main cargo spaces. Where the break of a superstructure lies within the midship 0,5**L**, the required shell and deck scantlings for the midship 0,4**L** may be required to be extended to introduce a gradual taper of the structure, and the deck stringer plate and sheer strake are to be increased. See 3.5.1 and 3.5.2. Where the breaks of the forecastle or poop are appreciably beyond the midship 0,5**L**, the requirements for the deck stringer plate and sheer strake, as specified in 3.5.1 and 3.5.2, may be modified.

1.1.8 Variations

Ship-type installations of a special type or design, differing from those described in this Guidelines, will be specially considered on the basis of equivalent strength.

1.1.9 Loading Guidance

Loading guidance is to be as required by Rules for Hull (Pt.1, Vol.II), Sec.5, A.4 and E, except that 3.3 will apply for allowable shear stresses.

1.1.10 Pressure-Vacuum Valve Setting

Where pressure-vacuum valves of cargo oil tanks are set at a pressure in excess of the pressure appropriate to the length of the installation [see table below], the tank scantlings will be specially considered.

	Vessel Size	Pressure/Vacuum setting
a.)	103 m in length or more	P ≤ 0,21 bar V ≥ –0,07 bar
b.)	61 m in length or less	P ≤ 0,12 bar V ≥ –0,07 bar
c.)	Vessels of intermediate lengths	Interpolate between (a) and (b)
d.)	Vessels with specially designed integral tanks	P ≤ 0,69 bar
P = Pressure above atmospheric; V = Pressure below atmospheric *In addition, calculations are to be submitted to show that the cargo tanks will not be subjected to a pressure or vacuum in excess of their design pressure.*		

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

1.1.11 Protection of Structure

For the protection of structure, Rules for Hull (Pt.1, Vol.II), Sec.38.

1.1.12 Aluminium Paint

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

1.2 Special Requirements for Deep Loading

1.2.1 General

Where an installation is intended to operate at the minimum freeboard allowed by the International Convention on Load Lines, 1966 for Type-A vessels, the conditions in 1.2.2 through 1.2.6 are to be complied with.

1.2.2 Machinery Casings

Machinery casings are normally to be protected by an enclosed poop or bridge, or by a deckhouse of equivalent strength. The height of such structure is to be not less than 2,3 m. The bulkheads at the forward ends of these structures are to have scantlings not less than required for bridge-front bulkheads (See Rules for Hull (Pt.1, Vol.II), Sec.16). Machinery casings may be exposed, provided that they are specially stiffened and there are no openings giving direct access from the freeboard deck to the machinery space. A door complying with the requirements of Rules for Hull (Pt.1, Vol.II), Sec.21, S may, however, be permitted in the exposed machinery casing, provided that it leads to a space or passageway which is as strongly constructed as the casing and is separated from the engine room by a second door complying with Rules

for Hull (Pt.1, Vol.II), Sec.21, S. The sill of the exterior door is not to be less than 600 mm, and the sill of the second door is not to be less than 230 mm.

1.2.3 Access

Satisfactory arrangements are to be provided to safeguard the crew in reaching all areas used in the necessary work of the installation. See Rules for Hull (Pt.1, Vol.II), Sec.21, O - R.

1.2.4 Hatchways

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

1.2.5 Freeing Arrangements

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

1.2.6 Flooding

Attention is called to the requirement of the International Convention on Load Lines, 1966, that ship-type installations over 150 m in freeboard length (see Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.2), to which freeboards less than those based solely on Table B are assigned, must be able to withstand the flooding of certain compartments.

1.2.7 Ventilators

Ventilators to spaces below the freeboard deck are to be specially stiffened or protected by superstructures or other efficient means. See also Rules for Hull (Pt.1, Vol.II), Sec.21, F.5 and G.

1.3 Arrangement

1.3.1 General

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

1.3.2 Subdivision

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

1.3.3 Cofferdams

Cofferdams, thoroughly oil tight and vented, and having widths as required for ready access, are to be provided in order to separate all cargo tanks from galleys and living quarters, general cargo spaces which

are below the uppermost continuous deck, boiler rooms and spaces containing propulsion machinery or other machinery where sources of ignition are normally present. Pump rooms, compartments arranged solely for ballast and fuel oil tanks may be considered as cofferdams for the purpose of this requirement.

1.3.4 Gastight Bulkheads

Gastight bulkheads are to be provided in order to isolate all cargo pumps and piping from spaces containing stoves, boilers, propelling machinery, electric apparatus or machinery where sources of ignition are normally present. These bulkheads are to comply with the requirements of Rules for Hull (Pt.1, Vol.II), Sec.11 and 21.

1.3.5 Cathodic Protection

.1 Anode Installation Plan

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

.2 Magnesium and Magnesium Alloy Anodes

Magnesium and magnesium alloy anodes are not to be used.

.3 Aluminium Anodes

Aluminium anodes may be used in the cargo tanks of ship-type installations, but only in locations where the potential energy does not exceed 275 N-m. The height of the anode is to be measured from the bottom of the tank to the center of the anode, and the weight is to be taken as the weight of the anode as fitted, including the fitting devices and inserts.

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

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

.4 Anode Attachment

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

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

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

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

1.3.6 Ports (Opening) in Pump Room Bulkheads

Where fixed ports are fitted in the bulkheads between a pump room and the machinery or other non-hazardous space, they are to maintain the gastight and watertight integrity of the bulkhead. The ports are to be effectively protected against the possibility of mechanical damage and are to be fire resistant. Hinged

port covers of steel, having non-corrosive hinge pins and secured from the non-hazardous space side, are to be provided. The covers are to provide strength and integrity equivalent to the unpierced bulkhead. Except where it may interfere with the function of the ports, the covers are to be secured in the closed position. The use of material other than steel for the covers will be subject to special consideration. Lighting fixtures providing strength and integrity equivalent to that of the port covers will be accepted as an alternative.

1.3.7 Location of Cargo Oil Tank Openings

Cargo oil tank openings, including those for tank cleaning, which are not intended to be secured gastight at all times during the normal operation of the installation, are not to be located in enclosed spaces. For the purpose of this requirement, spaces open on one side only are to be considered enclosed. See also 1.3.12.

1.3.8 Structural Fire Protection

The applicable requirements of Rules for Hull (Pt.1, Vol.II), Sec.22 are to be complied with.

1.3.9 Allocation of Spaces

.1 Tanks Forward of the Collision Bulkhead

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

.2 Double Bottom Spaces and Wing Tank Spaces

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

1.3.10 Access to Upper Parts of Ballast Tanks on Double Hull Ship-type Installations

Where the structural configuration within ballast tanks is such that it will prevent access to upper parts of the tanks for required close-up examination [see Rules for Classification and Surveys (Pt.1, Vol.I), Sec.4.I.B and C] by conventional means, such as a raft on partly filled tank, permanent means of safe access is to be provided. Details of the access are to be submitted for review.

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

1.3.11 Access to all spaces in the cargo area

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

For access through horizontal openings, hatches or manholes, the access is to be of a size such as to allow a person wearing a self-contained, air-breathing apparatus and protective equipment (see Rules for Hull (Pt.1, Vol.II), Sec.21, O) to ascend or descend any ladder without obstruction and also to provide a clear opening to facilitate the hoisting of an injured person from the bottom of the space. In general, the minimum clear opening is not to be less than 600 mm by 600 mm.

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

1.3.12 Duct Keels or Pipe Tunnels in Double Bottom

Duct keels or pipe tunnels are not to pass into machinery spaces. Provision is to be made for at least two exits to the open deck, arranged at a maximum distance from each other. One of these exits may lead to the cargo pump room, provided that it is watertight and fitted with a watertight door complying with the requirements of Rules for Hull (Pt.1, Vol.II), Sec.11, A and in addition complying with the following :

1) In addition to bridge operation, the watertight door is to be capable of being closed from outside the main pump room entrance; and
2) A notice is to be affixed at each operating position to the effect that the watertight door is to be kept closed during normal operations of the installation, except when access to the pipe tunnel is required.

For the requirements of ventilation and gas detection in duct keels or pipe tunnels, see Rules for Machinery Installations (Pt.1, Vol.III), Sec.15.

1.3.13 Ventilation

Holes are to be cut in every part of the structure where otherwise there might be a chance of gases being "pocketed". Special attention is to be paid to the effective ventilation of pump rooms and other working spaces adjacent to oil tanks. In general, floor plating is to be of an open type not to restrict the flow of air, see Rules for Machinery Installations (Pt.1, Vol.III), Sec.15. Efficient means are to be provided for clearing the oil spaces of dangerous vapors by means of artificial ventilation or steam. For cargo tank venting, see Rules for Machinery Installations (Pt.1, Vol.III), Sec.15.

1.3.14 Pumping Arrangements

See applicable requirements in Rules for Machinery Installations (Pt.1, Vol.III), Sec.15.

1.3.15 Electrical Equipment

See Rules for Electrical Installations (Pt.1, Vol.IV), Sec.15.

1.3.16 Testing

Requirements for testing are contained in Rules for Machinery Installations (Pt.1, Vol.III), Sec.15 and Rules for Electrical Installations (Pt.1, Vol.IV), Sec.15.

1.3.17 Machinery Spaces

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

1.3.18 Produced Water Tanks

Where a tank is designated for produced water, such tanks are to be identified in the General Arrangement or Capacity plan. Where the specific gravity of the liquid exceeds 1,025, the design head, h, in this section is to be increased by the ratio of the specific gravity of the liquid to be carried, to 1,025.

Coating protection and Nominal Design Corrosion Values (NDCV) for produced water tank are to be not less than that required for ballast water tank.

2. Loads

2.1 General

2.1.1 The Concept and Application of Environmental Severity Factors

This Sub-section referred to in A. provides an explanation of the ship-type hull structural design and analysis criteria. Previously, it was customary to specify that ship-type offshore installations were to meet structural design and analysis criteria for unrestricted full ocean service conditions, i.e., a trading oil tanker. In reality, many such installations were sited at locations with dynamic components of their loading that are less than those arising from unrestricted service conditions.

At the same time, the approach to major ship design that has been developed and advocated by BKI in the last decade has relied on a two phase method. In the first phase, initial design scantlings of the installation are selected, considering nominal, maximum expected loadings that a component is likely to experience in its lifetime for the full ocean service. This step is called the Initial Scantling Calculation (ISCal) and is governed by the criteria contained in 2. A second step requires structural analyses of major portions of the hull structure to verify the adequacy of the structural system's performance, including strength checks for failure modes associated with yielding, buckling and ultimate strength. This step is referred to as the Global Strength Assessment (GSA) and is governed by the criteria specified in 4.

To adjust the loadings and load effects produced by the site-specific long-term environment at the installation site (compared to the full ocean service), a series of "Environmental Severity Factors" (ESFs) have been derived. There are two types of ESFs, which are referred to as "Alpha" type (α) and "Beta" type (β). The α factors are used to adjust fatigue strength performance expectations between the full ocean service (Rule basis) and the long-term site-specific environment. The β factors are used primarily to adjust the dynamic component of loads that are used to establish: hull girder strength (i.e., wave-induced hull girder loads), individual scantling design equations, the loads used in the strength analyses of the hull, and ancillary forces, such as those from the motion of equipment masses located on or above the main deck. In practice, the hull may be loaded over a large range of tank loading patterns and external drafts. The implied value of all ESFs of both the alpha and beta types for the full ocean service is 1,0.

The determination of the environmental severity factors is to be carried out in accordance with Annex 4.

2.1.2 Load Components

In the design of the hull structure of ship-type installations, all load components with respect to the hull girder and local structure as specified in this Sub-Section and Rules for Hull (Pt.1, Vol.II), Sec.4 and 5 are to be taken into account. These include static loads in still water, wave-induced motions and loads, sloshing, slamming, dynamic, thermal and ice loads, where applicable.

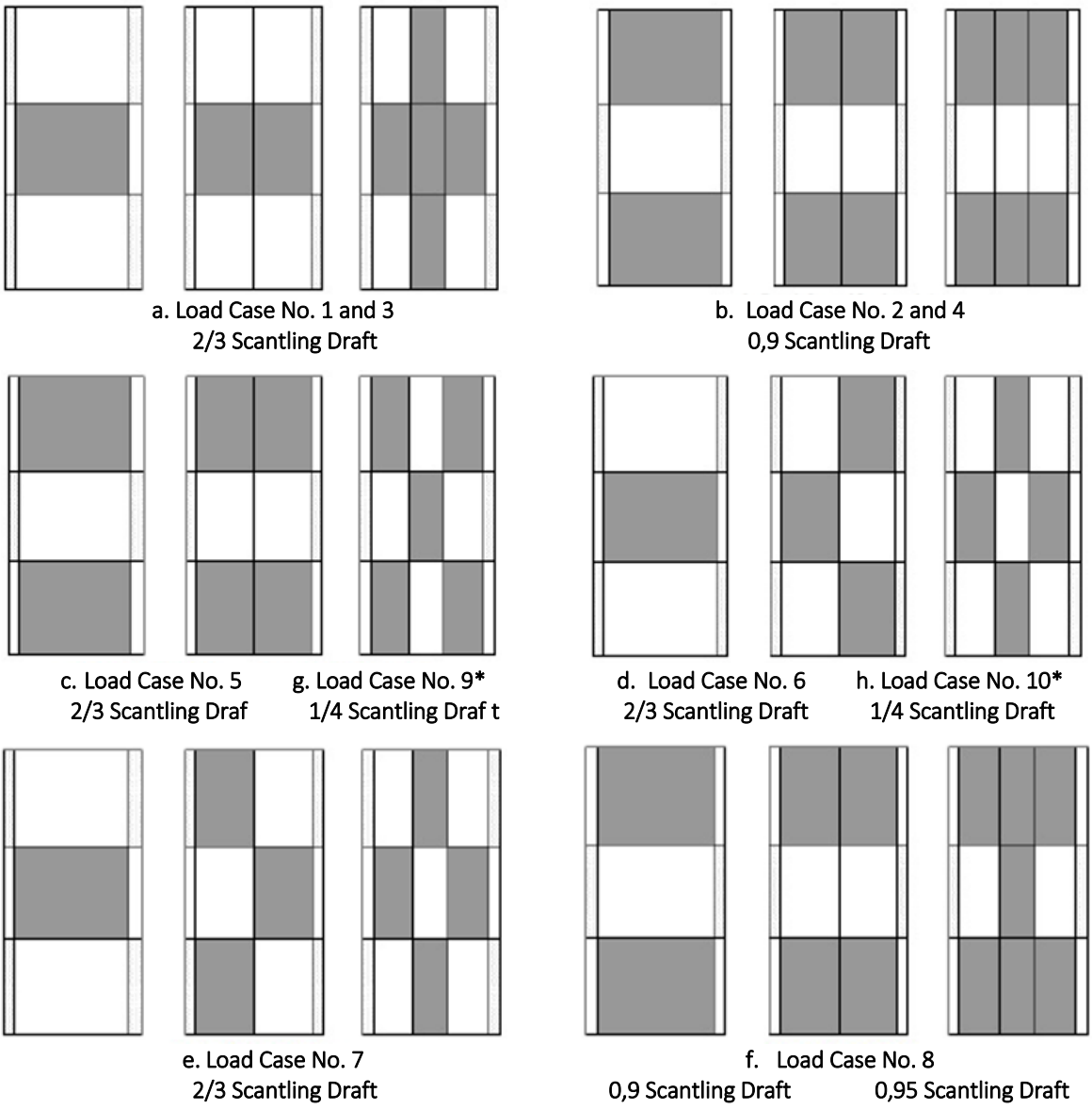
2.2 Static Loads

2.2.1 Still-water Bending Moment

For still-water bending moment calculations, see Rules for Hull (Pt.1, Vol.II), Sec.5, B.

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

Except for special loading cases, the loading patterns shown in Fig. 4.8A to 4.8C are to be considered in determining local static loads.



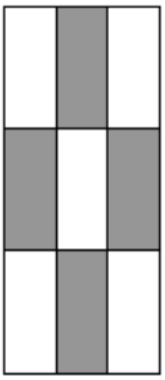
For detailed loading information see Fig. 4.8A to 4.8C.

** For L.C. 9 and 10, where static conditions, such as tank testing, that have the same loading pattern as the center row of tanks resulting in a draft less than 1/4 Design Draft, the actual static condition draft is to be used. The value of k_s = 1,0 is to be used in all tanks. The tanks are to be loaded considering the actual height of the overflow pipe.*

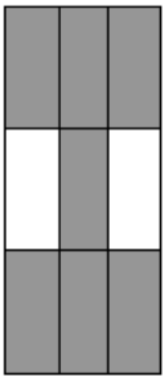
For a hull structure with the main supporting members that are asymmetric forward and aft of the mid-tank transverse bulkheads, the above load cases are to be evaluated by turning the finite element model by 180 degrees with respect to the vertical axis.

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

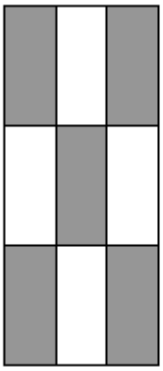
Fig. 4.8A - Loading Pattern - Double Hull and Double Side Single Bottom FPSO/FSO



a. Load Case No. 1 and 3
2/3 Scantling Draft

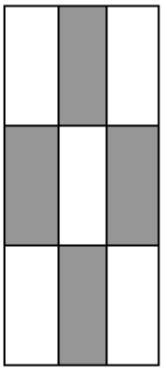


b. Load Case No. 2 and 4
0,95 Scantling Draft



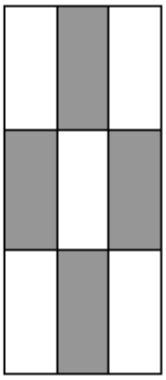
c. Load Case No. 5
2/3 Scantling Draft

g. Load Case No. 9*
1/3 Scantling Draft

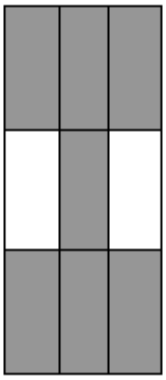


d. Load Case No. 6
2/3 Scantling Draft

h. Load Case No. 10*
1/3 Scantling Draft



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



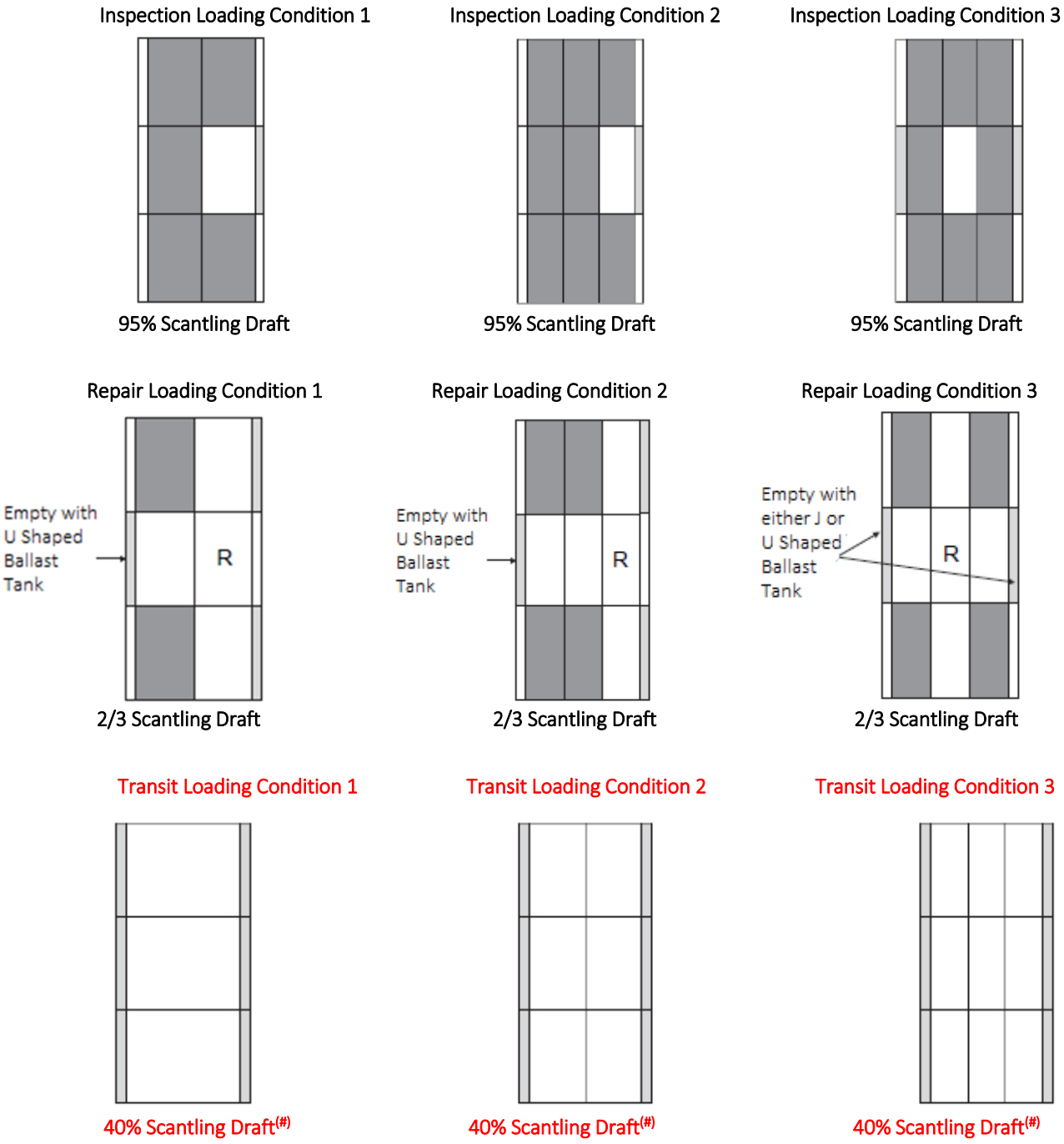
f. Load Case No. 8
0,95 Scantling Draft

For detailed loading information see Fig. 4.8A to 4.8C .

** For L.C. 9 and 10, where static conditions, such as tank testing, that have the same loading pattern as the center row of tanks resulting in a draft less than 1/3 Design Draft, the actual static condition draft is to be used. The value of k_s = 1,0 is to be used in all tanks. The tanks are to be loaded considering the actual height of the overflow pipe.*

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

Fig. 4.8 B Loading Pattern - Single Hull FPSO/FSO

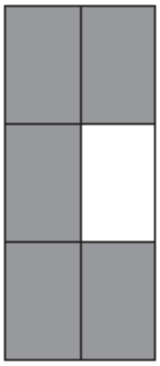


Notes:

- *Unless more severe inspection or repair loading condition is specified by the operator, the following minimum design inspection and repair loading conditions are to be used.*
- ** For double hull or double side structure with one cargo tank across, no loading conditions for inspection and repair are given above as they are covered under standard loading conditions shown in Fig. 4.8A and Table 4.9A.*
- *# Transit Condition: the draft can be changed to actual transit draft between 10% scantling draft to 60% scantling draft.*

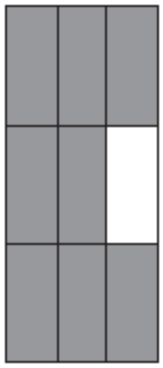
Fig. 4.8C Loading Pattern - Repair and Inspection Conditions for Double Hull and Double Side Single Bottom FPSO/FSO*

Inspection Loading Condition 1



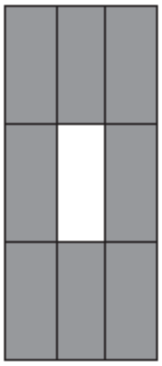
95% Scantling Draft

Inspection Loading Condition 2



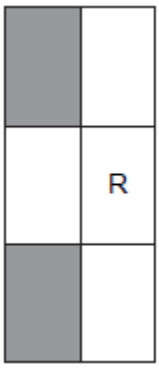
95% Scantling Draft

Inspection Loading Condition 3



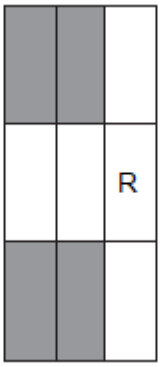
95% Scantling Draft

Repair Loading Condition 1



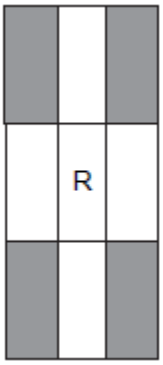
2/3 Scantling Draft

Repair Loading Condition 2



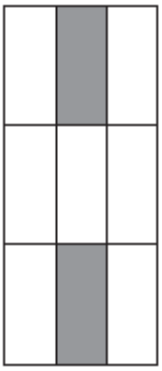
2/3 Scantling Draft

Repair Loading Condition 3



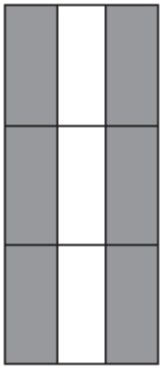
2/3 Scantling Draft

Transit Loading Condition 1



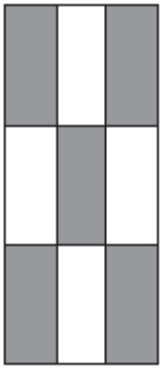
40% Scantling Draft(#)

Transit Loading Condition 2



40% Scantling Draft(#)

Transit Loading Condition 3



40% Scantling Draft(#)

Notes:

- *Unless more severe inspection or repair loading condition is specified by the operator, the following minimum design inspection and repair loading conditions are to be used.*
- *# Transit Condition: the draft can be changed to actual transit draft between 10% scantling draft to 60% scantling draft.*

Fig. 4.8 D Loading Pattern - Repair and Inspection Conditions for Single Hull FPSO/FSO

2.3 Wave-induced Loads

2.3.1 General

Where a direct calculation of the wave-induced loads is not available, the approximation equations given in the following sections and specified in Rules for Hull (Pt.1, Vol.II), Sec.5, B with Environmental Severity Factors (ESFs) may be used to calculate the design loads.

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

2.3.2 Vertical Wave Bending Moment and Shear Force

.1 Wave Bending Moment Amidships

The wave bending moment, expressed in kN-m, may be obtained from the following equations.

$$M_{ws} = -110 \cdot \beta_{VBM} \cdot C_o \cdot L^2 \cdot B \cdot (C_B + 0{,}7) \cdot 10^{-3} \quad \text{[kN-m]} \quad \text{Sagging Moment}$$

$$M_{wh} = -110 \cdot \beta_{VBM} \cdot C_o \cdot L^2 \cdot B \cdot (C_B + 0{,}7) \cdot 10^{-3} \quad \text{[kN-m]} \quad \text{Hogging Moment}$$

Where

β_{VBM} = ESF for vertical bending moment

C_0 = $10{,}75 - \left(\frac{300-L}{100}\right)^{1,5}$ $\quad 90 \le L \le 300$

= $10{,}75$ $\quad 300 < L \le 350$

= $10{,}75 - \left(\frac{L-350}{150}\right)^{1,5}$ $\quad 350 \le L \le 500$

L = length of vessel, as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1, [m]

B = breadth of vessel, as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.6, [m]

C_B = block coefficient, as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.4

.2 Envelope Curve of Wave Bending Moment

The wave bending moment along the length, L, of the vessel, may be obtained by multiplying the midship value by the distribution factor, M, given in Fig. 4.10.

.3 Wave Shear Force

The envelopes of maximum shearing forces induced by waves, Q_w, as shown in Fig. 4.11 and Fig. 4.12, may be obtained from the following equations.

$$Q_{wp} = +30 \cdot \beta_{VSF} \cdot F_1 \cdot C_o \cdot L \cdot B \cdot (C_B + 0{,}7) \cdot 10^{-2} \quad \text{[kN]} \quad \text{for positive shear force}$$

$$Q_{wn} = -30 \cdot \beta_{VSF} \cdot F_2 \cdot C_o \cdot L \cdot B \cdot (C_B + 0{,}7) \cdot 10^{-2} \quad \text{[kN]} \quad \text{for negative shear force}$$

where

Q_{wp}, Q_{wn} = maximum shearing force induced by wave, [kN]

C_o = as defined in 2.3.2.1

β_{VSF} = ESF for vertical shear force

L = length of vessel, as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1 [m]

B = breadth of vessel, as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.6, [m]

C_B = block coefficient, as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.4

F_1 = distribution factor, as shown in Fig. 4.11

F_2 = distribution factor, as shown in Fig. 4.12

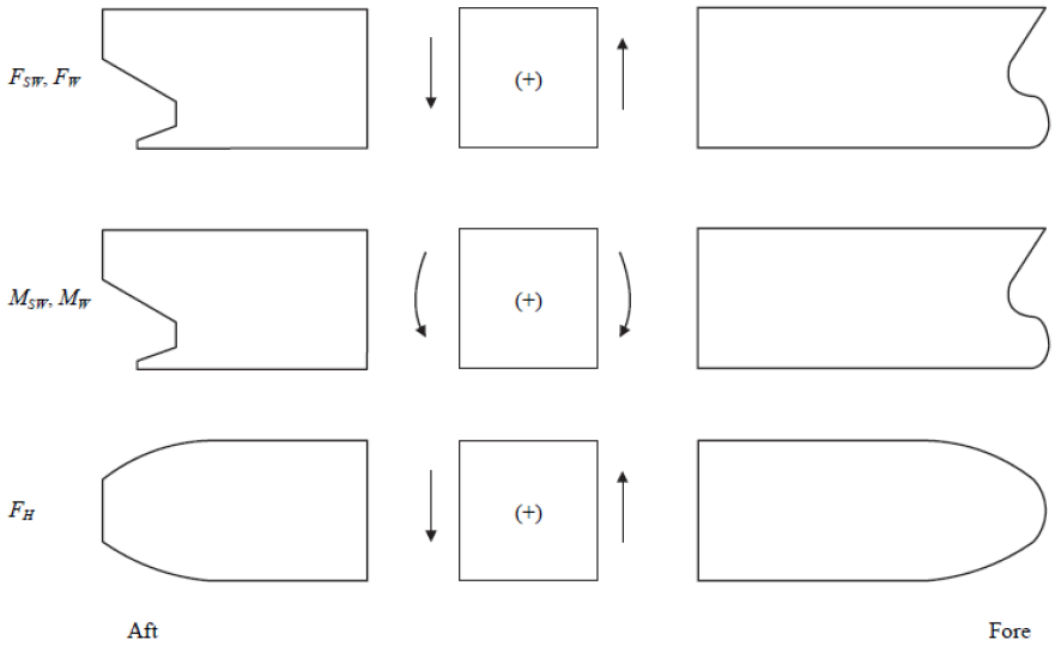


Fig. 4.9 Sign Convention

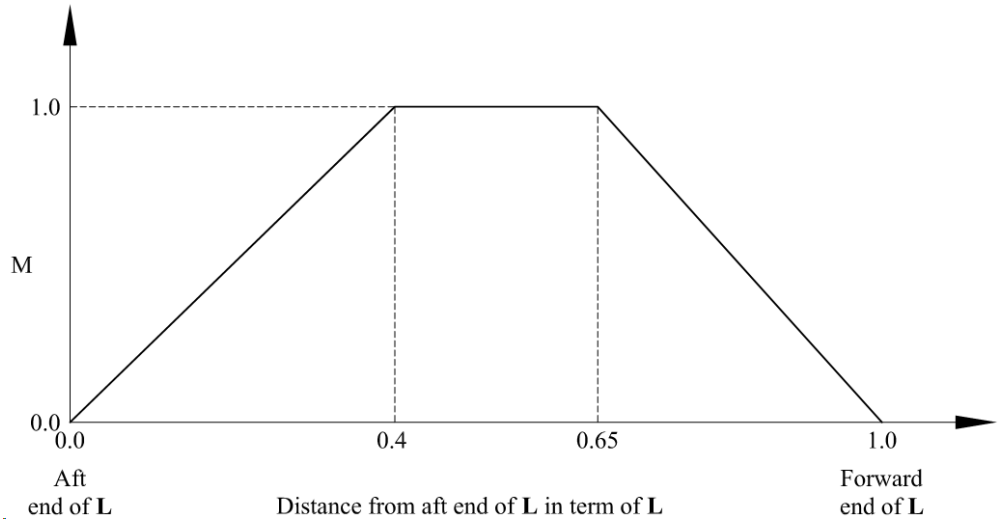


Fig. 4.10 Distribution Factor M

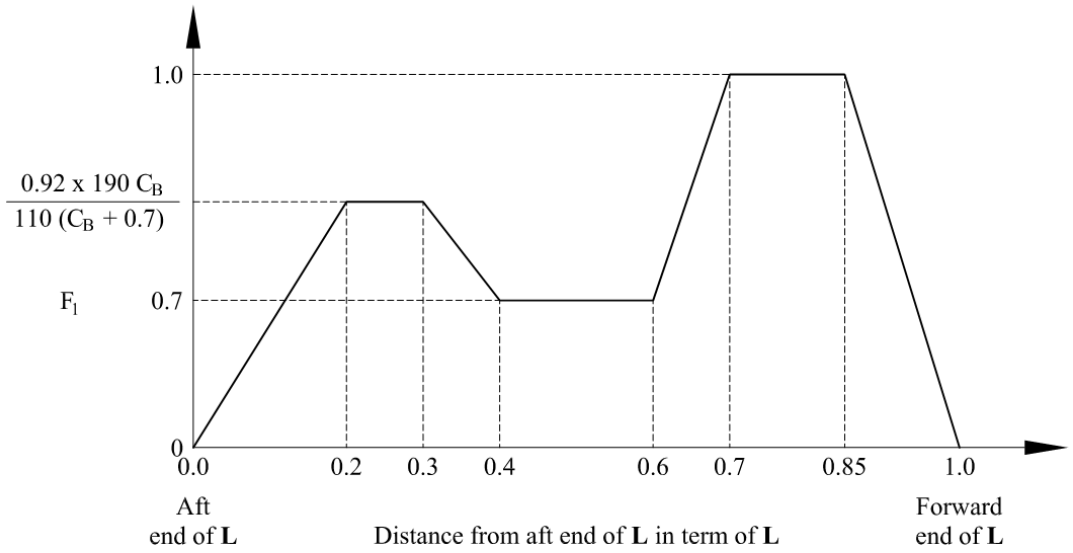


Fig. 4.11 Distribution Factor F_1

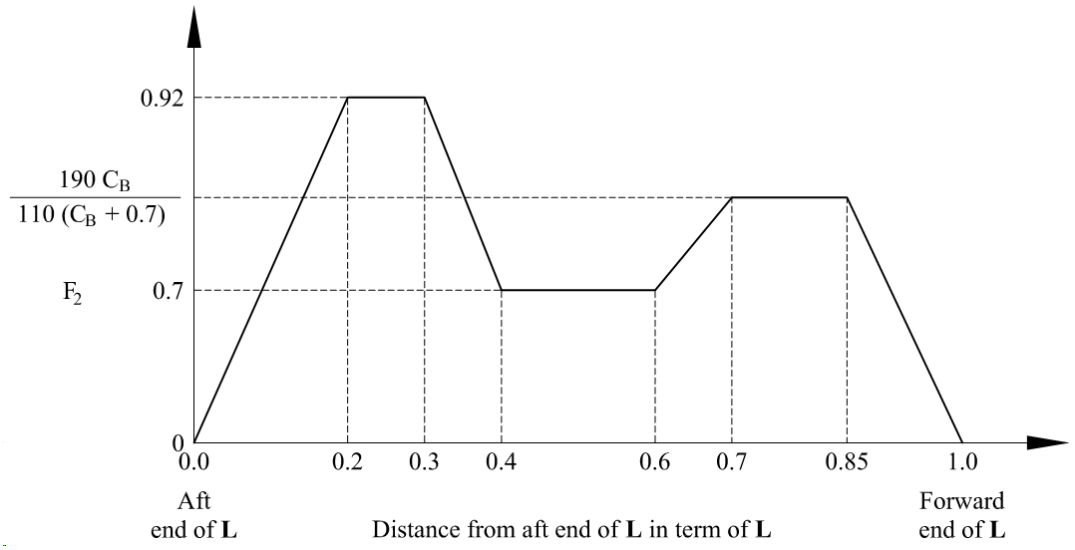


Fig. 4.12 Distribution Factor F_2

2.3.3 Horizontal Wave Bending Moment and Shear Force

.1 Horizontal Wave Bending Moment

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

$$M_H = \pm 180 \cdot m_h \cdot \beta_{HBM} \cdot C_0 \cdot L^2 \cdot H \cdot C_B \cdot 10^{-3} \quad [\text{kN-m}]$$

where

m_h = distribution factor, as given by Fig. 4.13

β_{HBM} = ESF for horizontal bending moment, as defined in Annex 4, B

H = hull depth of installation, as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H, 2.7 [m]

L and C_B are as given in Rules for Hull (Pt.1, Vol.II), Sec.1, H.

C_0 = wave coefficient as define in 2.3.2.1.

.2 Horizontal Wave Shear Force

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

$$Q_H = \pm 36 \cdot f_h \cdot \beta_{HSF} \cdot C_0 \cdot L \cdot H\,(C_B + 0{,}7) \cdot 10^{-2} \quad [kN]$$

where

f_h = distribution factor, as given in Fig. 4.14

β_{HSF} = ESF for horizontal shear force, as defined in Annex 4, B

C_0, **L**, **H** and C_B are as defined in 2.3.3.1 above.

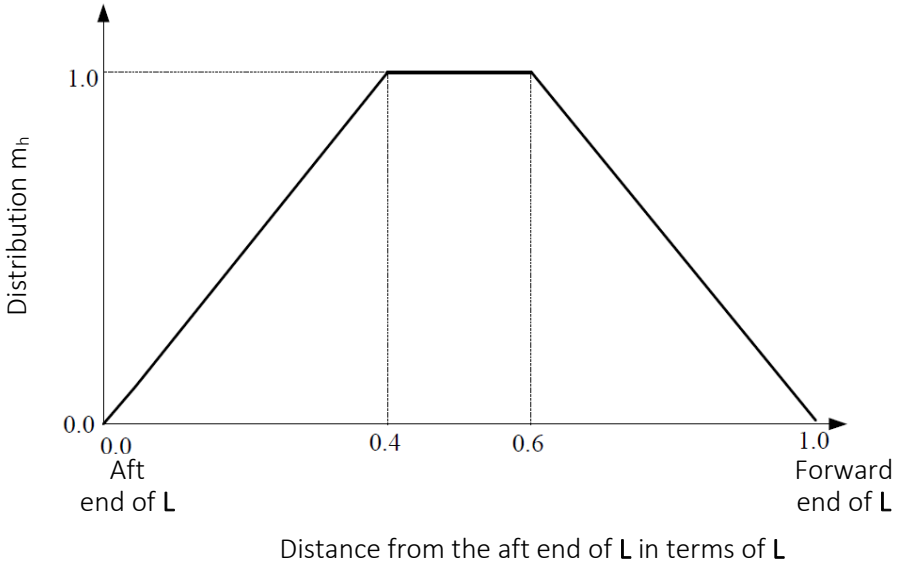


Fig. 4.13 Distribution Factor m_h

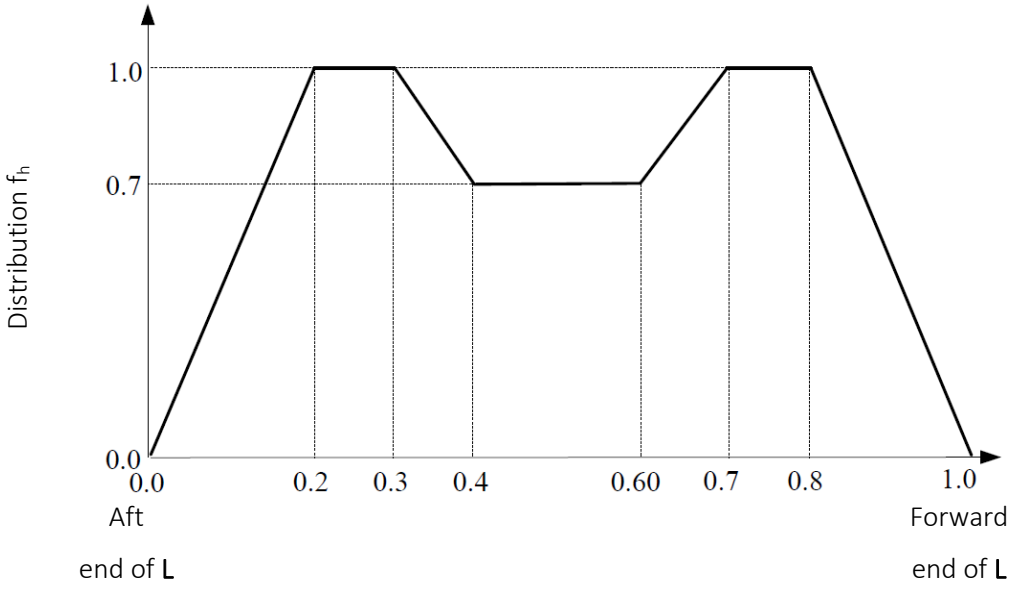


Fig 4.14 Distribution Factor f_h

2.3.4 External Pressures

.1 Pressure Distribution

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

$$p_e = \rho \cdot g\,(h_s + \beta_{EPS/EPP} \cdot k_u \cdot h_{de}) \geq 0 \quad [N/cm^2]$$

where

$\rho \cdot g$ = specific weight of sea water
= 1,005 N/cm^2-m

h_s = hydrostatic pressure head in still water [m]

$\beta_{EPS/EPP}$ = ESF for external pressure starboard/port, as defined in Annex 4, B

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

h_{de} = hydrodynamic pressure head induced by the wave [m], may be calculated as follows:
= $k_c \cdot h_{di}$

where

k_c = correlation factor for a specific combined load case, as given in 2.4.1 and 2.5

h_{di} = hydrodynamic pressure head, [m], at location i (i =1, 2, 3, 4 or 5; see Fig. 4.15)
= $k_\ell \cdot \alpha_i \cdot h_{d0}$ [m]

k_ℓ = distribution factor along the length of the installation
= $1 + (k_{\ell 0} - 1) \cos \mu$ $k_{\ell 0}$ is as given in Fig. 4.16
= 1,0 amidships

h_{do} = $1{,}36 \cdot k \cdot C_0$ [m]

C_0 = as defined in 2.3.3.1

α_i = distribution factor around the girth of installation at location i.
= $1{,}00 - 0{,}25 \cos \mu$ for i = 1, at WL, starboard
= $0{,}40 - 0{,}10 \cos \mu$ for i = 2, at bilge, starboard
= $0{,}30 - 0{,}20 \sin \mu$ for i = 3, at bottom centreline
= $2\alpha_3 - \alpha_2$ for i = 4, at bilge, port
= $0{,}75 - 1{,}25 \sin \mu$ for i = 5, at WL, port

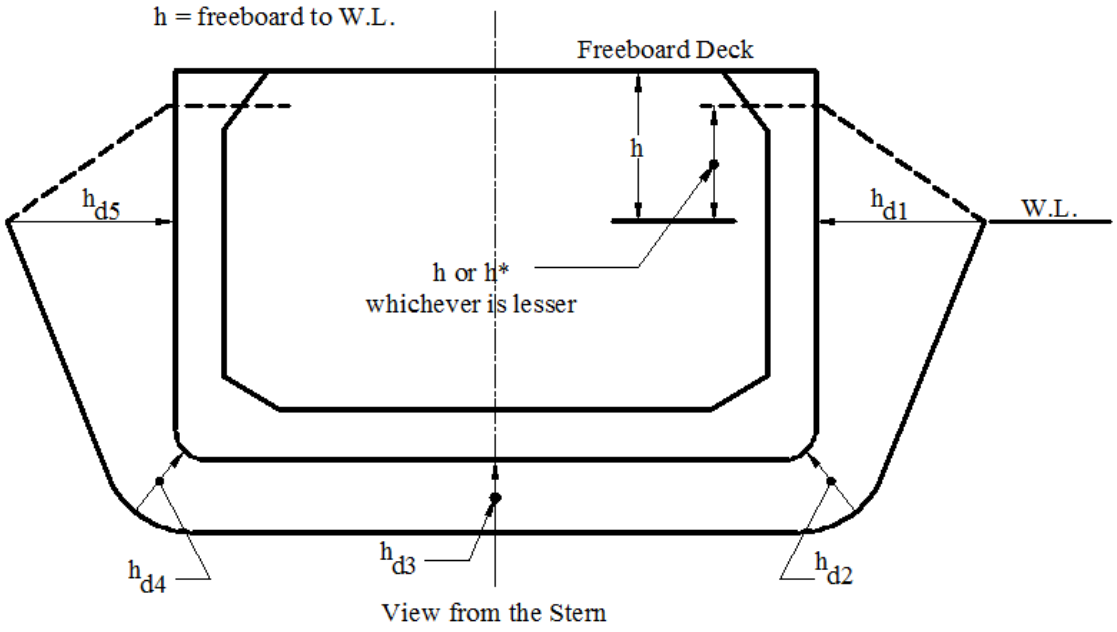
α_i at intermediate locations of i may be obtained by linear interpolation.

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

The distribution of the total external pressure including static and hydrodynamic pressure is illustrated in Fig. 4.17.

.2 Extreme Pressures

In determining the required scantlings of local structural members, the extreme external pressure, p_e, to be used, is as defined in 2.3.4.1 with k_u as given in 2.4 and 2.5.



Note:

$h^* = k_u \cdot k_c \cdot h_{d1}$ for nominal pressure

$h^* = k_f \cdot k_u \cdot h_{d1}$ for simultaneous pressure

Fig. 4.15 Distribution of hdi

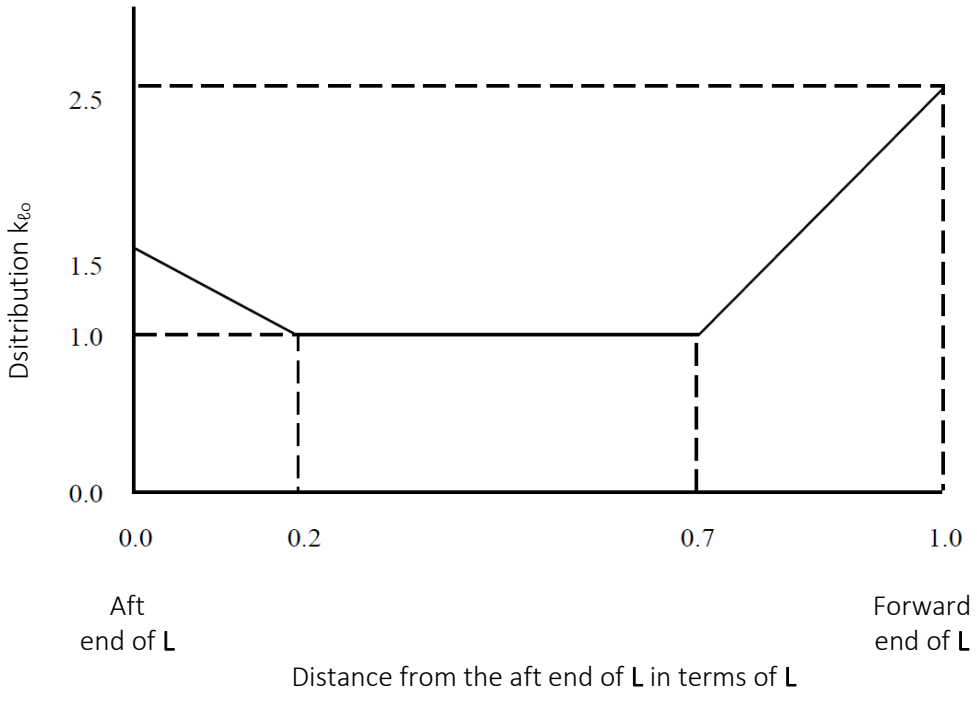
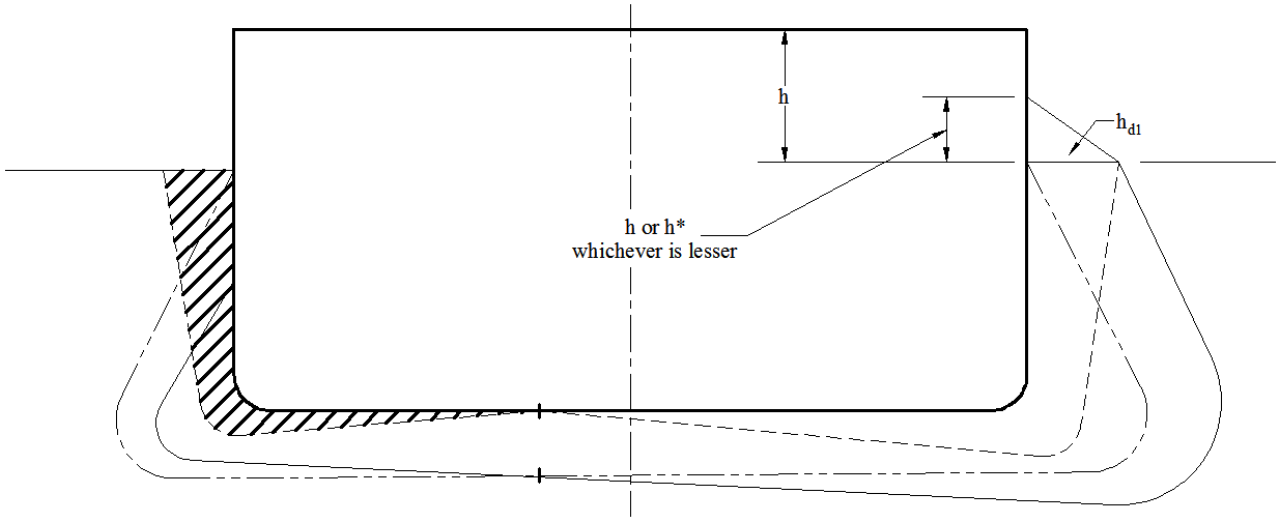


Fig. 4.16 Pressure Distribution Function $k_{\ell o}$



h_d : *Hydrostatic Pressure Head* *(Indicate negative)*

h_s : *Hydrostatic Pressure Head in Still Water*

: *Total External Pressure Head*

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

$h^* = k_f \cdot k_u \cdot h_{d1}$ *for simultaneous pressure*

Fig. 4.17 Illustration of Determining Total External Pressure

.3 Simultaneous Pressures

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

$$p_e = \rho \cdot g\,(h_s + \beta_{EPS/EPP} \cdot k_f \cdot k_u \cdot h_{de}) \geq 0 \qquad [N/cm^2]$$

where

$\beta_{EPS/EPP}$ = ESF for external pressure starboard/port, as defined in Annex 4, B

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

$$k_f = k_{f0}\left\{1 - \left[1 - \cos\frac{2 \cdot \pi\,(x - x_0)}{L}\right]\cos\mu\right\}$$

where

x = distance from A.P. to the station considered [m]

x_0 = distance from A.P. to the reference station* [m]

L = installation length [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1.

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

k_{fo} = ± 1,0, as specified in Table 4.9A through 4.9C

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

The simultaneous pressure distribution around the girth of the installation is to be determined based on the wave heading angles specified in 2.4 and 2.5.

2.3.5 Internal Pressures - Inertia Forces and Added Pressure Heads

.1 Ship Motions and Accelerations

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

1) **Pitch**. The pitch amplitude : (positive bow up)

$$\phi = \beta_{PM0} \cdot \frac{1030}{L} \cdot \sqrt[4]{\frac{10}{C_B}} \quad \text{in deg., but need not to be taken more than 10 deg.}$$

The pitch natural period:

$$T_P = 3{,}5 \sqrt{C_B \cdot T_i} \quad \text{seconds}$$

where

β_{PMO} = ESF for pitch motion, as defined in Annex 4, B

T_i = draft amidships for the relevant loading conditions.

L and C_B are defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1 and H.4, respectively.

2) **Roll**. The roll amplitude: (positive starboard down)

$$\theta = 1{,}05 \cdot \beta_{RM0} \left(35 - \frac{0{,}005 \cdot C_{di} \cdot \Delta}{1000} \right) \quad \text{if } T_r > 20 \text{ seconds}$$

$$\theta = 1{,}05 \cdot \beta_{RM0} \left(35 - \frac{0{,}005 \cdot C_{di} \cdot \Delta}{1000} \right) (1{,}5375 - 0{,}027 \cdot T_r) \quad \text{if } 12{,}5 \le T_r \le 20 \text{ seconds}$$

$$\theta = 1{,}05 \cdot \beta_{RM0} \left(35 - \frac{0{,}005 \cdot C_{di} \cdot \Delta}{1000} \right) (0{,}8625 + 0{,}027 \cdot T_r) \quad \text{if } T_r \le 12{,}5 \text{ seconds}$$

where

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

β_{RMO} = ESF for roll motion, as defined in Annex 4, B

$C_{di} = 1{,}06 \cdot \left(\frac{T_i}{T_f} \right) - 0{,}06$

T_i = draft amidships for the relevant loading conditions [m]

T_f = draft [m], as defined in Rules for Hull (Pt.1, Vo.II), Sec.1, H.2.8.

$\Delta = 10{,}05 \cdot L \cdot B \cdot T_f \cdot C_B$ [kN]

L and **B** are as defined in Rules for Hull (Pt.1, Vo.II), Sec.1, H.

The roll natural motion period:

$$T_r = \frac{2 \cdot k_r}{\sqrt{GM}} \quad \text{seconds}$$

where

k_r = roll radius of gyration, in m, and may be taken as 0,35 · **B** for full load conditions and 0,45 · **B** for ballast conditions.

GM = metacentric height, to be taken as:

= GM (full) for full draft

= 1,1 GM (full) for 9/10 T_f

= 1,5 GM (full) for 2/3 T_f

= 2,0 GM (full) for 1/2 T_f

GM (full) = metacentric height for fully loaded condition

If GM (full) is not available, GM (full) may be taken as 0,12 · **B** for the purpose of estimation.

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

$$a_v = C_V \cdot \beta_{VAC} \cdot k_v \cdot a_0 \cdot g \quad [m/sec^2] \quad \text{positive downward}$$

$$a_\ell = C_\ell \cdot \beta_{LAC} \cdot k_\ell \cdot a_0 \cdot g \quad [m/sec^2] \quad \text{positive forward}$$

$$a_t = C_t \cdot \beta_{TAC} \cdot k_t \cdot a_0 \cdot g \quad [m/sec^2] \quad \text{positive starboard}$$

where

a_0 = $k_o \left(\frac{2,4}{\sqrt{L}} + \frac{34}{L} - \frac{600}{L^2} \right)$

k_0 = $1,34 - 0,47 \cdot C_B$

C_v = $\cos\mu + \left(1 + \frac{2,4 \cdot z}{B} \right) \frac{\sin\mu}{k_v}$

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

β_{VAC} = ESF for vertical acceleration, as defined in Annex 4, B

β_{LAC} = ESF for longitudinal acceleration, as defined in Annex 4, B

β_{TAC} = ESF for transverse acceleration, as defined in Annex 4, B

k_v = $\sqrt{1 + 0,65 \left(5,3 - \frac{45}{L} \right)^2 \left(\frac{x}{L} - 0,45 \right)^2}$

C_ℓ = $0,35 - 0,0005 \, (L - 200)$

k_ℓ = $0,5 + 8 \cdot y/L$

C_t = $1,27 \sqrt{1 + 1,52 \left(\frac{x}{L} - 0,45 \right)^2}$

k_t = 0,35 + y/**B**

L and **B** are the length and breadth of the installation respectively, as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H, [m]

x = longitudinal distance from the A.P. to the station considered [m]

z = vertical distance from the waterline to the point considered [m], positive upward

y = transverse distance from the centerline to the point considered [m], positive starboard

g = acceleration of gravity = 9,8 m/sec^2

.2 Internal Pressures

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

$$p_i = k_s \cdot \rho \cdot g\,(\eta + k_u \cdot h_d) + p_o \geq 0 \qquad [N/cm^2]$$

$$p_0 = (p_{vp} - p_n) \geq 0 \qquad [N/cm^2]$$

where

p_{vp} = pressure setting on pressure/vacuum relief valve < 6,90 N/cm^2, for integral-gravity tanks

p_n = 2,06 [N/cm^2]

$\rho \cdot g$ = specific weight of the liquid, not to be taken less than 1,005 N/cm^2-m

η = local coordinate in vertical direction for tank boundaries measuring from the top of the tanks, as shown Fig. 4.18 [m]

For lower ballast tanks, a distance equivalent to 2/3 of the distance from the top of the tank to the top of the overflow [minimum 760 mm above deck] is to be added to η.

k_s = load factor - see also 3)

= 1,0 for structural members 1 through 10 in Table 4.11, and for all loads from ballast tanks

= 0,878 for $\rho \cdot g$ of 1,005 N/cm^2-m and 1,0 for $\rho \cdot g$ of 1,118 N/cm^2-m and above for structural members 11 through 17 in Table 4.11

For cargo $\rho \cdot g$ between 1,005 N/cm^2-m and 1,118 N/cm^2-m, the factor k_s may be determined by interpolation

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

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

$$= k_C\left(\frac{\eta \cdot a_i}{g} + \Delta h_i\right) \quad [m]$$

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

a_i = effective resultant acceleration [m/sec^2], at the point considered and may be approximated by

$$= 0{,}71 \cdot C_{dp}\left[w_v \cdot a_v + w_\ell\left(\frac{\ell}{h}\right) a_\ell + w_t\left(\frac{b}{h}\right) a_t\right]$$

C_{dp} is as specified in 4).

a_v, a_ℓ and a_t are as given in 2.3.5.1.3).

w_v, w_ℓ and w_t are weighted coefficients, showing directions, as specified in Tables 4.9A through 4.9C and Table 4.11.

Δh_i = added pressure head due to pitch and roll motions at the point considered, [m], may be calculated as follows

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

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

$$\zeta_e = b - \zeta$$

$$\eta_e = \eta$$

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

$$\Delta_{hi} = (\ell - \zeta)\sin\phi_e + C_{ru}(\zeta_e \sin(-\theta_e)\cos\phi_e + \eta_e \cos\theta_e \cos\phi_e - \eta)$$

$$\zeta_e = \zeta - \delta_b$$

$$\eta_e = \eta - \delta_h$$

ξ, ζ, η are the local coordinates, [m], for the point considered with respect to the origin in Fig. 4.18.

C_{ru} is as specified in 4).

δ_b and δ_h are local coordinates adjustments, [m], for the point considered with respect to the origin shown in Fig. 4.18.

where

θ_e = $0{,}71 \cdot C_\theta \cdot \theta$

ϕ_e = $0{,}71 \cdot C_\phi \cdot \phi$

ℓ = length of the tank [m]

h = depth of the tank [m]

b = breadth of the tank considered [m]

ϕ and θ are pitch and roll amplitudes, as given in 2.3.5.1(a) and 2.3.5.1(b).

C_ϕ and C_θ are weighted coefficients, showing directions as given in Tables 4.9A through 4.9C and Table 4.11.

Where pressure-vacuum valves of cargo tanks are set at greater than 2,06 N/cm^2, the value of p_i is to be increased appropriately.

2) **Extreme Internal Pressure.** For assessing local structures at a tank boundary, the extreme internal pressure with k_u, as specified in 2.4, is to be considered.

3) **Simultaneous Internal Pressures**. In performing a 3D structural analysis, the internal pressures may be calculated in accordance with 1) and 2) above for tanks in the mid-body. For tanks in the fore or aft body, the pressures should be determined based on linear distributions of accelerations and ship motions along the length of the installation.

Notes :

In performing a 3D structural analysis, k_s in (a) is to be taken as:

k_s	*= 1,0*	*for all loads from ballast tanks*
	= 0,878	*for $\rho \cdot g$ of 1,005 N/cm^2-m and 1,0 for $\rho \cdot g$ of 1,118 N/cm^2-m and above for all loads from cargo tanks*
		For cargo $\rho \cdot g$ between 1,005 N/cm^2-m and 1,118 N/cm^2-m, the factor k_s may be determined by interpolation

4) Definition of Tank Shape and Associated Coefficients

A) J-shaped Tank

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

$b/b_1 \geq 5,0$ and $h/h_1 \geq 5,0$

where

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

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

h = extreme height of the tank considered

h_1 = least height of double bottom part of the tank considered as shown in Fig. 4.18

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

C_{dp} = 0,7

C_{ru} = 1,0

B) Rectangular Tank

The following tank is considered as a rectangular tank:

$b/b_1 \leq 3,0$ or $h/h_1 \leq 5,0$

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

C_{dp} = 1,0

C_{ru} = 1,0

C) U-shaped Tank

A half of a "U-shaped" tank, divided at the centerline, should satisfy the condition of a "J-shaped" tank. The coefficients C_{dp} and C_{ru} are as follows:

C_{dp} = 0,5

C_{ru} = 0,7

D) In a case where the minimum tank ratio of b/b_1 or h/h_1 whichever is lesser, is greater than 3,0 but less than 5,0, the coefficients C_{dp} and C_{ru} of the tank are to be determined by the following interpolation :

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

C_{dp} = 1,0 – 0,3 (the min. tank ratio – 3,0) / 2,0

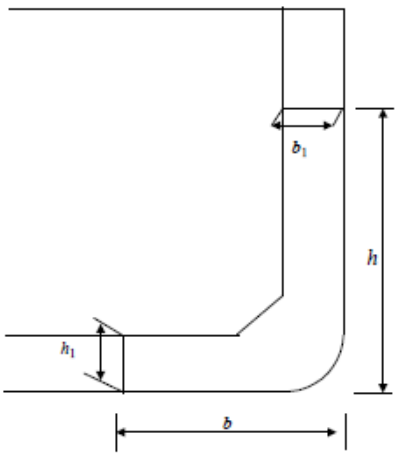
U-shaped Tank in non-head seas:

C_{dp} = 1,0 – 0,5 (the min. tank ratio – 3,0) / 2,0

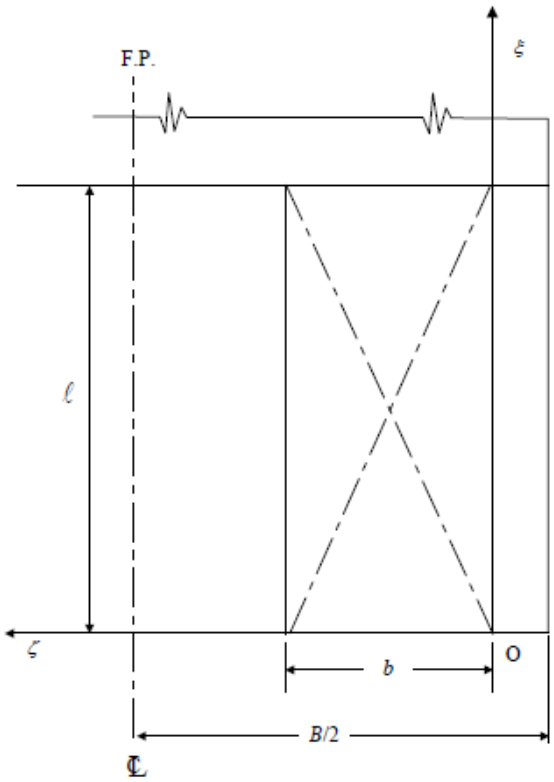
U-shaped Tank:

C_{ru} = 1,0 – 0,3 (the min. tank ratio – 3,0) / 2,0

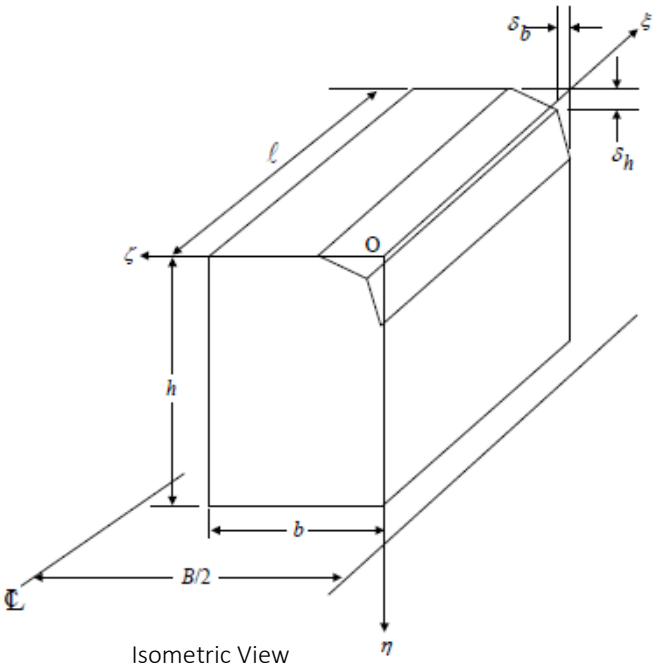
E) For non-prismatic tanks mentioned above, b_1, h and h_1 are to be determined based on the extreme section



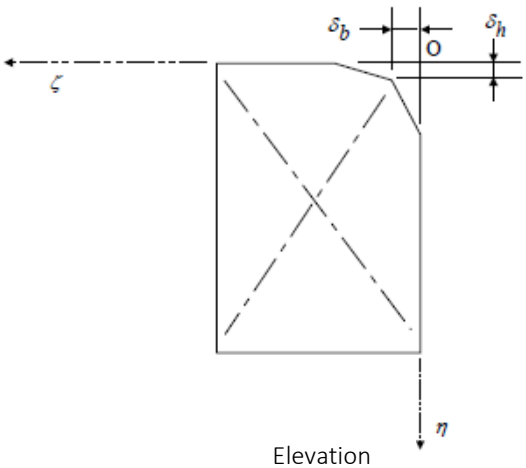
Tank shape parameter



Plan View



Isometric View



Elevation

For lower ballast tanks, η is to be measured from a point located at 2/3 the distance from the top of the tank to the top of the overflow (minimum 760 mm above deck).

Fig. 4.18 Definition of Tank Geometry

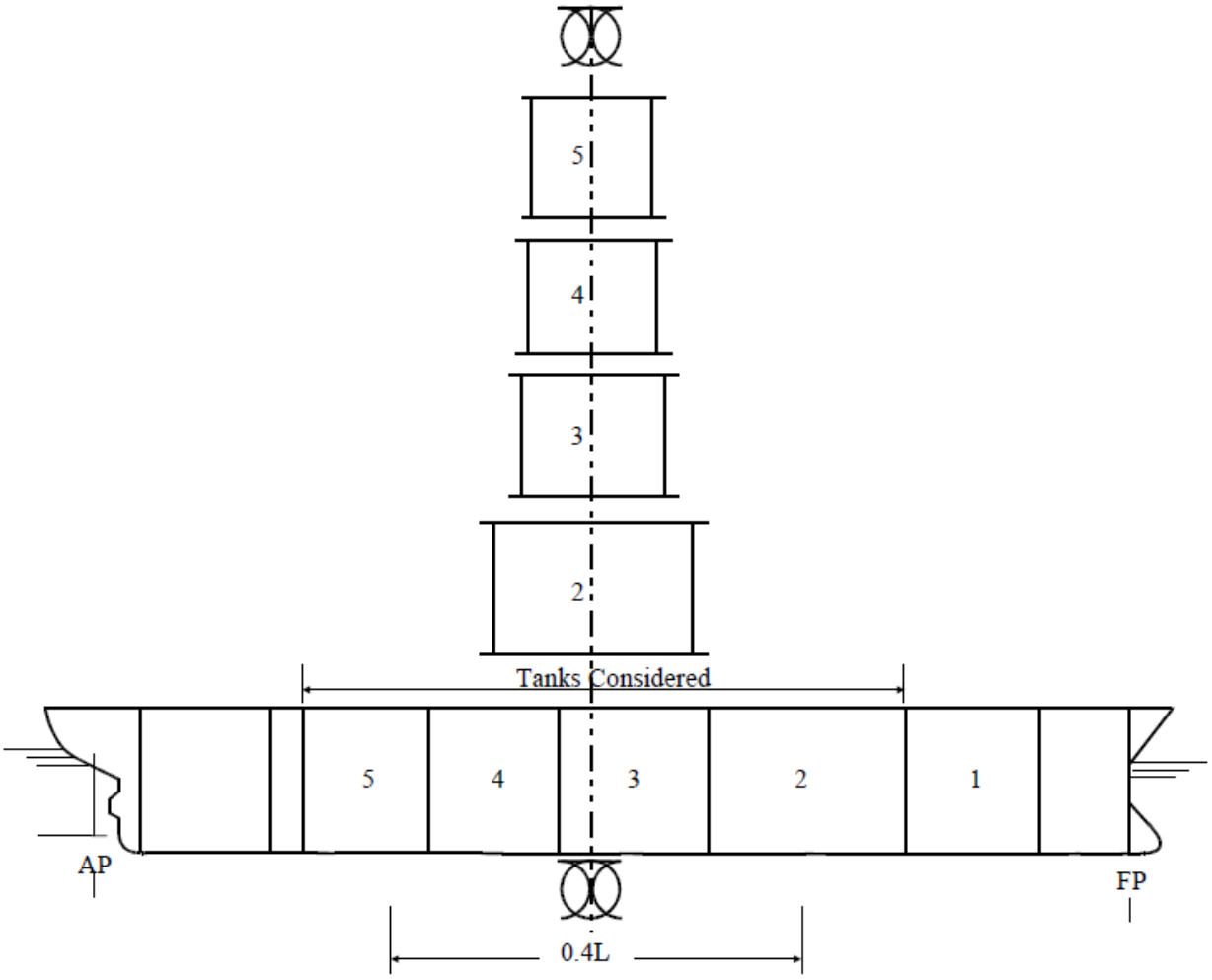


Fig. 4.19 Location of Tank for Nominal Pressure Calculation

Table 4.9A Combined Load Cases for Normal Operating and Transit Conditions*

	L.C. 1	L.C. 2	L.C. 3	L.C. 4	L.C. 5	L.C. 6	L.C. 7	L.C. 8	L.C. 9	L.C. 10
A. Hull Girder Loads (See 2.3)**										
Vertical B.M.	Sag (-)	Hog (+)	Sag (-)	Hog (+)	Sag (-)	Hog (+)	Sag (-)	Hog (+)	—	—
k_c	1,0	1,0	0,7	0,7	0,3	0,3	0,4	0,4	0,0	0,0
Vertical S.F.	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	—	—
k_c	0,5	0,5	1,0	1,0	0,3	0,3	0,4	0,4	0,0	0,0
Horizontal B.M.					(-)	(+)	(-)	(+)	—	—
k_c	0,0	0,0	0,0	0,0	0,3	0,3	1,0	1,0	0,0	0,0
Horizontal S.F.					(+)	(-)	(+)	(-)	—	—
k_c	0,0	0,0	0,0	0,0	0,3	0,3	0,5	0,5	0,0	0,0
B. External Pressure (See 2.3.4)										
k_c	0,5	0,5	0,5	1,0	0,5	1,0	0,5	1,0	0,0	0,0
k_{f0}	-1,0	1,0	-1,0	1,0	-1,0	1,0	-1,0	1,0	0,0	0,0
C. Internal Tank Pressure (See 2.3.5)										
k_c	0,4	0,4	1,0	0,5	1,0	0,5	1,0	0,5	0,0	0,0
w_v	0,75	-0,75	0,75	-0,75	0,25	-0,25	0,4	-0,4	0,0	0,0
w_ℓ	Fwd Bhd 0,25	Fwd Bhd -0,25	Fwd Bhd 0,25	Fwd Bhd -0,25	—	—	Fwd Bhd 0,2	Fwd Bhd -0,2	—	—
	Aft Bhd -0,25	Aft Bhd 0,25	Aft Bhd -0,25	Aft Bhd 0,25	—	—	Aft Bhd -0,2	Aft Bhd 0,2	—	—
w_t	—	—	—	—	Port Bhd -0,75	Port Bhd 0,75	Port Bhd -0,4	Port Bhd 0,4	—	—
	—	—	—	—	Stbd Bhd 0,75	Stbd Bhd -0,75	Stbd Bhd 0,4	Stbd Bhd -0,4	—	—
c_ϕ, Pitch	-0,35	0,35	-0,70	0,70	0,0	0,0	-0,30	0,30	0,0	0,0
c_θ, Roll	0,0	0,0	0,0	0,0	1,0	-1,0	0,30	-0,30	0,0	0,0
D. Reference Wave Heading and Motion of Installation										
Heading Angle	0	0	0	0	90	90	60	60	—	—
Heave	Down	Up	Down	Up	Down	Up	Down	Up	—	—
Pitch	Bow Down	Bow Up	Bow Down	Bow Up	—	—	Bow Down	Bow Up	—	—
Roll	—	—	—	—	Stbd Down	Stbd Up	Stbd Down	Stbd Up	—	—

* k_u = 1,0 for all load components. For the transit condition, only load cases **LC.1** through **LC.8** are considered

** Boundary forces should be applied to produce the above specified hull girder bending moment at the middle of the structural model and the specified hull girder shear force at one end of the middle hold of the model. The sign convention for the shear force corresponds to the forward end of the middle hold.

Table 4.9 B Combined Load Cases for Inspection Condition*

	I.L.C. 1	I.L.C. 2	I.L.C. 3	I.L.C. 4	I.L.C. 5	I.L.C. 6	I.L.C. 7	I.L.C. 8	I.L.C. 9	I.L.C. 10
A. Hull Girder Loads (See 2.3)**										
Vertical B.M.	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)
k_c	1,00	1,00	0,50	0,50	0,15	0,15	0,70	0,70	0,60	0,60
Vertical S.F.	(+)	(–)	(+)	(–)	(+)	(–)	(+)	(–)	(+)	(–)
k_c	0,55	0,55	1,00	1,00	0,20	0,20	0,20	0,20	0,30	0,30
Horizontal B.M.					(–)	(+)	(–)	(+)	(–)	(+)
k_c	0,00	0,00	0,00	0,00	0,25	0,25	1,00	1,00	1,00	1,00
Horizontal S.F.					(+)	(–)	(+)	(–)	(+)	(–)
k_c	0,00	0,00	0,00	0,00	0,25	0,25	0,85	0,85	0,80	0,80
B. External Pressure (See 2.3.4)										
k_c	0,85	0,85	0,70	0,70	0,90	0,90	0,80	0,80	0,95	0,95
k_{f0}	-1,00	1,00	-1,00	1,00	-1,00	1,00	-1,00	1,00	-1,00	1,00
C. Internal Tank Pressure (See 2.3.5)										
k_c	0,75	0,75	0,30	0,30	0,80	0,80	0,10	0,10	0,50	0,50
w_v	0,85	-0,85	0,55	-0,55	0,60	-0,60	0,10	-0,10	0,30	-0,30
w_ℓ	Fwd Bhd 0,20	Fwd Bhd -0,20	Fwd Bhd 0,65	Fwd Bhd -0,65	—	—	Fwd Bhd 0,30	Fwd Bhd -0,30	Fwd Bhd 1,00	Fwd Bhd -1,00
	Aft Bhd -0,20	Aft Bhd 0,20	Aft Bhd -0,65	Aft Bhd 0,65	—	—	Aft Bhd -0,30	Aft Bhd 0,30	Aft Bhd -1,00	Aft Bhd 1,00
w_t	—	—	—	—	Port Bhd -1,00	Port Bhd 1,00	Port Bhd -0,05	Port Bhd 0,05	Port Bhd -0,10	Port Bhd 0,10
	—	—	—	—	Stbd Bhd 1,00	Stbd Bhd -1,00	Stbd Bhd 0,05	Stbd Bhd -0,05	Stbd Bhd 0,10	Stbd Bhd -0,10
c_ϕ, Pitch	-0,30	0,30	-0,60	0,60	-0,15	0,15	-0,10	0,10	-0,80	0,80
c_θ, Roll	0,00	0,00	0,00	0,00	1,00	-1,00	0,05	-0,05	0,15	-0,15
D. Reference Wave Heading and Motion of Installation										
Heading Angle	0	0	0	0	90	90	60	60	30	30
Heave	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up
Pitch	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up
Roll	—	—	—	—	Stbd Down	Stbd Up	Stbd Down	Stbd Up	Stbd Down	Stbd Up

* k_u = 1,0 for all load components.

** Boundary forces should be applied to produce the above specified hull girder bending moment at the middle of the structural model and the specified hull girder shear force at one end of the middle hold of the model. The sign convention for the shear force corresponds to the forward end of the middle hold.

Table 4.9C Combined Load Cases for Repair Condition*

	R.L.C. 1	R.L.C. 2	R.L.C. 3	R.L.C. 4	R.L.C. 5	R.L.C. 6	R.L.C. 7	R.L.C. 8	R.L.C. 9	R.L.C. 10
A. Hull Girder Loads (See 2.3)**										
Vertical B.M.	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)
k_c	1,00	1,00	0,50	0,50	0,25	0,25	0,80	0,80	0,60	0,60
Vertical S.F.	(+)	(–)	(+)	(–)	(+)	(–)	(+)	(–)	(+)	(–)
k_c	0,55	0,55	1,00	1,00	0,15	0,15	0,40	0,40	0,20	0,20
Horizontal B.M.					(–)	(+)	(–)	(+)	(–)	(+)
k_c	0,00	0,00	0,00	0,00	0,10	0,10	1,00	1,00	1,00	1,00
Horizontal S.F.					(+)	(–)	(+)	(–)	(+)	(–)
k_c	0,00	0,00	0,00	0,00	0,15	0,15	0,80	0,80	0,80	0,80
B. External Pressure (See 2.3.4)										
k_c	0,85	0,85	0,80	0,80	0,90	0,90	0,90	0,90	0,55	0,55
k_{f0}	-1,00	1,00	-1,00	1,00	-1,00	1,00	-1,00	1,00	-1,00	1,00
C. Internal Tank Pressure (See 2.3.5)										
k_c	0,55	0,55	0,40	0,40	0,70	0,70	0,20	0,20	0,40	0,40
w_v	0,60	-0,60	0,35	-0,35	0,55	-0,55	0,15	-0,15	0,25	-0,25
w_ℓ	Fwd Bhd 0,20	Fwd Bhd -0,20	Fwd Bhd 0,65	Fwd Bhd -0,65	—	—	Fwd Bhd 0,45	Fwd Bhd -0,45	Fwd Bhd 0,75	Fwd Bhd -0,75
	Aft Bhd -0,20	Aft Bhd 0,20	Aft Bhd -0,65	Aft Bhd 0,65	—	—	Aft Bhd -0,45	Aft Bhd 0,45	Aft Bhd -0,75	Aft Bhd 0,75
w_t	—	—	—	—	Port Bhd -0,95	Port Bhd 0,95	Port Bhd -0,05	Port Bhd 0,05	Port Bhd -0,10	Port Bhd 0,10
	—	—	—	—	Stbd Bhd 0,95	Stbd Bhd -0,95	Stbd Bhd 0,05	Stbd Bhd -0,05	Stbd Bhd 0,10	Stbd Bhd -0,10
c_ϕ, Pitch	-0,20	0,20	-0,45	0,45	-0,05	0,05	-0,10	0,10	-0,35	0,35
c_θ, Roll	0,00	0,00	0,00	0,00	1,00	-1,00	0,05	-0,05	0,05	-0,05
D. Reference Wave Heading and Motion of Installation										
Heading Angle	0	0	0	0	90	90	60	60	30	30
Heave	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up
Pitch	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up
Roll	—	—	—	—	Stbd Down	Stbd Up	Stbd Down	Stbd Up	Stbd Down	Stbd Up

* k_u = 1,0 for all load components.

** Boundary forces should be applied to produce the above specified hull girder bending moment at the middle of the structural model and the specified hull girder shear force at one end of the middle hold of the model. The sign convention for the shear force corresponds to the forward end of the middle hold.

Table 4.10 Load Cases for Sloshing

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

	Hull Girder Loads (1)				External Pressures			Sloshing Pressures (2)		Reference Wave Heading and Motions			
	M_{WV} [M_{WH}	Q_{WV} Q_{WH}	k_u k_u	k_c k_c]	k_u	k_c	k_{fo}	k_u	k_c	Heading Angle	Heave	Pitch	Roll
LC S - 1	(-) [(-)	(+) (+)	1,0 1,0	0,4 0,7]	1,0	0,5	-1,0	1,0	1,0	60°	Down	Bow Down	Stbd Down
LC S - 2	(+) [(+)	(-) (-)	1,0 1,0	0,4 0,7]	1,0	1,0	1,0	1,0	1,0	60°	Up	Bow Up	Stbd Up

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

	Hull Girder Loads (1)				External Pressures			Sloshing Pressures (2)		Reference Wave Heading and Motions			
	M_{WV} [M_{WH}	Q_{WV} Q_{WH}	k_u k_u	k_c k_c]	k_u	k_c	k_{fo}	k_u	k_c	Heading Angle	Heave	Pitch	Roll
LC S - 1	(-) [(-)	(+) (+)	1,0 1,0	0,4 0,7]	1,0	0,5	1,0	1,0	1,0	60°	Up	Bow Up	Stbd Up
LC S - 2	(+) [(+)	(-) (-)	1,0 1,0	0,4 0,7]	1,0	1,0	-1,0	1,0	1,0	60°	Down	Bow Down	Stbd Down

Notes:

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

where:

M_{WV} = *Vertical Wave Bending Moment*

Q_{WV} = *Vertical Wave Shear Force*

M_{WH} = *Horizontal Wave Bending Moment*

Q_{WH} = *Horizontal Wave Shear Force*

2 *The vertical distribution of the sloshing pressure P_{ls} is shown in Fig. 4.20.*

Table 4.11 Design Pressure for Local and Supporting Members

A. Plating & Longitudinals/Stiffeners

The nominal pressure, $p = |p_i - p_e|$, is to be determined from load cases "a" & "b" below, whichever is greater, with $k_u = 1{,}10$ and $k_c = 1{,}0$ unless otherwise specified in the table

B. Main Supporting Members

The nominal pressure, $p = |pi - pe|$, is to be determined at the mid-span of the structural member at starboard side of installation from load cases "a" & "b" below, whichever is greater, with $k_u = 1{,}0$ and $k_c = 1{,}0$ unless otherwise specified in the table

	Case "a" - At fwd end of the tank				Case "b" - At mid tank/fwd end of tank			
Structural Members/ Components	Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients		Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients	
			p_i	p_e			p_i	p_e
1. Bottom Plating & Long'l	$^2/_3$ design draft/0°	Full ballast tank	A_i	A_e	design draft/0°	Midtank of empty ballast tanks	-	B_e
2. Inner Bottom Plating & Long'l	$^2/_3$ design draft/0°	Full ballast tank, cargo tanks empty	A_i	-	design draft/0°	Fwd end of full cargo tank, ballast tanks empty	A_i	-
3. Side Shell Plating & Long'l	$^2/_3$ design draft/60°	Starboard side of full ballast tank	B_i	A_e	design draft/60°	Midtank of empty ballast tanks	-	B_e
4. *Deck Plating & Long'l (Cargo Tank)	design draft/0°	Full cargo tank	D_i	-				
5. Deck Plating & Long'l (Ballast Tank)	$^2/_3$ design draft/0°	Full ballast tank	D_i	-				
6. *Inner Skin Long'l Bhd. Plating & Long'l	design draft/60°	Starboard side of full cargo tank, ballast tank empty	B_i	-	2/3 design draft/60°	Fwd. end and starboard side of full ballast tank, cargo tank empty	B_i	-
7. *Centerline Long'l Bhd. Plating & Long'l	design draft/60°	Full starboard cargo and ballast tanks, adjacent tank empty	E_i	-				
8. *Other Long'l Bhd. Plating & Long'l	design draft/60°	Starboard side of full inward cargo tanks, adjacent tank empty	B_i	-	design draft/60°	Fwd. end and starboard side of full outboard cargo tanks, adjacent tank empty	B_i	-
9. *Trans. Bhd. Plating & Stiffener (Cargo Tank)	design draft/0°	Fwd. bhd. of full cargo tank, adjacent tanks empty	A_i	-				
10. *Trans. Bhd. Plating & Stiffener (Ballast Tank)	$^2/_3$ design draft/0°	Fwd. bhd. of full ballast tank, adjacent tanks empty	A_i	-				

* See note 4

Table 4.11 Design Pressure for Local and Supporting Members (*continued*)

Structural Members/ Components	Case "a" - Mid-tank for Transverses				Case "b" - Mid-tank for Transverses			
	Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients		Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients	
			p_i	p_e			p_i	p_e
11. Double Bottom Floor & Girder	$^2/_3$ design draft/0°	Full cargo tank, ballast tanks empty	A_i	A_e	design draft/0°	Mid-tank, cargo and ballast tanks empty	-	B_e
12. Side Transverse	$^2/_3$ design draft/60°	Wing cargo tanks full	B_i	-	design draft/60°	Center cargo tank full, wing cargo tanks empty	-	B_e
13. Transverse on Long'l. Bhd.: Ship-type installation with C.L. Long'l, Bhd., without cross ties, (Fig. 4.31A-b, Fig. 4.31A-c): Ship-type installation with four Long'l. Bhds. With cross ties:	$^2/_3$ design draft/60°	Starboard cargo tank full, port- empty	F_i	-				
Cross Ties in wing cargo tanks (Fig. 4.31A-d)	$^2/_3$ design draft/90°	Center cargo tank full, wing cargo tanks empty	C_i	-	2/3 design draft/90°	Center cargo tank empty, wing cargo tanks full	G_i	-
Cross Tie in center cargo tank, (Fig. 4.31A-e)	$^2/_3$ design draft/60°	Wing cargo tanks full, center cargo tank empty	F_i	-	2/3 design draft/60°	Center cargo tank full, wing cargo tanks empty	B_i	-
Ship-type installation with four Long'l. Bhds. without cross ties, (Fig. 4.31A-f)	$^2/_3$ design draft/60°	Wing cargo tanks full, center cargo tank empty	F_i	-	2/3 design draft/60°	Center cargo tank full, wing cargo tanks empty	C_i	-
14. Horizontal Girder and Vertical Web on Transverse Bulkhead	$^2/_3$ design draft/60°	Fwd Bhd. of full cargo tank, adjacent tanks empty	B_i	-				
15. Cross Ties: Cross Ties in wing cargo tanks Fig. 4.31A-d)	$^2/_3$ design draft/90°	Center cargo tank full, wing cargo tanks empty	C_i	-	design draft/60°	Wing cargo tanks empty, center cargo tank full (starboard)	-	B_e
Cross tie in center cargo tank (Fig. 4.31A-e)	$^2/_3$ design draft/60°	Wing cargo tanks full, center cargo tank empty	F_i	-				

Table 4.11 Design Pressure for Local and Supporting Members (*continued*)

Structural Members/ Components	Case "a" - Mid-tank for Transverses				Case "b" - Mid-tank for Transverses			
	Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients		Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients	
			p_i	p_e			p_i	p_e
16. Deck Transverses:			B_i	-				
Ship-type installation without cross ties (Fig. 4.31A-a, Fig. 4.31A-b, Fig. 4.31-c & Fig. 4.31A-f) and ship-type installations with cross tie in center cargo tanks (Fig. 4.31A-e)	$^2/_3$ design draft/60°	Cargo tank full, adjacent tanks empty						
Ship-type installation with cross ties in wing cargo tanks (Fig. 4.31A-d)	$^2/_3$ design draft/90°	Cargo tank full, adjacent tanks empty	C_i	-				
17. Deck girders	$^2/_3$ design draft/0°	Cargo tank full, adjacent tanks empty	A_i	-	2/3 design draft/60°	Cargo tank full, adjacent tanks empty	B_i	-

Notes:

1. *For calculating p_i and p_e, the necessary coefficients are to be determined based on the following designated groups:*
   a. *For p_i*
      A_i: $w_v = 0,75$, w_ℓ (fwd bhd) = 0,25, w_ℓ(aft bhd) = -0,25, $w_t = 0,0$, $c_\phi = -0,7$, $c_\vartheta = 0,0$
      B_i: $w_v = 0,4$, w_ℓ (fwd bhd) = 0,2, w_ℓ(aft bhd) = -0,2, w_t (starboard) = 0.4, w_t (port) = -0.4, $c_\phi = -0,7$, $c_\vartheta = 0,7$
      C_i: $w_v = 0,25$, $w_\ell = 0$, w_t (starboard) = 0,75, w_t (port) = -0,75, $c_\phi = 0,0$, $c_\vartheta = 1,0$
      D_i: $w_v = -0,75$, w_ℓ (fwd bhd) = 0,25, $w_t = 0,0$, $c_\phi = -0,7$, $c_\vartheta = 0,0$
      E_i: $w_v = 0,4$, w_ℓ (fwd bhd) = 0,2, w_t (centerline) = 0,4, $c_\phi = -0,7$, $c_\vartheta = -0,7$
      F_i: $w_v = 0,4$, w_ℓ (fwd bhd) = 0,2, w_ℓ (aft bhd) = -0,2, w_t (starboard) = -0,4, w_t (port) = 0,4, $c_\phi = -0,7$, $c_\vartheta = -0,7$
      Gi: $w_v = 0,25$, $w_\ell = 0$, w_t (starboard) = -0,75, w_t (port) = 0,75, $c_\phi = 0,0$, $c_\vartheta = -1,0$
   b *For p_e*
      A_e: $k_{\ell 0} = 1,0$, $k_u = 1,0$, $k_c = -0,5$
      Be: $k_{\ell 0} = 1,0$
2. *For structures within $0,4 \cdot L$ amidships, the nominal pressure is to be calculated for a tank located amidships. Each cargo tank or ballast tank in the region should be considered as located amidships, as shown in Fig. 4.19.*
3. *In calculation of the nominal pressure, $\rho \cdot g$ of the fluid cargoes is not to be taken less than 1,005 N/cm^2-m.*
4. *For structural members 4 and 6 to 10, sloshing pressures are to be considered in accordance with 2.6.2. For calculation of sloshing pressures, refer to 2.6.3 with $\rho \cdot g$ not less than 1,005 N/cm^2-m.*

2.4 Nominal Design Loads

2.4.1 General

The nominal design loads specified below are to be used for determining the required scantlings of hull structures in conjunction with the specified permissible stresses given in 3.

2.4.2 Hull Girder Loads - Longitudinal Bending Moments and Shear Forces

.1 Total Vertical Bending Moment and Shear Force

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

$$M_T = M_{sw} + k_u \cdot k_c \cdot \beta_{VBM} \cdot M_{wv} \quad [kN\text{-}m]$$

$$Q_T = Q_{sw} + k_u \cdot k_c \cdot \beta_{VSF} \cdot Q_{wv} \quad [kN]$$

where

M_{sw}, M_{wv} = still-water bending moment and wave-induced bending moment, respectively, as specified in Rules for Hull (Pt.1, Vol.II), Sec.5, B for either hogging or sagging conditions.

Q_{sw}, Q_{wv} = still-water and wave-induced shear forces, respectively, as specified in Rules for Hull (Pt.1, Vol.II), Sec.5, B for either positive or negative shears.

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

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

β_{VBM} = ESF for vertical bending moment as defined in Annex 4, B.

β_{VSF} = ESF for vertical shear force as defined in Annex 4, B.

For determining the hull girder section modulus for 0,4 · L amidships, as specified in 3, the maximum still-water bending moments, either hogging or sagging, are to be added to the hogging or sagging wave bending moments, respectively. Elsewhere, the total bending moment may be directly obtained based on the envelope curves, as specified in 2.2.1 and 2.3.1.

For this purpose, k_u = 1,0, and k_c = 1,0

.2 Horizontal Wave Bending Moment and Shear Force

For non-head sea conditions, the horizontal wave bending moment and the horizontal shear force, as specified in 2.3.3, are to be considered as additional hull girder loads, especially for the design of the side shell and inner skin structures. The effective horizontal bending moment and shear force, M_{WHE} and Q_{WHE}, may be determined by the following equations:

$$M_{WHE} = k_u \cdot k_c \cdot M_{WH} \quad [kN\text{-}m]$$

$$Q_{WHE} = k_u \cdot k_c \cdot Q_{WH} \quad [kN]$$

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

2.4.3 Local Loads for Design of Supporting Structures

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

1) Maximum internal pressures for a fully filled tank with the adjacent tanks empty and minimum external pressures, where applicable.
2) Empty tank with the surrounding tanks full and maximum external pressures, where applicable.

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

1) $p_i = k_s \cdot \rho \cdot g\,(\eta + k_u \cdot h_d)$ max. and
   $p_e = \rho \cdot g\,(h_s + \beta_{EPS/EPP} \cdot k_u \cdot h_{de})$ min.

2) p_i = 0 and

p_e = $\rho \cdot g\,(h_s + \beta_{EPS/EPP} \cdot k_u \cdot h_{de})$ max.

where

k_u = 1,0

$\beta_{EPS/EPP}$ = ESF for external pressure starboard/port, as defined in Annex 4, B

$\rho \cdot g$, η, h_d, h_s, h_{de}, k_s are as defined in 2.3.4 and 2.3.5.

Specific information required for calculating the nominal loads are given in Table 4.11 for various structural members and configurations.

2.4.4 Local Pressures for Design of Plating and Longitudinals

In calculating the required scantlings of plating, longitudinals and stiffeners, the nominal pressures should be considered for the two load cases given in 2.4.3, using k_u = 1,1 for p_i and p_e instead of k_u = 1,0 as shown above.

The necessary details for calculating p_i and p_e are given in Table 4.11.

2.5 Combined Load Cases

2.5.1 Combined Load Cases for Structural Analysis

For assessing the strength of the hull girder structure and in performing a structural analysis as outlined in 4. For the three cargo tank length model structural analysis, the combined load cases specified in Tables 4.9A through 4.9C are to be considered. Additional combined load cases may be required as warranted. The loading patterns are shown in Fig. 4.8A through 4.8C for three cargo tank lengths. The necessary correlation factors and relevant coefficients for the loaded tanks are also given in Tables 4.9A through 4.9C. The total external pressure distribution including static and hydrodynamic pressure is illustrated in Fig. 4.17.

For the cargo block model structural analysis, the loading conditions in 3.2.3.2 are to be considered.

2.5.2 Combined Load Cases for Failure Assessment

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

.1 Yielding, Buckling and Ultimate Strength of Local Structures

For assessing the yielding, buckling and ultimate strength of local structures, the combined load cases as given in Tables 4.9A through 4.9C are to be considered.

.2 Fatigue Strength

For assessing the fatigue strength of structural joints, the combined load cases given in 2.5.1 are to be used for a first level fatigue strength assessment as outlined in Annex 5.

2.6 Sloshing Loads

2.6.1 General

.1 Except for tanks that are situated wholly within the double side or double bottom, the natural periods of liquid motions and sloshing loads are to be examined in assessing the strength of boundary structures for all cargo or ballast tanks which will be partially filled between 20% and 90% of tank capacity. The sloshing pressure heads given in this Sub-Section may be used for determining the strength

requirements for the tank structures. Alternatively, sloshing loads may be calculated either by model experiments or numerical simulation using three-dimensional flow analysis for unrestricted service conditions and for sea conditions of the specific site of operation. Methodology and procedures of tests and measurements or analysis methods are to be fully documented and submitted for review.

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

2.6.2 Strength Assessment of Tank Boundary Structures

.1 Tank Length and Pitch Induced Sloshing Loads

Tanks of length 54 m or greater are to satisfy requirements of either of the preventative measures given in .3 or .4. Where the tank has smooth surfaces, one or more swash bulkheads are to be fitted. Structural reinforcement is to be provided to the tank ends, when the calculated pressure is higher than the pressure, p_i, as specified in 2.7.

Tanks of length 54 m or greater that have ring webs are to have a partial non-tight bulkhead (i.e. non-full depth swash bulkhead) to eliminate the possibility of resonance at all filling levels. The partial non-tight bulkhead may be waived if it can be demonstrated through the application of model experiments or numerical simulation using three-dimensional flow analysis that sloshing impacts do not occur. The height of the swash bulkhead is to be determined on the basis of calculation using three-dimensional flow analysis as described in 2.6.1.1.

Where the tank length is less than 54 m, and if either of the preventative measures given in 2.6.2.3 or 2.6.2.4 is not satisfied, the tank boundary structures are to be designed in accordance with 2.7 to withstand the sloshing pressures specified in 2.6.3.

.2 Roll Induced Sloshing Loads

Tanks that do not satisfy either of the preventative measures given in 2.6.2.3 or 2.6.2.4, with respect of roll resonance, are to have their tank boundary structures designed in accordance with 2.7 to withstand the sloshing pressures specified in 2.6.3.

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

Long tanks have length, ℓ, exceeding $0{,}1 \cdot L$. Wide tanks have width, b, exceeding $0{,}6 \cdot B$.

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

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

$$T_x = \frac{\sqrt{\beta_T \cdot \ell_e}}{k} \quad \text{in the longitudinal direction}$$

$$T_y = \frac{\sqrt{\beta_L \cdot b_e}}{k} \quad \text{in the transverse direction}$$

where

ℓ_e = effective length of the tank, as defined in 2.6.3.1 [m]

b_e = effective breadth of the tank [m], as defined in 2.6.3.1.

$k = \sqrt{\frac{g \cdot \tanh H_1}{4 \cdot \pi}}$

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

β_T, β_L, d_ℓ and d_b are as defined in 2.6.3.1. The natural periods given in 2.3.5 for pitch and roll of the installation, T_p and T_r, using the actual GM value, if available, may be used for this purpose.

2.6.3 Sloshing Pressures

.1 Nominal Sloshing Pressure

For cargo tanks with filling levels within the critical range specified in 2.6.2.2, the internal pressures p_{is}, including static and sloshing pressures, positive toward tank boundaries, may be expressed in terms of equivalent liquid pressure head, he, as given below:

$$p_{is} = k_s \cdot \rho \cdot g \cdot h_e \geq 0 \qquad [N/cm^2]$$

where

k_s = load factor as defined in 2.3.5.2.1)

h_e = $k_u \left[h_c + \frac{(h_t - h_c)(y - d_m)}{h - d_m} \right]$ for $y > d_m$

= $c_m \cdot h_m + k_u \cdot h_c$ for $0{,}15 \cdot h < y < d_m$ ($c_m \cdot h_m$ need not exceed h)

h_e calculated at $y = 0{,}15 \cdot h$ for $y < 0{,}15 \cdot h$, but h_e should not be smaller than $c_m \cdot h_m$.

c_m = coefficient in accordance with Fig. 4.21

h_m = static pressure head, taken as the vertical distance [m], measured from the filling level, d_m, down to the point considered. d_m, the filling level for maximum h_c calculated with $C_{\phi s}$ and $C_{\theta s}$ equal to 1,0, should not be taken less than $0{,}55 \cdot h$.

d_m = filling level [m], as shown in Fig. 4.20

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

h_c = maximum average sloshing pressure heads [m], to be obtained from calculations as specified below for at least two filling levels, $0{,}55 \cdot h$ and the one closest to the resonant period of ship motions, between $0{,}2 \cdot h$ and $0{,}9 \cdot h$.

h_c may be taken as constant over the tank depth, h (See Fig. 4.20)

h_t = sloshing pressure heads for upper bulkhead [m], to be obtained from calculation below

h = depth of tank [m]

y = vertical distance [m], measured from the tank bottom to the point considered

$\rho \cdot g$ is as defined in 2.3.5.2.

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

$$h_c = k_c \sqrt{C_{\phi s} \cdot h_\ell^2 + C_{\theta s} \cdot h_b^2} \qquad [m]$$

$$h_t = k_c \sqrt{C_{\phi s} \cdot h_{t\ell}^2 + C_{\theta s} \cdot h_{tb}^2} \quad [m]$$

where

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

$$h_\ell = \phi_{es} \cdot \ell_e \cdot C_{t\ell} \cdot \beta_T \left[0{,}018 + C_{f\ell} \frac{1{,}0 - d_\ell / H_\ell}{\phi_{es}} \right] \frac{d_\ell}{H_\ell} \quad [m] \text{ for } \phi_{es}$$

$$h_b = \theta_{es} \cdot b_e \cdot C_{tb} \cdot \beta_L \left[0{,}016 + C_{fb} \frac{1{,}0 - d_b / H_b}{\theta_{es}} \right] \frac{d_b}{H_b} \quad [m] \text{ for } \theta_{es}$$

$C_{\phi s}$ and $C_{\theta s}$ are the weighted coefficients as given in Fig. 4.21.

where

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

ϕ_{es} = $0{,}71 \cdot \phi$

θ_{es} = $0{,}71 \cdot \theta$

The pitch amplitude ϕ and roll amplitude θ are as defined in 2.3.5.1 with $d_i = 2/3\ \mathbf{T}_i$ and V = 10 knots

ℓ_e = effective tank length that accounts for the effect of deep ring-web frames, [m]

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

b_e = effective tank width that accounts for the effect of deep ring-web frames, [m]

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

β* = 1,0 for tanks without deep ring webs,

= $0{,}25 \left[4{,}0 - (1 - \alpha^*) - (1 - \alpha^*)^2 \right]$ for α* to be determined at d_0,

β_T^* represents β* for transverse bulkheads.

β_L^* represents β* for longitudinal bulkheads.

β = $(\beta_0)(\beta_u)(\beta_s)$

β_T represents β for transverse bulkheads.

β_L represents β for longitudinal bulkheads.

β_0 = 1,0 for tanks without a swash bulkhead

= $0{,}25 \left[4{,}0 - (1 - \alpha_o) - (1 - \alpha_o)^2 \right]$ for tanks with a swash bulkhead

β_u = 1,0 for tanks without any deep bottom transverse and deep bottom longitudinal girder

= $0{,}25 \left[4{,}0 - \frac{d_{\ell 1}}{h} - \left(\frac{d_{\ell 1}}{h} \right)^2 \right]$ for tanks with deep bottom transverses

= $0{,}25 \left[4{,}0 - \frac{d_{b1}}{h} - \left(\frac{d_{b1}}{h} \right)^2 \right]$ for tanks with deep bottom longitudinal girders

β_s = 1,0 for boundary bulkheads that :

i) do not contain any deep horizontal girder; or

ii) do contain deep horizontal girders but with an opening ratio, αs, less than 0,2 or greater than 0,4

$= 0,25\left[4,0 - (1 - \alpha_s) - (1 - \alpha_s)^2\right]$ for bulkheads with deep horizontal girders having an opening ratio, αs, between 0,2 and 0,4

α = opening ratio (see Fig. 4.22)

For α_0 Fig. 4.23(1), opening ratios of swash bulkheads, shall be used for all filling levels considered. Also, Fig. 4.23(2), local opening ratio for $d_0 = 0,7 \cdot h$, bounded by the range between $0,6 \cdot h$ and $0,9 \cdot h$, shall be considered for openings within the range. The smaller of the two opening ratios calculated, based on Fig. 4.23(1) and Fig. 4.23(2) for this filling level, shall be used as the opening ratio.

For α*, Fig. 4.23(3), opening ratio of deep ring-webs, filling level d_0 shall be used.

For α_s, Fig. 4.23(4), opening ratio of a deep horizontal girder on a boundary bulkhead, is applicable to a filling level just above the horizontal girder in the zones illustrated in the figure. Not to be considered for $d_0 = 0,7 \cdot h$, unless a sizable girder is installed between $0,7 \cdot h$ and h. Also not to be considered if opening area in the girder is less than 20% or greater than 40% of the area of the girder (i.e., $\alpha_s = 1$)

$$C_{f\ell} = 0,792\sqrt{\frac{d_\ell}{\beta_T \cdot \ell_e}} + 1,98$$

$$C_{fb} = 0,704\sqrt{\frac{d_b}{\beta_L \cdot b_e}} + 1,76$$

$$C_{t\ell} = \frac{0,9 \cdot x_{o1}}{1 + 9\,(1 - x_o)^2} \geq 0,25$$

$$x_0 = \frac{T_x}{T_p}$$

$x_{01} = x_0$ if $x_0 \leq 1,0$

$= \frac{1}{x_o}$ if $x_0 > 1,0$

$$C_{tb} = \frac{0,9 \cdot y_{o1}}{1 + 9 \cdot (1 - y_o)^2} \geq 0,25$$

$y_0 = \frac{T_y}{T_r}$ If roll radius of gyration is not known, 0,39 · **B** may be used in the calculation of T_r

$y_{01} = y_0$ if $y_0 \leq 1,0$

$= \frac{1}{y_o}$ if $y_0 > 1,0$

T_x and T_y are as defined in 2.6.2.4.

T_p and T_r are as defined in 2.3.5.

d_0 = filling depth, [m]

d_ℓ = $d_o - d_{\ell 1}\sqrt{1 - \sigma_n^2 \frac{n+1}{2}}\, k_{\ell 1} - 0{,}45 \cdot d_{\ell 2} \cdot k_{\ell 2}$ and $\geq 0{,}0$

d_b = $d_0 - d_{b1}\sqrt{1 - \sigma_m^2 \frac{m+1}{2}}\, k_{b1} - 0{,}45 \cdot d_{b2} \cdot k_{b2}$ and $\geq 0{,}0$

H_ℓ = $h - d_{\ell 1}\sqrt{1 - \sigma_n^2 \frac{n+1}{2}}\, k_{\ell 1} - 0{,}45 \cdot d_{\ell 2} \cdot k_{\ell 2}$

H_b = $h - d_{b1}\sqrt{1 - \sigma_m^2 \frac{m+1}{2}}\, k_{b1} - 0{,}45 \cdot d_{b2} \cdot k_{b2}$

$d_{\ell 1}$ = height of deep bottom transverses measured from the tank bottom, (Fig. 4.24), [m]

$d_{\ell 2}$ = bottom height of the lowest openings in non-tight transverse bulkhead measured above the tank bottom or top of bottom transverses (Fig. 4.24) [m]

n = number of deep bottom transverses in the tank

d_{b1} = height of deep bottom longitudinal girders measured from the tank bottom (Fig. 4.24) [m]

d_{b2} = bottom height of the lowest openings in non-tight longitudinal bulkhead measured above the tank bottom, or top of bottom longitudinal girders (Fig. 4.24) [m]

m = number of deep bottom longitudinal girders in the tank

$k_{\ell 1}$ = -1 if $d_0 \leq d_{\ell 1}$

= 1 if $d_0 > d_{\ell 1}$

$k_{\ell 2}$ = -1 if $d_0 \leq d_{\ell 2}$

= 1 if $d_0 > d_{\ell 2}$

k_{b1} = -1 if $d_0 \leq d_{b1}$

= 1 if $d_0 > d_{b1}$

k_{b2} = -1 if $d_0 \leq d_{b2}$

= 1 if $d_0 > d_{b2}$

σ_n = $\dfrac{\frac{4}{\pi}(n+1)}{n(n+2)\cos\frac{\pi}{2(n+1)}}$

σ_m = $\dfrac{\frac{4}{\pi}(m+1)}{m(m+2)\cos\frac{\pi}{2(m+1)}}$

ℓ_s (b_s) shall be used in place of ℓ_e (b_e) for a filling level below the completely solid portion of the nontight bulkhead, i.e., the region below the lowest opening, (Fig. 4.24), where ℓ_s (b_s) is taken as the distance bounded by the solid portion of the nontight bulkhead below the lowest opening and the tight bulkhead. d_ℓ, H_ℓ and d_b, H_b need not consider the effect of $d_{\ell 2}$ and d_{b2}, respectively.

$$h_{tl} = 0{,}0068 \cdot \beta'_T \cdot \ell_e \; C'_{t\ell} \; (\phi_{es} + 40) \sqrt{\phi_{es}} \quad [m]$$

$$h_{tb} = 0{,}0055 \cdot \beta'_L \cdot b_e \; C'_{tb} \; (\theta_{es} + 35) \sqrt{\theta_{es}} \quad [m]$$

where

$C'_{t\ell}$ and C'_{tb} are $C_{t\ell}$ and C_{tb} for $h_m = 0{,}70 \cdot h$; β'_T and β'_L correspond to β for $d_0 = 0{,}7 \cdot h$; ϕ_{es} and θ_{es} are as defined previously. $C_{\phi s}$ and $C_{\theta s}$ are weighted coefficients, as given in Fig. 4.21. $h_{t\ell}$ shall not be less than h_p; h_{tb} shall not be less than h_r

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

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

.2 Sloshing Loads for Assessing Strength of Structures at Tank Boundaries

1) In assessing the strength of tank boundary supporting structures, the two combined load cases with loading pattern shown in Fig. 4.25, with the specified sloshing loads shown in Table 4.10 for the respective side on which the horizontal girder is located, are to be considered when performing a 3D structural analysis.

2) In assessing the strength of plating and stiffeners at tank boundaries, local bending of the plating and stiffeners with respect to the local sloshing pressures for structural members/elements is to be considered in addition to the nominal loadings specified for the 3D analysis in 1) above. In this regard, k_u should be taken as 1,15 instead of 1,0, shown in 1) above for the combined load cases, to account for the maximum pressures due to possible non-uniform distribution.

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

In addition to the sloshing loads acting on the bulkhead plating, the sloshing loads normal to the web plates of horizontal and vertical girders are to be also considered for assessing the strength of the girders. The magnitude of the normal sloshing loads may be approximated by taking 25% of h_c or h_t for k_u = 1,0, whichever is greater, at the location considered.

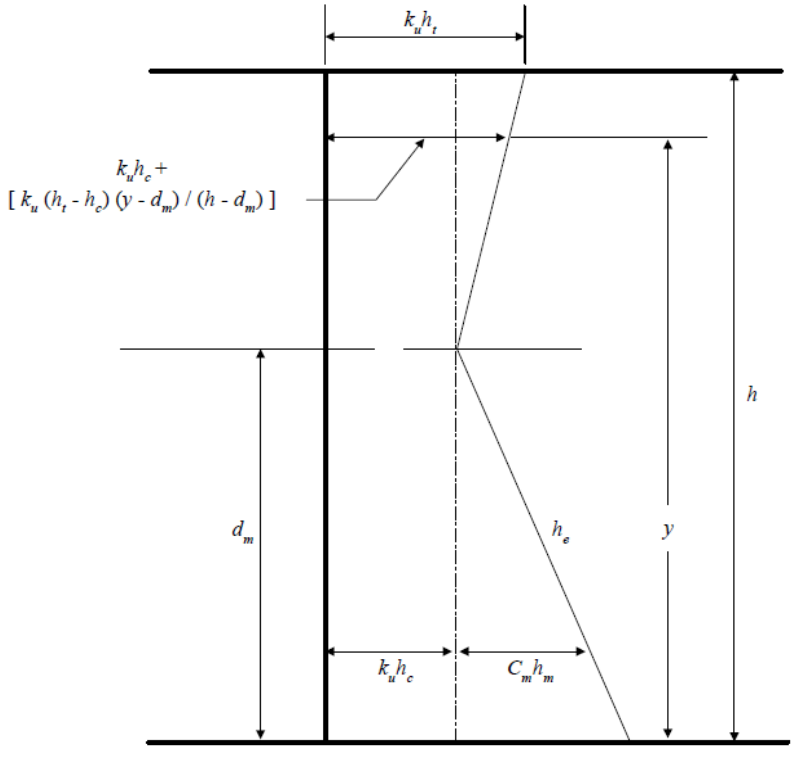
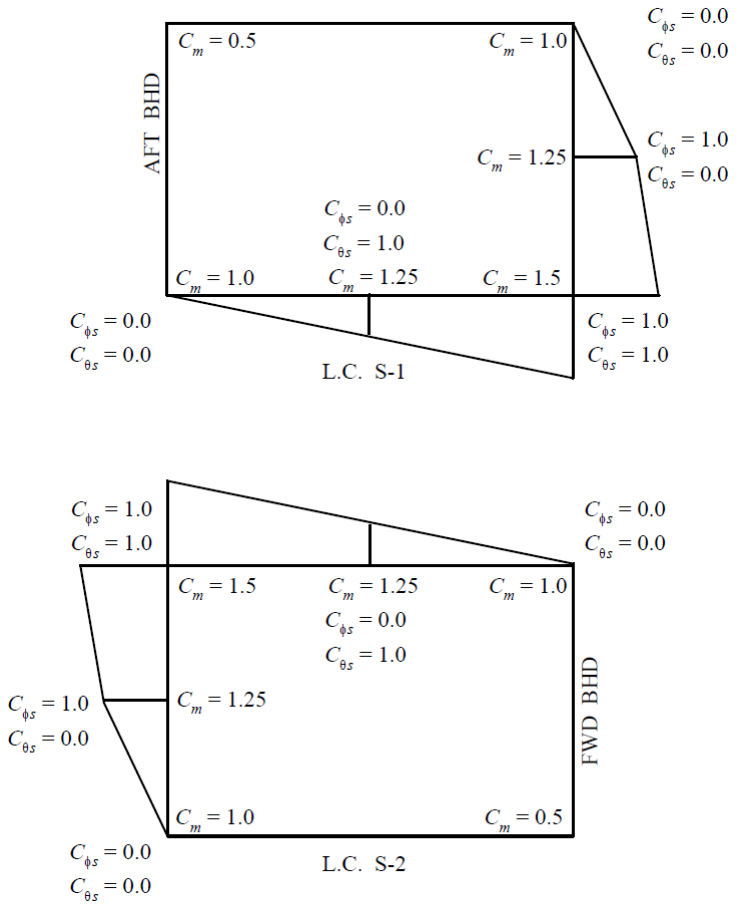


Fig. 4.20 Vertical Distribution of Equivalent Slosh Pressure Head, h_e



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

Fig. 4.21 Horizontal Distribution of Simultaneous Slosh Pressure Heads, h_c (ϕ_s θ_s) or h_t (ϕ_s θ_s)

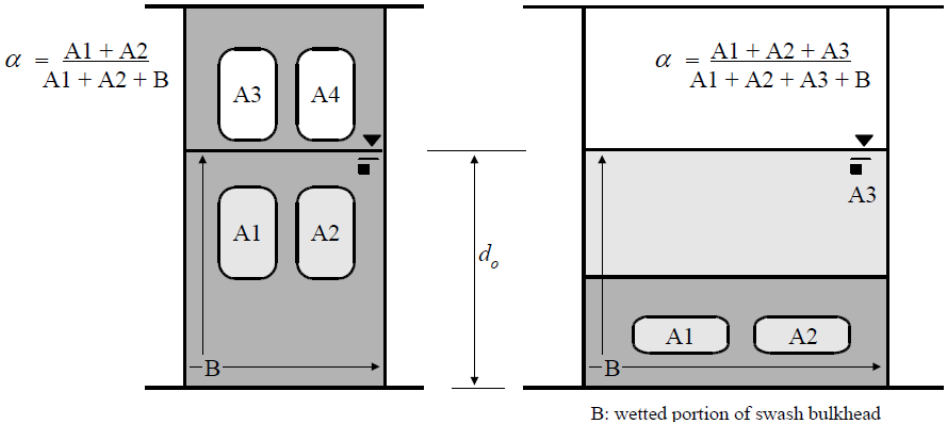
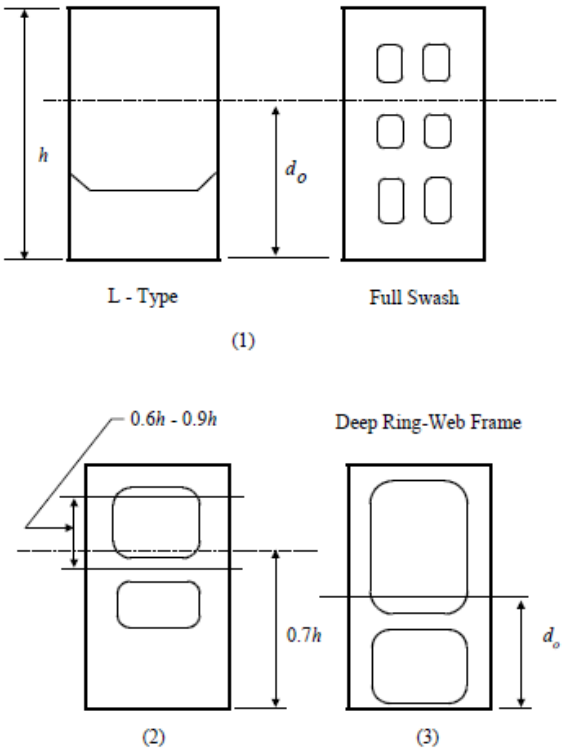
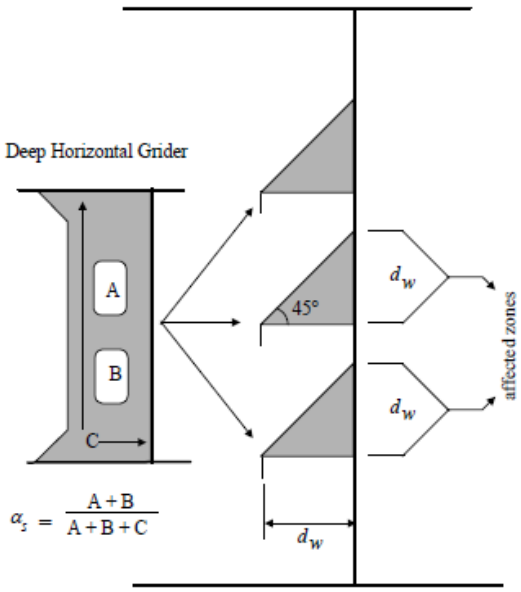


Fig. 4.22 Definitions for Opening Ratio, α



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



(4) Opening Ratio of Deep Horizontal Girders Boundary Bulkheads

Fig. 4.23 Opening Ratios

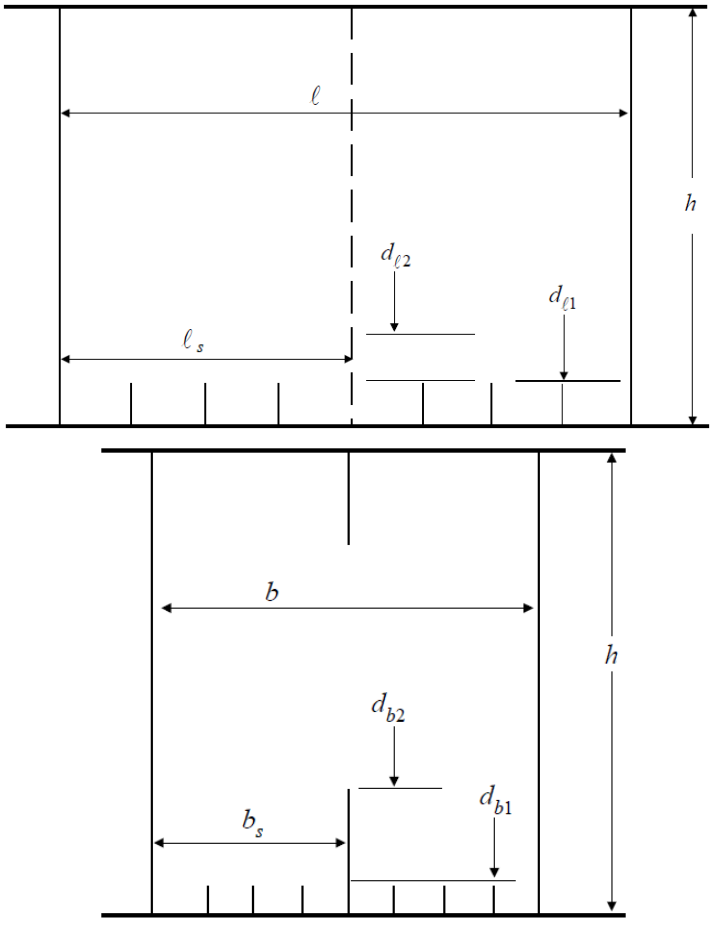
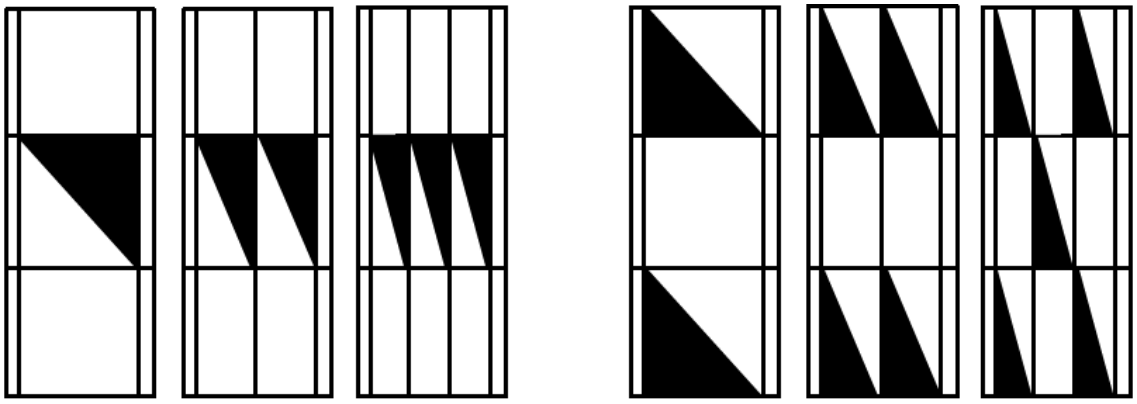


Fig. 4.24 Dimensions of Internal Structures

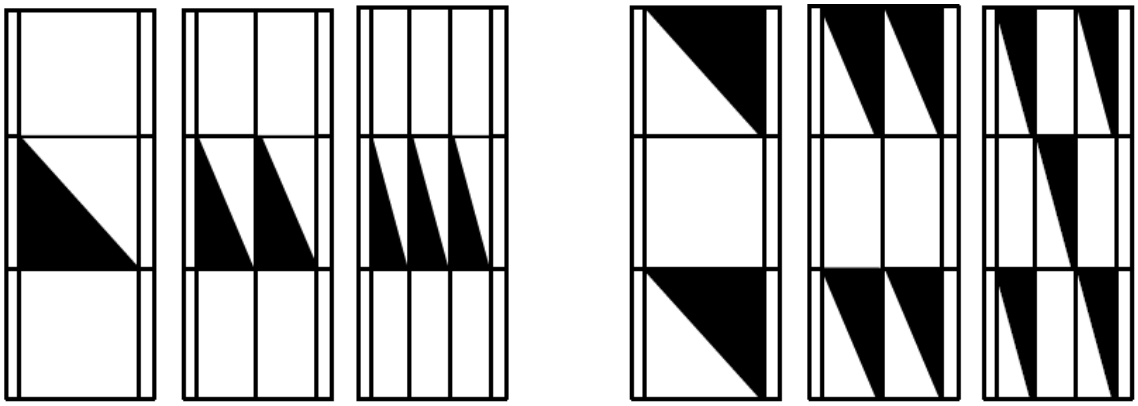
Type A: Where the Horizontal Girder is on the Aft Side of Transverse Bulkhead



a. Load Case S-1; 2/3 Design Draft

b. Load Case S-2; 2/3 Design Draft

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



a. Load Case S-1; 2/3 Design Draft

b. Load Case S-2; 2/3 Design Draft

Fig. 4.25 Loading Patterns for Sloshing Load Cases

2.7 Impact Loads

2.7.1 Impact Loads on Bow

When experimental data or direct calculations are not available, nominal bow impact pressures due to wave celerity above the load waterline (LWL) in the region from the forward end to the collision bulkhead may be obtained from the following equation:

$$P_{ij} = k \cdot C_k \cdot C_{ij} \cdot V_{ij}^2 \cdot \sin\gamma_{ij} \qquad [kN/m^2]$$

where

k = 1,025

C_{ij} = $\{1 + \cos^2 [90 (F_{bi} - 2\, a_j)/F_{bi}]\}^{1/2}$

V_{ij} = $\omega_1 \cdot \sin \alpha_{ij} + \omega_2 (\beta_{WHT} \cdot L)^{1/2}$

ω_1 = 3,09 [m]

ω_2 = 1,0 [m]

β_{WHT} = ESF for Wave Height as defined in Annex 4, B

γ_{ij} = local bow impact angle measured to the shell from the horizontal to the tangent line at the position considered, but is not to be less than 50°. Where this angle is not available, it can be taken as $\tan^{-1}(\tan \beta_{ij}/\cos \alpha_{ij})$.

α_{ij} = local waterline angle measured from the centerline, see Fig 4.26

β_{ij} = local body plan angle measured from the horizontal, see Fig 4.26

F_{bi} = freeboard from the highest deck at side to the load waterline (LWL) at station i, see Fig. 4.26

a_j = vertical distance from LWL to WL-j, see Fig. 4.26

i, j = station and waterline to be taken to correspond to the locations under consideration, as required by 5.2.1.1

C_k = 0,7 at collision bulkhead and 0,9 at 0,0125**L**, linear interpolation for in between

= 0,9 between 0,0125**L** and **FP**

= 1,0 at and forward of **FP**.

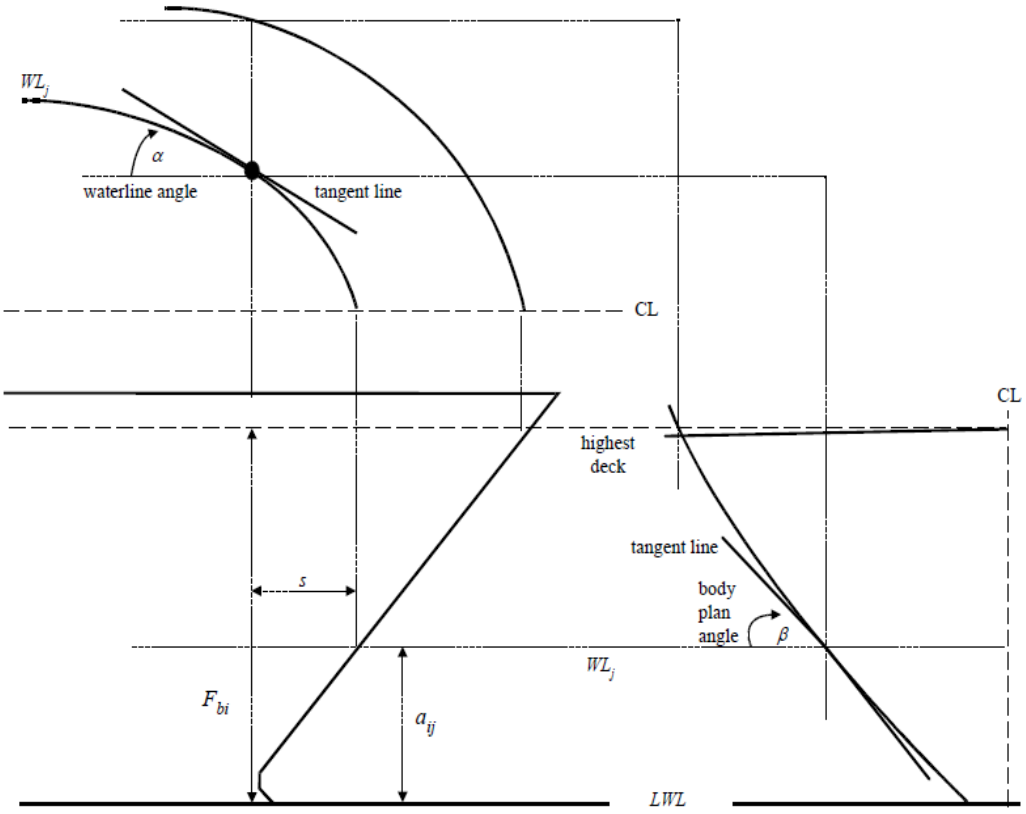


Fig. 4.26 Definition of Bow Geometry

2.7.2 Bottom Slamming

For ship-type installations with heavy weather ballast draft forward less than 0,04 **L** but greater than 0,025**L**, bottom slamming loads are to be considered for assessing strength of the flat of bottom plating forward and the associated stiffening system in the fore body region.

.1 Bottom Slamming Pressure

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

$$P_{ij} = k \cdot k_i \cdot \left[v_o^2 + M_{Vi} \cdot E_{ni}\right] \cdot E_f \qquad [kN/m^2]$$

where

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

k = 1,025

k_i = $2,2 \cdot b^*/d_0 + \alpha \le 40$

b^* = half width of flat of bottom at the i-th ship station, see Fig. 4.27

d_0 = $^1/_{10}$ of the section draft at the heavy ballast condition, see Fig. 4.27

α = a constant as given in Table 4.12

E_f = $f_1 \cdot \omega_1 \cdot \sqrt{L}$

f_1 = 0,004

where b represents the half breadth at the 1/10 draft of the section, see Fig. 4.27. Linear interpolation may be used for intermediate values.

v_0 = $c_0 \cdot \sqrt{L}$ [m/s]

c_0 = 0,29

M_{Ri} = $1,391 \cdot A_i \cdot \beta_{vm} \cdot \sqrt{\frac{L}{C_B}}$

β_{vm} = ESF for vertical relative motion as defined in Annex 4, B

C_B = as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.4.

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

A_i and B_i are as given in Table 4.13.

G_{ei} = $e^{-\left(\frac{v_0^2}{M_{Vi}} + \frac{d_i^2}{M_{Ri}}\right)}$

d_i = local section draft [m]

E_{ni} = natural log of n_i

n_i = $5730\sqrt{\frac{M_{Vi}}{M_{Ri}}} \cdot G_{ei}$,if $n_i < 1$ then $P_{si} = 0$

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

= $23400 \cdot \sqrt{\frac{B \cdot H^3}{\Delta_S \cdot C_B{}^3 \cdot L^3}} + c_0 \ge 3,7$

where

Δ_S = $\Delta_b\,[1,2 + B / (3 \cdot d_b)]$

Δ_b = installation displacement at the heavy ballast condition [kN]

d_b = mean draft of installation at the heavy ballast condition [m]

c_0 = 1,0 for heavy ballast draft

L, B and H are as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.

Table 4.12 Values of α

b/d_0	α	b/d_0	α
1,00	0,00	4,00	20,25
1,50	9,00	5,00	22,00
2,00	11,75	6,00	23,75
2,50	14,25	7,00	24,50
3,00	16,50	7,50	24,75
3,50	18,50	25,0	24,75

Table 4.13 Values of A_i and B_i

Section i from F.P.	Ai	Bi
-0,05 L	1,25	0,3600
0	1,00	0,4000
0,05 L	0,80	0,4375
0,10 L	0,62	0,4838
0,15 L	0,47	0,5532
0,20 L	0,33	0,6666
0,25 L	0,22	0,8182
0,30 L	0,22	0,8182

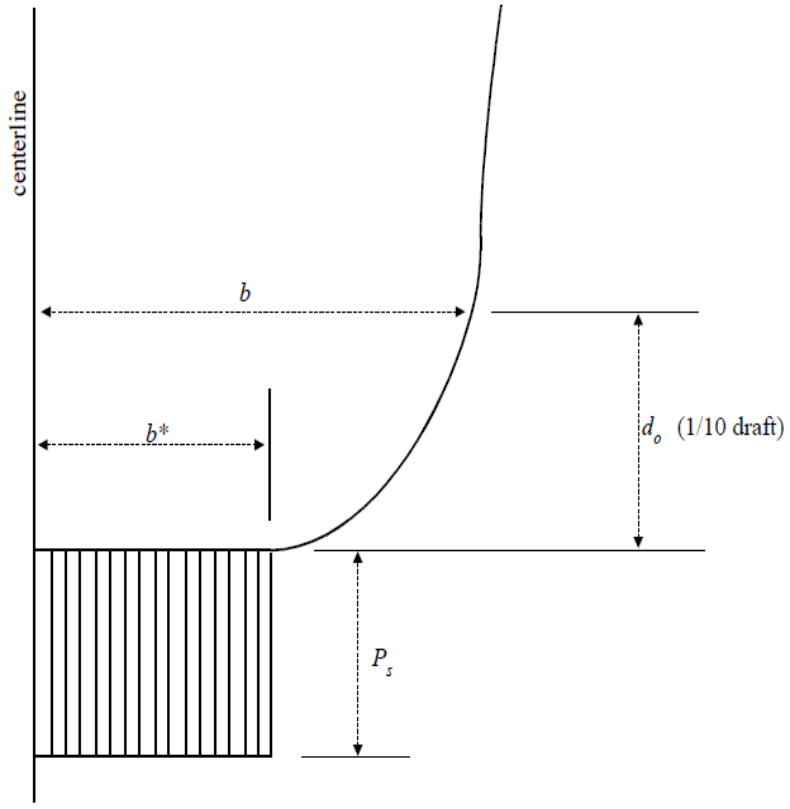


Fig. 4.27 Distribution of Bottom Slamming Pressure along the Section Girth

2.7.3 Bowflare Slamming

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

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

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

$$= \left(\frac{b_T}{H}\right)^2 \cdot \sum b_j \sqrt{1+\left(\frac{s_j}{b_j}\right)^2} \quad , j = 1,n \; ; \; n \geq 3$$

where

n = number of segments

b_T = Σb_j

H = Σs_j

b_j = local change (increase) in beam for the j-th segment at station i (see Fig. 4.28)

s_j = local change (increase) in freeboard up to the highest deck for the j-th segment at station i forward (see Fig. 4.28)

.1 Nominal Bowflare Slamming

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

P_{ij} = P_{0ij} or P_{bij} as defined below, whichever is greater

$$P_{0ij} = 9{,}807 \cdot \sqrt{9 \cdot M_{Ri} - h_{ij}^2} \qquad [kN/m^2]$$

$$P_{bij} = 1{,}025\,[\,39{,}2 + K_{ij} \cdot M_{vi} \cdot (1 + E_{ni})] \qquad [kN/m^2]$$

where

$$n_{ij} = 5730\sqrt{\frac{M_{Vi}}{M_{Ri}}} \qquad G_{ij} \geq 1{,}0$$

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

$$G_{ij} = e^{-\frac{h_{ij}^2}{M_{Ri}}}$$

$$M_{Ri} = 1{,}391 \cdot A_i \cdot \beta_{RVM} \sqrt{\frac{L}{C_B}}$$

A_i = as shown in Table 4.14

β_{RVM} = ESF for relative vertical motion as defined in Annex 4, B

C_B = as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.4.

L = length of installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.4.

M_{Vi} = $B_i \cdot M_{Ri}$,where B_i is given in Table 4.14

h_{ij} = vertical distance measured from the load waterline (LWL) at station i to WL_j on the bowflare. The value of h_{ij} is not to be taken less than 2,0 m

$$K_{ij} = f_{ij}\sqrt{\left(\frac{r_j}{b_{ij} + 0.5 \cdot h_{ij}}\right)^3} \cdot \frac{\ell_{ij}}{r_j}$$

r_j = $\sqrt{M_{Ri}}$

b_{ij} = local half beam of WL_j at station i. The value of b_{ij} is not to be taken less than 2,0 m

ℓ_{ij} = longitudinal distance of WL_j at station i measured from amidships

f_{ij} = $\left[\frac{90}{\beta_{ij}} - 1\right]^2 \left[\frac{\tan\beta_{ij}}{3{,}14}\right]^2 \cos\gamma$

β_{ij} = local body plan angle measured from the horizontal, in degrees, need not be taken less than 35 degrees, see Fig. 4.28

γ = installation stem angle at the centerline measured from the horizontal, Fig. 4.29, in degrees, not to be taken greater than 75 degrees

Table 4.14 Values of A_i and B_i*

	A_i	B_i
-0,05 L	1,25	0,3600
FP	1,00	0,4000
0,05 L	0,80	0,4375
0,10 L	0,62	0,4838
0,15 L	0,47	0,5532
0,20 L	0,33	0,6666
0,25 L	0,22	0,8182
0,30 L	0,22	0,8182

* Linear interpolation may be used for intermediate values.

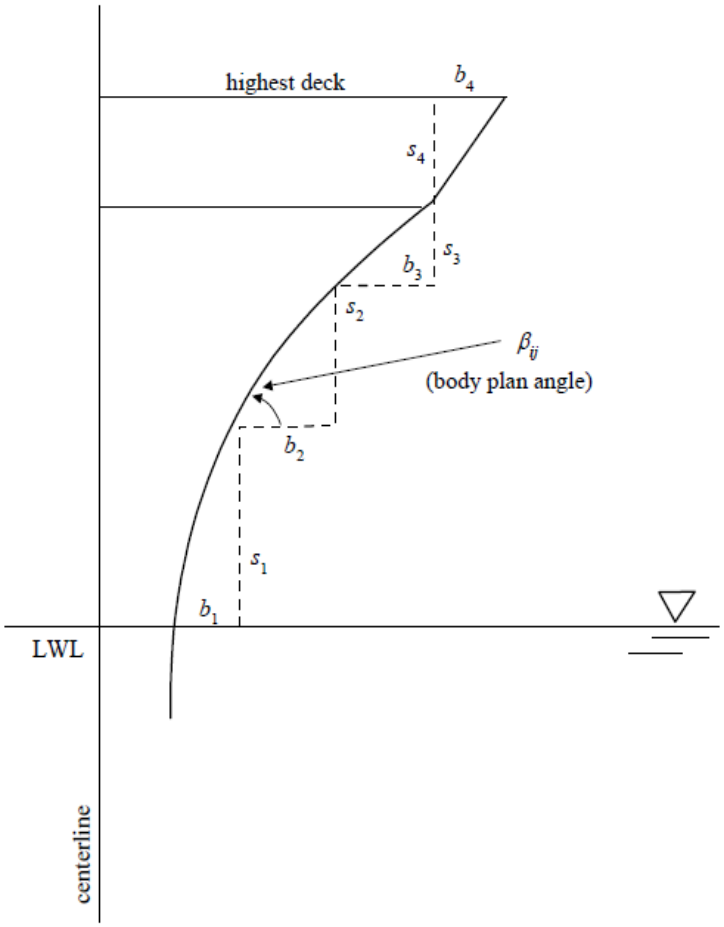


Fig. 4.28 Definition of Bowflare Geometry for Bowflare Shape Parameter

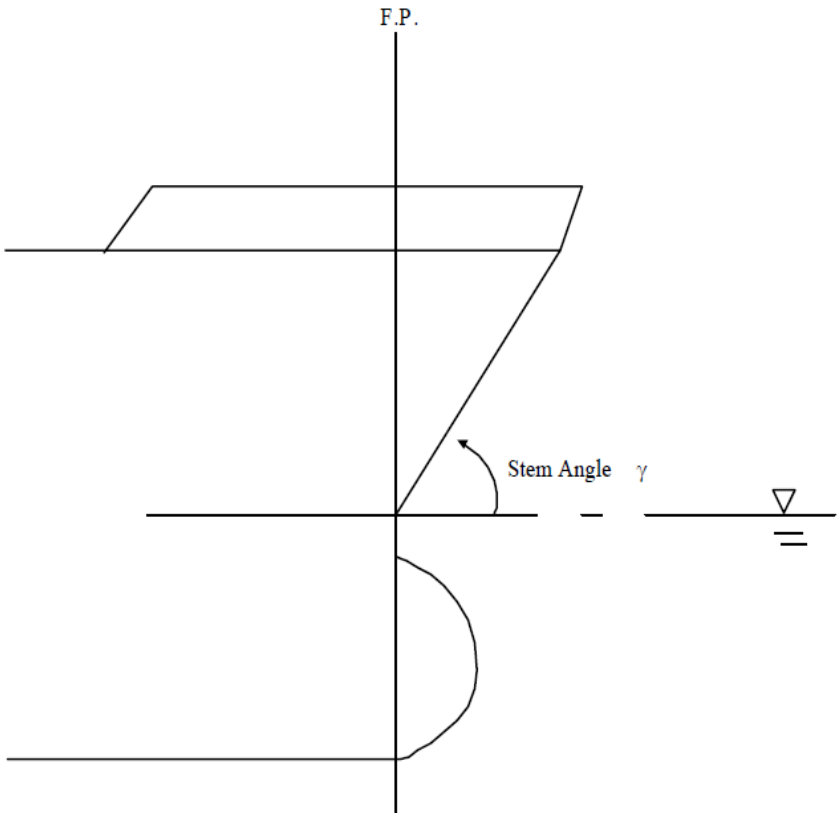


Fig. 4.29 Ship-Type Installation Stem Angle, γ

.2 Simultaneous Bowflare Slamming Pressure

For performing structural analyses to determine overall responses of the hull structures, the spatial distribution of instantaneous bowflare slamming pressures on the forebody region of the hull may be expressed by multiplying the calculated maximum bowflare slamming pressures, P_{ij}, at forward ship stations by a factor of 0,71 for the region between the stem and 0,3 · **L** from the **F.P.**

2.7.4 Green Water on Deck

When experimental data or direct calculations are not available, nominal green water pressure imposed on deck along the installation length, including the extension beyond the **F.P.**, may be obtained from the following equations.

$$P_{gi} = 10{,}052 \cdot \left\{ \left(\frac{\beta_{VRM} \cdot A_i \cdot \sqrt[4]{\frac{B}{L}}}{C_B} \right) - F_{bi} \right\} \qquad [kN/m^2]$$

where

P_{gi} = Green water pressure, uniformly distributed across the deck at specified longitudinal section i along the installation length under consideration (see Table 4.15 below). Pressure in between is obtained by linear interpolation. P_{gi} is not to be taken less than 20,6 kN/m^2.

A_i = as shown in Table 4.11

β_{RVM} = ESF factor of relative vertical motion, as defined in Annex 4, B

C_B = as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.4.

L = scantling length of installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1.

B = greatest molded breath of installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2

F_{bi} = freeboard from the highest deck at side to the load waterline (LWL) at station i, [m], see Fig. 4.26

Table 4.15 Values of A_i

Section i from F.P.	A_i
-0,05L	23,3
0	20,7
0,05L	18,2
0,10L	16,1
0,15L	14,7
0,20L	14,3
0,25L	14,2
0,30L	14,1
0,35L	14
0,40L	14
0,45L	14
0,50L	14
0,55L	14
0,60L	14
0,65L	14
0,70L	14
0,75L	14,2
0,80L	14,2
0,85L	14,2
0,90L	14,7
0,95L	17,1
1,00L	19,9

2.8 Deck Loads

2.8.1 General

For the design and evaluation of deck structures, the following loads due to on deck production facilities are to be considered:

1) Static weight of on deck production facilities in upright condition.
2) Dynamic loads due to ship motions.
3) Wind load.

2.8.2 Loads for On-Site Operation

The nominal forces from each individual deck production module at the center of gravity of the module can be obtained from the following equations:

$$F_V = W_m \cdot \left(\cos(0{,}71 \cdot C_\phi \phi) \cdot \cos(0{,}71 \cdot C_\theta \theta) + \frac{0{,}71 \cdot c_v \cdot a_v}{g} \right) \quad [kN]$$

$$F_t = W_m \cdot \left(\sin(0{,}71 \cdot C_\theta \theta) + \frac{0{,}71 \cdot c_T \cdot a_t}{g} \right) + k_t \cdot F_{wind} \quad [kN]$$

$$F_\ell = W_m \cdot \left(-\sin\left(0{,}71 \cdot C_\phi \phi\right) + \frac{0{,}71 \cdot c_L \cdot a_\ell}{g} \right) + k_\ell \cdot F_{wind} \qquad [kN]$$

where,

ϕ and θ are the pitch and roll amplitudes defined in 2.3.5.1.

ϕ, in degrees, need not to be taken more than 10 degrees.

θ, in degrees, need not to be taken more than 30 degrees.

a_v, a_t and a_ℓ are the vertical, transverse and longitudinal accelerations, as specified in 2.3.5.1 for heading angles μ in Table 4.16.

Note:

The accelerations specified in 2.3.5.1 are to be considered preliminary values and may be used only when values from model tests or ship motion calculations are not yet available. The final design forces from deck production modules are to be calculated using acceleration values obtained from model test data or ship motions calculations for the site location.

F_v = vertical load from each production module [kN], positive downward

F_t = transverse load from each production module [kN], positive starboard

F_ℓ = longitudinal load from each production module [kN], positive forward

W_m = weight of the production module [kN]

F_{wind} = $k \cdot A_{wind} \cdot C_s \cdot C_h \cdot V_{wind}^2$ [kN]

Two combinations of wave-induced and wind forces are to be considered:

F_v, F_t with factor $k_t = 1$ and F_ℓ with factor $k_\ell = 0$

F_v, F_t with factor $k_t = 0$ and F_ℓ with factor $k_\ell = 1$

The deck load is to be obtained for the maximum weight of on deck production facilities for head sea (Load Case A), beam sea (Load Case B) and oblique sea (Load Case C) listed in Table 4.16, where the correlation factors c_v, c_T, c_L, C_ϕ and C_θ for each load case are also shown.

Table 4.16 Correlation Factors c_v, c_T, c_L, C_ϕ and C_θ

Load Case	LC A (head sea)	LC B (beam sea)	LC C (oblique)
c_v	0,8	0,4	0,7
c_L	0,6	0	0,7
c_T	0	0,9	0,7
C_ϕ	-1	0	-0,7
C_θ	0	1	0,7
Wave heading angle μ in deg.	0	90	60

where

V_{wind} = wind velocity based on 1-hour average speed

A_{wind} = projected area of windage on a plane normal to the direction of the wind [m^2]

C_s = shape coefficient, defined in Section 2, B.4.

C_h = height coefficient, defined in Section 2, B.4, for 1-hour average wind

The forces from each deck production module can be obtained based on long-term prediction for the realistic sea states of the specific site of operation. In no case are the forces F_v, F_t and F_ℓ to be less than those obtained using the values of Environmental Severity Factors (ESFs) established from Annex 4, B.

2.8.3 Loads in Transit Condition

Nominal loads of the production facility modules on deck during transit condition can be obtained from the equations in item 2.8.2, above. Alternatively, corresponding forces can be calculated based on the sea condition for the specific voyage. Also see Section 2, B.

3. Initial Scantling Calculation (ISCal)

3.1 General

3.1.1 Strength Requirement

This Section specifies the minimum strength requirements for hull structure with respect to the determination of initial scantlings, including the hull girder, shell and bulkhead plating, longitudinals/stiffeners and main supporting members. Once the minimum scantlings are determined, the strength of the resulting design is to be assessed in accordance with 4. The assessment is to be carried out by means of an appropriate structural analysis as per 4.6, in order to establish compliance with the failure criteria in 4.2. Structural details are to comply with 3.1.3.

The requirements for hull girder strength are specified in 3.2. The required scantlings of double bottom structures, side shell and deck, and longitudinal and transverse bulkheads are specified in 3.4 through 3.9 below. Fig. 4.30 shows the appropriate Subsections giving scantling requirements for the various structural components of typical double hull ship-type installations. For hull structures beyond 0,4**L** amidships, the initial scantlings are determined in accordance with 5.

3.1.2 Calculation of Load Effects

Equations giving approximate requirements are given in 3.4 through 3.7 for calculating the maximum bending moments and shear forces for main supporting members clear of the end brackets, and axial loads for cross ties for typical structural arrangements and configurations (Fig 4.31A and 4.31B). For designs with different structural configurations, these local load effects may be determined from a 3D structural analysis at the early design stages, as outlined in 4.6, for the combined load cases specified in 2.5, excluding the hull girder load components. In this regard, the detailed analysis results are to be submitted for review.

3.1.3 Structural Details

The strength criteria specified in this Section and in 5 are based on assumptions that all structural joints and welded details are properly designed and fabricated and are compatible with the anticipated working stress levels at the locations considered. It is critical to closely examine the loading patterns, stress concentrations and potential failure modes of structural joints and details during the design of highly stressed regions. In this exercise, failure criteria specified in 4.2 may be used to assess the adequacy of structural details.

3.1.4 Evaluation of Grouped Stiffeners

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

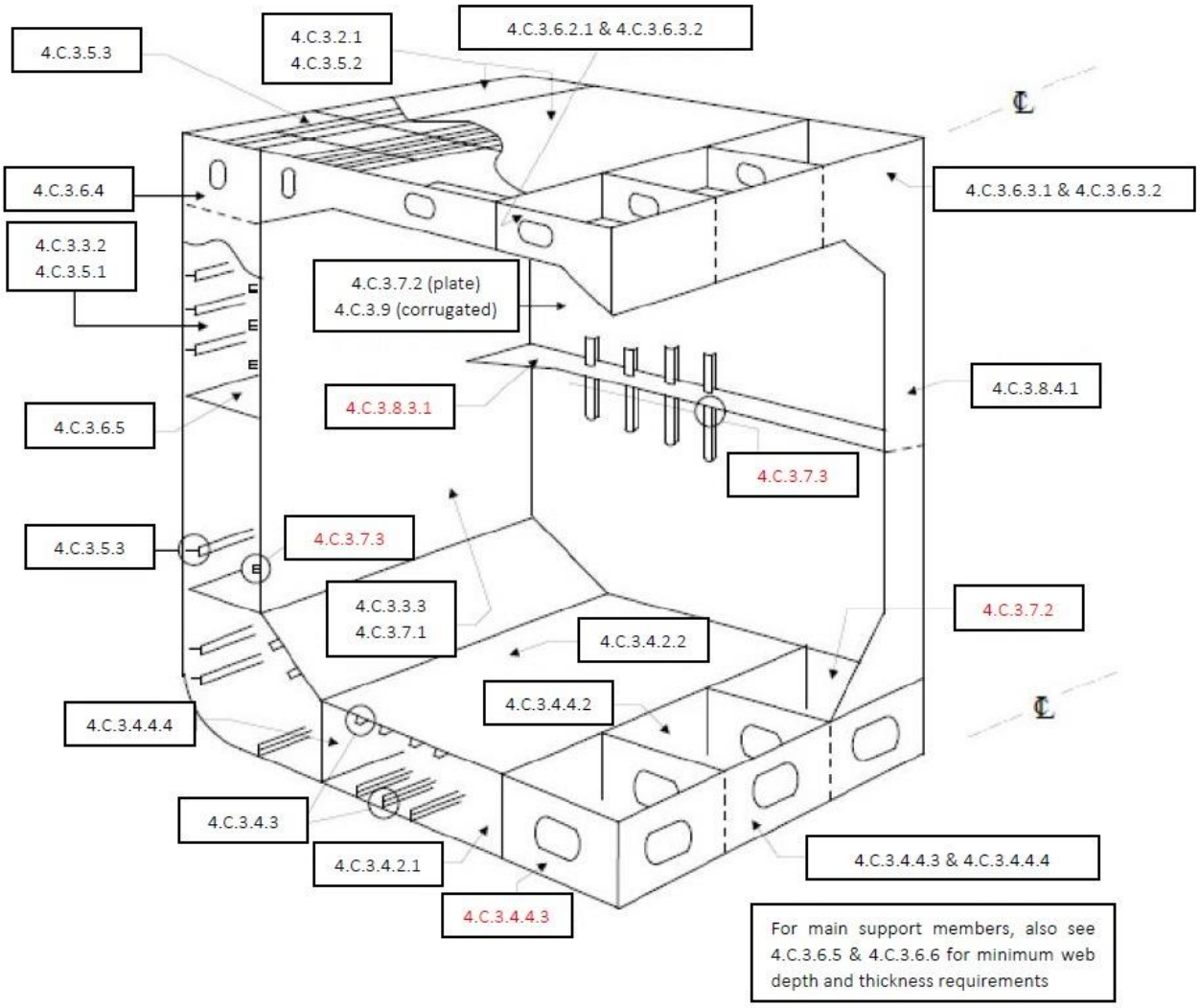
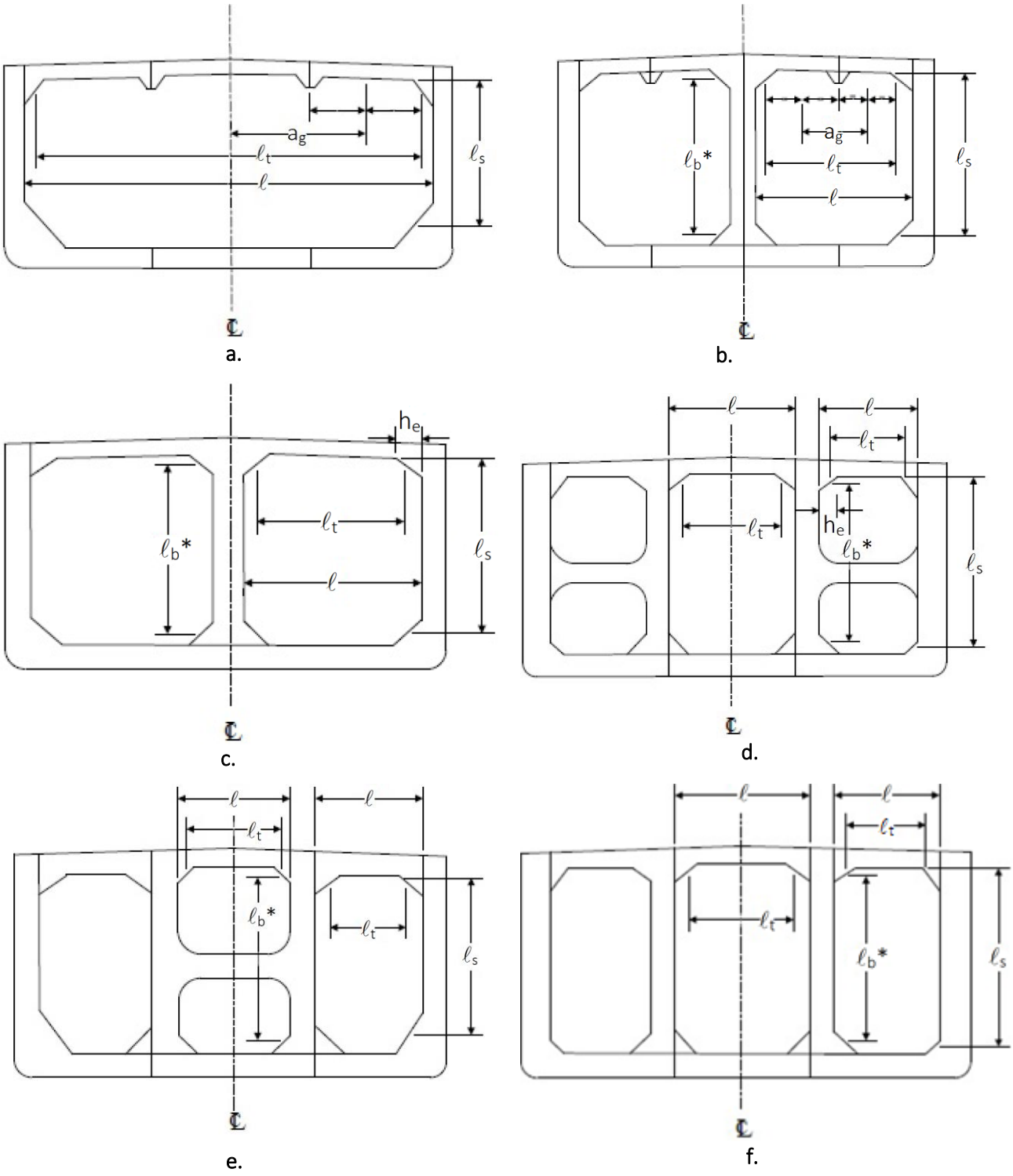
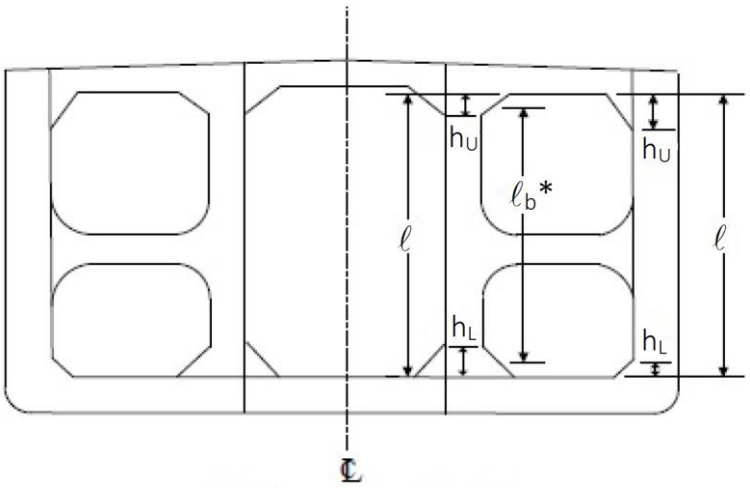


Fig. 4.30 Scantling Requirement Reference by Subsection

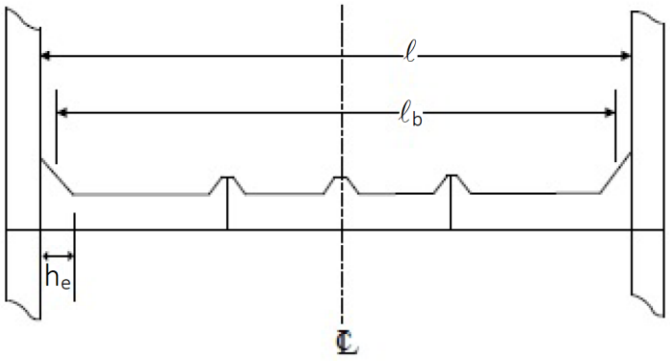


* *Where both lower and upper ends of the vertical web are fitted with a bracket of the same or larger size on the opposite side, the span ℓ_b may be taken between the toes of the effective lower and upper brackets.*

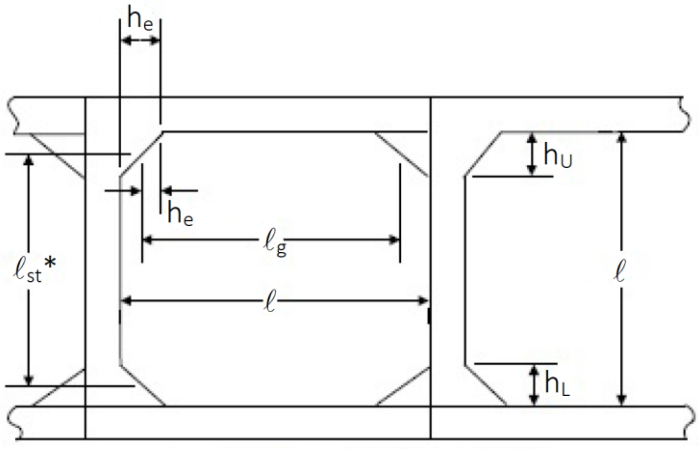
Fig. 4.31A Definitions of Spans (A)



a. Side Transvers and Vertical Web on Longitudinal Bulkhead



b. Horizontal Girder on Transverse Bulkhead



c. Deck Girder and Vertical Web on Transverse Bulkhead

* *Where both lower and upper ends of the vertical web are fitted with a bracket of the same or larger sizeon the opposite side, the span ℓb b or ℓst may be taken between the toes of the effective lower and upper brackets.*

Fig. 4.31B Definitions of Spans (B)

3.2 Hull Girder Strength

3.2.1 Hull Girder Section Modulus

.1 Hull Girder Section Modulus Amidships

The required hull girder section modulus 0,4**L** amidships is to be calculated in accordance with Rules for Hull (Pt.1, Vol. II) Sec. 5, C.1 and C.4 and A.2.1 of this Guidelines. For the determination of initial net structural scantlings, the net hull girder section modulus amidships, W_{net}, is to be calculated in accordance with 3.2.1.2 below.

.2 Effective Longitudinal Members

The hull girder section modulus calculation is to be carried out in accordance Rules for Hull (Pt.1, Vol. II) Sec. 5, C.4, as modified below. To suit the strength criteria based on a "net" ship concept, the nominal design corrosion values specified in Table 4.8 are to be deducted in calculating the net section modulus, W_{net}.

.3 Extent of Midship Scantlings

The items included in the hull girder section modulus amidships are to be extended as necessary to meet the hull girder section modulus required at the location being considered. The required hull girder section modulus can be obtained as M_t/σ_p at the location being considered except if $(M_t)_{max}/\sigma_p$ is less than W_{min} in A.2.1 In this case, the required section modulus is to be obtained by multiplying W_{min} by the ratio of $M_{ti}/(M_t)_{max}$ where M_{ti} is the total bending moment at the location under consideration and $(M_t)_{max}$ is the maximum total bending moment amidships.

3.2.2 Hull Girder Moment of Inertia

The hull girder moment of inertia is to be not less than:

$$I = L \cdot \left(\frac{W}{33{,}3} \right) \quad [cm^2\text{-}m^2]$$

where

L = length of installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.

W = required hull girder section modulus [cm^2-m^2]. See A.2.

3.2.3 Hull Girder Ultimate Strength

In addition to the strength requirements specified in 3.2.1, the vertical hull girder ultimate strength for either hogging or sagging conditions for the FPI design environmental condition (DEC) is to satisfy the limit state as specified below. It need only be applied within the 0,4**L** amidship region.

$$\gamma_{SW} \cdot M_{SW} + \gamma_{WV} \cdot \beta_{VBM} \cdot M_{WV} \leq \frac{M_U}{\gamma_U}$$

where

M_{SW} = permissible still-water bending moment, in accordance with Rules for Hull (Pt.1, Vol.II), Sec.5, B.2 [KN-m].

M_{WV} = vertical wave-induced bending moment in accordance with Rules for Hull (Pt.1, Vol.II), Sec.5, B.3.1 [kN-m]

M_U = hull girder ultimate strength [kN-m], which may be determined from the equations as given in Annex 6

β_{VBM} = ESF for vertical wave-induced bending moment for DEC

γ_{SW} = load factor for the maximum permissible still-water bending moment, but not to be taken as less than 1.

γ_{WV} = load factor for the wave-induced bending moment, but not to be taken as less than below for the given limits

= 1,3 for $M_{SW} < 0,2 \cdot M_T$ or $M_{SW} > 0,5 \cdot M_T$

= 1,2 for $0,2 \cdot M_T \leq M_{sw} \leq 0,5 \cdot M_T$

M_T = total bending moment [kN-m]

= $M_{SW} + \beta_{VBM} \cdot M_{wv}$ [kN-m]

γ_u = safety factor for the vertical hull girder bending capacity, but not to be taken as less than 1,15

3.3 Shearing Strength

3.3.1 General

The net thickness of the side shell and longitudinal bulkhead plating is to be determined based on the total vertical shear force, Q_T, and the permissible shear stress, τ_s, given below, where the outer longitudinal bulkheads (inner skin) are located no further than 0,075**B** from the side shell.

The nominal design corrosion values as given in Table 4.8 for the side shell and longitudinal bulkhead plating are to be added to the "net" thickness thus obtained.

$$Q_t = Q_{SW} + \beta_{VSF} \cdot Q_{WV} \quad [kN]$$

$$t = \frac{Q \cdot S_y}{I \cdot \tau_S} \quad [cm]$$

where

Q_{SW} = still-water shear force [kN], based on the still-water shear force envelope curve for all anticipated loading conditions in accordance with Rules for Hull (Pt.1, Vol. II), Sec.5, B.2, at location considered.

β_{VSF} = ESF for vertical shear force, as defined in Annex 4, B

Q_{WV} = vertical wave shear force [kN], as given in Rules for Hull (Pt.1, Vol.II), Sec.5, B.3.2.

Q_{WV} for in-port condition may be taken as zero.

t = t_s or t_i (see 3.3.2 and 3.3.3)

Q = $Q_T \cdot D_s$ or $(Q_T + R_i) \cdot D_i$ (see 3.23.2 and 3.3.3 below)

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

I = moment of inertia of the "net" hull girder section at the position considered [cm^4]

τ_s = 11,96/ k [kN/cm^2] at sea

= 10,87/ k [kN/cm^2] in port

k = material conversion factor

= 1,0 for normal strength steel

= 0,78 for Grade H32 steel

= 0,72 for Grade H36 steel

= 0,68 for Grade H40 steel

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

3.3.2 Net Thickness of Side Shell Plating

$$t_s \geq \frac{Q_t \cdot D_s \cdot D_y}{I \cdot \tau_s} \quad [cm]$$

where

D_s = shear distribution factor for side shell, as defined in 3.3.2.1, 3.3.2.2 or 3.3.2.3 below.

Q_T, S_y, I and τ_s are as defined in 3.3.1 above.

.1 Shear Distribution Factor for Ship-type Installations with Two Outer Longitudinal Bulkheads (inner skin only)

$$D_s = 0{,}384 - \frac{0{,}167 \cdot A_{ob}}{A_s} - \frac{0{,}190 \cdot b_s}{B}$$

where

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

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

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

B = breadth of the installation, [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.6.

.2 Shear Distribution Factor for Ship-type Installations with Two Outer Longitudinal Bulkheads and a Centerline Swash or Oil-tight Longitudinal Bulkhead

$$D_s = 0{,}347 - \frac{0{,}057 \cdot A_{cb}}{A_s} - \frac{0{,}137 \cdot A_{ob}}{A_s} - \frac{0{,}070 \cdot b_s}{B}$$

where

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

A_s, A_{ob}, b_s and B are as defined in 3.3.2.1 above.

.3 Shear Distribution Factor for Ship-type Installations with Two Outer and Two Inner Longitudinal Bulkheads

$$D_s = 0{,}333 - \frac{0{,}218 \cdot A_{ob}}{A_s} - \frac{0{,}043 \cdot b_s}{B}$$

Where A_s, A_{ob}, b_s and **B** are as defined in 3.3.2.1 above.

3.3.3 Thickness of Longitudinal Bulkheads

$$t_s \geq \frac{(Q_t + R_i) \cdot D_i \cdot S_y}{I \cdot \tau_s} \quad [cm]$$

where

D_i = shear distribution factor

R_i = local load correction

i = o_b for outer longitudinal bulkhead (inner skin)

= i_b for inner longitudinal bulkhead

= c_b for centerline longitudinal bulkhead

Q_T, I, S_y and τ_s are as defined above.

The other parameters, depending on the configuration of the ship-type installation, are defined in 3.3.3.1, 3.3.3.2 and 3.3.3.3 below.

.1 Ship-type Installations with Two Outer Longitudinal Bulkheads (Inner Skin Only)

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

$$t_s \geq \frac{Q_t \cdot D_{ob} \cdot S_y}{I \cdot \tau_s} \quad [cm]$$

where

$$D_s = 0{,}105 + \frac{0{,}156 \cdot A_{ob}}{A_s} + \frac{0{,}190 \cdot b_s}{B}$$

A_s, A_{ob}, b_s, **B**, Q_T, I, S_y and τ_s are defined above.

.2 Ship-type Installations with Two Outer Longitudinal Bulkheads and a Centerline Swash or Oil-tight Longitudinal Bulkhead

1) The net thickness of the centerline longitudinal bulkhead plating at the position considered:

$$t_{cb} \geq \frac{(Q_T + R_{cb}) \cdot D_{cb} \cdot S_y}{I \cdot \tau_s} \quad [cm]$$

where

$$R_{cb} = W_c \left[\frac{2 \cdot N_{wcb} \cdot k_{cb} \cdot I}{3 \cdot H_{cb} \cdot D_{cb} \cdot S_y} - 1 \right] \geq 0$$

$$k_{cb} = 1 + \frac{A^*_{cb}}{A_{cb}} \le 1{,}9$$

$$D_{cb} = 0{,}229 + \frac{0{,}152 \cdot A_{cb}}{A_s} - \frac{0{,}10 \cdot A_{ob}}{A_s} - \frac{0{,}198 \cdot b_s}{B}$$

W_c = local load [kN], calculated according to 3.3.4 and Fig. 4.32(a)

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

= $(0{,}66 \cdot D_{cb} + 0{,}25)\,(n - 1)/n$

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

H_{cb} = depth of the centerline longitudinal bulkhead above inner bottom [cm]

A_{cb}^* = total area of the net centerline longitudinal bulkhead plating above the lower edge of the strake under consideration [cm^2]

All other parameters are as defined in 3.3.2.

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

$$t_{ob} \ge \frac{Q_T \cdot D_{ob} \cdot S_y}{I \cdot \tau_s} \quad [cm]$$

where

$$D_{ob} = 0{,}106 - \frac{0{,}093 \cdot A_{cb}}{A_s} - \frac{0{,}164 \cdot A_{ob}}{A_s} - \frac{0{,}202 \cdot b_s}{B}$$

All other parameters are as defined in 3.3.2 and 3.3.3.

.3 Ship-type Installations with Two Outer and Two Inner Longitudinal Bulkheads

1) The net thickness of the inner longitudinal bulkhead plating at the position considered :

$$t_{ib} \ge \frac{(Q_T + R_{ib}) \cdot D_{ib} \cdot S_y}{I \cdot \tau_s} \quad [cm]$$

where

$$R_{ib} = W_{c1}\left[\frac{2 \cdot N_{wib1} \cdot k_{ib} \cdot I}{3 \cdot H_{ib} \cdot D_{ib} \cdot S_y} - 1\right] + W_{c2}\left[\frac{2 \cdot N_{wib2} \cdot k_{ib} \cdot I}{3 \cdot H_{ib} \cdot D_{ib} \cdot S_y} - 1\right] \ge 0$$

$$k_{ib} = 1 + \frac{A^*_{ib}}{A_{ib}} \le 1{,}9$$

$$D_{ib} = 0{,}058 + \frac{0{,}173 \cdot A_{ib}}{A_s} - \frac{0{,}043 \cdot b_s}{B}$$

W_{c1}, W_{c2} = local load, [kN], calculated according to 3.3.4 and Fig. 4.3 2(b)

A_{ib} = total area of the net inner longitudinal bulkhead plating above inner bottom [cm^2]

A_{ib}^* = total area of the net inner longitudinal bulkhead plating above the lower edge of the strake under consideration [cm^2]

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

N_{wib1} = $(0,49D_{ib} + 0,18)\cdot(n - 1)/n$ for local load W_{c1}

N_{wib2} = $(0,60D_{ib} + 0,10)\cdot(n - 1)/n$ for local load W_{c2}

H_{ib} = depth of the inner longitudinal bulkhead above inner bottom [cm]

All other parameters are as defined above.

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

$$t_{ob} \geq \frac{Q_t \cdot D_{ob} \cdot S_y}{I \cdot \tau_s} \quad [cm]$$

where

$$D_{ob} = 0,013 + \frac{0,153 \cdot A_{ob}}{A_s} + \frac{0,172 \cdot b_s}{B}$$

All other parameters are as defined above.

3.3.4 Calculation of Local Loads

In determining the shear forces at the ends of cargo tanks, the local loads are to be calculated as shown in the following example. The tank arrangement for this example is as shown in Fig. 4.32. The ballast tanks within double bottom and double side are to be considered as being empty in calculating excess liquid head.

.1 Ship-type Installations with Two Outer Longitudinal Bulkheads and a Centerline Swash or Oil-tight Longitudinal Bulkhead

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

$$W_C(f) = W_C(a) = 0,5 \cdot \rho \cdot g \cdot b_C \cdot \ell_C \cdot \left[k_S \cdot H_C + 0,71 \cdot k_S \frac{a_V}{g} H_C + 0,47 \cdot k_S \cdot \ell_C \cdot \sin\phi - 0,55 \cdot \left(\frac{\rho_0}{\rho}\right) \cdot T + 0,2 \cdot \left(\frac{\rho_0}{\rho}\right) \cdot C_0 \right] \geq 0$$

but need not be taken greater than $0,5 \cdot k_s \cdot \rho \cdot g \cdot b_c \cdot \ell_c \cdot H_c$

Where:

k_s = load factor

= 1,0 for all loads from ballast tanks

= 0,878 for $\rho \cdot g$ of 10,05 kN/m^3 and 1,0 for $\rho \cdot g$ of 11,18 kN/m^3 and above for all loads from cargo tanks.

For cargo $\rho \cdot g$ between 10,05 kN/m^3 and 11,18 kN/m^3, the factor k_s may be determined by interpolation

$\rho \cdot g$ = specific weight of the liquid, not to be taken less than 10,05 kN/m^3

$\rho_o \cdot g$ = specific weight of sea water, 10,05 kN/m^3

ℓ_c, b_c = length and breadth, respectively, of the center tanks, in m, as shown in Fig 4.32(a)

H_c = liquid head in the center tank [m]

a_v = vertical acceleration amidships with a wave heading angle of 0 degrees [m/sec^2], as defined in 2.3.5.1(c)

g = acceleration of gravity = 9,8 m/sec^2

ϕ = pitch amplitude in degrees, as defined in 2.3.5.1(a)

T = draft [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.7.

C_0 = as defined in Rules for Hull (Pt.1, Vol.II), Sec.4, A.2

.2 Ship-type Installations with Two Outer and Two Inner Longitudinal Bulkheads

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

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

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

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

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

Where:

k_s = load factor, as defined in 3.3.4.1

$\rho \cdot g$ = specific weight of the liquid, not to be taken less than 10,05 kN/m^3

ℓ_c = length of the center tank [m], as shown in Fig. 4.32(b)

ℓ_1, ℓ_2 = longitudinal distances from the respective center tank ends to the intermediate wing tank transverse bulkheads [m], as shown in Fig. 4.32(b)

b_{c1} = breadth of the center tank [m], as shown in Fig. 4.32(b)

b_{c2} = breadth of the center and wing tanks [m], as shown in Fig. 4.32(b)

H_1, H_2 = liquid heads in the wing tanks [m], as shown in Fig. 4.32(b)

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

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

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

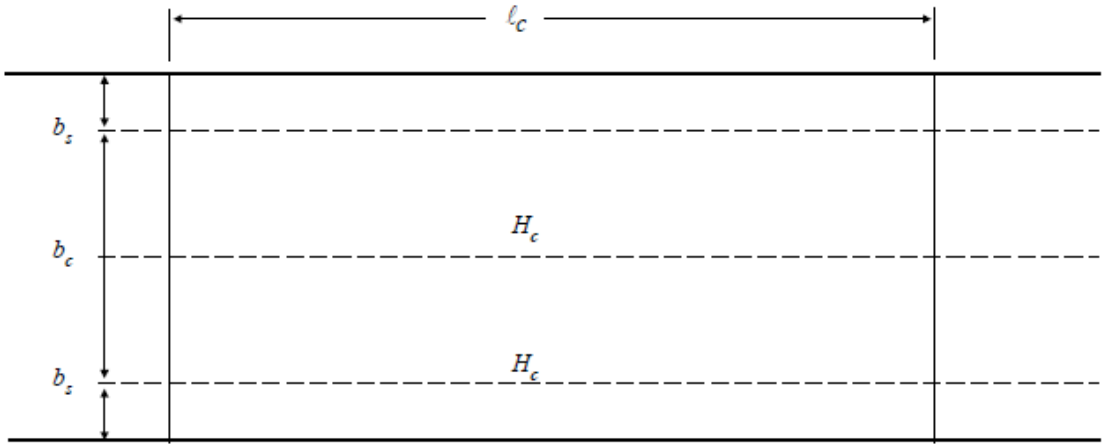
h_{c4} = H_c or H_2, whichever is lesser

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

3.3.5 Three Dimensional Analysis

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

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



b. Tankers with Four Longitudinal Bulkhead

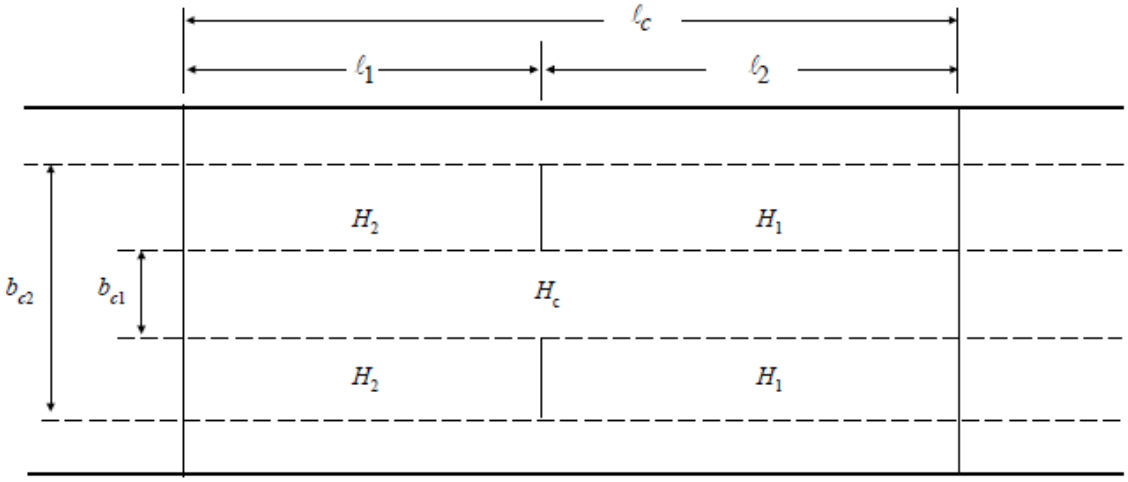


Fig 4.32 Center Tank Region

3.4 Double Bottom Structures

3.4.1 General

.1 Arrangement

The depth of the double bottom and arrangement of access openings are to be in compliance with 1.3. Centreline and side girders are to be fitted, as necessary, to provide sufficient stiffness and strength for docking loads as well as those specified in 2.

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

.2 Keel Plate

The net thickness of the flat plate keel is to be not less than that required for the bottom shell plating at that location by 3.4.2.1 increased by 1,5 mm, except where the submitted docking Rules for Hull (Pt.1, Vol.II), Sec.8, D specifies all docking blocks be arranged away from the keel.

.3 Bottom Shell Plating - Definition

The term "bottom shell plating" refers to the plating from the keel to the upper turn of the bilge for 0,4 L Amidships.

.4 Bilge Longitudinals

Longitudinals around the bilge are to be graded in size from that required for the lowest side longitudinal to that required for the bottom longitudinals. Where longitudinals are omitted in way of the bilge, the bottom and side longitudinals are to be arranged so that the distance between the nearest longitudinal and the turn of the bilge is not more than 0,4**a** (**a** is the spacing of bottom (a_b) or side (a_s) longitudinals), as applicable (see Fig.4.33).

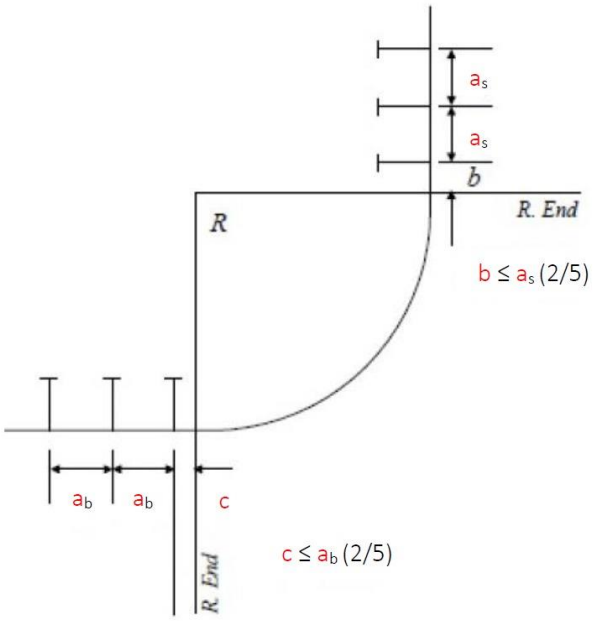


Fig. 4.33 Bilge Longitudinal

3.4.2 Bottom Shell and Inner Bottom Plating

The thickness of the bottom shell and inner bottom plating over the midship 0,4**L** is to satisfy the hull girder section modulus requirements in Rules for Hull (Pt.1, Vol.II), Sec.5, C.1. The buckling and ultimate strength are to be in accordance with the requirements in 4.3. For transversely stiffened and unstiffened bilge shell plating, buckling strength is to be assessed in total strength assessment in accordance with the requirements in 4.3.7. In addition, the net thickness of the bottom shell and inner bottom plating is to be not less than the following..

.1 Bottom Shell Plating

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

$$t_1 = 0{,}73 \cdot \mathbf{a} \cdot \sqrt{\frac{0{,}342 \cdot p}{\sigma_1}} \quad [mm]$$

$$t_2 = 0{,}73 \cdot \mathbf{a} \cdot \sqrt{\frac{0{,}5 \cdot p}{\sigma_2}} \quad [mm]$$

$$t_3 = c \cdot \mathbf{a} \cdot \sqrt{\frac{S_m \cdot R_{eH}}{E}} \quad [mm]$$

where

a = spacing of bottom longitudinals [mm]

p = p_a - p_{uh} or p_b, whichever is greater [N/cm^2]

p_{uh} = $0,12 \cdot \gamma \sqrt{h \cdot \ell_{wt} \tan\phi_e}$ where $\ell_{wt} > 0,20\ L$

= 0 where $\ell_{wt} < 0,15\ L$

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

p_a and p_b are nominal pressures, [N/cm^2], as defined in load case "a" and "b" in Table 4.11 for bottom plating, respectively.

γ = specific weight of the ballast water, 1,005 [N/cm^2-m]

h = height of double side ballast tank at installation's side [m]

ℓ_{wt} = length at tank top of double side ballast tank [m]

L = installation length [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1

ϕ_e = effective pitch amplitude, as defined in 2.3.5.2 with C_ϕ = 1.0

σ_1 = permissible bending stress in the longitudinal direction [N/cm^2]

$$= \left(1 - \frac{0,70 \cdot \alpha_1 \cdot W_{RB}}{W_B}\right) S_m \cdot R_{eH} \le 0,40 \cdot S_m \cdot R_{eH}$$

$$= \left(1 - \frac{0,70 \cdot \alpha_1 \cdot W_{RB}}{W_B}\right) S_m \cdot R_{eH} \le \left(0,40 + \frac{0,1(190 - L)}{40}\right) S_m \cdot R_{eH} \quad \text{for } L < 190 \text{ m}$$

$$\alpha_1 = \frac{S_{m1} \cdot R_{eH1}}{S_m \cdot R_{eH}}$$

W_{RB} = reference net hull girder section modulus [cm^2-m], based on the material factor of the bottom flange of the hull girder

= 0,92 · W [cm^2-m]

W = required gross hull girder section modulus at the location under consideration [cm^2-m], in accordance with Rules for Hull (Pt.1, Vol.II), Sec.5, C.1.1, with multiplied by 10^4 to converting the unit into cm^2-m, based on the material factor of the bottom flange of the hull girder.

W_B = design (actual) net hull girder section modulus to the bottom [cm^2-m], at the location under consideration

σ_2 = permissible bending stress in the transverse direction [N/cm^2]

= 0,80 · S_m · R_{eH} [N/cm^2]

S_m = strength reduction factor

= 1 for Normal Strength Steel, as specified in Rules for Material (Pt.1, Vol.V), Table 4.7

= 0,95 for Grade H32, as specified in Rules for Material (Pt.1, Vol.V), Table 4.7

= 0,908 for Grade H36, as specified in Rules for Material (Pt.1, Vol.V), Table 4.8

= 0,875 for Grade H40, as specified in Rules for Material (Pt.1, Vol.V), Table 4.8

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

R_{eH} = minimum specified yield point of the material [N/cm^2]

R_{eH1} = minimum specified yield point of the bottom flange of the hull girder [N/cm^2]

E = modulus of elasticity of the material, may be taken as 2,06 × 10^7 [N/cm^2] for steel

c = $0,7 \cdot N^2 - 0,2$, not to be less than $0,4\sqrt{k}$

N = $R_b\sqrt{\frac{k}{k_b}}$

R_b = $\sqrt{\frac{W_{RBH}}{W_B}}$

W_{RBH} = reference net hull girder section modulus for hogging bending moment based on the material factor of the bottom flange of the hull girder [cm^2-m]

= $0,92 \cdot W_{min}$ [cm^2-m]

W_{min} = required gross hull girder section modulus [cm^2-m], in accordance with Rules for Hull (Pt.1, Vol.II), Sec.5, C.1.1, with multiplied by 10^4 to converting the unit into cm^2-m, for hogging total bending moment at the location under consideration, based on the material factor of the bottom flange of the hull girder.

k, k_b = material conversion factor in 3.3.1 for the bottom shell plating under consideration and the bottom flange of the hull girder, respectively.

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

In addition to the foregoing, the net thickness of the bottom shell plating, outboard of 0,3**B** from the centerline of the installation, is to be not less than that of the lowest side shell plating required by 3.5.1 adjusted for the spacing of the longitudinals and the material factors.

.2 Inner Bottom Plating

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

t_1 = $0,73 \cdot \mathbf{a}\sqrt{\frac{0,342 \cdot p}{\sigma_1}}$ [mm]

t_2 = $0,73 \cdot \mathbf{a}\sqrt{\frac{0,5 \cdot p}{\sigma_2}}$ [mm]

t_3 = $c \cdot \mathbf{a} \cdot \sqrt{\frac{S_m \cdot R_{eH}}{E}}$ [mm]

where

a = spacing of bottom longitudinals, in [mm]

p = p_a - p_{uh} or p_b, whichever is greater [N/cm^2]

p_a and p_b are nominal pressures, [N/cm^2], as defined in load case "a" and "b" in Table 4.11 for inner bottom plating, respectively.

p_{uh} is defined in 3.4.2.1.

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

σ_1 = permissible bending stress in the longitudinal direction [N/cm^2]

$= \left(1 - \frac{0{,}52 \cdot \alpha_1 \cdot W_{RB}}{W_B}\right) S_m \cdot R_{eH} \leq 0{,}57 \cdot S_m \cdot R_{eH}$, where $\frac{W_{RBH}}{W_B}$ is not taken more than 1,4

σ_1 = permissible bending stress in the transverse direction [N/cm^2]

= $0{,}85 \cdot S_m \cdot R_{Eh}$ [N/cm^2]

α_1 = $\frac{S_{m1} \cdot R_{eH1}}{S_m \cdot R_{eH}}$

S_m = strength reduction factor obtained from 3.4.2.1 for the steel grade of inner bottom material

S_{m1} = strength reduction factor obtained from 3.4.2.1 for the steel grade of bottom flange material

R_{eH} = minimum specified yield point of the material [N/cm^2]

R_{eH1} = minimum specified yield point of the bottom flange of the hull girder [N/cm^2]

c = $0{,}7 \cdot N^2 - 0{,}2$, not to be less than $0{,}4\sqrt{k}$

N = $R_b \sqrt{\left(\frac{k}{k_b}\right)\left(\frac{y}{y_n}\right)}$

k = material conversion factor in 3.3.1 for the inner bottom plating.

y = vertical distance [m], measured from the inner bottom to the neutral axis of the hull girder section

y_n = vertical distance [m], measured from the bottom to the neutral axis of the hull girder section

W_{RB}, W_B, R_b, k_b and E are as defined in 3.4.2.1.

Where the breadth of the center tank exceeds 0,6**B**, or the wing ballast tanks are U-shaped, the net thickness of the inner bottom plating in the center tank, outboard of 0,3**B** from the centerline of the tank, is also to be not less than that of the adjacent strake on the outer longitudinal bulkhead (inner skin) required by 3.7.1, adjusted for the spacing of the longitudinals and the material factors.

3.4.3 Bottom and Inner Bottom Longitudinal

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

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

where

M = $10^3 \cdot p \cdot \mathbf{a} \cdot \frac{\ell^2}{12}$ [N-cm]

a = spacing of bottom longitudinals [mm]

ℓ = span of lthe longitudinal between effective supports [m], as shown Fig. 4.34

p = nominal pressure [N/cm^2], as specified in 3.4.2.1 and 3.4.2.2 for bottom and inner bottom longitudinals, respectively

σ_1 = permissible bending stress in the longitudinal direction [N/cm^2]

$$= \left(1 - \frac{0{,}65 \cdot \alpha_1 \cdot W_{RB}}{W_B}\right) S_m \cdot R_{eH} \leq 0{,}55 \cdot S_m \cdot R_{eH} \quad \text{for bottom longitudinals}$$

$$= \left(1 - \frac{0{,}65 \cdot \alpha_1 \cdot W_{RB}}{W_B}\right) S_m \cdot R_{eH} \leq 0{,}55 \cdot S_m \cdot R_{eH} \quad \text{for inner bottom longitudinals}$$

α_1 = $\dfrac{S_{m1} \cdot R_{eH1}}{S_m \cdot R_{eH}}$

S_m = strength reduction factor obtained from 3.4.2.1 for the steel grade of inner bottom material considered

S_{m1} = strength reduction factor obtained from 3.4.2.1 for the steel grade of bottom flange material

R_{eH} = minimum specified yield point of the material [N/cm^2]

R_{eH1} = minimum specified yield point of the bottom flange of the hull girder [N/cm^2]

W_{RB} and W_B, are as defined in 3.4.2.1

The net section modulus of the bottom longitudinals, outboard of 0,3**B** from the centerline of the installation, is also to be not less than that of the lowest side longitudinal required by 3.5.3, adjusted for the span and spacing of the longitudinals and the material factors.

Where the breadth of center tank exceeds 0,6**B**, or the wing ballast tanks are U-shaped, the net section modulus of the inner bottom longitudinals in the center tank, outboard of 0,3**B** from the centerline of the tank, is also to be not less than that of the lowest outer longitudinal bulkhead longitudinal required by 3.7.3, adjusted for the span and spacing of the longitudinals and the material factors.

In determining compliance with the foregoing, an effective breadth, be, of attached plating is to be used in calculation of the section modulus of the design longitudinal. be is to be obtained from line a) of Fig. 4.35.

3.4.4 Bottom Girders/Floors

The minimum scantlings for bottom girders/floors are to be determined from 3.4.4.1, 3.4.4.2, 3.4.4.3 and 3.4.4.3, as follows:

Note:

The minimum scantling requirements of t_1 for bottom girders/floors may be reduced for the conversion of an existing CSR tanker to a ship-type FPI, provided that the strength of the resultant design is verified with the subsequent global strength assessment in 4. However, in no case should they be taken less than 85% of the requirement below.

.1 Bottom Centerline Girder

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

t_1 = $(0{,}045 \cdot L + 4{,}5)\, R$ [mm]

t_2 = $\dfrac{10 \cdot Q_1}{d_b \cdot \tau_s}$ [mm]

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

$$t_3 = c \cdot \mathbf{a} \cdot \sqrt{\frac{S_m \cdot R_{eH}}{E}} \quad [mm]$$

where Q_1 is the maximum shear force in the center girder, as obtained from the equations given below (see also 3.1.2). Alternatively, Q_1 may be determined from finite element analyses, as specified in 4.6, with the combined load cases in 4.6.5. However, in no case should Q_1 be taken less than 85% of that determined from the equations below :

$$Q_1 = 10^3 \cdot \alpha_1 \cdot \gamma \cdot n_1 \cdot n_2 \cdot p \cdot \ell_s \cdot s_1 \quad [N] \quad \text{for } \lambda \le 1,5$$

$$= 414 \cdot \gamma \cdot n_1 \cdot n_2 \cdot p \cdot b_s \cdot s_1 \quad [N] \quad \text{for } \lambda > 1,5$$

where

$\alpha_1 = 0,606 - 0,22 \cdot \lambda$

$\lambda = \dfrac{\ell_s}{b_s}$

$\gamma = \dfrac{2 \cdot x}{\ell_s - s_3} \le 1.0$

$n_1 = 0,0374 \left(\dfrac{s_1}{s_3}\right)^2 - 0,326 \left(\dfrac{s_1}{s_3}\right) + 1,289$

$n_2 = 1,3 - \dfrac{s_3}{12}$

ℓ_s = unsupported length of the double bottom structures under consideration [m], as shown in Fig. 4.36

b_s = unsupported width of the double bottom structures under consideration [m], as shown in Fig.4.36

s_1 = sum of one-half of girder spacing on each side of the center girder [m]

s_3 = spacing of floors [m]

x = longitudinal distance from the mid-span of unsupported length (ℓ_s) of the double bottom to the section of the girder under consideration [m]

p = nominal pressure [kN/m^2], as specified in Table 4.11

d_b = depth of double bottom [cm]

τ_s = permissible shear stresses [N/cm^2]

$= 0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

c = $0,7 \cdot N^2 - 0,2$, not to be less than $0,4\sqrt{k}$ but need not be greater than $0,45\sqrt{\dfrac{k}{k_b}}$

$N = R_b \cdot \sqrt{\dfrac{k}{k_b}}$

k = material conversion factor in 3.3 for the bottom girder

a = spacing of longitudinal stiffeners on the girder [mm]

R = 1,0 for normal strength steel

$= \frac{R_{eHm}}{S_m \cdot R_{eHh}}$ for higher strength material

R_{eHm} = specified minimum yield point for ordinary strength steel [N/cm^2]

R_{eHh} = specified minimum yield point for higher tensile steel [N/cm^2]

L = length of installation [m], as defined Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1

S_m, E, R_b, k_b and R_{eH} are as defined in 3.4.2.1.

.2 Bottom Side Girder

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

$t_1 = (0{,}026 \cdot \mathbf{L} + 4{,}5)\, R$ [mm]

$t_2 = \frac{10 \cdot Q_2}{d_b \cdot \tau_s}$ [mm]

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

$t_3 = c \cdot \mathbf{a} \cdot \sqrt{\frac{S_m \cdot R_{eH}}{E}}$ [mm]

where Q_2 is the maximum shear force in the side girders under consideration, as obtained from the equations given below (see also 3.1.2). Alternatively, Q_2 may be determined from finite element analyses, as specified in 4.6, with the combined load cases in 4.6.4. However, in no case should Q_2 be taken less than 85% of that determined from the equations below:

$Q_2 = 10^3 \cdot \alpha_2 \cdot \beta_1 \cdot \gamma \cdot n_3 \cdot n_4 \cdot p \cdot \ell_s \cdot s_2$ [N] for $\lambda \le 1{,}5$

$= 0{,}285 \cdot 10^3 \cdot \beta_1 \cdot \gamma \cdot n_3 \cdot n_4 \cdot p \cdot b_s \cdot s_2$ [N] for $\lambda > 1{,}5$

where

$\alpha_2 = 0{,}445 - 0{,}17 \cdot \lambda$

$\beta_1 = 1{,}25 - 2 \cdot \frac{z_1}{b_s}$ for ship-type installations with inner skin only [Fig. 4.36(d)]

= 1,0 for all other ship-type installations

$n_3 = 1{,}072 - 0{,}0715 \cdot \frac{s_2}{s_3}$

$n_2 = 1{,}2 - \frac{s_3}{18}$

s_2 = sum of one-half of girder spacings on both sides of the side girders [m]

z_1 = transverse distance from the centerline of the unsupported width b_s of the double bottom to the girder under consideration [m]

c = $0,7 \cdot N^2 - 0,2$, not to be less than $0,4 \cdot \sqrt{k}$ but need not be greater than $0,45 \cdot \sqrt{\frac{k}{k_b}}$

N = $R_b \cdot \sqrt{\frac{k}{k_b}}$

k = material conversion factor in 3.3 for the bottom girder

a = spacing of longitudinal stiffeners on the girder [mm]

γ, ℓ_s, b_s, λ, s_3, p, d_b, f_s, **L**, R, S_m and R_{eH} are as defined above.

.3 Floors

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

$t_1 = (0,026 \cdot L + 4,5)\, R$ [mm]

$t_2 = \frac{10 \cdot Q_3}{d_b \cdot \tau_s}$ [mm]

Where Q_3 is the maximum shear force in the floors under consideration, as obtained from the equation given below (see also 3.1.2). Alternatively, Q_3 may be determined from finite element analyses, as specified in 4.6 with the combined load cases in 4.6.4. However, in no case should Q_3 be taken less than 85% of that determined from the equation below.

$Q_3 = 10^3 \cdot \alpha_3 \cdot \beta_2 \cdot p \cdot b_s \cdot s_3$ [N]

where

α_3 as shown in Fig. 4.36.

ρ_0 = $\eta \cdot (0,66 - 0,08 \cdot \eta)$ for $\eta \le 2,0$

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

β_2 = $1,05 \cdot \left(\frac{2 \cdot z_2}{b_s}\right)^2$ for ship-type installations with inner skin only Fig. 4.36(d).

= $\frac{2 \cdot z_2}{b_s}$ for all other ship-type installations

$\eta = \sqrt[4]{\left(\frac{\ell_s}{b_s}\right)\left(\frac{s_0}{s_3}\right)}$

s_0 = average spacing of girders [m]

z_2 = transverse distance from the centreline of the unsupported width b_s of the double bottom to the section of the floor under consideration [m]

$\tau_s = 0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

ℓ_s, b_s, s_3, R, p, d_b, **L**, S_m and R_{eH} are as defined above.

.4 Bottom Girders under Longitudinal Bulkhead

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

$$t_1 = (0{,}045 \cdot L + 3{,}5)\, R \quad [mm]$$

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

$$t_2 = c \cdot a \cdot \sqrt{\frac{S_m \cdot R_{eH}}{E}} \quad [mm]$$

where

c = $0{,}7 \cdot N^2 - 0{,}2$, not to be less than $0{,}4 \cdot \sqrt{k}$

N = $R_b \sqrt{\frac{k}{k_b}}$

k = material conversion factor in 3.3 for the bottom girder

a = spacing of longitudinal stiffeners on the girder [mm]

L, R, S_m and R_{eH} are as defined above. E, R_b and k_b are as defined in 3.4.2.1.

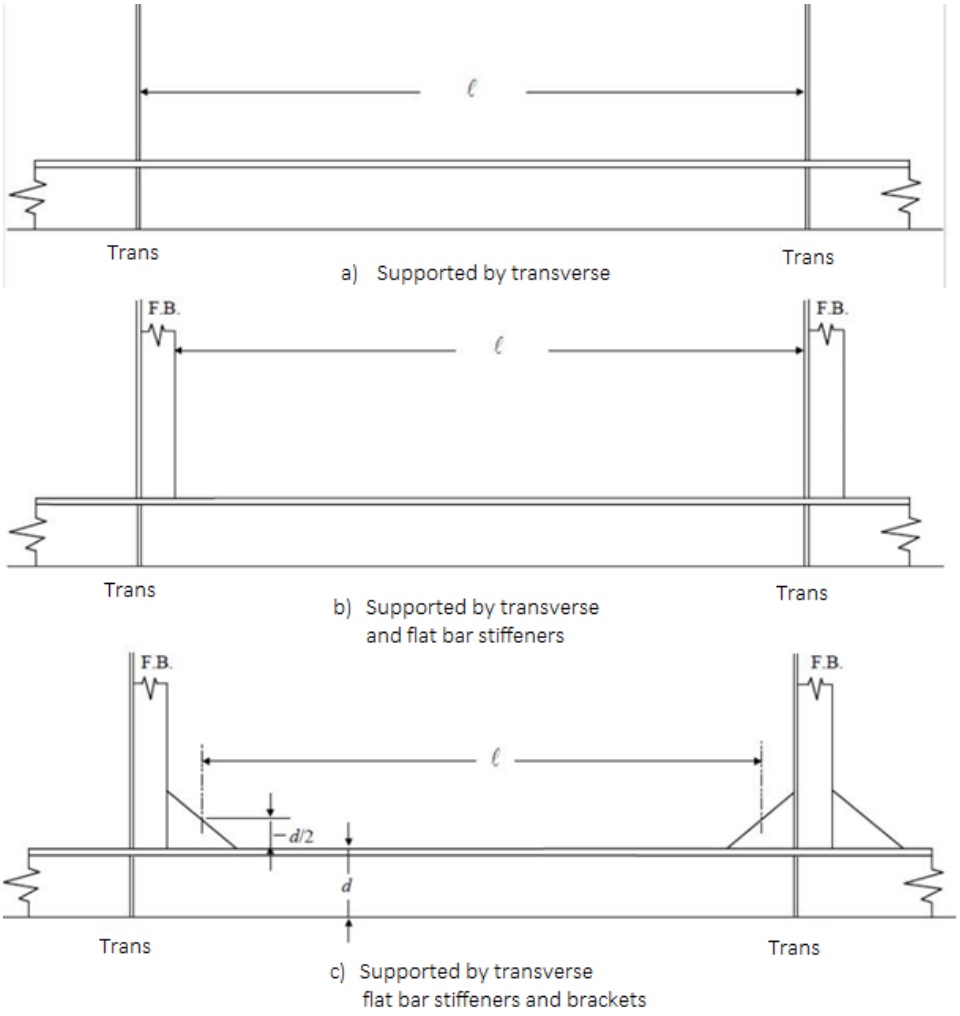
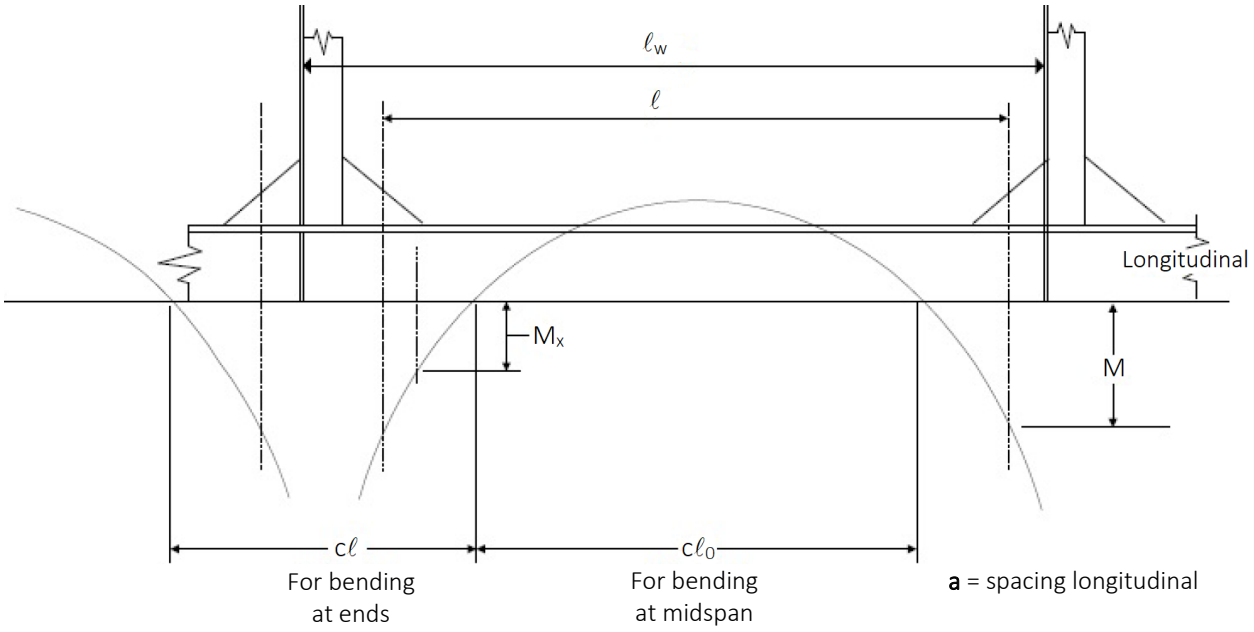


Fig. 4.34 Unsupported Span of Longitudinal



a) For bending at midspan

$$b_e/a = 1{,}219 - \frac{0{,}965}{c \cdot \ell_0/a} \qquad \text{when } c \cdot \ell_0/a < 4{,}5$$

otherwise

$$b_e/a = 1{,}0$$

$c\ell_0/a$	1,5	2	2,5	3	3,5	4	4,5 and greater
b_e/a	0,58	0,73	0,83	0,90	0,95	0,98	1,0

b) For bending at ends

$$b_e/a = \sqrt{0{,}124 \cdot c \cdot \ell_0/a - 0{,}062} \qquad \text{when } c \cdot \ell_0/a < 8{,}5$$

otherwise

$$b_e/a = 1{,}0$$

$c\ell_0/a$	1	1,5	2	2,5	3	3,5	4,0
b_e/a	0,25	0,35	0,43	0,5	0,55	0,6	0,67

Fig. 4.35 Effective Breadth of Plating b_e

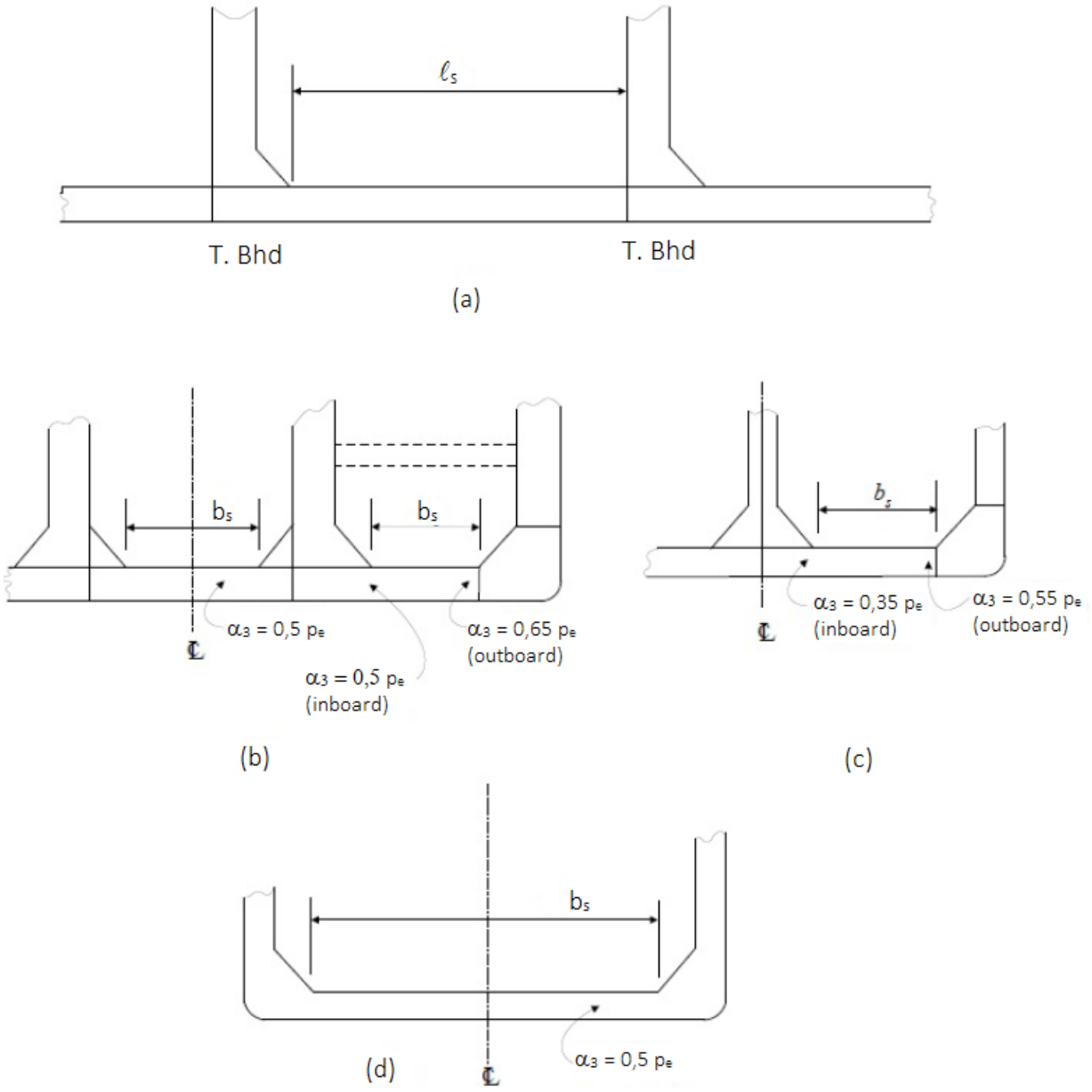


Fig. 4.36 Definitions of α_3, ℓ_s and b_s

3.5 Side Shell and Deck - Plating and Longitudinals

3.5.1 Side Shell Plating

The net thickness of the side shell plating, in addition to compliance with 3.3.2, is to be not less than t_1, t_2 and t_3, as specified below for the midship 0,4**L**.

$$t_1 = 0,73 \cdot \mathbf{a} \cdot \sqrt{\frac{0,342 \cdot p}{\sigma_1}} \quad [mm]$$

$$t_2 = 0,73 \cdot \mathbf{a} \cdot \sqrt{\frac{0,5 \cdot p}{\sigma_2}} \quad [mm]$$

$$t_3 = c \cdot \mathbf{a} \cdot \sqrt{\frac{S_m \cdot R_{eH}}{E}} \qquad [mm]$$

where

a = spacing of bottom longitudinals [mm]

p = $p_a - p_{uo}$ or p_b , whichever is greater [N/cm^2]

p_{uo} = $0,24 \cdot \gamma \cdot \sqrt[3]{h \cdot \ell_{wt} \cdot b_{wt} \cdot \tan\phi_e \cdot \tan\theta_e}$ where $\ell_{wt} > 0,20$ **L**

= 0 where $\ell_{wt} < 0,15$ **L**

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

p_a and p_b are nominal pressures, [N/cm^2], as defined in load case "a" and "b" in Table 4.11 for bottom plating, respectively. Where the wing ballast tanks are U-shaped, the nominal pressure may be taken at the lower edge of each plate, but is not to be less than that calculated at upper turn of bilge for J-shaped ballast tanks.

b_{wt} = breadth at tank top of double side ballast tank [m]

ϕ_e = effective pitch amplitude, as defined in 2.3.4.2, with $C_\phi = 0,7$

θ_e = effective roll amplitude, as defined in 2.3.4.2, with $C_\theta = 0,7$

L is length [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1.

γ, h and ℓ_{wt} are also defined in 3.4.2.1.

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

σ_1 = permissible bending stress in the longitudinal direction [N/cm^2]

$$= \left[0,86 - 0,50 \cdot \alpha_1 \left(\frac{W_{RB}}{W_B}\right)\left(\frac{y}{y_b}\right)\right] S_m \cdot R_{eH}$$

$\leq 0,43 \cdot S_m \cdot R_{eH}$ for **L** ≥ 190 m, below neutral axis

$$\leq \left(0,43 + \frac{0,17 \cdot (190 - \mathbf{L})}{40}\right) \cdot S_m \cdot R_{eH}$$ for **L** < 190 m, below neutral axis

$\frac{W_B}{W_{RB}}$ is not to be taken more than 1,4

= $0,43 \cdot S_m \cdot R_{eH}$ for **L** ≥ 190 m, above neutral axis

$$= \left(0,43 + \frac{0,17(190 - \mathbf{L})}{40}\right) \cdot S_m \cdot R_{eH}$$ for **L** < 190 m, above neutral axis

σ_2 = permissible bending stress in the transverse direction [N/cm^2]

= $0,80 \cdot S_m \cdot R_{eH}$ [N/cm^2]

$$\alpha_1 = \frac{S_{m1} \cdot R_{eH1}}{S_m \cdot R_{eH}}$$

S_m = strength reduction factor obtained from 3.4.2.1 for the steel grade of of side shell plating material

S_{m1} = strength reduction factor obtained from 3.4.2.1 for the steel grade of bottom flange material

R_{eH} = minimum specified yield point of of the side shell material [N/cm^2]

R_{eH1} = minimum specified yield point of the bottom flange of the hull girder [N/cm^2]

y_b = vertical distance [m], measured from the upper turn of bilge to the neutral axis of the section

c = $0,7 \cdot N^2 - 0,2$, not to be less than $0,4\sqrt{k}$

N = $R_d\sqrt{\frac{k}{k_d}}$ for the sheer strake

= $R_d\sqrt{\left(\frac{k}{k_d}\right)\left(\frac{y}{y_n}\right)}$ for other locations above neutral axis

= $R_b\sqrt{\left(\frac{k}{k_b}\right)\left(\frac{y}{y_n}\right)}$ for locations below neutral axis

R_d = $\sqrt{\frac{W_{RDS}}{W_D}}\,a$

y = vertical distance [m], measured from the neutral axis of the hull girder transverse section to the lower edge (upper edge) of the side shell strake, when the strake under consideration is below (above) the neutral axis for N.

= vertical distance [m], measured from the neutral axis of the hull girder transverse section to the lower edge of the side shell strake under consideration for σ_1.

W_{RDS} = reference net hull girder section for sagging bending moment, based on the material factor of the deck flange of the hull girder [cm^2-m]

= $0,92 \cdot W_s$ [cm^2-m]

W_s = required gross hull girder section modulus [cm^2-m], in accordance with Rules for Hull (Pt.1, Vol.II), Sec.5, C.2, with multiplied by 10^4 to converting the unit into cm^2-m, for sagging total bending moment at the location under consideration, based on the material factor of the deck flange of the hull girder.

k, k_d = material conversion factor in 3.3.1 for the bottom shell plating under consideration and the deck flange of the hull girder, respectively.

y_n = vertical distance, [m], measured from the bottom (deck) to the neutral axis of the section, when the strake under consideration is below (above) the neutral axis.

W_{RB}, W_B, R_b, Q_b and E are as defined in 3.4.2.1. W_D is as defined in 3.5.3.

The minimum width of the sheer strake for the midship 0,4 **L** is to be in accordance with Rules for Hull (Pt.1, Vol.II), Sec.6, C.

The thickness of the sheer strake is to be increased 25% in way of breaks of superstructures, but this increase need not exceed 6,5 mm.

In addition, the net thickness of the side shell plating of FPI's subject to side offloading is not to be taken less than t_4 obtained from the following equation :

$$t_4 = 90\left(\frac{a}{1000} + 0,7\right)\sqrt[4]{\frac{B \cdot T}{(S_m \cdot R_{eh})^2}} + 0,5 \quad [mm]$$

where

a = spacing of side longitudinal stiffeners [mm]

B = breadth [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.6

T = draft [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.6, H.2.8

All other parameters are as defined above.

The net thickness, t_4, is to be applied to the following extent of the side shell plating :

- **Longitudinal extent.** Between a section aft of amidships where the breadth at the waterline exceed 0,9**B**, and a section forward of amidships where the breadth at the waterline exceeds 0,6**B**.
- **Vertical extent.** Between 300 mm below the lowest ballast waterline to 0,25**T** or 2,2 m, whichever's greater, above the summer load line.

Alternatively, in lieu of the t_4 requirements above, side shell strength calculations may be submitted to demonstrate the structural adequacy of the side shell to the impact absorbing characteristics of fenders or equivalent, and their arrangement.

3.5.2 Deck Plating

The thickness of the strength deck plating is to be not less than that needed to meet the hull girder section modulus requirement in Rules for Hull (Pt.1, Vol.II), Sec.5, C. The buckling and ultimate strength are to be in accordance with the requirements in 4.5. In addition, the net thickness of deck plating is to be not less than t_1, t_2 and t_3, as specified below for the midship 0,4**L** :

$$t_1 = 0{,}73 \cdot \mathbf{a} \cdot \sqrt{\frac{0{,}342 \cdot p}{\sigma_1}} \quad [\text{mm}]$$

$$t_2 = 0{,}73 \cdot \mathbf{a} \cdot \sqrt{\frac{0{,}5 \cdot p}{\sigma_2}} \quad [\text{mm}]$$

$$t_3 = c \cdot \mathbf{a} \cdot \sqrt{\frac{S_m \cdot R_{eH}}{E}} \quad [\text{mm}]$$

where

a = spacing of bottom longitudinals [mm]

p = p_n [N/cm^2] in cargo tank

= $p_n - p_{uh}$ [N/cm^2] in ballast tank

In no case is p to be taken less than 2,06 N/cm^2.

p_n is nominal pressure, in N/cm^2, as defined in Table 4.11 for deck plating.

p_{uh} is defined in 3.4.2.1.

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

σ_1 = permissible bending stress in the longitudinal direction [N/cm^2]

= $0{,}15 \cdot S_m \cdot R_{eH}$ [N/cm^2]

σ_2 = permissible bending stress in the transverse direction [N/cm^2]

$= 0{,}80 \cdot S_m \cdot R_{Eh}$ [N/cm^2]

c $= 0{,}5\left(0{,}6 + 0{,}0015 \cdot L\right)$

$\geq (0{,}7 \cdot N^2 - 0{,}2)$ for installations $L \leq 267$ m

L = length [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1

$N = R_d \sqrt{\frac{k}{k_d}}$

$R_d = \sqrt{\frac{W_{RDS}}{W_D}}$

k = material conversion factor in 3.3 for the deck plating

S_m, R_{eH} and E are as defined in 3.4.2.1.

W_{RDS} and k_d are as defined in 3.5.1.

W_D is as defined in 3.5.3.

The t_3 requirement for a converted ship-type FPI may be adjusted based on the ratio M_r, where M_r = total maximum sagging bending moment as a ship-type FPI/total maximum sagging bending moment as a trading vessel. The total sagging bending moment as a ship-type FPI is the sum of the maximum sagging still water and wave bending moments for the on site condition. The sagging wave bending moment may be obtained from 2.3.2.1.

The t_3 requirement for a new build ship-type FPI may be adjusted based on the ratio M_T, where M_T = (maximum sagging still water bending moment + sagging wave bending moment for the on-site DEC)/ (maximum sagging still water bending moment + wave sagging bending moment for North Atlantic environment).

M_T	Adjusted t_3
$M_T < 0{,}7$	$0{,}85 \cdot t_3$
$0{,}7 < M_T < 1{,}0$	Varies linearly between $0{,}85 \cdot t_3$ and t_3
$M_T > 1.0$	$1{,}0 \cdot t_3$

The thickness of the stringer plate is to be increased 25% in way of breaks of superstructures, but this increase need not exceed 6,5 mm. The required deck area is to be maintained throughout the midship 0,4 L of the installation or beyond the end of a superstructure at or near the midship 0,4 L point. From these locations to the ends of the installation, the deck area may be gradually reduced in accordance with:

- The deck sectional area at 0,15L from the ends may be one-half of the amidships deck area.
- In way of a superstructure beyond the amidship 0,4L, the strength deck area may be reduced to approximately 70% of the deck area required at that location if there were no superstructure.

Where bending moment envelope curve are used to determine hull girder section modulus, the foregoing requirements for strength deck area may be modified in accordance with Rules for Hull (Pt.1, Vol.II), Sec.3, H.2. Where so modified, the strength deck area is to be maintained a suitable distance from superstructure breaks and is to be extended into the superstructure to provide adequate structural continuity.

3.5.3 Deck and Side Longitudinals

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

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^3 \cdot p \cdot \mathbf{a} \cdot \frac{\ell^2}{12} \quad [N\text{-}cm]$$

where

p = $p_{ai} - p_{uo}$ or p_b $[N/cm^2]$ whichever is greater, for side longitudinals

= p_n $[N/cm^2]$ for deck longitudinals in cargo tank

= $p_n - p_{uh}$ $[N/cm^2]$ for deck longitudinals in ballast tank,

In no case is p to be taken less than 2,06 N/cm^2.

p_a and p_b are nominal pressures, $[N/cm^2]$, as defined in load case "a" and "b", at the side longitudinal considered, in Table 4.11 for side longitudinals, respectively.

p_n is nominal pressure, $[N/cm^2]$, as defined in Table 4.11 for deck longitudinals.

p_{uo} and p_{uh} are defined in 3.5.1 and 3.4.2.1, respectively.

a and ℓ are as defined in 3.4.3.

σ_1 = permissible bending stress in the longitudinal direction $[N/cm^2]$

$$= \left(1 - 0{,}60 \cdot \alpha_2 \frac{W_{RD}}{W_D}\right) S_m \cdot R_{eH}$$ for deck longitudinal

$$= \left[0{,}86 - 0{,}52 \cdot \alpha_1 \left(\frac{W_{RB}}{W_B}\right)\left(\frac{y}{y_n}\right)\right] S_m \cdot R_{eH} \le 0{,}75 \cdot S_m \cdot R_{eH}$$ for side longitudinal below neutral axis

$$= 2 \cdot \left[0{,}86 - 0{,}52 \cdot \alpha_2 \left(\frac{W_{RD}}{W_D}\right)\left(\frac{y}{y_n}\right)\right] S_m \cdot R_{eH} \le 0{,}75 \cdot S_m \cdot R_{eH}$$ for side longitudinal above neutral axis

$$\alpha_2 = \frac{S_{m2} \cdot R_{eH2}}{S_m \cdot R_{eH}}$$

S_m, R_{eH} and α_2 are as defined in 3.4.3.

S_{m2} = strength reduction factor, as obtained from 3.4.2.1 for the steel grade of top flange material of the hull girder.

R_{eH2} = minimum specified yield point of the top flange material of the hull girder $[N/cm^2]$

W_{RD} = reference net hull girder section modulus $[cm^2\text{-}m]$ based on the material factor of the top flange of the hull girder

= $0{,}92 \cdot W$ $[cm^2\text{-}m]$

W = required gross hull girder section modulus at the location under consideration $[cm^2\text{-}m]$, in accordance with Rules for Hull (Pt.1, Vol.II), Sec.5, C, with multiplied by 10^4 to

converting the unit into cm^2-m, based on the material factor of the top flange of the hull girder.

W_D = design (actual) net hull girder section modulus at the deck [cm^2-m], at the location under consideration

W_{RB} and W_B are as defined in 3.4.2.1.

y = vertical distance in m measured from the neutral axis of the section to the longitudinal under consideration at its connection to the associated plate

y_n = vertical distance, in m, measured from the deck (bottom) to the neutral axis of the section, when the longitudinal under consideration is above (below) the neutral axis.

Where the wing ballast tanks are U-shaped, the net section modulus of deck longitudinals in the wing ballast tanks is to be not less than that of the uppermost side longitudinal, adjusted for the span and spacing of the longitudinal and the material factors.

Where the breadth of center tank exceeds 0,6**B**, the net section modulus of deck longitudinals in the center tank, located outboard of 0,3**B** from the centerline of the tank, is also to be not less than that of the uppermost boundary longitudinal bulkhead longitudinal required by 3.7.3, adjusted for the span and spacing of the longitudinal and the material factors.

In determining compliance with the foregoing, an effective breadth, b_e, of attached plating is to be used in the calculation of the section modulus of the design longitudinal. b_e is to be obtained from line a) of Fig. 4.35.

The net moment of inertia about the neutral axis of deck longitudinals and side longitudinals within the region of 0,1**H** from the deck, in association with the effective plating ($b_{wL}\, t_n$), is to be not less than obtained from the following equation :following equation :

$$i_0 = 1{,}22 \cdot 10^3 \cdot A_e \cdot \ell^2 \cdot \frac{R_{eH}}{E} \quad [cm^4]$$

where

A_e = net sectional area of the longitudinal with the associated effective plating b_{wL} . t_n, [cm^2]

b_{wL} = $c \cdot \mathbf{a}$

c = $\frac{2{,}25}{\beta} - 1.25 \cdot \beta^2$ for $\beta \geq 1{,}25$

= 1,0 for $\beta < 1{,}25$

β = $\sqrt{\frac{R_{eH}}{E}} \cdot \frac{s}{t_n}$

t_n = net thickness of the plate [mm]

H = depth of installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.7.

ℓ, **a** and R_{eH} are as defined in 3.4.3. E is as defined in 3.4.2.1.

3.6 Side Shell and Deck - Main Supporting Members

3.6.1 General

The main supporting members, such as transverses and girders, are to be arranged and designed with sufficient stiffness to provide support to the installation's hull structures. In general, the deck transverses,

side transverses and bottom floors are to be arranged in one plane to form continuous transverse rings. Deck girders, where fitted, are to extend throughout the cargo tank spaces and are to be effectively supported at the transverse bulkheads.

Generous transitions are to be provided at the intersections of main supporting members to provide smooth transmission of loads and to minimize the stress concentrations. Abrupt changes in sectional properties and sharp re-entrant corners are to be avoided. It is recommended that the intersection of the inner skin and inner bottom be accomplished by using generous sloping or large radiused bulkheads. Stool structures, where fitted, are to have sloping bulkheads on both sides.

The net section modulus and sectional area of the main supporting members required by this subsection apply to those portions of the member clear of the end brackets. They are considered as the requirements of initial scantlings for deck transverses, side transverses, vertical webs on longitudinal bulkheads and horizontal girders and vertical webs on transverse bulkheads, and may be reduced, provided that the strength of the resultant design is verified with the subsequent Global Strength Assessment in 4. However, in no case should they be taken less than 85% of those determined from 3.6 or 3.8 (See also 4.6). The structural properties of the main supporting members and end brackets are to comply with the failure criteria specified in 4.2.

The section modulus of the main supporting members is to be determined in association with the effective plating to which they are attached, as specified in Rules for Hull (Pt.1, Vol.II), Sec.3, E.

In the calculation of the nominal pressure, $\rho \cdot g$ of the liquid cargoes is not to be taken less than 0,1025 kgf/cm^2-m for main supporting members.

Section modulus and web sectional area of the deck transverses and deck girders may be obtained in accordance with the procedure given below or other recognized design procedures.

The Section modulus and web sectional area of the deck transverse and deck girders are not to be less than loading pattern 1 as specified in 3.6.2.

For a deck transverse and/or deck girder that is subjected to reactions (forces and moments) from the topside structure, the section modulus and web sectional area of the deck transverse and/or deck girders are also not to be less than for loading pattern 1 as specified in 3.6.2 and for loading pattern 2 as specified in 3.6.3.

3.6.2 Deck Transverses and Deck Girder – Loading Pattern 1

.1 Section Modulus of Deck Transverses

The net section modulus of deck transverses is to be not less than obtained from the following equation (see also 3.1.2):

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

For deck transverses in wing cargo tanks (See Fig. 4.31A a, b, c, d, e, and f):

$$M = \left(10^4 \cdot c_1 \cdot \varphi \cdot p \cdot a \cdot \ell_t^{\,2} + \beta_s \cdot M_s\right) \geq M_0 \quad [N\text{-}cm]$$

For deck transverses in center cargo tanks (see Fig. 4.31A d, e and f)

$$M = \left(10^4 \cdot c_1 \cdot \varphi \cdot p \cdot a \cdot \ell_t^{\,2} + \beta_s \cdot M_s\right) \geq M_0 \quad [N\text{-}cm]$$

where

$M_s = 10^4 \cdot c_2 \cdot p_s \cdot a \cdot \ell_s^2$

$M_b = 10^4 \cdot c_2 \cdot p_b \cdot a \cdot \ell_b^2$

$M_0 = 10^4 \cdot c_3 \cdot p \cdot a \cdot \ell_t^2$

p = nominal pressure [kN/m^2], at the mid span of the deck transverse under consideration, as specified in Table 4.11, item 16. In no case is p be taken less than 2,06 N/cm^2.

p_s = corresponding nominal pressure [kN/m^2], at the mid-span of the side transverse (Table 4.11, item 12)

p_b = corresponding nominal pressure [kN/m^2], at the mid-span of the vertical web on longitudinal bulkhead (Table 4.11, item 13)

c_1 for tanks without deck girders:

= 0,30 for Fig. 4.31A c with non-tight centerline bulkhead

= 0,42 for all other cases

c_1 for tanks with deck girders:

= $0,30 \cdot \alpha^2$ for Fig. 4.31A b with a non-tight centerline bulkhead, 0,05 min. and 0,3 max.

= $0,42 \cdot \alpha^2$ for Fig. 4.31A a or Fig. 4.31A b with an oil-tight centerline bulkhead, 0,05 min. and 0,42 max.

$\alpha = \left(\frac{\ell_g}{\ell_t}\right) \sqrt[4]{\left(\frac{a_g}{a}\right)\left(\frac{I_t}{I_g}\right)}$

ℓ_g = span of the deck girder [m], as indicated in Fig. 4.31B c.

ℓ_t = span of the deck transverse [m], as indicated in Fig. 4.31A, but is not to be taken as less than 60% of the breadth of the tank, except for tankers with a non-tight centerline bulkhead (Fig. 4.31A-b), for which the span is not to be taken as less than 30% of the breadth of the tank.

I_g, I_t = moments of inertia [cm^4], of the deck girder and deck transverse, clear of the brackets, respectively

a_g = spacing of the deck girder [m]

a = spacing of the deck transverses [m]

When calculating α, if more than one deck girder is fitted, average values of a_g, ℓ_g and I_g are to be used when the girders are not identical.

$\varphi = 1 - 5\left(\frac{h_a}{\alpha \cdot \ell_t}\right)$ for cargo tanks with deck girders, 0,6 minimum

$= 1 - 5\left(\frac{h_a}{\ell_t}\right)$ for cargo tanks without deck girders, 0,6 minimum

h_a = distance [m], from the end of the span to the toe of the end bracket of the deck transverse, as indicated in Fig. 4.37.

$\beta_s = 0,9 \left(\frac{\ell_s}{\ell_t}\right)\left(\frac{I_t}{I_s}\right)$ 0,10 min. and 0,65 max.

$\beta_b = 0,9 \left(\frac{\ell_b}{\ell_t}\right)\left(\frac{I_t}{I_b}\right)$ 0,10 min. and 0,50 max.

ℓ_s and ℓ_b = spans [m], of side transverse and vertical web on longitudinal bulkhead, respectively, as indicated in Fig. 4.31A. Where a cross tie is fitted and is located at a distance greater than $0,7 \cdot \ell_s$ or $0,7 \cdot \ell_b$ from the deck transverse, the effective span of the side transverse or the vertical web may be taken as that measured from the deck transverse to the cross tie and all coefficients determined as if there were no cross tie.

I_s and I_b = moments of inertia [cm^4], clear of the brackets, of side transverse and vertical web on longitudinal bulkhead, respectively

σ_b = permissible bending stress [N/cm^2]

= $0,70 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH}, as defined in 3.4.2.1.

c_2 is given in Table 4.17.

c_3 = $2,0 \cdot c_1$ for tankers with oil-tight longitudinal bulkheads and without deck girders (Fig. 4.31A-c, d, e and f)

= $1,6 \cdot c_1$ for tankers with non-tight centerline longitudinal bulkhead and without deck girders (Fig. 4.31A-c)

= $1,1 \cdot c_1$ for cargo tanks with deck girders

The section modulus of the deck transverse in the wing cargo tank is to be not less than that of the deck transverse in the center tank.

.2 Sectional Area of Deck Transverses

The net sectional area of the web portion of deck transverses is to be not less than obtained from the following equation:

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

$$Q = 10^3 \left[c_1 \cdot p \cdot \mathbf{a} \cdot (0,50 \cdot \ell - h_e) + c_2 \cdot \mathbf{H} \cdot B_c \cdot \mathbf{a}\right] \quad [N]$$

where

c_2 = 0,05 for wing cargo tanks of tankers with four longitudinal bulkheads (Fig. 4.31A-d, e, f)

= 0 for other tanks (Fig. 4.31A-a, b, c, d, e and f)

c_1 for tanks with deck girders:

= $0,9 \cdot \sqrt{\alpha}$ for Fig. 4.41A-a without longitudinal bulkhead and for Fig. 4.31A-b with an oil-tight centreline bulkhead, 0,50 min. and 1,0 max.

= $0,6 \cdot \sqrt{\alpha}$ for Fig. 4.31A-b with a non-tight centreline bulkhead 0,45 min. and 0,85 max.

c_1 for tanks without deck girders:

= 1,10 for Fig. 4.31A-c, with a nontight centreline longitudinal bulkhead

= 1,30 for all other cases (Fig. 4.31A-c, d, e and f)

ℓ = span of the deck transverse [m], as indicated in Fig. 4.31A

h_e = length of the bracket [m], as indicated in Fig. 4.31A-c and Fig. 4.31A-d and Fig. 4.37

H = depth of the vessel [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.7

B_c = breadth of the centre tank [m]

p, **a** and α, as defined in 3.6.2.1

τ_s = permissible shear stress [N/cm^2]

= $0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH}, as defined in 3.4.2.1.

.3 Section Modulus of Deck Girders

The net section modulus of deck girders is to be not less than obtained from the following equation (see also 3.1.2):

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

M equals M_1 or M_2, whichever is greater, as given below :

$$M_1 = 4,2 \cdot 10^3 \cdot p \cdot \mathbf{a_g} \cdot \ell_g^{\,2} \quad [N\text{-}cm]$$

$$M_2 = 3 \cdot 10^3 \cdot \varphi \cdot p \cdot \mathbf{a_g} \cdot \ell_g^{\,2} + 0,15 \cdot M_s \quad [N\text{-}cm]$$

$$M_b = 10^4 \cdot p_{st} \cdot \mathbf{a_g} \cdot \ell_{st}^{\,2} \quad [N\text{-}cm]$$

where

ℓ_g = span [m], of the deck girder, as indicated in Fig. 4.31B-c

ℓ_{st} = span [m], of the vertical web on transverse bulkhead, as indicated in Fig. 4.31B-c

$\mathbf{a_g}$ = spacing [m], of the deck girder considered, as indicated in Fig. 4.31A

$\varphi = 1 - 5\left(\frac{h_a}{\ell_g}\right)$, 0,6 minimum

h_a = distance [m], from the end of the span to the toe of the end bracket of the deck girder, as indicated in Fig. 4.31B-c and Fig. 4.38.

p = nominal pressure [kN/m^2], as specified in Table 4.11, item 17 for the girder considered. Where three or more deck girders are fitted in the cargo tank, p is to be not less than its value determined for the outermost girder clear of the end bracket of the deck transverse. In no case is p to be taken less than 2,06 N/cm^2.

p_{st} = corresponding nominal pressure [kN/m^2], at the mid-span of the vertical web on the forward transverse bulkhead of cargo tank under consideration (Table 4.11, item 17)

σ_b = permissible bending stress [N/cm^2]

= $0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

$$= \left(1 - 0{,}55 \cdot \alpha_2 \frac{W_{RD}}{W_D}\right) S_m \cdot R_{eH} \leq 0{,}52 \cdot S_m \cdot R_{eH} \qquad \text{for } L < 190 \text{ m}$$

S_m and R_{eH}, as defined in 3.4.2.1..

.4 Sectional Area of Deck Girders

The net sectional area of the web portion of deck girders is to be not less than obtained from the following equation:

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

$$Q = 10^3 \cdot c \cdot p \cdot \mathbf{a_g} \left(0{,}50 \cdot \ell - h_e\right) \quad [N]$$

where

c = 0,55 for for one or two girders in the tank
= 0,67 for three or more girders in the tank

ℓ = span of the deck girder [m], as indicated in Fig. 4.31B-c

h_e = length of the bracket [m], as indicated in Fig. 4.31B-c and Fig. 4.38.

p and $\mathbf{a_g}$ are defined in 3.6.3.1.

τ_s = permissible shear stress, [N/cm^2]
= $0.30 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH}, as defined in 3.4.2.1.

3.6.3 Deck Transverses and Deck Girders - Loading Pattern 2

.1 Section Modulus of Deck Transverses

The net section modulus of deck transverses, in association with the effective deck plating, is to be obtained from the following equation:

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$M = 10^5 \cdot (M_p + M_g + M_s)$ [N-cm] for deck transverses in wing tanks

$M = 10^5 \cdot (M_p + M_g + M_b)$ [N-cm] for deck transverses in center tanks

where

M_p = bending moment due to reactions from topside structure
= $\left|(M_v + M_m) \cdot \sigma_t\right|$ [kN-m]

M_v = $\ell_t \sum_n P_n (k_{1n} + k_{2n})$ [kN-m]

M_m = $\sum_n M_n (k_{3n} + k_{4n})$ [kN-m]

P_n = reaction deck force number n, [kN], applied to the deck transverse in tank under consideration, see Fig. 4.37.

M_n = reaction deck moment number n, [kN-m], applied to the deck transverse in tank under consideration, see Fig. 4.37.

n = 1, 2,…..,N_v to obtain bending moment M_v

= 1, 2,…..,N_m to obtain bending moment M_m

N_v = total number of reaction forces at deck transverse under consideration, (in tank under consideration)

N_m = total number of reaction moments at deck transverse under consideration (in tank under consideration).

ℓ_t = span of the deck transverse under consideration [m], as defined in Fig. 4.31A.

$k_{1n} = \left(1 - \bar{a}_n\right)^2 \left[\bar{a}_n - \bar{z}\left(1 + 2\bar{a}_n\right)\right]$

k_{2n} = 0 if $\bar{z} \le \bar{a}_n$

= $\left(\bar{z} - \bar{a}_n\right)$ if $\bar{z} > \bar{a}_n$

$k_{3n} = \left(1 - \bar{a}_n\right)\left(3 \cdot \bar{a}_n - 1 - 6 \cdot \bar{a}_n \cdot \bar{z}\right)$

k_{4n} = 0 if $\bar{z} \le \bar{a}_n$

= 1 if $\bar{z} > \bar{a}_n$

$\bar{a}_n = \dfrac{a_n}{\ell_t}$

$\bar{z} = \dfrac{z}{\ell_t}$, $(0 \le \bar{z} \le 1)$

a_n = distance [m], from a point of application of reaction (force P_n or moment M_n) to the end of the deck transverse span ℓ_t, as shown in Fig. 4.37.

z = coordinate (measured from the end of the span ℓ_t) of the section of the deck transverse under consideration [m], as shown in Fig. 4.37.

For the toe of the deck transverse end brackets, $\bar{z} = h_a/\ell_t$ and $\bar{z} = 1 - h_a/\ell_t$

h_a = distance [m], from the end of the span to the toe of the end bracket of the deck transverse, as shown in Fig. 4.38.

Note:

For a wide topside bracket, the vertical load on a deck transverse can be considered uniformly distributed with pressure $q_n = P_n/c$, and the concentrated bending moment can be substituted by force couples

$$P_m = \frac{M_n}{k \cdot c} \quad [kN]$$

where

P_m, M_n = concentrated force and moment obtained from FE analysis of topside structure

c = width of the topside bracket

k = shape bracket factor, and may be taken as 0,8, unless otherwise specified

Bending moment at the toe of the end brackets due to green water pressure, M_g:

$$M_g = 0,1 \cdot c_3 \cdot \varphi \cdot P_{gi} \cdot \mathbf{a} \cdot \ell_t^2 \quad [\text{kN-m}]$$

where

P_{gi} = nominal green water pressure imposed on the deck [kN/m^2], as defined in 2.7.4.

$\mathbf{a}$ = spacing [m], of the deck transverses

c_3 = $2,0 \cdot c_1$ for ship-type vessels with oil-tight longitudinal bulkheads and without deck girders (Fig. 4.31A -c, d, e and f)

= $1,6 \cdot c_1$ for ship-type vessels with non-tight centerline longitudinal bulkhead and without deck girders (Fig. 4.31A -c)

= $1,1 \cdot c_1$ for cargo tanks with deck girders

φ = $1-\left[5\cdot\left(\frac{h_a}{\alpha\cdot\ell_t}\right)\right]$ for cargo tanks with deck girders, 0,6 minimum

= $1-5\cdot\left(\frac{h_a}{\ell_t}\right)$ for cargo tanks without deck girders, 0,6 minimum.

h_a = distance [m], from the end of the span to the toe of the end bracket of the deck transverse, as indicated in Fig. 4.38.

ℓ_t = span of the deck transverse [m], as indicated in Fig. 4.31A, but is not to be taken as less than 60% of the breadth of the tank, except for ship-type vessels with a non-tight centerline bulkhead (Fig. 4.31A -b), for which the span is not to be taken as less than 30% of the breadth of the tank.

c_1 for tanks without deck girders:

= 0,30 for Fig. 4.31A-c with non-tight centerline bulkhead

= 0,42 for all other cases

c_1 for tanks with deck girders:

= $0,30 \cdot \alpha^2$ for Fig. 4.31A-b with a non-tight centerline bulkhead, 0,05 min and 0,3 max.

= $0,42 \cdot \alpha^2$ for Fig. 4.31A -a or -b with an oil-tight centerline bulkhead, 0,05 min and 0,42 max.

α = $\left(\frac{\ell_g}{\ell_t}\right)\cdot\sqrt[4]{\left(\frac{\mathbf{a_g}}{\mathbf{a}}\right)\left(\frac{I_t}{I_g}\right)}$

ℓ_g = span of the deck girder [m], as indicated in Fig. 4.31B-c.

I_g, I_t = moments of inertia [cm^4], of the deck girder and deck transverse with effective deck plating, clear of the end brackets, respectivel

$\mathbf{a_g}$ = spacing of the deck girder [m], as shown in Fig. 4.31A.

a = spacing of the deck transverses [m].

When calculating α, if more than one deck girder is fitted, average values of $\mathbf{a_g}$, ℓ_g and I_g are to beused when the girders are not identical.

Bending moments due to pressure on side transverse and vertical web of longitudinal bulkhead:

$$M_s = k_s \cdot \beta_s \cdot C_2 \cdot P_s \cdot \mathbf{a} \cdot \ell s2$$

$$M_b = k_b \cdot \beta_b \cdot C_2 \cdot P_b \cdot \mathbf{a} \cdot \ell_b^2$$

where

k_s = 0,1, and k_b = 0,1, unless otherwise specified.

ℓ_s ℓ_b = spans [m], of side transverse and vertical web on longitudinal bulkhead, respectively, as indicated in Fig. 4.31A. Where a cross tie is fitted and is located at a distance greater than $0{,}7\ell_s$ or $0{,}7\ell_b$ from the deck transverse, the effective span of the side transverse or the vertical web may be taken as that measured from the deck transverse to the cross tie and all coefficients determined as if there were no cross tie.

p_s = nominal pressure [kN/m²], at the mid-span of side transverse when wing tank is empty, adjacent tanks full (Table 4.11, item 12)

p_b = nominal internal cargo pressure [kN/m²], at the mid-span of the vertical web on longitudinal bulkhead when center tank is empty, adjacent tanks full (Table 4.11, item 13)

$\beta_s = 0{,}9 \cdot \left[\left(\frac{\ell_s}{\ell_t}\right)\left(\frac{I_t}{I_g}\right)\right]$,0,1 min. and 0,65 max.

$\beta_b = 0{,}9 \cdot \left[\left(\frac{\ell_b}{\ell_t}\right)\left(\frac{I_t}{I_b}\right)\right]$,0,1 min. and 0,50 max.

I_s, I_b = moments of inertia [cm⁴], clear of the brackets, of side transverse and vertical web on longitudinal bulkhead, respectively

c_2 are given in Table 4.17.

σ_t = 1 for tanks without deck girders

= $1 - \left[\frac{0{,}67}{(1+2\cdot\delta)}\right] \geq 0{,}70$ for tanks with deck girders

$\delta = \left(\frac{\ell_g}{\ell_t}\right)^3 \cdot \left(\frac{I_t}{I_g}\right)$

σ_b = permissible bending stress [N/cm²]

= $0{,}7 \cdot S_m \cdot R_{eH}$ [N/cm²]

S_m and R_{eH} as defined in 3.4.2.1.

.2 Section Modulus of Deck Girders

The net section modulus of deck girder with effective deck plating is to be not less than that obtained from the following equation:

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^5 \cdot (M_p + M_g) \quad [N\text{-}cm]$$

1) Bending moment due to reactions from topside structure, M_p

$$M_p = \left|(M_v + M_m)\cdot \sigma_g\right| \quad [kN\text{-}m]$$

$$M_v = \ell_g \sum_n P_n (k_{1n} + k_{2n}) \quad [kN\text{-}m]$$

$$M_m = \sum_n M_n (k_{3n} + k_{4n}) \quad [kN\text{-}m]$$

where

P_n = reaction force number n, [kN], applied to the deck girder under consideration

M_n = reaction moment number n, [kN-m], applied to the deck girder under consideration

N = 1, 2,….., N_v to obtain bending moment M_v

N = 1, 2,….., N_m to obtain bending moment M_m

N_v = total number of reaction forces at the deck girder between transverse bulkheads in the tank under consideration

N_m = total number of reaction moments at the deck girder between transverse bulkheads in the tank under consideration

$$k_{1n} = \left(1-\bar{b}_n\right)^2\left[\bar{b}_n - \bar{x}\left(1+2\cdot\bar{b}_n\right)\right]$$

k_{2n} = 0 if $\bar{x} \le \bar{b}_n$

$$= \left(\bar{x}-\bar{b}_n\right) \quad \text{if } \bar{x} > \bar{b}_n$$

$$k_{3n} = \left(1-\bar{b}_n\right)\left(3\cdot\bar{b}_n - 1 - 6\cdot\bar{b}_n\cdot\bar{x}\right)$$

k_{4n} = 0 if $\bar{x} \le \bar{b}_n$

= 1 if $\bar{x} > \bar{b}_n$

$$\bar{b}_n = \frac{b_n}{\ell_g}$$

$$\bar{x}_n = \frac{x}{\ell_g}$$

b_n = distance [m], from reaction force P_n to the end of the deck girder span ℓ_g

x = coordinate [m], of the section of the deck girder under consideration, measured from the end of span ℓ_g

For the toe of the brackets, $\bar{x} = h_a/\ell_g$ and $\bar{x} = 1 - h_a/\ell_g$

h_a = distance, [m], from the end of the deck girder span to the toe of the end of the bracket, as shown in Fig. 4.31B -c and Fig. 4.38.

$$\sigma_g = \underline{1-0{,}13\left[\left(\frac{\ell_g}{\ell_t}\right)^3\left(\frac{\ell_g}{a}\right)\left(\frac{I_t}{I_g}\right)\right]^{0{,}25}} \geq 0{,}65$$

I_t, I_g, **a**, ℓ_g, ℓ_t are as defined in 3.6.3.1, above.

2) Bending moment at the toe of the end brackets due to green water pressure, M_p

$$M_g = 0{,}083 \cdot \varphi \cdot p_{gi} \cdot \mathbf{a_g} \cdot \ell_g^2$$

Where p_{gi} and $\mathbf{a_g}$ are as defined 3.6.3.1, above.

$$\varphi = \underline{1-5\cdot\left(\frac{h_a}{\ell_g}\right)} \geq 0{,}6$$

σ_b = permissible bending stress [N/cm^2]

$$= 0{,}45 \cdot S_m \cdot R_{eH} \text{ [N/cm}^2\text{]}$$

$$= \left(1{,}0-0{,}55\cdot\alpha_2\cdot\frac{W_{RD}}{W_D}\right)\cdot S_m\cdot R_{eH} \leq 0{,}52\cdot S_m\cdot R_{eH} \text{ [N/cm}^2\text{]} \qquad \text{for } \mathbf{L} < 190 \text{ m}$$

α_2, W_{RD} and W_D are as defined in 3.5.3. S_m and R_{eH}, are as defined in 3.4.2.1

.3 Web Sectional Area of Deck Transverses

The net sectional area of the web portion of deck transverse is to be obtained from the following equation:

$$A = \underline{\frac{Q}{\tau_s}} \quad [\text{cm}^2]$$

where

$Q = 10^3 \cdot (Q_p + Q_g + c_2 \cdot \mathbf{a} \cdot \mathbf{H} \cdot B_c)$ [N]

$Q_p = \underline{\left|(Q_v + Q_m)\cdot\sigma_1\right|}$

$Q_v = \underline{\sum_n \left[P_n(1-\bar{a}_n)^2(2\cdot\bar{a}_n+1)+\Delta Q\right]}$

$Q_m = \underline{6\cdot\sum_n \bar{a}_n(1-\bar{a}_n)\cdot\frac{M_n}{\ell_t}}$

$Q_g = c_1 \cdot p_{gi} \cdot \mathbf{a}\,(0{,}5 \cdot \ell - h_e)$

$\Delta Q = 0$ if $\bar{z} \le \bar{a}_n$

$= -P_n$ if $\bar{z} > \bar{a}_n$

$\sigma_1 = 1 - \left[\frac{0,5}{(1+4\cdot\delta)}\right]$

$c_2 = 0,05$ for wing cargo tanks of ship-type vessels with four longitudinal bulkheads (Fig. 4.31A -d, e and f)

$= 0$ for other tanks (Fig. 4.31A -a, b, c, d, e and f)

c_1 for tanks with deck girders:

$= 0,9 \cdot \sqrt{\alpha}$ for Fig. 4.31A -a without longitudinal bulkhead and for Fig. 4.31A -b with an oil-tight centerline bulkhead, 0,50 min. and 1 max.

$= 0,6 \cdot \sqrt{\alpha}$ for Fig. 4.31A-b with a non-tight centerline bulkhead, 0,45 min. and 0,85 max.

c_1 for tanks without deck girders:

$= 1,10$ for Fig. 4.31A -c, with a nontight centerline longitudinal bulkhead

$\ell = 1,3$ for all other cases (Fig. 4.31A-c, d, e and f)

h_e = span of the deck transverse [m], as indicated in Fig. 4.31A

H = depth of a vessel [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.7

B_c = breadth of the center tank [m]

τ_s = permissible shear stress

$= 0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

P_n, M_n, P_{gi}, ℓ_t, a, $\bar{a}_n$, $\bar{z}$, α and δ are as defined in 3.6.3.1, above.

.4 Web Sectional Area of Deck Girders

The net sectional area of the web portion of deck girders is to be not less than that obtained from the following equation:

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

where

$Q = 10^3 \cdot (Q_p + Q_g)$ [N]

$Q_p = \left|(Q_v + Q_m)\cdot f_g\right|$

$Q_v = \sum_n P_n\left(1-\bar{b}_n\right)^2\left(2\cdot\bar{b}_n+1\right)\left(1+2\cdot\bar{b}_n\right)+\Delta Q$

$Q_m = 6\cdot\sum_n \bar{b}_n\left(1-\bar{b}_n\right)\cdot\frac{M_n}{\ell_g}$

$\Delta Q_n = 0$ if $\bar{x} \le \bar{b}_n$

$= -P_n$ if $\bar{x} > \bar{b}_n$

$Q_g = c \cdot p_{gi} \cdot (0,5 \cdot \ell - h_e) \cdot \mathbf{a_g}$

c = 0,55 for one or two girders in the tank

= 0,67 for three or more girders in the tank

ℓ = span of the deck girder [m], as indicated in Fig. 4.31B -c

h_e = length of the bracket [m], as indicated in Fig. 4.31B -c and Fig. 4.38.

τ_s = permissible shear stress [N/cm^2]

$= 0,3 \cdot S_m \cdot R_{eH}$ [N/cm^2]

P_n, M_n, ℓ_g, $\mathbf{a_g}$, $\bar{b}_n$, $\bar{x}_n$, p_{gi}, f_g, S_m, R_{eH} are as defined in 3.6.3.2, above.

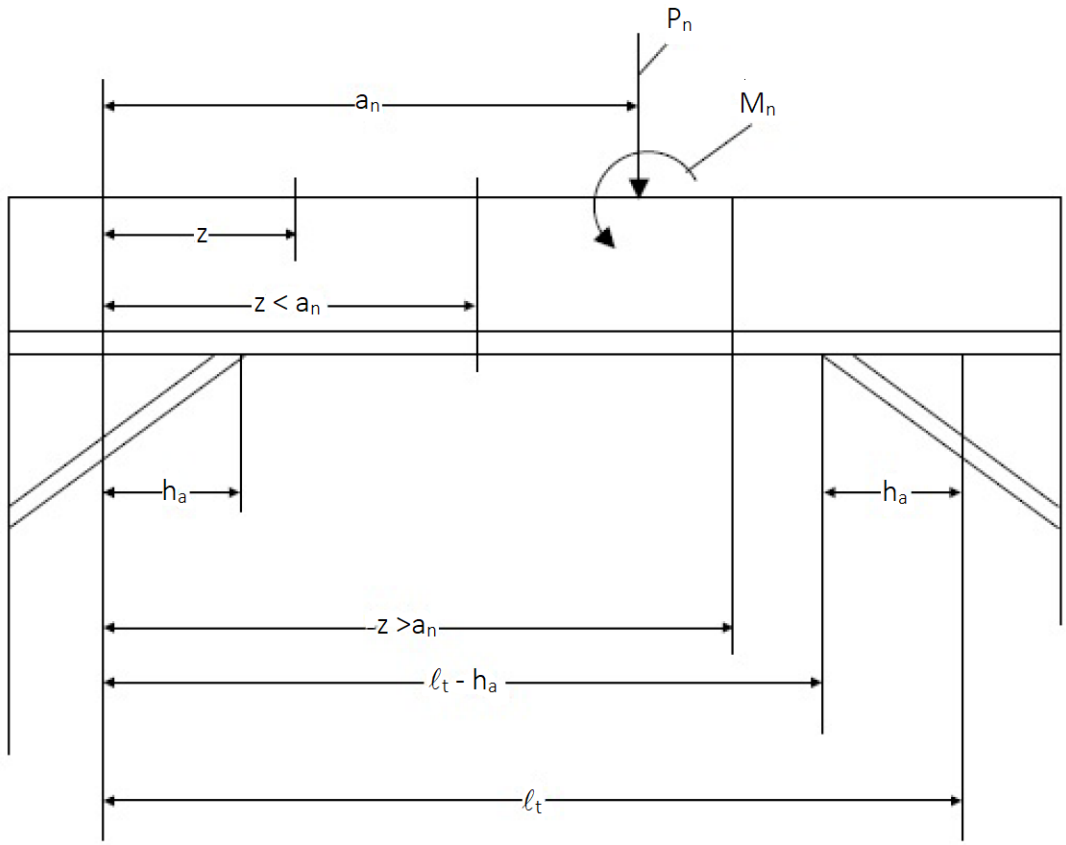


Fig. 4.37 Deck Transvers-Definition of Parameters

3.6.4 Web Sectional Area of Side Transverses

The net sectional area of the web portion of side transverses is to be not less than obtained from the following equation:

The net sectional area of the web portion of side transverses is to be not less than obtained from the following equation:

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

The shear force Q, in N, for the side transverse can be obtained from the following equations (see also 3.1.2) :

$$Q = 10^3 \cdot a \cdot [K_u \cdot \ell \cdot (P_u + P_L) - h_u \cdot P_u] \quad [N] \quad \text{for upper part of transverse}$$

$$Q = 10^3 \cdot a \cdot [K_L \cdot \ell \cdot (P_u + P_L) - h_L \cdot P_L] \quad [N] \quad \text{or}$$

$$= 0{,}35 \cdot 10^3 \cdot a \cdot K_L \cdot \ell \cdot (P_u + P_L) \quad [N] \quad \text{whichever is greater for lower part of transverse}$$

In no case is the shear force for the lower part of the transverse to be less than 120% of that for the upper part of the transverse.

where

ℓ = span [m], of the side transverse, as indicated in Fig. 4.31B-a. Where one cross tie is fitted in the wing tank and is located at a distance of more than $0{,}7 \cdot \ell$ from the deck transverse, the effective span of the side transverse may be measured from the deck transverse to the cross tie and all coefficients determined as if there were no cross tie.

a = spacing [m], of the side transverses

P_U = nominal pressure p [kN/m^2], at the mid-length of upper bracket, as specified in Table 4.11

P_L = nominal pressure p [kN/m^2], at the mid-length of lower bracket, as specified in Table 4.11.

h_U = length of the upper bracket [m], as indicated in Fig. 4.31B-a

h_L = length of the lower bracket [m], as indicated in Fig. 4.31B-a

τ_s = permissible shear stress [N/cm^2]

= $0{,}45 \cdot S_m \, R_{eH}$ [N/cm^2]

K_U and K_L are given in Table 4.18.

S_m and R_{eH}, as defined in 3.4.3.1.

For ship-type installations without cross ties in the wing cargo tank, the required sectional area of the lower side transverse is to extend to $0{,}15\ell$ from the toe of the lower bracket or $0{,}33\ell$ from the lower end of the span, whichever is greater.

For ship-type installations with one cross tie, the sectional area required for the lower portion of the transverse is to be maintained up to the cross tie..

3.6.5 Minimum Thickness for Web Portion of Main Supporting Members

In general, the net thickness of the web plate of the main supporting members, except stringers in double side structures, is to be not less than t, as obtained below :

$$t = 0{,}012 \cdot L + 7{,}7 \quad [mm]$$

but t need not be taken greater than 11 mm

The net thickness of side stringers in double side structures is not to be less than t_1 and t_2, as specified below:

$$t_1 = 0{,}012 \cdot L + 6{,}7 \quad [mm]$$

but t_1 need not be taken greater than 10 mm

$$t_2 = c \cdot a \cdot \sqrt{\frac{S_m \cdot R_{eH}}{E}} \quad [mm]$$

where

L = length of the installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1

c = $0,7 \cdot N^2 - 0,2$, not to be less than 0,33

a = spacing of longitudinals [mm]

S_m = strength reduction factor, obtained from 3.4.2.1 for the steel grade of the side stringer

R_{eH} = minimum specified yield point of the side stringer material [N/cm^2]

N = $R_d \sqrt{\left(\frac{k}{k_d}\right)\left(\frac{y}{y_n}\right)}$ for side stringers above neutral axis

= $R_b \sqrt{\left(\frac{k}{k_b}\right)\left(\frac{y}{y_n}\right)}$ for side stringers below neutral axis

k = material conversion factor 3.3 for the side stringer under consideration

y = vertical distance [m], measured from the neutral axis of the hull girder transverse section to the side stringer under consideration

E, R_b and k_b are as defined in 3.4.2.1. R_d, k_d and y_n are as defined in 3.5.1.

3.6.6 Proportions

In general, webs, girders and transverses are not to be less in depth than specified below, as a percentage of the span, ℓ_t, ℓ_b or ℓ_g, where applicable (see Fig. 4.31A and 4.31B). Alternative designs with stiffness equivalent to the specified depth/length ratio and the required section modulus may be considered, provided that the calculated results are submitted for review.

.1 Deck Transverse

23% for deck transverses in wing cargo tanks of ship-type installations with four side longitudinal bulkheads where no deck girders are fitted (see Fig. 4.31A-d, e and f).

12,5% for deck transverses in center cargo tanks of ship-type installations with four side longitudinal bulkheads where no deck girders are fitted (see Fig. 4.31A-d, e and f). In this case, the depth is also to be not less than that of the transverse in the wing tank.

12,5% for deck transverses without deck girders for ship-type installations with centerline longitudinal bulkhead (See Fig. 4.31A-c).

8,5% for deck transverses in cargo tanks with one deck girder.

5,5% for deck transverses in cargo tanks with two deck girders.

3,5% for deck transverse in cargo tanks with three or more deck girders.

.2 Deck Girder

20% for deck girders where only one is fitted in a tank.

12,5% for deck girders where two are fitted in a tank.

9,0% for deck girders where three or more are fitted in a tank.

.3 Longitudinal Bulkhead Webs/Girders

14% for vertical webs of longitudinal bulkheads without strut and horizontal girders of longitudinal bulkheads.

9,0% for vertical webs of longitudinal bulkheads with one or more struts

.4 Transverse Bulkhead Webs/Girders

20,0% for vertical webs of transverse bulkheads where only one is fitted in a tank.

12,5% for vertical webs of transverse bulkheads where two are fitted in a tank.

9,0% for vertical webs of transverse bulkheads where three or more are fitted in a tank.

28% for horizontal girders of transverse bulkheads in wing tanks for ship-type installations with four side longitudinal bulkheads (Fig. 4.31A-d, e and f).

20% for horizontal girders of transverse bulkheads in center tanks for ship-type installations with four side longitudinal bulkheads (See Fig. 4.31A-d, e and f), but not less in depth than horizontal girders in wing tanks

20% for horizontal girders of transverse bulkheads without vertical webs for ship-type installations with centerline longitudinal bulkhead (Fig. 4.31A-c)

10% for horizontal girders of transverse bulkhead with one vertical web in the cargo tank

7% for horizontal girders of transverse bulkhead with two or more vertical webs in the cargo tank, except in the case where more than two vertical webs are fitted for ship-type installations with centerline longitudinal bulkheads (Fig. 4.31A-b), or more than five vertical webs are fitted for ship-type installations with outer longitudinal bulkheads only (See Fig. 4.31A-a). In that case, horizontal girders are not to be less in depth than 15% of the maximum distance between two adjacent vertical webs or the end of span lb of the horizontal girder and next vertical web.

In no case are the depths of supporting members to be less than three times the depth of the slots for longitudinals. The thickness of the webs is to be not less than required by 3.6.5.

3.6.7 Brackets

Generally, brackets are to have a thickness not less than that of the member supported, are to have flanges or face plates at their edges and are to be suitably stiffened.

3.6.8 Web Stiffeners and Tripping Brackets

.1 Web Stiffeners

Stiffeners are to be fitted for the full depth of the webs of the main supporting member at the following intervals:

Floor	every longitudinal
Side	every longitudinal
Bulkhead	every second stiffener
Deck	every third longitudinal

Special attention is to be given to the stiffening of web plate panels close to change in contour of the web or where higher strength steel is used.

Web stiffener attachment to the deep webs, longitudinals and stiffeners is to be effected by continuous welds.

Where depth/thickness ratio of the web plating exceeds 200, a stiffener is to be fitted parallel to the flange or face plate at approximately one-quarter depth of the web from the flange or face plate.

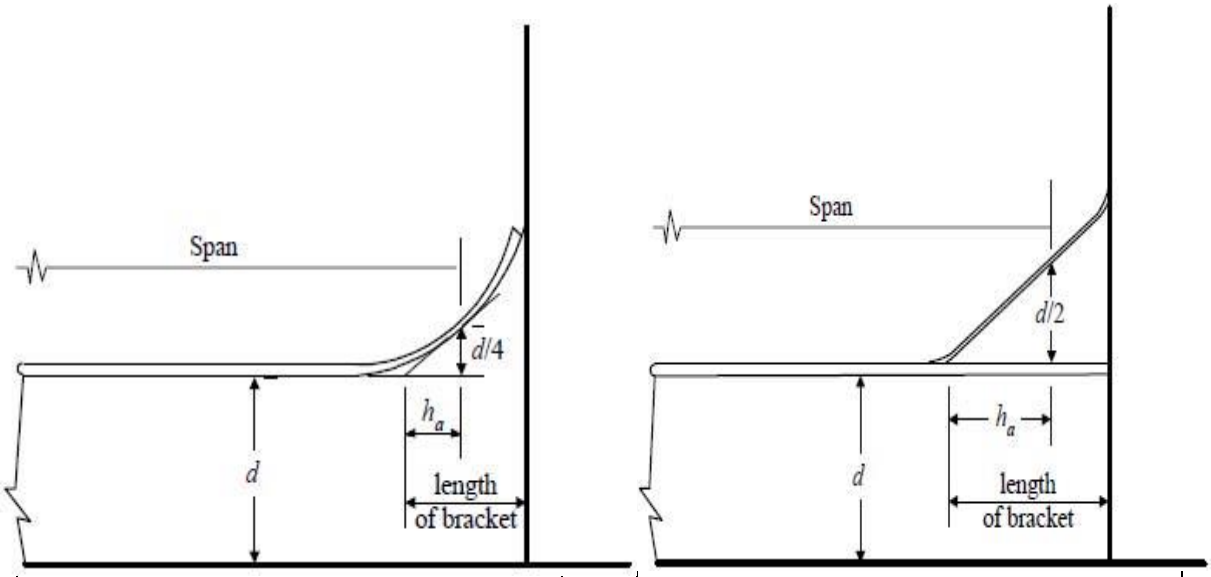
Alternative system of web-stiffening of the main supporting members may be considered based on the structural stability of the web and satisfactory levels of the shear stresses in the welds of the longitudinals to the web plates.

.2 Tripping Bracket

Tripping brackets, arranged to support the flanges, are to be fitted at intervals of about 3 m, close to any changes of section, and in line with the flanges of struts.

3.6.9 Slots and Lightening Holes

When slots and lightening holes are cut in transverses, webs, floors, stringers and girders, they are to be kept well clear of other openings. The slots are to be neatly cut and well rounded. Lightening holes are to be located midway between the slots and at about one-third of the depth of the web from the shell, deck or bulkhead. Their diameters are not to exceed one-third the depth of the web. In general, lightening holes are not to be cut in those areas of webs, floors, stringers, girders and transverses where the shear stresses are high. Similarly, slots for longitudinals are to be provided with filler plates or other reinforcement in these same areas. Where it is necessary to cut openings in highly stressed areas, they are to be effectively compensated. Continuous fillet welds are to be provided at the connection of the filler plates to the web and at the connection of the filler plate to the longitudinals.



Where face plate on the member is carried along the face of the bracket.	Where face plate on the member is not carried along the face of the bracket, and where the face plate area on the bracket is at least one-half the face plate area on the member.

Fig . 4.38 Effectiveness of Brackets

Brackets are not to be considered effective beyond the point where the arm of the girder or web is 1,5 times the arm on the bulkhead or base.

Table 4.17 Coefficient c_2 For Deck Transverses

Structural Arrangement	No cross ties (Fig. 4.31A-a, b, c and f)	Cross ties in wing cargo tank (Fig. 4.31A-d)		Cross ties in center cargo Tank (Fig. 4.31A-e)	
Location of Deck Transverse	All cargo tanks	Wing tank	Center tank	Wing tank	Center tank
c_2	0,40[1]	0,37	0,13	0,40	0,14

Note:

[1] c_2 = 0,50 *for ship-type installations with an oil-tight centerline bulkhead which will be loaded from one side only*

Table 4.18 Coefficients K_U and K_L for Side Transverses

Arrangement of Cross Ties	K_U [1]	K_L [1]
No cross ties (Fig. 4.31A-a, b, c and f)	0,13	0,30
One cross tie in center cargo tank (Fig. 4.31A-e)		
One cross tie in wing cargo tank (Fig. 4.31A-d)	0,09	0,21

Note:

[1] *For ship-type installations without cross ties in wing cargo tank (Fig. 4.31A-a, b, c, e and f) and having three or more side stringers, K_U = 0,10 and K_L = 0,22*

3.7 Longitudinal and Transverse Bulkheads

3.7.1 Longitudinal Bulkhead Plating

The net thickness of the longitudinal bulkhead plating, in addition to complying with 3.3.3, is to be not less than t_1, t_2 and t_3, as specified below:

$$t_1 = 0{,}73 \cdot \mathbf{a} \cdot \sqrt{0{,}342 \cdot \frac{p}{\sigma_1}} \quad [\text{mm}]$$

$$t_2 = 0{,}73 \cdot \mathbf{a} \cdot \sqrt{0{,}5 \cdot \frac{p}{\sigma_2}} \quad [\text{mm}]$$

$$t_3 = c \cdot \mathbf{a} \cdot \sqrt{S_m \cdot \frac{R_{eH}}{E}} \quad [\text{mm}]$$

but not less than 9,5 mm

where

a = spacing of longitudinal bulkhead longitudinals [mm]

p = pressure at the lower edge of each plate, p_i, or maximum slosh pressure, p_s, whichever is greater [N/cm^2].

In no case is p to be taken less than 2,06 N/cm^2.

p_i = p_n in cargo tank [N/cm^2]

= $p_n - p_{uo}$ in ballast tank [N/cm^2]

p_n is nominal pressure, [N/cm^2], at the lower edge of each plate, as defined in Table 4.11 for longitudinal bulkhead plating.

p_{uo} is also defined in 3.5.1.

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

p_s = $k_s\, p_{is}$, not to be taken less than $k_s\, p_{is(mid)}$

p_{is} = nominal slosh pressure [N/cm^2], as specified in 2.6.3.1

$p_{is(mid)}$ = nominal slosh pressure at the mid-tank of the bulkhead at the same height as the point

k_s = $\frac{b_t}{l_t}$ $0{,}9 \geq k_s \geq 0{,}65$ (k_s = 0,9 for $p_{is(mid)}$)

σ_1 = permissible bending stress [N/cm^2], in the vertical direction.

$= 1-0,28\cdot\frac{z}{B}-0,52\cdot\alpha_1\cdot\left(\frac{W_{RB}}{W_B}\right)\cdot\left(\frac{y}{y_n}\right)\cdot S_m\cdot R_{eH}$ below neutral axis

$= 1-0,28\cdot\frac{z}{B}-0,52\cdot\alpha_2\cdot\left(\frac{W_{RD}}{W_D}\right)\cdot\left(\frac{y}{y_n}\right)\cdot S_m\cdot R_{eH}$ above neutral axis

b_t and ℓ_t are the width and length, respectively, of the cargo tank being considered.

$\left(\frac{W_B}{W_{RB}}\right)$ is not to be taken more than $1,2\cdot\alpha_1$ or 1,4, whichever is lesser.

$\alpha_1 = \frac{S_{m1}\cdot R_{eH1}}{S_m\cdot R_{eH}}$

$\alpha_2 = \frac{S_{m2}\cdot R_{eH2}}{S_m\cdot R_{eH}}$

S_m = strength reduction factor of the steel grade for the longitudinal bulkhead plating obtained from 3.4.2.1

R_{eH} = minimum specified yield point of the longitudinal bulkhead plating [N/cm^2]

z = transverse distance [m], measured from the centerline of the section to the bulkhead strake under consideration

y_n = vertical distance [m], measured from the deck (bottom) to the neutral axis of the section, when the strake under consideration is above (below) the neutral axis

σ_2 = permissible bending stress [N/cm^2], in the vertical direction.

$= S_m\cdot R_{eH}$ [N/cm^2]

c = $0,7\cdot N^2-0,2$

c for the top strake is not to be taken less than $0,4\sqrt{k}$, but need not be greater than 0,45.

c for other strakes is not to be taken less than 0,33, but need not be greater than $0,45\sqrt{\frac{k}{k_d}}$ for strakes above the neutral axis nor greater than $0,45\sqrt{\frac{k}{k_b}}$ for strakes below the neutral axis.

N $= R_d\sqrt{\left(\frac{k}{k_d}\right)\left(\frac{y}{y_n}\right)}$ for strake above the neutral axis

$= R_b\sqrt{\left(\frac{k}{k_b}\right)\left(\frac{y}{y_n}\right)}$ for strake below the neutral axis

y = vertical distance [m], measured from the neutral axis of the hull girder transverse section to the upper edge (lower edge) of the bulkhead strake, when the strake under consideration is above (below) the neutral axis for N

= vertical distance [m], measured from the neutral axis of the hull girder transverse section to the lower edge of the bulkhead strake under consideration for σ_1

k = material conversion factor in 3.3.1 for the longitudinal bulkhead plating

B = installation's breadth [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.6

W_{RB}, W_B, R_b, k_b and E are as defined in 3.4.2.1.

S_{m1} and R_{eH1} are as defined in 3.4.3.

R_d and k_d are as defined in 3.5.1.

W_{RD}, W_D, S_{m2} and R_{eH2} are as defined in 3.5.3.

The minimum width of the top strake for the midship 0,4**L** is to be obtained from the following equation:

b = 5 **L** + 800 [mm] for **L** ≤ 200 m

= 1800 [mm] for 200 < **L** ≤ 500 m

L = length of installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1.

b = width of top strake [mm]

3.7.2 Transverse Bulkhead Plating

The net thickness of transverse bulkhead plating is to be not less than t, as specified below:

$$t = 0{,}73 \cdot \mathbf{a} \cdot \sqrt{0{,}5 \cdot \frac{p}{\sigma_2}}$$

but not less than 9,5 mm

where

a = spacing of transverse bulkhead stiffeners [mm]

p = p_i or maximum slosh pressure, p_s, whichever is greater [N/cm^2]

In no case is p to be taken less than 2,06 N/cm^2.

p_i = p_n in cargo tank [N/cm^2]

= p_n - p_{uh} in ballast tank [N/cm^2]

p_n is nominal pressure [N/cm^2], at the lower edge of each plate, as defined in Table 4.11 for transverse bulkhead plating.

p_{uh} is also defined in 3.4.2.1.

p_s = k_s p_{is}, not to be taken less than k_s $p_{is(mid)}$

p_{is} = nominal slosh pressure, as specified in 3.6.3.1.

$p_{is(mid)}$ = nominal slosh pressure at the mid-tank of the bulkhead at the same height as the point under consideration.

k_s = ℓ_t/b_t , $0{,}9 \geq k_s \geq 0{,}65$ (k_s = 0,9 for $p_{is(mid)}$)

σ_2 = permissible bending stress [N/cm^2]

= $0{,}85 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1.

ℓ_t, b_t are defined in 3.7.1

Where the wing ballast tanks are U-shaped, the net thickness of transverse bulkhead plating in the wing ballast tanks is also to be not less than as obtained from the above equation with the following substituted for p and σ_2.

where

p = nominal pressure [N/cm^2], as specified for side shell structure (item 3 case a) in Table 4.11, at the lower edge level of each transverse bulkhead plate

σ_2 = $S_m \cdot R_{eH}$ [N/cm^2]

where the breadth of center tank exceeds 0,6**B**, the net thickness of transverse bulkhead plating in the center tank, outboard of 0,3**B** from the centerline of the tank, is also to be not less than as obtained from the above equation with the following substituted for p and σ_2:

p = nominal pressure [N/cm^2], as specified for inner skin longitudinal bulkhead structure (item 6 case a) in Table 4.11, at the lower edge level of each transverse bulkhead plate

σ_2 = $S_m \cdot R_{eH}$ [N/cm^2]

3.7.3 Longitudinals and Vertical/Horizontal Stiffeners

The net section modulus of each individual longitudinal or vertical/horizontal stiffener on longitudinal and transverse bulkheads, in association with the effective plating to which it is attached, is to be not less than obtained from the following equation:

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^3 \cdot c_1 \cdot p \cdot \mathbf{a} \cdot \frac{\ell^2}{12} \quad [N\text{-}cm]$$

where

c_1 = 1,0 for longitudinals and horizontal stiffeners

= $1 + \frac{\gamma \cdot \ell}{10 \cdot p}$ for vertical stiffeners

γ = specific weight of the liquid, $\geq$ 1,005 N/cm^2-m

a = spacing of longitudinals or vertical/horizontal stiffeners [mm]

ℓ = span of longitudinals or stiffeners between effective supports [m]

p = pressure, p_i, [N/cm^2], at the longitudinal or stiffener considered, as specified in 3.7.1 and 3.7.2, or maximum slosh pressure, p_s, whichever is greater. For vertical stiffeners, pressure is to be taken at the middle of span of each stiffener.

p_s = $c_3\, p_{is}$, not to be taken less than $c_3\, p_{is(mid)}$

$p_{is(mid)}$ = nominal slosh pressure at the mid-tank of the bulkhead at the same height as the point under consideration

p_{is} = nominal slosh pressure, as specified in 2.6.3.1

c_3 = as specified below:

for transverse bulkheads

0,60 for angle or T-bar, 0,68 for bulb plate or flat bar, and 0,73 for corrugation, if tank length ℓ_t is greater than 1,4 times tank width b_t and no transverse swash bulkheads in the tank.

Otherwise, $c_3 = c_{s\ell}$ ($c_{s\ell} = 1$ for $p_{is(mid)}$)

$c_{s\ell}$ = $\frac{\ell_t}{b_t}$; $1 \geq c_{s\ell} \geq 0{,}71$

for longitudinal bulkheads

0,60 for angle or T-bar, 0,68 for bulb plate or flat bar and 0,73 for corrugation, if tank width b_t is greater than 1,4 times tank length ℓ_t and no longitudinal swash bulkheads in the tank.

Otherwise $c_3 = c_{s\ell}$ ($c_{s\ell} = 1$ for $p_{is(mid)}$)

$c_{s\ell}$ = $\frac{b_t}{\ell_t}$; $1 \geq c_{s\ell} \geq 0{,}71$

σ_b = permissible bending stresses [N/cm^2].

= $0{,}70 \cdot S_m \cdot R_{eH}$ [N/cm^2] for transverse bulkhead stiffeners

= $1{,}4\left[1-0{,}28\cdot\frac{z}{B}-0{,}52\cdot\alpha_2\cdot\left(\frac{W_{RB}}{W_B}\right)\cdot\left(\frac{y}{y_n}\right)\right]\cdot S_m\cdot R_{eH} \leq 0{,}90\cdot S_m\cdot R_{eH}$

for longitudinal bulkhead longitudinals below neutral axis

= $2{,}2\left[1-0{,}28\cdot\frac{z}{B}-0{,}52\cdot\alpha_2\cdot\left(\frac{W_{RD}}{W_D}\right)\cdot\left(\frac{y}{y_n}\right)\right]\cdot S_m\cdot\sigma_b \leq 0{,}90\cdot S_m\cdot R_{eH}$

for longitudinal bulkhead longitudinals above neutral axis

z = transverse distance [m], measured from the centerline of the installation to the longitudinal under consideration at its connection to the associated plate

h = vertical distance [m], measured from the tank bottom to the longitudinal under consideration

H = depth of the tank [m]

B = installation's breadth [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.6

S_m, R_{eH} and α_1 are as defined in 3.4.3.

α_2, y, y_n, W_{RD} and W_D are as defined in 3.5.3.

W_{RB} and W_B are as defined in 3.4.2.1.

The effective breadth of plating, b_e, is as defined in Fig. 4.35 line a).

Where the wing ballast tanks are U-shaped, the net section modulus of transverse bulkhead stiffeners in the wing ballast tanks is also to be not less than as obtained from the above equation with the following substituted for p and σ_b :

p = nominal pressure [N/cm^2], as specified for side shell structure (item 3 case a) in Table 4.11 at each transverse bulkhead stiffener level.

σ_b = $S_m \cdot R_{eH}$ [N/cm^2]

Where the breadth of center tank exceeds 0,6**B**, the net section modulus of transverse bulkhead stiffeners in the center tank, located outboard of 0,3**B** from the centerline of the tank, is also to be not less than as obtained from the above equation with the following substituted for p and f_b:

p = nominal pressure, [N/cm^2], as specified for inner skin longitudinal bulkhead structure (item 6 case a) in Table 4.11 at each transverse bulkhead stiffener level

σ_b = $S_m \cdot R_{eH}$ [N/cm^2].

The net moment of inertia of longitudinal on the longitudinal bulkhead, with the associated effective plating, within the region of 0,1**H** from the deck is to be not less than io, as specified in 3.5.3.

3.8 Bulkheads - Main Supporting Members

3.8.1 General

The main supporting members of longitudinal and transverse bulkheads are to be arranged and designed, as indicated in 3.6.1..

3.8.2 Vertical Web on Longitudinal Bulkhead

.1 Section Modulus of Vertical Web on Longitudinal Bulkhead

The net section modulus of the vertical web is to be not less than obtained from the following equation (see also 3.1.2).

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^4 \cdot c \cdot p \cdot \mathbf{a} \cdot \ell_b^{\,2} \quad [N\text{-}cm]$$

where

ℓ_b = span of member [m], as indicated in Fig. 4.31B-a. Where a cross tie (in wing or centre tank) is fitted and is located at a distance greater than $0,7 \cdot \ell_b$ from the deck transverse, the effective span of the vertical web may be measured from the deck transverse to the cross tie and all coefficients determined as if there were no cross ties. Where both the lower and upper ends of the vertical web are fitted with a bracket of the same or larger size on the opposite side, the span ℓ_b may be taken between the toes of the effective lower and upper brackets.

a = spacing of vertical webs [m]

p = nominal pressure [kN/m^2], at the mid-span of the vertical web, as specified in Table 4.11

σ_b = permissible bending stress [N/cm^2]

= $0,70 \cdot Sm\ R_{eH}$ [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1.

c is given in Table 4.19.

For ship-type installations without cross ties, and fitted with an oil-tight centerline bulkhead, the required section modulus of the web is to be maintained for $0,6\ \ell_b$, measured from the lower end of the web. The value of the bending moment, M, used for calculation of the required section modulus of the remainder of the web may be appropriately reduced, but by not more than 20%. Where the centerline bulkhead is non-tight, the required section modulus is to be maintained throughout.

.2 Web Sectional Area of Vertical Webs on Longitudinal Bulkheads

The net sectional area of the web portion of vertical members is to be not less than obtained from the following equation:

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

The shear force Q, [N], may be obtained from the following equations (see also 3.1.2).

$$Q = 10^3 \cdot a \cdot [K_U \cdot \ell \cdot (P_U + P_L) - h_U \cdot P_U] \quad \text{for upper part of vertical web}$$

$$Q = 10^3 \cdot a \cdot [K_L \cdot \ell \cdot (P_U + P_L) - h_L \cdot P_L] \quad \text{for lower part of vertical web}$$

but Q for lower part of vertical web is not to be less than

$$Q = 10^3 \cdot \gamma \cdot a \cdot K_L \cdot \ell \cdot (P_U + P_L)$$

where

P_U = nominal pressure, p, [kN/m^2], at the mid-length of upper bracket, as specified in Table 4.11

P_L = nominal pressure, p, [kN/m^2], at the mid-length of lower bracket, as specified in Table 4.11

ℓ = span of the vertical web [m], as indicated in Fig. 4.31B-a. Where a cross tie (in wing or center tank) is fitted and is located at a distance greater than 0.7ℓ from the deck transverse, the effective span of the vertical web may be measured from the deck transverse to the cross tie and all coefficients determined as if there were no cross ties.

a = spacing of the vertical webs [m]

h_U = length [m], of the upper bracket of the vertical web, as indicated in Fig. 4.31B-a and Fig. 4.38

h_L = length [m], of the lower bracket of the vertical web, as indicated in Fig. 4.31B-a and Fig. 4.38

γ = 0,57 for ship-type installations without cross ties, (Fig. 4.31 A-b, c and f)

= 0,50 for ship-type installations with one cross ties, (Fig. 4.31 A-d and e)

τ_s = permissible shear stress, [N/cm^2]

= $0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1.

Coefficients K_U and K_L are given in Table 4.20.

For ship-type installations without cross ties, the required sectional area of the lower part of the web is to be maintained for $0,6\ell$ measured from the lower end of the web. For ship-type installations with one cross tie, the required sectional area of the lower part of the web is to be maintained up to the cross tie.

In no case is the shear force for the lower part of the vertical web to be taken less than 120% of that for the upper part of the vertical web.

Table 4.19 Coefficient c for Vertical Web on Longitudinal Bulkheads

Arrangement of Cross Ties	For Upper Part	For Lower Part
No Cross Ties (Fig. 4.31 A-b, c & f) 1) Tight Bhd	0,80	
2) Non-tight Centerline Bhd	0,28	
One Cross Tie in Center Tank, (Fig. 4.31 A-e)	0,14	0,31
One Cross Tie in Wing Cargo Tank, (Fig. 4.31 A-d)	0,18	0,36

Table 4.20 Coefficients K_U and K_L for Vertical Web on Longitudinal Bulkhead

Arrangement of Cross Ties	K_U	K_L
No Cross Ties (Fig. 4.31 A -b, c & f) 1) Tight Bhd	0,18	0,28
2) Non-tight Centerline Bhd.	0,09	0,14
One Cross Tie in Center or Wing Cargo Tank, (Fig. 4.31 A-d & e)	0,08	0,18

3.8.3 Horizontal Girder on Transverse Bulkhead

.1 Section Modulus of Horizontal Girder on Transverse Bulkhead

The net section modulus of the horizontal girder is to be not less than obtained from the following equation (see also 3.1.2).

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^4 \cdot c \cdot p \cdot \mathbf{a} \cdot \ell_b^2 \quad [N\text{-}cm]$$

where

ℓ_b = span of the horizontal girders [m], as indicated in Fig. 4.31 B-c

For ship-type installations with four longitudinal bulkheads, (Fig. 4.31 A-d, e and f), ℓ_b is to be taken not less than 60% of the breadth of the wing cargo tanks.

a = sum of the half lengths [m], of the frames supported on each side of the horizontal girder

p = nominal pressure [kN/m^2], calculated at the mid-span of the horizontal girder under consideration, as specified in Table 4.11

σ_b = permissible bending stress [N/cm^2]

= $0,70 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH}, as defined in 3.4.2.1.

c for transverse bulkheads without vertical webs

= 0,73 for ship-type installations with an oil-tight centerline bulkhead (Fig. 4.31 A-c)

= 0,55 for ship-type installations with a non-tight centerline bulkhead (Fig. 4.31 A-c)

= 0,83 in wing cargo tanks of installations with four longitudinal bulkheads (Fig. 4.31 A-d, e and f)

= 0,63 in the center tanks of installations with four longitudinal bulkheads (Fig. 4.31 A-d, e and f)

c for transverse bulkheads with vertical webs

For Fig. 4.31 A-b, ship-type installations with oil-tight centerline bulkhead and Fig. 4.31 A-a:

= $0,73\ \alpha^2$ for $\alpha < 0,5$

= $0,467\ \alpha^2 + 0,0657$ for $0,5 \le \alpha \le 1,0$

= $0,1973\ \alpha + 0,3354$ for $\alpha > 1,0$

c is not to be taken less than 0.013 and need not be greater than 0,73.

For Fig. 4.31 A-b, ship-type installations with a non-tight centerline bulkhead:

$= 0,55\ \alpha^2$ for $\alpha < 0,5$

$= 0,35\ \alpha^2 + 0,05$ for $0,5 \leq \alpha \leq 1,0$

$= 0,15\ \alpha + 0,25$ for $\alpha > 1,0$

c is not to be taken less than 0,013 and need not to be greater than 0,55.

$$\alpha = 0,9 \cdot \left(\frac{\ell_{st}}{\ell_b}\right) \cdot \sqrt[4]{\left(\frac{I}{I_V}\right)\left(\frac{a_v}{a}\right)}$$

if more than one vertical web is fitted on the bulkhead, average values of ℓ_{st}, a_v and I_v are to be used when these values are not the same for each web.

ℓ_{st} = span of the vertical web [m] (Fig. 4.31 B-b)

a_v = spacing of the vertical webs [m]

I, I_v = moments of inertia [cm^4], of the horizontal girder and the vertical web clear of the end brackets

.2 Web Sectional Area of the Horizontal Girder on Transverse Bulkhead

The net sectional area of the web portion of the horizontal girder is to be not less than obtained from the following equation:

$$A = \frac{Q}{\tau_s} \ [cm^2]$$

$$Q = 10^3 \cdot a \cdot c \cdot p \cdot (0,5 \cdot \ell - h_e) \ [N]$$

where

c = 0,80 for transverse bulkheads without vertical webs

$= 0,72 \cdot \sqrt{\alpha}$ for transverse bulkheads with vertical webs for $\alpha \geq 0,70$

$= 0,877 \cdot \alpha - 0,02$ for transverse bulkheads with vertical webs for $\alpha < 0,7$, 0,1 min. and 0,8 max.

ℓ = distance [m], between longitudinal bulkheads, as indicated in Fig. 4.31B-b

a = sum of the half lengths [m], on each side of the horizontal girder, of the frames supported

h_e = length of the bracket [m], as indicated in Fig. 4.31B-b, p and α are as defined in 3.8.3.1.

τ_s = permissible shear stress [N/cm^2]

$= 0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1.

3.8.4 Vertical Web on Transverse Bulkhead

.1 Section Modulus of Vertical Web on Transverse Bulkhead

The net section modulus of the vertical web is to be not less than obtained from the following equation (see also 3.1.2):

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^4 \cdot c \cdot p \cdot \mathbf{a} \cdot \ell_{st}^{\,2} \quad [N\text{-}cm]$$

where

c = 0,83 for bulkheads without horizontal girders

= $0,83 - 0,52 \cdot \alpha$ (but not less than 0,3) for transverse bulkheads with horizontal girders.

ℓ_{st} = span of the vertical web [m], (Fig. 4.31 B-c)

a = spacing of vertical webs [m]

p = nominal pressure [kN/m^2], at the mid-span of the vertical web, as specified in Table 4.11

α = as defined in 3.8.3.1, except that the values of **a**, ℓ_b and I are to be averaged in the case that more than one horizontal girder is fitted on the bulkhead

σ_b = permissible bending stress, [N/cm^2]

= $0,70 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH}, as defined in 3.4.2.1.

The required section modulus for the web is to be maintained for a distance of 0,6 ℓ_{st} from the lower end of the span. Above that point, the value of the bending moment, M, used for the calculation of the required section modulus may be reduced by not more than 20%.

.2 Web Sectional Area of Vertical Web on Transverse Bulkheads

The net sectional area of the web portion of vertical members is to be not less than obtained from the following equation:

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

The shear force F in N may be obtained from the following equations (see also 3.1.2).

$Q = 10^3 \cdot \mathbf{a} \cdot [0,18 \cdot c \cdot \ell \cdot (P_U + P_L) - h_U \cdot P_U]$ for upper part of vertical web

$Q = 10^3 \cdot \mathbf{a} \cdot [0,3 \cdot c \cdot \ell \cdot (P_U + P_L) - h_L \cdot P_L]$ or $120 \cdot \mathbf{a} \cdot c \cdot \ell \cdot (P_U + P_L)$ whichever is greater, for lower part of vertical web

where

c = 1,0 for transverse bulkheads without horizontal girders

= $1,13 - 0,6 \cdot \alpha$ for transverse bulkheads with horizontal girders, 0,6 min. and 1 max.

P_U = nominal pressure, p, [kN/m^2], at the mid-length of upper bracket, as specified in Table 4.11

P_L = nominal pressure, p, [kN/m^2], at the mid-length of lower bracket, as specified in Table 4.11

ℓ = span of the vertical web [m], as indicated in Fig. 4.31 B-c

a = spacing of the vertical webs [m]

h_U = length [m], of the upper bracket, as indicated in Fig. 4.31 B-c and Fig. 4.38

h_L = length [m], of the lower bracket, as indicated in Fig. 4.31 B-c and Fig. 4.38

α is as defined in 3.8.4.1

τ_s = permissible shear stress [N/cm^2]

= $0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1.

The required sectional area of the lower portion of the web is to be maintained for a distance of 0,15 ℓ from the toe of the lower bracket or 0,33 ℓ measured from the lower end of the span, whichever is greater.

In no case is the shear force for the lower part of the vertical web to be taken less than 120% of that for the upper part of the vertical web.

3.8.5 Minimum Web Thickness, Proportions, Brackets, Stiffeners, Tripping Brackets, Slots and Lightening Holes

Requirements for these items are given in 3.6.5, 3.6.6, 3.6.7, 3.6.8 and 3.6.9.

3.8.6 Cross Ties

Where cross ties are fitted as effective supports for the tank structural members, they are to be spaced so as to divide the supported members into spans of approximately equal length. The axial load imposed on cross ties, P_{ct}, is to be not greater than the permissible load, P_a, both are as specified below (see also 3.1.2). Alternatively, P_{ct} may be determined from finite element analyses, as specified in 4.6, with the combined load cases in 2.5. However, in no case should P_{ct} be taken less than 85% of that determined from the approximate equation below. For this purpose, an additional load case is also to be investigated, modifying load case 5 (of Table 4.9A) with a full design draft and K_{f0} = 1,0 for external pressure where cross ties are located in wing cargo tanks. (See also 4.6.1).

$$P_{ct} = p \cdot b \cdot \mathbf{a} \qquad \text{[kN]}$$

$$P_a = 0,45 \cdot R_{eH} \cdot \left[1 - 0,0254 \cdot \left(\frac{R_{eH}}{E}\right) \cdot \left(\frac{\ell}{r}\right)^2\right] \cdot A_s \qquad \text{[kN]} \quad \text{when } \left(\frac{r}{\ell}\right)^2 \cdot \left(\frac{E}{R_{eH}}\right) > 0,0507$$

$$P_a = 4,44 \cdot E \cdot \left(\frac{r}{\ell}\right)^2 A_s \qquad \text{[kN]} \quad \text{when } \left(\frac{r}{\ell}\right)^2 \cdot \left(\frac{E}{R_{eH}}\right) \le 0,0507$$

where

b = mean breadth of the area supported [m]

a = spacing of transverses [m]

p = nominal pressure [kN/m^2], at the center of the area supported by the cross tie, as specified in Table 4.11, item 15

ℓ = unsupported span of the cross tie [cm]

r = least radius of gyration of the cross tie [cm]

A_s = net cross section area of the cross tie [cm^2]

R_{eH} = minimum specified yield point of the material [kN/cm^2]

E = $2,06 \times 10^4$ [kN/cm^2]

Special attention is to be paid to the adequacy of the welded connections for transmission of the tensile forces and also to the stiffening arrangements at the ends, in order to provide effective means for transmission of the compressive forces into the webs. In addition, horizontal stiffeners are to be located in line with and attached to the first longitudinal above and below the ends of the cross ties.

3.8.7 Nontight Bulkheads

Nontight bulkheads referred to in 2.6.2.1 are to be fitted in line with transverse webs, bulkheads or other structures with equivalent rigidity. They are to be suitably stiffened. Openings in the nontight bulkhead are to have generous radii and their aggregate area is not to exceed 33%, nor to be less than 10% of the area of the nontight bulkhead, but it is recommended to be as close to 33% as practicable. The opening area is to be evenly distributed between 0,1 and 0,9 of the bulkhead depth. The net thickness of nontight bulkheads is to be not less than 11,0 mm. Section moduli of stiffeners and webs may be half of those required for watertight bulkheads in 3.7.3, 3.8.2.1, 3.8.3.1, 3.8.4.1 and 3.8.5.

Alternatively, the opening ratio and scantlings may be determined by an acceptable method of engineering analysis.

3.9 Corrugated Bulkheads

3.9.1 General

All vertically corrugated transverse and longitudinal bulkheads in cargo tanks are to be designed in compliance with the requirements specified in this Subsection and the strength assessment criteria with respect to yielding, buckling and ultimate strength, and fatigue, as specified in 4.

In general, the approximation equations given below are applicable to vertical corrugations with corrugation angles, φ (Fig. 4.39 or Fig. 4.40), within the range between 60 and 90 degrees. For corrugation angles less than 60 degrees and corrugation in the horizontal direction, direct calculations may be required.

3.9.2 Plating

The net thickness of the vertically corrugated plating is not to be less than t_1, t_2, t_3 and t_4, obtained from the following equations:

$$t_1 = 0{,}516 \cdot k_1 \cdot a \cdot \sqrt{\frac{p}{\sigma_1}} \quad \text{[mm]} \quad \text{for flange and web plating}$$

$$t_2 = 0{,}42 \cdot k_2 \cdot a \cdot \sqrt{\frac{R_{eH}}{E}} \quad \text{[mm]} \quad \text{for flange plating}$$

$$t_3 = 0{,}728 \cdot \frac{a}{k_3} \cdot \sqrt{\sigma_3} \cdot 10^{-3} \quad \text{[mm]} \quad \text{for flange plating}$$

$$t_3 = 100 \cdot \frac{Q}{d \cdot \sigma_4} \quad \text{[mm]} \quad \text{for web plating but not less than 9,5 mm}$$

where

a = width of flange plating [mm] (Fig. 4.39 or Fig. 4.40)

c = width of web plating [mm] (Fig. 4.39 or Fig. 4.40)

d = depth of corrugation [mm] (Fig. 4.39 or Fig. 4.40)

ϕ = corrugation angle (Fig. 4.39 or Fig. 4.40)

$k_1 = \sqrt{1 - \frac{c}{a} + \frac{c^2}{a^2}}$

$k_2 = \frac{\sigma_2}{0{,}73 \cdot R_{eH}}$

$k_3 = 7{,}65 - 0{,}26 \cdot \left(\frac{c}{a}\right)^2$

Q = shear force [N], imposed on the web plating at the lower end of corrugation span

$= 10 \cdot \mathbf{a} \cdot \ell \cdot (0{,}375 \cdot p_\ell + 0{,}125 \cdot p_U)$

a = spacing of corrugation [mm], i.e., $a + \cos \phi$, (Fig. 4.39 or Fig. 4.40)

ℓ = span of corrugation [m], taken as the distance between lower and upper stools at centerline

p_ℓ, p_u = nominal pressure [N/cm^2], at the lower and upper ends of span, respectively, as specified in Table 4.11

σ_1 = permissible bending stress [N/cm]

$= 0.9 \cdot S_m \cdot R_{eH}$ [N/cm^2]

σ_2 = maximum vertical bending stress [N/cm^2], in the flange at the mid-depth of corrugation span to be calculated from 3.9.3 below.

σ_3 = maximum vertical bending stress [N/cm^2], in the flange at the lower end of corrugation span to be calculated from 3.9.3 below.

σ_4 = permissible shear stress [N/cm^2]

$= 0{,}40 \cdot S_m \cdot R_{eH}$ [N/cm^2]

E, S_m and R_{eH} are as defined in 3.4.2.1.

The plate thickness, as determined above based on the maximum anticipated pressures, is to be generally maintained throughout the entire corrugated bulkhead, except that the net thickness of plating above $^2/_3$ of span, ℓ, from the top of the lower stool may be reduced by 20%.

3.9.3 Stiffness of Corrugation

.1 Depth/Length Ratio

The depth/length ratio (d/ℓ) of the corrugation is not to be less than $^1/_{15}$, where d and ℓ are as defined in 3.9.2 above.

.2 Section Modulus

The net section modulus for any unit corrugation is not to be less than obtained from the following equation for all anticipated service loading conditions.

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^3 \cdot \left(\frac{C_i}{C_j}\right) \cdot p \cdot \mathbf{a} \cdot \frac{\ell_0^{\,2}}{12} \qquad \text{[N-cm]}$$

where

ℓ_o = nominal length of the corrugation [m], measured from the mid-depth of the lower stool to the mid-depth of the upper stool

$p = \frac{P_U + P_\ell}{2}$ [N/cm]

σ_b = permissible bending stress [N/cm^2]

= $0,9 \cdot S_m \cdot R_{eH}$ [N/cm^2] for lower end of corrugation span ℓ

= $c_e \cdot R_{eH} \le 0,9 \cdot S_m \cdot R_{eH}$ [N/cm^2] for the mid $\ell/3$ region of the corrugation

$c_e = \frac{2,25}{\beta} - \frac{1,25}{\beta}$ for $\beta \ge 1,25$

= 1,0 for $\beta < 1,25$

$\beta = \sqrt{\frac{R_{eH}}{E}} \cdot \frac{\mathbf{a}}{t_f}$

t_f = net thickness of the corrugation flange [mm]

C_i = bending moment coefficients, as given below

Values of C_i (All Bulkheads with Lower and Upper Stools)

Bulkhead	Lower End of Span ℓ	Mid-depth	Upper End of Span ℓ
Trans. Bhd :			
(w/Long'l Bhd)	C_1	C_{m1}	0,8 C_{m1}
(w/out Long'l Bhd)	C_2	C_{m2}	0,65 C_{m2}
Long'l. Bhd	C_3	C_{m3}	0,65 C_{m3}

$C_1 = a_1 + b_1 \cdot \sqrt{\frac{k \cdot A_{dt}}{B_d}}$ where: $a_1 = 0,95 - \frac{0,26}{R_b}$, $b_1 = -20 + \frac{0,05}{R_b}$

$C_{m1} = a_{m1} + b_{m1} \cdot \sqrt{\frac{k \cdot A_{dt}}{B_d}} \ge 0,55$ where: $a_{m1} = 0,63 - \frac{0,16}{R_b}$, $b_{m1} = -0,25 + \frac{0,07}{R_b}$

$C_2 = a_2 + b_2 \cdot \sqrt{\frac{k \cdot A_{dt}}{B_d}} \ge 0,6$ where: $a_2 = 0,84 - \frac{0,07}{R_b}$, $b_1 = -0,24 + \frac{0,02}{R_b}$

$C_{m2} = a_{m2} + b_{m2} \cdot \sqrt{\frac{k \cdot A_{dt}}{B_d}} \ge 0,55$ where: $a_{m2} = 0,56 - \frac{0,05}{R_b}$, $b_1 = -0,34 + \frac{0,03}{R_b}$

$C_3 = a_3 + b_3 \cdot \sqrt{\frac{k \cdot A_{dt}}{B_d}} \ge 0,6$ where: $a_3 = 1,07 - \frac{0,21}{R_b}$, $b_3 = -0,21 + \frac{0,04}{R_b}$

$C_{m3} = a_{m3} + b_{m3} \cdot \sqrt{\frac{k \cdot A_{dt}}{B_d}} \ge 0,55$ where: $a_{m3} = 0,30 - \frac{0,07}{R_b}$, $b_{m3} = -0,12 + \frac{0,03}{R_b}$

C_j = bending moment factors due to sloshing effect

Values of C_j (All Bulkheads with Lower and Upper Stools)

Bulkhead	Mid-depth	Upper End of Span ℓ
Trans. Bhd:	C_{mj1}	C_{mj2}
Long'l. Bhd.	C_{mj3}	C_{mj4}

$$C_{mj1} = 1{,}83 \cdot \frac{P}{P_s} - 0{,}74 \geq 0{,}40 \quad \text{if } \frac{P}{P_s} < 0{,}95$$

$$= 1 \quad \text{if } \frac{P}{P_s} \geq 0{,}95$$

$$C_{mj2} = 3{,}73 \cdot \frac{P}{P_s} - 2{,}36 \geq 0{,}62 \quad \text{if } \frac{P_n}{P_s} < 0{,}90$$

$$= 1 \quad \text{if } \frac{P_n}{P_s} \geq 0{,}90$$

$$C_{mj3} = 4{,}14 \cdot \frac{P}{P_s} - 3{,}14 \geq 0{,}75, \quad \text{if } \frac{P}{P_s} < 1{,}00$$

$$= 1 \quad \text{if } \frac{P}{P_s} \geq 1{,}00$$

$$C_{mj4} = 2{,}36 \cdot \frac{P}{P_s} - 1{,}71 \geq 0{,}72, \quad \text{if } \frac{P}{P_s} < 1{,}15$$

$$= 1 \quad \text{if } \frac{P}{P_s} \geq 1{,}15$$

$$P_s = \frac{p_{SU} + p_{S\ell}}{2} \ [\text{N/cm}^2] \quad ; P = \frac{p_U + p_\ell}{2} \ [\text{N/cm}^2]$$

$p_{s\ell}$, p_{su} = sloshing pressure [N/cm^2], at the lower and upper ends of span, respectively, as specified in 2.6.3, calculated at the same locations indicated for p_ℓ and p_u.

p_ℓ, p_u = nominal pressure [N/cm^2], at the lower and upper ends of span, respectively, as specified in Table 4.11, to be calculated at a section located **B**/4 from the C.L. when the installation has one or no longitudinal bulkheads. For installations with two longitudinal bulkheads, the nominal pressure is to be calculated at a section located b/4 from the outboard boundary of the center or the wing tank.

R_b = $k \cdot H_{st} \cdot (B_{ct} + B_{st}) \dfrac{\left(1 + \frac{L_b}{B_b} + 0{,}5 \cdot \frac{H_b}{L_b}\right)}{2 \cdot B_b}$ for transverse bulkheads

= $H_{s\ell} \cdot (B_{c\ell} + B_{s\ell}) \dfrac{\left(1 + \frac{L_b}{B_b} + 0{,}5 \cdot \frac{H_b}{L_b}\right)}{2 \cdot L_b}$ for longitudinal bulkheads

A_{dt} = cross sectional area [m^2], enclosed by the outside lines of upper stool of transverse bulkhead

$A_{d\ell}$ = cross sectional area [m^2], enclosed by the outside lines of upper stoolof longitudinal bulkheads

B_{ct} = width of the bottom stool of transverse bulkhead [m], at the top (Fig. 4.39 or Fig. 4.40)

$B_{c\ell}$ = width of the bottom stool of longitudinal bulkhead [m], at the top (Fig. 4.40)

B_{st} = width of the bottom stool of transverse bulkhead [m], at the inner bottom level (Fig. 4.40)

$B_{s\ell}$ = width of the bottom stool of longitudinal bulkhead [m], at the inner bottom level (Fig. 4.40)

H_b = double bottom height [m]

H_{st} = height of the bottom stool of transverse bulkhead [m], from the inner bottom to the top (Fig. 4.39 or Fig. 4.40)

$H_{s\ell}$ = height of the bottom stool of longitudinal bulkhead [m], from the inner

B_b = transverse distance [m], between hopper tanks at the inner bottom level (Fig. 4.39 or Fig. 4.40)

B_d = transverse distance [m], between upper wing tanks or between upper wing tank and centerline deck structure, at the deck level (Fig. 4.39 or Fig. 4.40)

L_b = longitudinal distance [m], between bottom stools in the loaded tanks at the inner bottom level (Fig. 4.39 or Fig. 4.40)

L_d = longitudinal distance [m], between upper stools in the loaded tanks at the deck level (Fig. 4.40)

k = 1

B = breadth of installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.6.

b = width of tank under consideration [m].

a, ℓ, **a**, p_u and p_ℓ are as defined in 3.9.2 above.

E is as defined in 3.4.2.

S_m and R_{eH} are as defined in 3.4.3.

The developed net section modulus, W, may be obtained from the following equation, where a, c, d, t_f (net), and t_w(net), all in cm, are as indicated in Fig. 4.39

$$W = d \cdot \frac{(3 \cdot a \cdot t_f + c \cdot t_w)}{6}$$

3.9.4 Bulkhead Stools

.1 Lower Stool

The height of the lower stool is to be not less than three times the minimum depth of corrugation required by 3.9.3.1 above. The net thickness and material of the stool top plate is not to be less than that required for the bulkhead plating in 3.9.2 above. The net thickness and material of the upper portion of vertical or sloping stool side plate within the region of one meter from the stool top is not to be less than the required flange plate thickness to meet the bulkhead stiffness requirement at the lower end of the corrugation in 3.9.3 above. The net thickness of the stool side plating and the net section modulus of the stool side stiffeners are not to be less than those required for plane transverse or longitudinal bulkhead plating and stiffeners in 3.7.1, 3.7.2 and 3.7.3, with the corresponding tank pressure specified in Table 4.11. The ends of stool side vertical stiffeners are to be attached to brackets at the upper and lower ends of the stool.

The extension of the top plate beyond the corrugation is not to be less than the as-built flange thickness of the corrugation. The stool bottom is to be installed in line with double bottom floors or girders, fitted with proper brackets, and diaphragms are to be provided in the stool to effectively support the panels of the corrugated bulkhead. The width of the stool at the inner bottom is to be not less than 2,5 times the mean depth of the corrugation. Scallops in the brackets and diaphragms in way of the top and bottom connections to the plates and in the double bottom floors or girders are to be avoided.

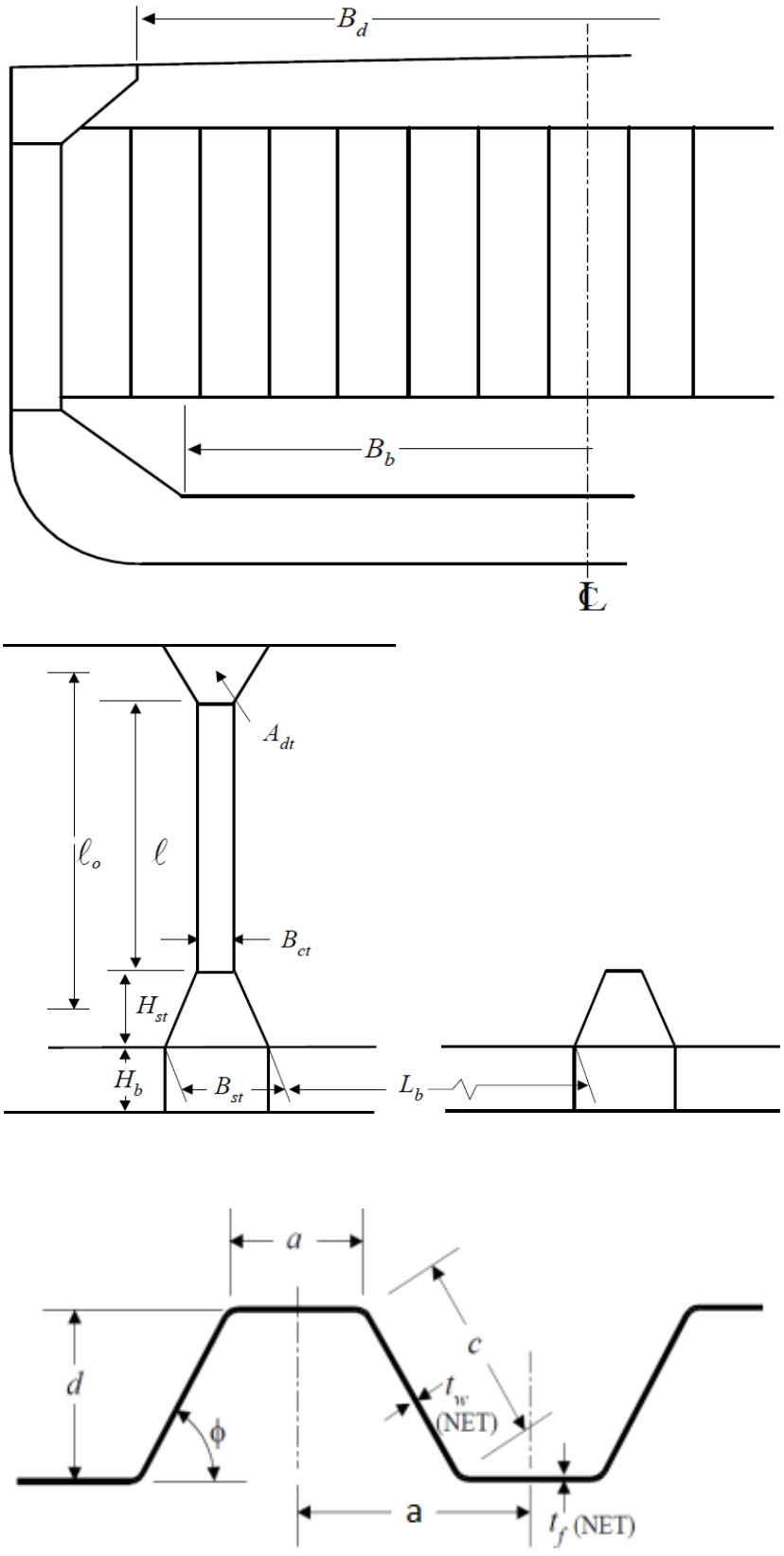


Fig. 4.39 Definition of Parameters for Corrugated Bulkhead (Ship-type Installations without Longitudinal Bulkhead at Centerline)

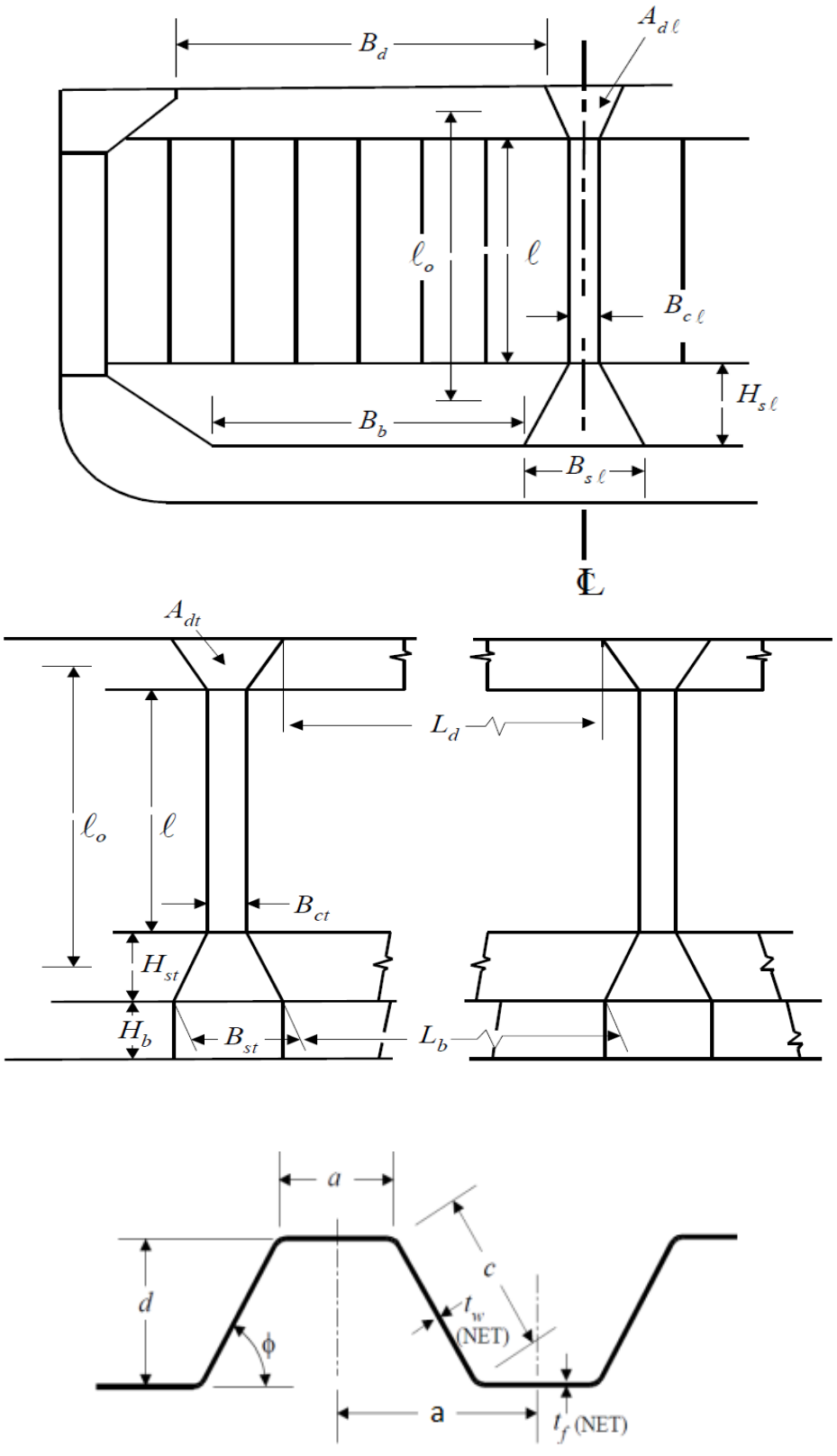


Fig. 4.40 Definition of Parameters for Corrugated Bulkhead (Ship-type Installations with Longitudinal Bulkhead at Centerline)

.2 Upper Stool

The upper stool is to have a depth generally not less than twice the minimum depth of corrugation, as specified in 3.9.3, and is to be properly supported by girders or deep brackets.

The width of the stool bottom plate should generally be the same as that of the lower stool top plate. The net thickness of the stool bottom plate should generally be the same as that of the bulkhead plating, and the net thickness of the lower portion of the stool side plate is not to be less than 80% of that required for the bulkhead plating in 3.9.2 above for the upper one-third portion of the bulkhead. The net thickness of the stool side plating and the net section modulus of the stool side stiffeners are not to be less than those required for plane transverse bulkhead plating and stiffeners in 3.9.1, 3.9.2 and 3.9.3, with the corresponding tank pressure specified in Table 4.11. The ends of stool side stiffeners are to be attached to brackets at the upper and lower ends of the stool. Brackets or diaphragms are to be fitted to effectively support the web panels of the corrugated bulkhead. Scallops in the brackets and diaphragms in way of the connection to the stool bottom plate are to be avoided.

.3 Alignment

Stool side vertical stiffeners and their brackets in the lower stool of the transverse bulkhead should align with the inner bottom longitudinal to provide appropriate load transmission between the stiffening members.

3.9.5 End Connections

The structural arrangements and size of the welding at the ends of corrugations are to be designed to develop the required strength of the corrugated bulkhead. Where shedder plates (slanting plates) are fitted at the end connection of the corrugation to the lower stool, appropriate means are to be provided to prevent the possibility of gas pockets being formed in way of these plates within the cargo tanks.

Welding for all connections and joints is to be in compliance with the Rules. The welded connection of the bulkhead to the stools within 10% of the depth of the corrugation from the outer surface of the corrugation, d_1, is to be double continuous with fillet size not less than 0,7 times the thickness of bulkhead plating or penetration welds of equal strength (see Fig. 4.41).

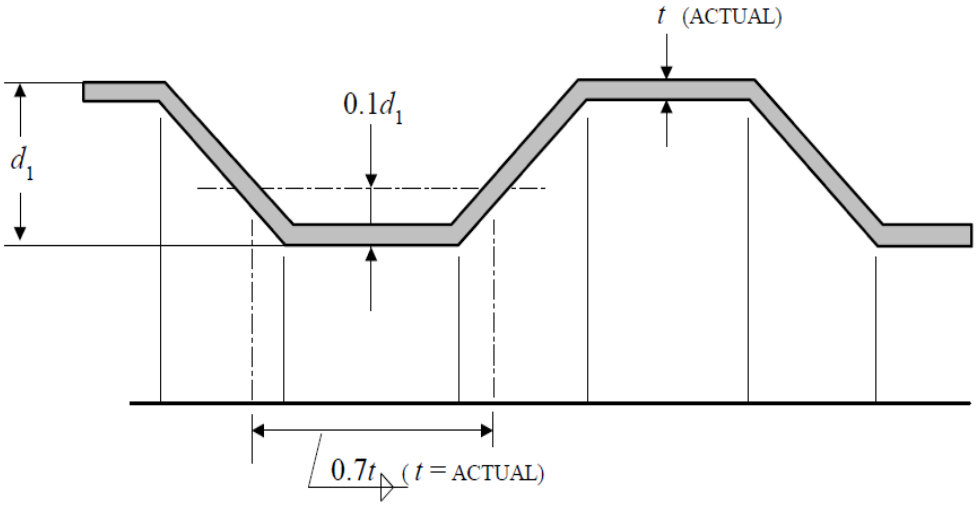


Fig. 4.41 Corrugated Bulkhead End Connections

4. Global Strength Assessment

4.1 General Requirements

4.1.1 General

In assessing the adequacy of the structural configuration and the initially selected scantlings, the strength of the hull girder and the individual structural member or element is to be in compliance with the failure criteria specified in 4.2 below. In this regard, the structural response is to be calculated by performing a structural analysis, as specified in 4.6, or by other equivalent and effective means. Due consideration is to be given to structural details, as specified in 3.1.3..

4.1.2 Loads and Load Cases

In determination of the structural response, the combined load cases given in 2.5.2 are to be considered together with sloshing loads specified in 2.6. Deck loads as specified in A.4 and A.5 are also to be considered. If this information is not yet available, the deck loads as indicated in 2.8 are to be used. Bowflare/bottom slamming and other loads, as specified in 2.7, are also to be considered as necessary.

4.1.3 Stress Components

The total stress in stiffened plate panels are divided into the following three categories:

.1 Primary

Primary stresses are those resulting from hull girder bending. The primary bending stresses may be determined by simple beam method using the specified total vertical and horizontal bending moments and the effective net hull girder section modulus at the section considered. These primary stresses, designated by σ_{L1} (σ_{L1V}, σ_{L1H} for vertical and horizontal bending, respectively), may be regarded as uniformly distributed across the thickness of plate elements, at the same level measuring from the relevant neutral axis of the hull girder.

.2 Secondary

Secondary stresses are those resulting from bending of large stiffened panels between longitudinal and transverse bulkheads, due to local loads in an individual cargo or ballast tank.

The secondary bending stresses, designated by σ_{L2} or σ_{T2}, are to be determined by performing a 3D FEM analysis, as outlined in this Section.

For stiffened hull structures, there is another secondary stress due to the bending of longitudinals or stiffeners with the associated plating between deep supporting members or floors. The latter secondary stresses are designated by σ^*_{L2} or σ^*_{T2}, and may be approximated by simple beam theory.

The secondary stresses, σ_{L2}, σ_{T2}, σ^*_{L2} or σ^*_{T2}, may be regarded as uniformly distributed in the flange plating and face plates.

.3 Tertiary

Tertiary stresses are those resulting from the local bending of plate panels between stiffeners. The tertiary stresses, designated by σ_{L3} or σ_{T3}, can be calculated from classic plate theory. These stresses are referred to as point stresses at the surface of the plate.

4.2 Failure Criteria - Yielding

4.2.1 General

The calculated stresses in the hull structure are to be within the limits given below for the entire combined load cases specified in 2.5.2.

4.2.2 Structural Members and Elements

For all structural members and elements, such as longitudinals/stiffeners, web plates and flanges, the combined effects of all of the calculated stress components are to satisfy the following limits:

$$\sigma_i \leq S_m \cdot R_{eH}$$

where

σ_i = stress intensity

$$= \sqrt{\sigma_L^2 + \sigma_T^2 - \sigma_L \cdot \sigma_T + 3 \cdot \tau_{LT}^2} \quad [N/cm^2]$$

σ_L = calculated total in-plane stress in the longitudinal direction including primary and secondary stresses

$$= \sigma_{L1} + \sigma_{L2} + \sigma_{L2}^* \quad [N/cm^2]$$

σ_{L1} = direct stress due to the primary (hull girder) bending [N/cm^2]

σ_{L2} = direct stress due to the secondary bending between bulkheads in the longitudinal direction [N/cm^2]

σ_{L2}^* = direct stress due to local bending of longitudinal between transverses in the longitudinal direction [N/cm^2]

σ_T = calculated total direct stress in the transverse/vertical direction, including secondary stresses

$$= \sigma_{T1} + \sigma_{T2} + \sigma_{T2}^* \quad [N/cm^2]$$

τ_{LT} = calculated total in-plane shear stress [N/cm^2]

σ_{T1} = direct stress due to sea and cargo load in the transverse/vertical direction [N/cm^2]

σ_{T2} = direct stress due to the secondary bending between bulkheads in the transverse/vertical direction [N/cm^2]

σ_{T2}^* = direct stress due to local bending of stiffeners in the transverse/vertical direction [N/cm^2]

R_{eH} = specified minimum yield point [N/cm^2]

S_m = strength reduction factor, as defined in 3.4.2.1

For this purpose, σ_{L2}^* and σ_{T2}^* in the flanges of longitudinal and stiffener at the ends of span may be obtained from the following equation:

$$\sigma_{LS}^* \left(\sigma_{T2}^*\right) = 0{,}071 \cdot \mathbf{a} \cdot p \frac{\ell^2}{W_L \left(W_T\right)} \quad [N/cm^2]$$

where

a = spacing of longitudinals (stiffeners) [cm]

ℓ = unsupported span of the longitudinal (stiffener) [cm]

p = net pressure load [N/cm^2], for the longitudinal (stiffener)

W_L (W_T) = net section modulus [cm^3], of the longitudinal (stiffener)

4.2.3 Plating

For plating away from knuckle, horizontal girder or stringer or cruciform connections of high stress concentrations and subject to both in-plane and lateral loads, the combined effects of all of the calculated stress components are to satisfy the limits specified in 4.2.2 with σ_L and τ_T modified as follows:

$$\sigma_L = \sigma_{L1} + \sigma_{L2} + \sigma^*_{L2} + \sigma_{L3} \quad [N/cm^2]$$

$$\sigma_T = \sigma_{T1} + \sigma_{T2} + \sigma^*_{T3} + \sigma_{T3} \quad [N/cm^2]$$

where

σ_{L3}, σ_{T3} = plate bending stresses between stiffeners in the longitudinal and transverse directions, respectively, and may be approximated as follows.

$$\sigma_{L3} = 0{,}182 \cdot p \left(\frac{a}{t_n}\right)^2 \quad [N/cm^2]$$

$$\sigma_{T3} = 0{,}266 \cdot p \left(\frac{a}{t_n}\right)^2 \quad [N/cm^2]$$

p = lateral pressures for the combined load case considered (see 2.5) [N/cm^2]

a = spacing of longitudinals or stiffeners [mm]

t_n = net plate thickness [mm]

σ_{L1}, σ_{L2}, σ^*_{L2}, σ_{T1}, σ_{T2} and σ^*_{T2} are as defined in 4.2.2.

For plating within two longitudinals or stiffeners from knuckle or cruciform connections of high stress concentrations, the combined effects of the calculated stress components are to satisfy the following stress limit:

$$\sigma \leq 0{,}80 \cdot S_m \cdot R_{eH}$$

where

σ_i = stress intensity

$$= \sqrt{\sigma_L^2 + \sigma_T^2 - \sigma_L \cdot \sigma_T + 3 \cdot \tau_{LT}^2} \quad [N/cm^2]$$

σ_L = calculated total in-plane stress in the longitudinal direction including primary and secondary stresses

$= \sigma_{L1} + \sigma_{L2}$ [N/cm^2]

σ_T = calculated total direct stress in the transverse/vertical direction, including secondary stresses

$= \sigma_{T1} + \sigma_{T2}$ [N/cm^2]

In addition, the failure criteria for knuckle or cruciform connections in 4.7 are to be complied with.

4.3 Failure Criteria - Buckling and Ultimate Strength

4.3.1 General

.1 Approach

The strength criteria given here correspond to either serviceability (buckling) limit states or ultimate limit states for structural members and panels, according to the intended functions and buckling resistance capability of the structure. For plate panels between stiffeners, buckling in the elastic range is acceptable, provided that the ultimate strength of the structure satisfies the specified design limits. The critical buckling stresses and ultimate strength of structures may be determined based on either well-documented experimental data or a calibrated analytical approach. When a detailed analysis is not available, the equations given in 4.4.1 may be used to assess the buckling strength.

.2 Buckling Control Concepts

The strength criteria in 4.3.2 through 4.3.6 are based on the following assumptions and limitations with respect to buckling control in design.

1) The buckling strength of longitudinals and stiffeners is generally greater than that of the plate panels they support.
2) All longitudinals with their associated effective plating are to have moments of inertia not less than i_o given in 4.4.5.1.
3) The main supporting members, including transverses, girders and floors, with their associated effective plating are to have the moments of inertia not less than I_s given in 4.4.5.3.
4) Face plates and flanges of girders, longitudinals and stiffeners are proportioned such that local instability is prevented. (See 4.4.5.4)
5) Webs of longitudinals and stiffeners are proportioned such that local instability is prevented. (See 4.4.5.5).
6) Webs of girders, floors and transverses are designed with proper proportions and stiffening systems to prevent local instability. Critical buckling stresses of the webs may be calculated from equations given in 4.4.2.
7) Bracket plates, flanges of brackets and stiffeners of tripping brackets and main supporting members end brackets are proportioned such that local instability is prevented, see 4.4.5.6

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

4.3.2 Plate Panels

.1 Buckling Limit State

The buckling limit state for plate panels between stiffeners is defined by the following equation:

$$\left(\frac{\sigma_{Lb}}{\sigma_{cL}}\right)^2 + \left(\frac{\sigma_{Tb}}{\sigma_{cT}}\right)^2 + \left(\frac{\tau_{LT}}{\tau_{cLT}}\right)^2 \leq 1{,}0$$

where

σ_{Lb} = $\sigma_{L1} + \sigma_{L2}$ = calculated total compressive stress in the longitudinal direction for the plate [N/cm^2], induced by bending of the hull girder and large stiffened panels between bulkheads

σ_{Tb} = $\sigma_{T1} + \sigma_{T2}$ = calculated total compressive stress in the transverse/vertical direction [N/cm^2]

τ_{LT} = calculated total in-plane shear stress [N/cm^2]

σ_{cL}, σ_{cT} and τ_{cLT} are the critical buckling stresses corresponding to uniaxial compression in the longitudinal, transverse/vertical directions and edge shear, respectively, [N/cm^2], and may be determined from the equations given in 4.4.2.

σ_L, σ_T and τ_{LT} are to be determined for the panel in question under the load cases specified in 2.5.2.1 including the primary and secondary stresses, as defined in 4.2.1.

.2 Effective Width

When the buckling limit state specified in 4.3.2.1 above is not satisfied, the effective width b_{wL} or b_{wT} of the plating given below is to be used instead of the full width between longitudinals, **a**, for verifying the ultimate strength, as specified in 4.3.2.3 below. When the buckling limit state in 4.3.2.1 above is satisfied, the full width between longitudinals, **a**, may be used as the effective width, b_{wL}, for verifying the ultimate strength of longitudinals and stiffeners specified in 4.3.3.

1) For long plate:

$$\frac{b_{wL}}{\mathbf{a}} = C$$

$$C = \frac{2{,}25}{\beta} - \frac{1{,}25}{\beta^2} \quad \text{for } \beta \geq 1{,}25$$

$$= 1{,}0 \quad \text{for } \beta < 1{,}25$$

$$\beta = \sqrt{\frac{R_{eH}}{E}} \cdot \frac{\mathbf{a}}{t_n}$$

a = longitudinal spacing [mm]

t_n = net thickness of the plate [mm]

E = Young's modulus, $2{,}06 \times 10^7$ [N/cm^2] for steel

R_{eH} = specified minimum yield point of the material [N/cm^2]

2) For wide plate (compression in transverse direction):

$$\frac{b_{wT}}{\ell} = C \cdot \frac{\mathbf{a}}{\ell} + 0{,}115\left(1 - \frac{\mathbf{a}}{\ell}\right)\left(1 + \frac{1}{\beta^2}\right)^2 \leq 1{,}0$$

where

ℓ = spacing of transverses [cm]

a = longitudinal spacing [cm]

C, β are as defined in 1) above.

.3 Ultimate Strength

The ultimate strength of a plate panel between stiffeners is to satisfy all of the following equations:

$$\left(\frac{\sigma_{Lb}}{\sigma_{uL}}\right)^2 + \left(\frac{\tau_{LT}}{\tau_{uLT}}\right)^2 \leq S_m$$

$$\left(\frac{\sigma_{Tb}}{\sigma_{uT}}\right)^2 + \left(\frac{\tau_{LT}}{\tau_{uLT}}\right)^2 \leq S_m$$

$$\left(\frac{\sigma_{Lb}}{\sigma_{uL}}\right)^2 + \left(\frac{\sigma_{Lb}}{\sigma_{uT}}\right)^2 - \eta\left(\frac{\sigma_{Lb}}{\sigma_{uL}}\right)\left(\frac{\sigma_{Tb}}{\sigma_{uT}}\right) + \left(\frac{\tau_{LT}}{\tau_{uLT}}\right)^2 \leq S_m$$

where

σ_{Lb}, σ_{Tb} and τ_{LT} are as defined in 4.3.2.1 above.

S_m is as defined in 3.4.2.1.

$$\eta = 1{,}5 - \frac{\beta}{2} \geq 0$$

β is as defined in 4.3.2.2 above.

σ_{uL}, σ_{uT} and τ_{uLT} are the ultimate strengths with respect to uniaxial compression and edge shear, respectively, and may be obtained from the following equations, except that they need not be taken less than the corresponding critical buckling stresses specified in 4.3.2.1 above.

$$\sigma_{uL} = R_{eH} \cdot \frac{b_{wL}}{\mathbf{a}}$$

$$\sigma_{uT} = R_{eH} \cdot \frac{b_{wT}}{\ell}$$

$$\sigma_{uLT} = \tau_{cLT} + 0{,}5 \cdot \frac{R_{eH} - \sqrt{3} \cdot \tau_{cLT}}{\sqrt{1 + \alpha + \alpha^2}}$$

where

$$\alpha = \frac{\ell}{\mathbf{a}}$$

R_{eH}, b_{wL}, b_{wT}, $\mathbf{a}$, ℓ and τ_{cLT} are as defined above.

For assessing the ultimate strength of plate panels between stiffeners, special attention is to be paid to the longitudinal bulkhead plating in the regions of high hull girder shear forces and the bottom and inner bottom plating in the mid portion of cargo tanks subject to bi-axial compression.

4.3.3 Longitudinals and Stiffeners

.1 Beam-Column Buckling Limit States and Ultimate Strength

The buckling limit states for longitudinals and stiffeners are considered as the ultimate limit states for these members and are to be determined as follows:

$$\frac{\sigma_a}{\sigma_{ca} \cdot \frac{A_e}{A}} + m \cdot \frac{\sigma_b}{R_{eH}} \leq S_m$$

where

σ_a = nominal calculated compressive stress

= $\frac{P}{A}$ [N/cm^2]

P = total compressive load [N]

σ_{ca} = critical buckling stress, as given in 4.4.3.1, [N/cm^2]

A = total net sectional area [cm^2]

= $A_s + \mathbf{a} \cdot t_n$

A_s = net sectional area of the longitudinal, excluding the associated plating [cm^2]

A_e = effective net sectional area [cm^2]

= $A_s + b_{wL} \cdot t_n$

b_{wL} = effective width, as specified in 4.3.2.2 above

E = Young's modulus, 2.06×10^7 [N/cm^2] for steel

R_{eH} = minimum specified yield point of the longitudinal or stiffener under consideration [N/cm^2]

σ_b = bending stress [N/cm^2]

= $\frac{M}{W_e}$ [N/cm^2]

M = maximum bending moment induced by lateral loads

= $c_m \cdot p \cdot \mathbf{a} \cdot \frac{\ell^2}{12}$ [N-cm]

c_m = moment adjustment coefficient, and may be taken as 0,75

p = lateral pressure for the region considered [N/cm^2]

a = spacing of the longitudinals [cm]

W_e = effective section modulus of the longitudinal at flange, accounting for the effective breadth, b_e, [cm^3]

b_e = effective breadth, as specified in Fig. 4.35, line b

m = amplification factor

= $\frac{1}{1 - \frac{\sigma_a}{\pi^2} E \left(\frac{r}{\ell}\right)^2} \geq 1.0$

S_m is as defined in 3.4.3.1.

r and ℓ are as defined in 4.4.3.1.

.2 Torsional-Flexural Buckling Limit State

In general, the torsional-flexural buckling limit state of longitudinals and stiffeners is to satisfy the ultimate limit states given below:

$$\frac{\sigma_a}{\sigma_{ct} \cdot \frac{A_e}{A}} \leq S_m$$

where

σ_a = nominal calculated compressive stress [N/cm^2], as defined in 4.3.3.1 above

σ_{ct} = critical torsional-flexural buckling stress [N/cm^2], and may be determined by equations given in 4.4.3.2.

A_e and A are as defined in 4.3.3.1 above and S_m is as defined in 3.4.2.1.

4.3.4 Stiffened Panels

.1 Large Stiffened Panels between Bulkheads

For a double hull ship-type installation, assessment of buckling limit state is not required for the large stiffened panels of the bottom and inner bottom structures, side shell and inner skin. Assessments of the buckling limit states are to be performed for large stiffened panels of the deck structure and other longitudinal bulkheads. In this regard, the buckling strength is to satisfy the following condition for uniaxially or orthogonally stiffened panels.

$$\left(\frac{\sigma_{L1}}{\sigma_{cL}}\right)^2 + \left(\frac{\sigma_{T1}}{\sigma_{cT}}\right)^2 \leq S_m$$

where

σ_{L1}, σ_{T1} = calculated average compressive stresses in the longitudinal and transverse/vertical directions [N/cm^2], respectively, as defined in 4.2.2 above.

σ_{cL}, σ_{cT} = critical buckling stresses for uniaxial compression in the longitudinal and transverse direction [N/cm^2], respectively, and may be determined in accordance with 4.4.4.

S_m = strength reduction factor, as defined in 3.4.2.1.

.2 Uniaxially Stiffened Panels between Transverses and Girders

The bucking strength of uniaxially stiffened panels between deep transverses and girders is also to be examined in accordance with the specifications given in 4.3.4.1 above by replacing σ_{L1} and σ_{T1} with σ_{Lb} and σ_{Tb}, respectively. σ_{Lb} and σ_{Tb} are as defined in 4.3.2.1 above.

4.3.5 Deep Girders and Webs

.1 Buckling Criteria

In general, the stiffness of the web stiffeners along the depth of the web plating is to be in compliance with the requirements of 4.4.5.2. Web stiffeners which are oriented parallel to and near the face plate, and thus subject to axial compression, are also to satisfy the limits specified in 4.3.3, considering the combined effect of the compressive and bending stresses in the web. In this case, the unsupported span of these parallel stiffeners may be taken between tripping brackets, as applicable.

The buckling strength of the web plate between stiffeners and flange/face plate is to satisfy the limits specified below.

1) **For web plate :**

$$\left(\frac{\sigma_{Lb}}{\sigma_{uL}}\right)^2 + \left(\frac{\sigma_b}{\sigma_{cb}}\right)^2 + \left(\frac{\tau_{LT}}{\tau_{cLT}}\right)^2 \leq S_m$$

where

σ_{Lb} = calculated uniform compressive stress along the length of the girder [N/cm^2]

σ_b = calculated ideal bending stresses [N/cm^2]

τ_{LT} = calculated total in-plane shear stress [N/cm^2]

S_m = strength reduction factor, as defined in 3.4.2.1

σ_{Lb}, σ_b and τ_{LT} are to be calculated for the panel in question under the combined load cases specified in 2.5.2 and these stresses may be calculated from the relative displacements of four corner nodes. This method is useful when the meshing within the panel is irregular. However, care should be taken when one corner of the panel is located in an area of high stress concentration or the panel shape is significantly different from a rectangular shape. The calculated stresses from the above mentioned method tend to be on the conservative side. If one corner of the panel is highly stressed and if the mesh is sufficiently refined, the plate panel stresses may be calculated from the displacements slightly away from the corner point of the high stress concentration area. For a regularly meshed plate panel, σ_L, σ_b and τ_{LT} may also be calculated directly from the components stresses for the elements in the panel.

σ_{cL}, σ_{cb} and τ_{cLT} are critical buckling stresses with respect to uniform compression, ideal bending and shear, respectively, and may be determined in accordance with 4.4.

In the determination of σ_{cL} and τ_{cLT}, the effects of openings are to be considered.

For deck transverse web plating of existing vessels converted to FPIs, when the buckling limit state specified above is not satisfied and the Survey Record Review does not indicate any buckling problems for the deck transverse plating panels, it may be acceptable to apply the criteria specified in 4.3.2.2 and 4.3.2.3.

2) **For face plate and flange.**

The breadth to thickness ratio of face plate and flange is to satisfy the limits given in 4.4.5.

3) **For large brackets and sloping webs.**

The buckling strength is to satisfy the limits specified in 4.3.5.1(a) above for web plate.

4.3.6 Corrugated Bulkheads

.1 Local Plate Panels

1) **Buckling criteria.**

The buckling strength of the flange and web plate panels is not to be less than that specified below.

$$\left(\frac{\sigma_{Lb}}{R_\ell \cdot \sigma_{cL}}\right)^2 + \left(\frac{\sigma_{Tb}}{R_t \cdot \sigma_{cT}}\right)^2 + \left(\frac{\tau_{LT}}{\tau_{cLT}}\right)^2 \leq S_m \qquad \text{for flange panels}$$

$$\left(\frac{\sigma_{LB}}{R_\ell \cdot \sigma_{cL}}\right)^2 + \left(\frac{\sigma_b}{\sigma_{cb}}\right)^2 + \left(\frac{\tau_{LT}}{\tau_{cLT}}\right)^2 \leq S_m \qquad \text{for web panels}$$

where

R_t = reduction factor accounting for lateral load effects, and may be approximated by:

= $1{,}0 - 0{,}45 \cdot (q - 0{,}5)$

q = lateral load parameter

= $\dfrac{p_n \cdot \left(\dfrac{a}{t_n}\right)^4}{\pi^2 \cdot E}$, 0,5 minimum

p_n = lateral pressure for the combined load case considered (see 2.5) [N/cm^2]

a = longitudinal spacing [mm]

t_n = net thickness of the plate [mm]

E = Young's modulus [N/cm^2], for steel $2{,}06 \times 10^7$

All of the parameter definitions and calculations are as specified in 4.3.2.1 and 4.3.5.1.1), except that σ_{Lb} is the average compressive stress at the upper and lower ends of the corrugation, and an average value of σ_{Tb}, τ_{LT} and σ_b, calculated along the entire length of the panel, should be used in the above equation.

2) **Ultimate strength**.

The ultimate strength of flange panels in the middle one-third of the depth are to satisfy the following criteria, considering a portion of flange panel having a length of three times the panel width, a, with the worst bending moments in the mid-depth region for all load cases.

$$\left(\frac{\sigma_{Lb}}{\sigma_{uL}}\right)^2 + \left(\frac{\sigma_{Tb}}{\sigma_{uT}}\right)^2 \leq S_m$$

where

σ_{Lb} = the calculated average compressive bending stress in the region within 3·a in length [N/cm^2]

σ_{Tb} = horizontal compressive stresses, as specified in .1.1) above

σ_{uL} and σ_{uT} may be calculated in accordance with 4.3.2.3 above.

.2 Unit Corrugation

Any unit corrugation of the bulkhead may be treated as a beam column and is to satisfy the buckling criteria (same as the ultimate strength) specified in 4.3.3.1. The ultimate bending stress is to be determined in accordance with 4.4.3.3.

.3 Overall Buckling

The buckling strength of the entire corrugation is to satisfy the equation given in 4.3.4.1 with respect to the biaxial compression by replacing the subscripts "L" and "T" with "V" and "H" for the vertical and horizontal directions, respectively.

4.3.7 Curved Plate Panels

.1 Buckling Limit State

The buckling limit state for curved plate panels defined by the following equation is to be satisfied.

$$\left(\frac{\sigma_{Lb}}{R_{cL}\cdot\sigma_{cL}}\right)^2-\varphi_R\left(\frac{\sigma_{Lb}}{R_{cL}\cdot\sigma_{cL}}\right)\left(\frac{\sigma_T}{R_{cT}\cdot\sigma_{cT}}\right)+\left(\frac{\sigma_T}{R_{cT}\cdot\sigma_{cT}}\right)^2\le S_m$$

where

σ_{Lb} = calculated compressive stress in the longitudinal direction for the curved plate, as specified in 4.3.2.1 [N/cm^2]. In case of tensile stresses, $\sigma_{Lb} = 0$.

σ_T = calculated total direct stress in the transverse/vertical direction, including secondary stresses. In case of tensile stresses, $\tau_T = 0$.

= $\sigma_{Tb} + \sigma_p$

σ_{Tb} = calculated compressive stress in the transverse/vertical direction for the curved plate, as specified in 4.3.2.1 [N/cm^2].

σ_p = calculated hoop compressive stress resulted from the maximum net pressure [N/cm^2]

= $P\cdot\left(\frac{r+0{,}5\cdot t}{t}\right)$

P = lateral pressure for the combined load case considered in 2.5 [N/cm^2]

r = mean radius of curved plate [cm]

t = net thickness of the plate [cm]

σ_{CL} = critical buckling stress for axial compression or bending moment [N/cm^2], as given in 4.4.6.

σ_{CT} = critical buckling stress for external pressure [N/cm^2], as given in 4.4.6.

φ_R = coefficient to reflect interaction between longitudinal and hoop stresses (negative values are acceptable)

= $\left(\frac{\sigma_{CL}+\sigma_{CT}}{R_{eH}}\right)-1$

R_{eH} = specified minimum yield point of the material [N/cm^2]

S_m = strength reduction factor, as defined in 4.3.2.1

R_{CL} = 0,833 for $\sigma_{CL} \le 0{,}55 \cdot R_{eH}$

= $0{,}629+0{,}371\left(\frac{\sigma_{CL}}{R_{eH}}\right)$ for $\sigma_{CL} > 0{,}55 \cdot R_{eH}$

R_{CT} = 0,833 for $\sigma_{CT} \le 0{,}55 \cdot R_{eH}$

= $0{,}629+0{,}371\left(\frac{\sigma_{CT}}{R_{eH}}\right)$ for $\sigma_{CT} > 0{,}55 \cdot R_{eH}$

4.4 Calculation of Critical Buckling Stresses

4.4.1 General

The critical buckling stresses for various structural elements and members may be determined in accordance with this Subsection or other recognized design practices. Critical buckling stresses derived from experimental data or analytical studies may be considered, provided that well-documented supporting data are submitted for review.

4.4.2 Rectangular Plates

The critical buckling stresses for rectangular plate elements, such as plate panels between stiffeners; web plates of longitudinals, girders, floors and transverses; flanges and face plates, may be obtained from the following equations, with respect to uniaxial compression, bending and edge shear, respectively.

$$\sigma_{ci} = \sigma_{Ei} \qquad \text{for } \sigma_{Ei} \le P_r \cdot \sigma_{yi}$$

$$\sigma_{ci} = \sigma_{yi}\left[1 - P_r\left(1 - P_r\right) \cdot \frac{\sigma_{yi}}{\sigma_{Ei}}\right] \qquad \text{for } \sigma_{Ei} > P_r \cdot \sigma_{yi}$$

where

σ_{ci} = critical buckling stress with respect to uniaxial compression [N/cm^2], bending or edge shear, separately

σ_{Ei} = $K_i\left[\frac{\pi^2 \cdot E}{12\left(1 - v^2\right)}\right] \cdot \left(\frac{t_n}{a}\right)^2$ [N/cm^2]

K_i = buckling coefficient, as given in Table 4.21

E = modulus of elasticity of the material, may be taken as $2{,}06 \times 10^7$ [N/cm^2] for steel

v = Poisson's ratio, may be taken as 0,3 for steel

t_n = net thickness of the plate [cm]

a = spacing of longitudinals/stiffeners [cm]

P_r = proportional linear elastic limit of the structure, may be taken as 0.6 for steel

σ_{yi} = R_{eH} for uniaxial compression and bending

= $\frac{R_{eH}}{\sqrt{3}}$ for edge shear

R_{eH} = specified minimum yield point of the material [N/cm^2]

Table 4.21 - Buckling Coefficient, K_i

For Critical Buckling Stress Corresponding to σ_L, σ_T, σ_b or τ_{LT}

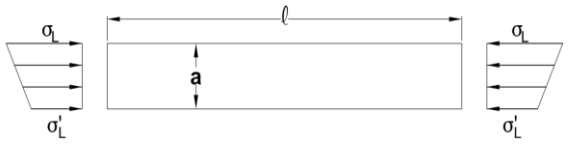
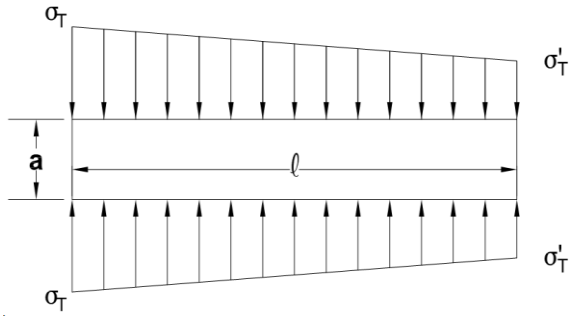
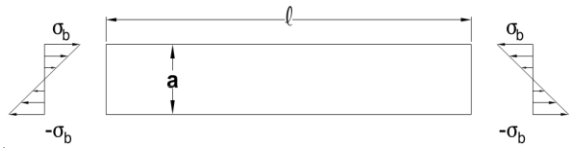
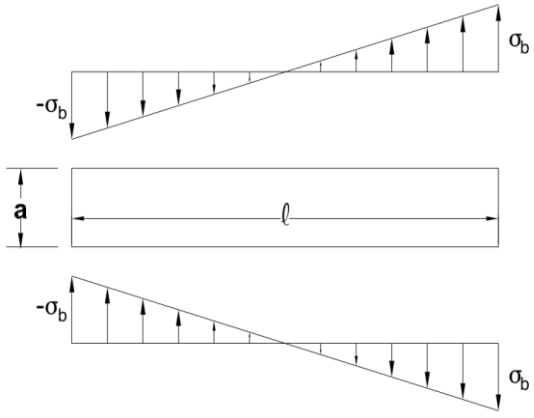
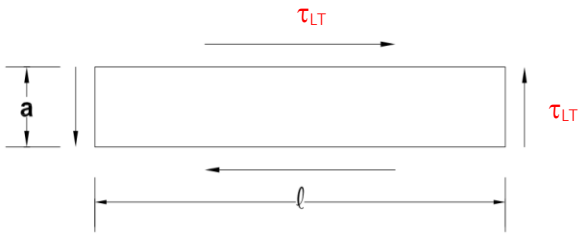
			Ki
I.	**Plate panel between stiffeners**		
A.	**Uniaxial compression**		
1.	Long plate $\ell \geq a$		
		a. For $\sigma'_L = \sigma_L$	$4\ C_1$
		b. For $\sigma'_L = \sigma_L/3$ (see note)	$5{,}8\ C_1$
2.	Wide plate $\ell \geq a$		
		a. For $\sigma'_T = \sigma_T$	$\left[1+\left(\frac{a}{\ell}\right)^2\right]^2 C_2$
		b. For $\sigma'_T = \sigma_T/3$ (see note)	$1{,}45\left[1+\left(\frac{a}{\ell}\right)^2\right]^2 C_2$
B.	**Ideal Bending**		
1.	Long plate $\ell \geq a$		$24\ C_1$
2.	Wide plate $\ell \geq a$		
		a. For $1{,}0 \leq \frac{\ell}{a} \leq 2{,}0$	$24\left(\frac{a}{\ell}\right)^2 C_2$
		b. For $2{,}0 < \frac{\ell}{a}$	$12\ \frac{a}{\ell}\ C_2$
C.	**Edge Shear**		$\left[5{,}34+4\left(\frac{a}{\ell}\right)^2\right] C_1$

Table 4.21 - Buckling Coefficient, K_i (*continued*)

D Values of C_1 and C_2

1. For plate panels between angles or tee stiffeners

   C_1 = 1,1

   C_2 = 1,3 within the double bottom or double side*

   C_2 = 1,2 elsewhere

2. For plate panels between flat bars or bulb plates

   C_1 = 1,0

   C_2 = 1,2 within the double bottom or double side*

   C_2 = 1,1 elsewhere

* applicable where shorter edges of a panel are supported by rigid structural members, such as bottom, inner bottom, side shell, inner skin bulkhead, double bottom floor/girder and double side web stringer.

II. Web of Longitudinal or Stiffener K_i

A Axial compression

Same as I.A.1 by replacing **a** with depth of the web and ℓ with unsupported span

a. For $\sigma'_L = \sigma_L$: 4C

b. For $\sigma'_L = \sigma_L/2$: 5,2C

(see note)

Where

C = 1,0 for angle or tee stiffeners

C = 0,33 for bulb plates

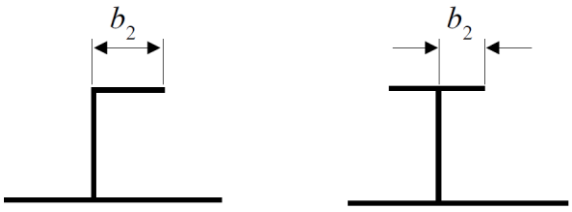
C = 0,11 for flat bars

B Ideal Bending

Same as I.B.1 by replacing **a** with depth of the web and ℓ with unsupported span 24C

III. Flange and Face Plate K_i

Axial Compression 0,44



a = b_2

ℓ = unsupported span

Note :

In I.A. (II.A), K_i for intermediate values of σ'_L/σ_L (σ'_T/σ_T) may be obtained by interpolation between a and b.

4.4.3 Longitudinals and Stiffeners

.1 Axial Compression

The critical buckling stress, σ_{ca}, of a beam-column, i.e., the longitudinal and the associated effective plating, with respect to axial compression may be obtained from the following equations:

$$\sigma_{ca} = \sigma_E \qquad \text{for } \sigma_E \le P_r \cdot R_{eH}$$

$$\sigma_{ca} = R_{eH}\left[1 - P_r\left(1 - P_r\right) \cdot \frac{R_{eH}}{\sigma_E}\right] \qquad \text{for } \sigma_E > P_r \cdot R_{eH}$$

where

$$\sigma_E = \frac{\pi^2 \cdot E}{\left(\frac{\ell}{r}\right)^2} \quad [N/cm^2]$$

ℓ = unsupported span of the longitudinal or stiffener, in cm, as defined in Fig.4.3.4

r = radius of gyration of area A_e [cm]

A_e = $A_s + b_{wL} \cdot t_n$

A_s = net sectional area of the longitudinals or stiffeners [cm^2], excluding the associated plating,

b_{wL} = effective width of the plating [cm], as given in 4.3.2.2.

t_n = net thickness of the plating [cm]

R_{eH} = minimum specified yield point of the longitudinal or stiffener under consideration, [N/cm^2]

P_r and E are as defined in 4.4.2.

.2 Torsional/Flexural Buckling

The critical torsional/flexural buckling stress with respect to axial compression of a longitudinal, including its associated plating (effective width, b_{wL}), may be obtained from the following equations:

$$\sigma_{ct} = \sigma_{ET} \qquad \text{for } \sigma_{ET} \le P_r \cdot R_{eH}$$

$$\sigma_{ct} = R_{eH}\left[1 - P_r\left(1 - P_r\right) \cdot \frac{R_{eH}}{\sigma_{ET}}\right] \qquad \text{for } \sigma_{ET} > P_r \cdot R_{eH}$$

where

σ_{ct} = critical torsional/flexural buckling stress with respect to axial compression [N/cm^2]

$$\sigma_{ET} = \frac{E\left[\frac{K}{2,6} + \left(\frac{n \cdot \pi}{\ell}\right)^2 \Gamma + C_0 \frac{\left(\frac{\ell}{n \cdot \pi}\right)^2}{E}\right]}{I_0\left[1 + C_0 \frac{\left(\frac{\ell}{n \cdot \pi}\right)^2}{I_0 \cdot \sigma_{cL}}\right]} \quad [N/cm^2]$$

K = St. Venant torsion constant for the longitudinal's cross section, excluding the associated plating.

$$= \frac{\left(b_f \cdot t_f^3 + d_w \cdot t_w^3\right)}{3}$$

I_o = polar moment of inertia of the longitudinal, excluding the associated plating, about the toe (intersection of web and plating) [cm^4]

$$= I_x + m \cdot I_y + A_s\left(x_0^2 + y_0^2\right)$$

I_x, I_y = moment of inertia of the longitudinal about the x-and y-axis, respectively, through the centroid of the longitudinal, excluding the plating (x-axis perpendicular to the web) [cm^4]

m = $1 - u\left(0,7 - 0,1 \cdot \frac{d_w}{b_f}\right)$

u = unsymmetry factor

$$= 1 - 2 \cdot \frac{b_1}{b_f}$$

x_o = horizontal distance between centroid of stiffener, A_s, and centerline of the web plate, [cm]

y_o = vertical distance between the centroid of the longitudinal's cross section and its toe, [cm]

d_w = depth of the web [cm]

t_w = net thickness of the web [cm]

b_f = total width of the flange/face plate [cm]

b_1 = smaller outstanding dimension of flange with respect to centerline of web (see Fig.4.42) [cm]

t_f = net thickness of the flange/face plate [cm]

C_o = $E \cdot \frac{t_n^3}{3 \cdot \mathbf{a}}$

Γ = warping constant

$$= m \cdot I_{yf} \cdot d_w^2 + \frac{d_w^3 \cdot t_w^3}{36}$$

$$I_{yf} = t_f \cdot b_f^3 \frac{\left(1 + 3 \cdot u^2 \cdot d_w \cdot \frac{t_w}{A_s}\right)}{12} \quad [cm]$$

σ_{cL} = critical buckling stress for the associated plating, corresponding to n-half waves [N/cm^2]

$$= \frac{\pi^2 \cdot E \left(\frac{n}{\alpha} + \frac{\alpha}{n}\right)^2 \cdot \left(\frac{t_n}{a}\right)^2}{12\left(1 - \nu^2\right)}$$

$$\alpha = \frac{\ell}{a}$$

n = number of half-wave which yield a smallest σ_{ET}

R_{eH} = minimum specified yield point of the longitudinal or stiffener under consideration [N/cm^2]

P_r, E, **a** and ν are as defined in 4.4.2.

A_s, t_n and ℓ are as defined in .1.

.3 Buckling Criteria for Unit Corrugation of Transverse Bulkhead

The critical buckling stress, which is also the ultimate bending stress, σ_{cb}, for a unit corrugation, may be determined from the following equation (See 4.3.6.2).

$$\sigma_{cb} = \sigma_{Ec} \quad \text{for} \quad \sigma_{Ec} \leq P_r \cdot R_{eH}$$

$$\sigma_{cb} = \left[1 - P_r\left(1 - P_r\right) \cdot \frac{R_{eH}}{\sigma_{Ec}}\right] \cdot R_{eH} \quad \text{for} \quad \sigma_{Ec} > P_r \cdot R_{eH}$$

where

$$\sigma_{Ec} = k_c \cdot E \left(\frac{t}{a}\right)^2$$

$$k_c = 0.09\left[7.65 - 0.26 \cdot \left(\frac{c}{a}\right)^2\right]^2$$

c and **a** are widths of the web and flange panels [cm^2], respectively.

t = net thickness of the flange panel [cm]

P_r, R_{eH} and E are as defined in 4.4.2.

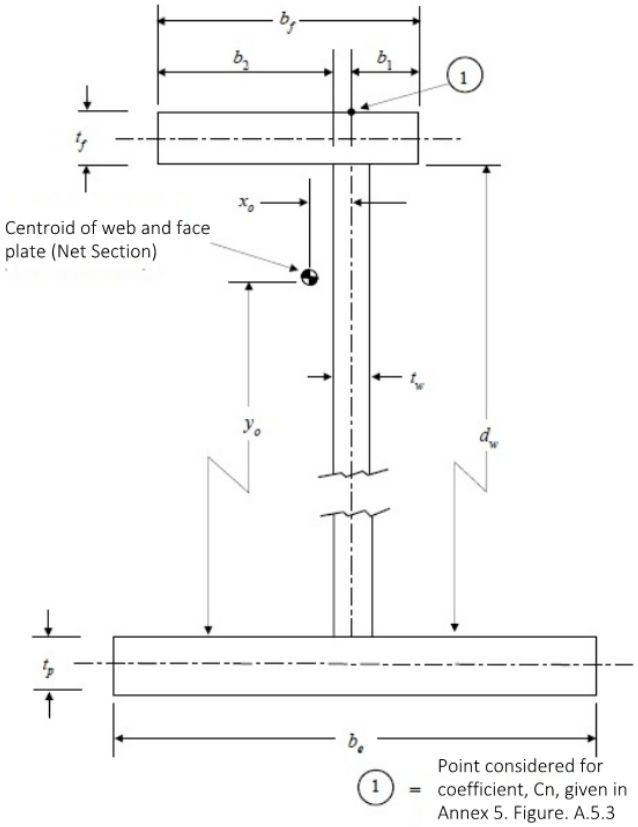


Fig. 4.42 Net Dimensions and Properties of Stiffeners

4.4.4 Stiffened Panels

.1 Large Stiffened Panels

For large stiffened panels between bulkheads or panels stiffened in one direction between transverses and girders, the critical buckling stresses with respect to uniaxial compression may be determined from the following equations:

$$\sigma_{ci} = \sigma_{Ei} \qquad \text{for} \quad \sigma_{Ei} \leq P_r \cdot R_{eH}$$

$$\sigma_{ci} = R_{eH} \cdot \left[1 - P_r \left(1 - P_r \right) \cdot \frac{R_{eH}}{\sigma_{Ei}} \right] \qquad \text{for} \quad \sigma_{Ei} > P_r \cdot R_{eH}$$

where

$$\sigma_{Ei} = k_L \cdot \pi^2 \cdot \frac{\sqrt{D_L \cdot D_T}}{t_L \cdot b^2} \qquad \text{in the longitudinal direction [N/cm}^2\text{]}$$

$$\sigma_{Ei} = k_T \cdot \pi^2 \cdot \frac{\sqrt{D_L \cdot D_T}}{t_T \cdot \ell^2} \qquad \text{in the transverse direction [N/cm}^2\text{]}$$

$$k_L = 4 \qquad \text{for} \quad \frac{\ell}{b} \geq 1$$

$$= \left[\frac{1}{\phi_L^2} + 2 \cdot \eta + \phi_L^2 \right] \qquad \text{for} \quad \frac{\ell}{b} < 1$$

k_T = 4 for $\frac{\ell}{b} \geq 1$

= $\left[\frac{1}{\phi_T^2} + 2 \cdot \eta + \phi_T^2\right]$ for $\frac{\ell}{b} < 1$

$D_L = \frac{E \cdot I_L}{a_L\left(1 - v^2\right)}$

$D_T = \frac{E \cdot I_T}{a_T\left(1 - v^2\right)}$

$D_T = \frac{E \cdot t_n^3}{12\left(1 - v^2\right)}$ if no stiffener in the transverse direction

ℓ, b = length and width between transverse and longitudinal bulkheads [cm], respectively, (See Fig.4.43)

t_L, t_T = net equivalent thickness of the plating and stiffener [cm], in the longitudinal and transverse direction, respectively.

= $\frac{a_L \cdot t_n + A_{sL}}{a_L}$ or $\frac{a_T \cdot t_n + A_{sT}}{a_T}$

a_L, a_T = spacing of longitudinals and transverses [cm], respectively (See Fig.4.43).

$\phi_L = \frac{\ell}{b} \cdot \sqrt[4]{\frac{D_T}{D_L}}$

$\phi_T = \frac{b}{\ell} \cdot \sqrt[4]{\frac{D_L}{D_T}}$

$\eta = \sqrt{\frac{I_{pL} \cdot I_{pT}}{I_L \cdot I_T}}$

A_{sL}, A_{sT} = net sectional area of the longitudinal and transverse [cm^2], excluding the associated plating, respectively.

I_{pL}, I_{pT} = net moment of inertia of the effective plating alone (effective breadth due to shear lag) about the neutral axis of the combined cross section, including stiffener and plating, [cm^4]

I_L, I_T = net moment of inertia of the stiffener (one) with effective plating in the longitudinal or transverse direction [cm^4], respectively. If no stiffener, the moment of inertia is calculated for the plating only.

R_{eH}, P_r, E and v are as defined in 4.4.2, t_n is as defined in 4.4.3.1.

With the exception of deck panels, when the lateral load parameter, q_o, defined below, is greater than 5, reduction of the critical buckling stresses given below is to be considered.

$$q_o = \frac{p_n \cdot b^4}{\pi^4 \cdot t_T \cdot D_T}$$

$$q_o = \frac{p_n \cdot \ell^4}{\pi^4 \cdot t_L \cdot D_L}$$

where

p_n = average net lateral pressure [N/cm^2]

D_T, D_L, b, ℓ, t_T, t_L and a_T are as defined above.

In this regard, the critical buckling stress may be approximated by:

$$\sigma'_{ci} = R_o \cdot \sigma_{ci} \quad [N/cm^2]$$

where

R_o = $1 - 0{,}045\,(q_o - 5)$ for $q_o \geq 5$

For deck panels, $R_o = 1.0$ and $\sigma'_{ci} = \sigma_{ci}$.

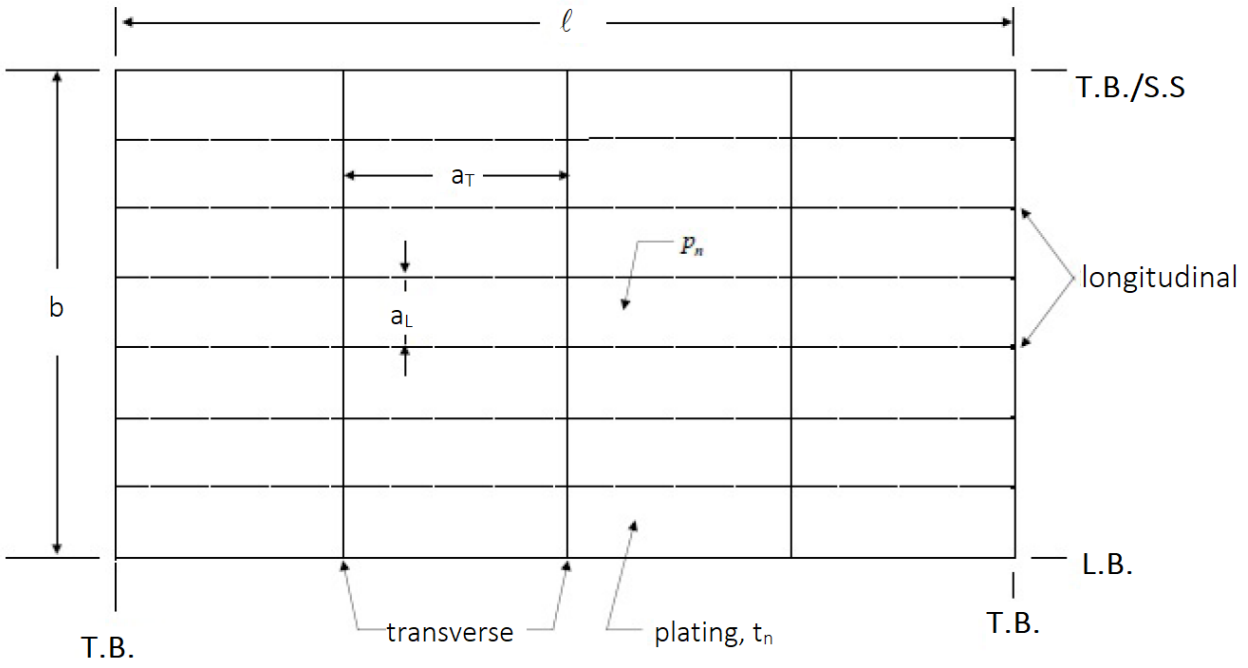


Fig. 4.43 Transverse and Longitudinal Stiffened Panel

.2 Corrugated Transverse Bulkheads

For corrugated transverse bulkheads, the critical buckling stresses with respect to uniaxial compression may be calculated from the equations given in .1 above by replacing the subscripts "L" and "T" with "V" and "H" for the vertical and horizontal directions, respectively, and with the following modifications. The rigidities D_V are D_H are defined as follows.

$$D_V = E \cdot \frac{I_V}{a}$$

$$D_H = \left(\frac{a}{a + c}\right)\left(\frac{E \cdot t^3}{12\left(1 - \nu^2\right)}\right)$$

$$K_V = 4 \quad \text{for } \frac{\ell}{b} \geq 0{,}5176 \cdot \sqrt[4]{\frac{D_V}{D_H}}$$

$$= \frac{1}{\phi_V^2} + \phi_V^2 \quad \text{for } \frac{\ell}{b} < 0{,}5176 \cdot \sqrt[4]{\frac{D_V}{D_H}}$$

$$K_H = 4 \quad \text{for } \frac{b}{\ell} \geq 0{,}5176 \cdot \sqrt[4]{\frac{D_V}{D_H}}$$

$$= \frac{1}{\phi_H^2} + \phi_H^2 \quad \text{for } \frac{b}{\ell} < 0{,}5176 \cdot \sqrt[4]{\frac{D_H}{D_V}}$$

where

I_v = moment of inertia of a unit corrugation with spacing **a**, $\mathbf{a} = a + c \cdot \cos N$

$$= \frac{t}{4}(c \cdot \sin\phi)^2 \left(\mathbf{a} + \frac{c}{4} + c \cdot \frac{\sin\phi}{12}\right) \quad [cm^4]$$

a, c = widths of the flange and web panels [cm], respectively.

t = net thickness of the corrugations [cm]

E and v are as defined in 4.4.2

ℓ = length of the corrugation [cm]

$\mathbf{a}_v$, $\mathbf{a}_H$ = **a**

η, I_{pH}, A_{sH} = 0

A_{sV} = $t \cdot c \cdot \sin\phi$

ϕ is as defined in Fig. 4.38 or Fig 4.39.

4.4.5 Stiffness and Proportions

To fully develop the intended buckling strength of the assemblies of structural members and panels, supporting elements of plate panels and longitudinals are to satisfy the following requirements for stiffness and proportion in highly stressed regions.

.1 Stiffness of Longitudinals

The net moment of inertia of the longitudinals, i_o, with effective breadth of net plating, is to be not less than that given by the following equation:

$$i_0 = \frac{\mathbf{a} \cdot t_n^3}{12\left(1 - v^2\right)} \gamma_0 \quad [cm^4]$$

where

$$\gamma_0 = \left(2{,}6 + 4 \cdot \delta\right) \cdot \alpha^2 + 12{,}4\,\alpha - 13{,}2 \cdot \sqrt{\alpha}$$

$$\delta = \frac{A}{\mathbf{a} \cdot t_n}$$

$\alpha = \frac{\ell}{a}$

a = spacing of longitudinals [cm]

t_n = net thickness of plating supported by the longitudinal [cm]

v = Poisson's ratio

= 0,3 for steel

A = net sectional area of the longitudinal (excluding plating) [cm^2]

ℓ = unsupported span of the longitudinal [cm]

.2 Stiffness of Web Stiffeners

The net moment of inertia, i, of the web stiffener, with the effective breadth of net plating not exceeding **a** or 0,33 ℓ, whichever is less, is not to be less than obtained from the following equations:

$$i = 0{,}17 \cdot \ell \cdot t^3 \cdot \left(\frac{\ell}{a}\right)^3 \quad [cm^4] \qquad \text{for } \frac{\ell}{a} \leq 2{,}0$$

$$i = 0{,}34 \cdot \ell \cdot t^3 \cdot \left(\frac{\ell}{a}\right)^2 \quad [cm^4] \qquad \text{for } \frac{\ell}{a} > 2{,}0$$

where

ℓ = length of stiffener between effective supports [cm]

t = required net thickness of web plating [cm]

a = spacing of stiffeners [cm]

.3 Stiffness of Supporting Members

The net moment of inertia of the supporting members, such as transverses and webs, is not to be less than that obtained from the following equation:

$$\frac{I_s}{i_o} = 0{,}2 \cdot \left(\frac{B_s}{\ell}\right)^3 \cdot \left(\frac{B_s}{a}\right)$$

where

I_s = moment of inertia of the supporting member, including the effective plating [cm^4].

I_0 = moment of inertia of the longitudinals, including the effective plating [cm^4].

B_s = unsupported span of the supporting member [cm].

ℓ and **a** are as defined in .1 above.

.4 Proportions of Flanges and Face Plates

The breadth-thickness ratio of flanges and face plates of longitudinals and girders is to satisfy the limits given below:

$$\frac{b_2}{t_f} = 0{,}4 \cdot \sqrt{\frac{E}{R_{eH}}}$$

where

b_2 = larger outstanding dimension of flange [cm], as given in Fig. 4.42.

t_f = net thickness of flange/face plate [cm]

E and R_{eH} are as defined in 4.4.3

.5 Proportions of Webs of Longitudinals and Stiffeners

The depth-thickness ratio of webs of longitudinals and stiffeners is to satisfy the limits given below.

$$\frac{d_w}{t_w} \le 1{,}5 \cdot \sqrt{\frac{E}{R_{eH}}} \quad \text{for angles and tee bars}$$

$$\frac{d_w}{t_w} \le 0{,}85 \cdot \sqrt{\frac{E}{R_{eH}}} \quad \text{for bulb plates}$$

$$\frac{d_w}{t_w} \le 0{,}5 \cdot \sqrt{\frac{E}{R_{eH}}} \quad \text{for flat bars}$$

where d_w and t_w, are as defined in 4.4.3.2 and E and R_{eH} are as defined in 4.4.2

When these limits are complied with, the assumption on buckling control stated in 4.3.1.2.5) is considered satisfied. If not, the buckling strength of the web is to be further investigated, as per 4.4.2.

.6 Proportions of Unstiffened or Stiffened Brackets

The depth of the bracket d_0, d_1 or d_2 shown in Fig.4.4, is to be less than the limits given below.

1) Plain (Un-Flanged) Brackets

Plain (un-flanged) brackets may be used where $d_0 \le 53{,}4$ cm.

$$d_0 \le 75 \cdot \left(t_b \sqrt{q} - c\right) \cdot \sin\alpha \quad \text{[cm]}$$

2) Flanged or Edge Stiffened Brackets

The depth of the edge flanged bracket d_1 is to be less than:

$$d_1 \le 153{,}8 \cdot \left(t_b \sqrt{q} - a\right) \cdot \sin\alpha \quad \text{[cm]}$$

The width of the flange or face bar f_w is not to be less than:

$$f_w \ge \left[\frac{0{,}08 \cdot d_1}{\sin(\alpha)} + b\right] \cdot \sqrt{\frac{1}{q}} \quad \text{[cm]}$$

3) Stiffened Edge Flanged Brackets

The depth of the stiffened edge flanges bracket is to be less than:

$$d_1 \le 153{,}8 \cdot \left(t_b \sqrt{q} - a\right) \cdot \sin\alpha \quad \text{[cm]}$$

$$d_2 \le 1{,}5 \cdot t_b \cdot \sqrt{\frac{E}{R_{eH}}} \qquad [cm]$$

Stiffeners as required in 2) and/or 3) may be designed in accordance with 4.4.5.5 where

a = 0,52

b = 1,4

c = 0,45

t_b = net thickness of the bracket [cm]

R_{eH} = specified minimum yield point of the bracket plate [N/cm^2]

q = $2{,}35 \cdot \frac{10^4}{R_{eH}}$

E = modulus of elasticity for steel, 2,06 x 10^7 [N/cm^2]

α = angle between longer arm of bracket and the tangentiality of face plate or edge Fig.4.44 [degree]

When these limits are complied with, the assumption on buckling control stated in 4.3.1.2.7) is considered satisfied. If not, a detailed analysis of buckling strength using an acceptable method is to be submitted for review.

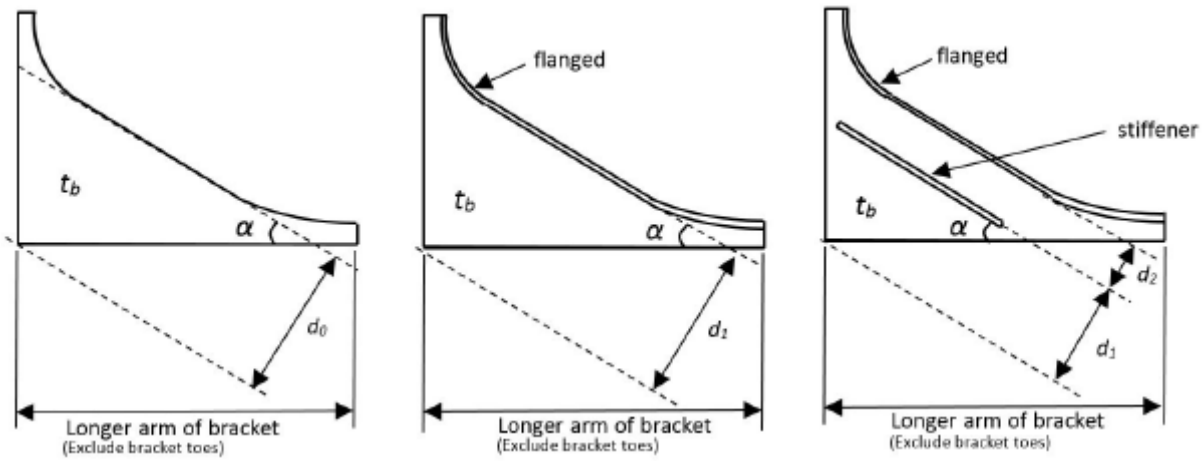


Fig. 4.44 Definitions of Brackets

4.4.6 Curved Plates

.1 Axial Compression or Bending Moment

The critical buckling stresses for curved plate panels such as bilge plate panels may be obtained from the following equations subjected to axial compression or bending moment.

$\sigma_{CL} = \sigma_{EL}$ for $\sigma_{EL} \le P_r \cdot R_{eH}$

$\sigma_C = R_{eH} \cdot \left[1 - \frac{P_r(1-P_r) \cdot R_{eH}}{\sigma_{EL}}\right]$ for $\sigma_{EL} > P_r \cdot R_{eH}$

where

P_r = proportional linear elastic limit of the structure, which may be taken as 0,6 for steel

σ_{EL} = elastic compressive buckling stress for an imperfect curved plate [N/cm^2]

= $\rho_X \cdot C \cdot \sigma_{CEL}$ [N/cm^2]

σ_{CEL} = classical compressive buckling stress for a perfect curved plate [N/cm^2]

= $0,605 \cdot \left(\frac{E_t}{r}\right)$ [N/cm^2]

C = length dependent coefficient

= 1,0 for $z \geq 2,85$

= $\left(\frac{1,425}{z} + 0,175 \cdot z\right)$ for $z < 2,85$

ρ_X = nominal or lower bound knock-down factor to allow for shape imperfections

= $0,75 + 0.003 \cdot z \cdot \left[1 - \frac{r}{300 \cdot t}\right]$ for $z < 1$

= $0,75 - 0,142 \cdot (z-1)^{0,4} + 0,003 \cdot z \cdot \left[1 - \frac{r}{300 \cdot t}\right]$ for $1 \leq z < 20$

= $0,35 - 0.0002 \cdot \left(\frac{r}{t}\right)$ for $20 \leq z$

z = Batdorf parameter

= $\sqrt{\left(1 - v^2\right)} \cdot \frac{\ell^2}{r \cdot t}$

ℓ = unsupported length [cm], (See Fig.4.45).

r = mean radius of curved plate [cm].

t = net thickness of the plate [cm].

E = Young's modulus, for steel 2,06 x 10^7 [N/cm^2].

v = Poisson's ratio, may be taken as 0,3 for steel

R_{eH} = specified minimum yield point of the material [N/cm^2].

.2 External Pressure

The critical buckling stresses for curved plate panels such as bilge plate panels may be obtained from the following equations subjected to external pressure.

$\sigma_{CT} = \phi \cdot \sigma_{ET}$

where

ϕ = plasticity reduction factor

= 1,0 for $\Delta \leq 0,55$

$= \frac{0,45}{\Delta} + 0,18$ for $0,55 < \Delta \leq 1,6$

$= \frac{1,31}{(1+1,15 \cdot \Delta)}$ for $1,6 < \Delta < 6,25$

$= \frac{1}{\Delta}$ for $\Delta \geq 6,25$

$\Delta = \frac{\sigma_{ET}}{R_{eH}}$

σ_{ET} = elastic hoop buckling stress for an imperfect curved plate, [N/cm^2]

$= \rho_R \cdot q_{CET} \cdot \frac{(r + 0,5 \cdot t)}{t}$

ρ_R = nominal or lower bound knock-down factor to allow for shape imperfections

= 0,8

q_{CET} = elastic buckling pressure, [N/cm^2]

$= \frac{1,27 \cdot E}{(A_L^{1,18} + 0,5)} \cdot \left(\frac{t}{r}\right)^2$ for $A_L \leq 2,5$

$= \frac{0,92 \cdot E}{A_L} \cdot \left(\frac{t}{r}\right)^2$ for $2,5 < A_L \leq 0,208(r/t)$

$= 0,836 \cdot C_P^{-1,061} \cdot E \cdot \left(\frac{t}{r}\right)^3$ for $0,208\ (r/t) < A_L \leq 2,85\ (r/t)$

$= 0,275 \cdot E \cdot \left(\frac{t}{r}\right)^3$ for $2,85\ (r/t) < A_L$

$A_L = \frac{\sqrt{z}}{\sqrt[4]{1-v^2}} - 1,17$

$C_p = \frac{A_L}{\left(\frac{r}{t}\right)}$

z, ℓ, r, t, E, vand fy are as defined in 4.4.6.1.

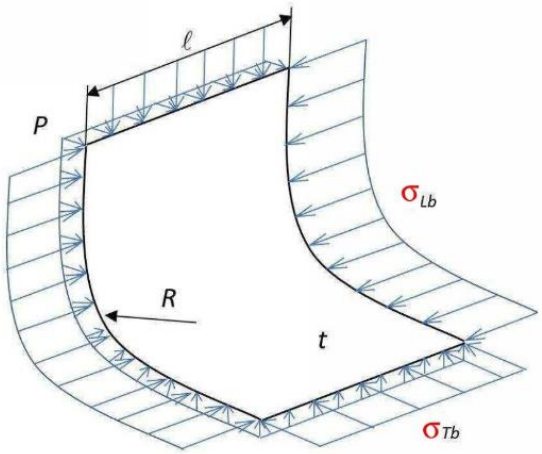


Fig. 4.45 Curved Plate Panel

4.5 Fatigue Life

4.5.1 General

An analysis is to be made of the fatigue strength of welded joints and details in highly stressed areas, especially where higher strength steel is used. Special attention is to be given to structural notches, cutouts and bracket toes, and also to abrupt changes of structural sections. A simplified assessment of the fatigue strength of structural details may be accepted when carried out in accordance with Annex 5.

The following subparagraphs are intended to emphasize the main points and to outline procedures where refined spectral analysis techniques are used to establish fatigue strength.

.1 Workmanship

As most fatigue data available were experimentally developed under controlled laboratory conditions, consideration is to be given to the workmanship expected during construction.

.2 Fatigue Data

In the selection of S-N curves and the associated stress concentration factors, attention is to be paid to the background of all design data and its validity for the details being considered. In this regard, recognized design data, such as those by AWS (American Welding Society) and API (American Petroleum Institute) should be considered. Sample fatigue data and their applications are shown in Annex 5.

If other fatigue data are to be used, the background and supporting data are to be submitted for review. In this regard, clarification is required whether or not the stress concentration due to the weld profile, certain structural configurations and also the heat effects are accounted for in the proposed S-N curve. Consideration is also to be given to the additional stress concentrations.

.3 Total Stress Range

For determining total stress ranges, the fluctuating stress components resulting from the load combinations specified in Annex 5, D.3 (for ship-type installations) or Annex 5, L.2 (for trading vessels) are to be considered.

.4 Design Consideration

In design, consideration is to be given to the minimization of structural notches and stress concentrations. Areas subject to highly concentrated forces are to be properly configured and stiffened to dissipate the concentrated loads. See also 3.1.3.

4.5.2 Procedures

The analysis of fatigue strength for a welded structural joint/detail may be performed in accordance with the following procedures.

The class designations and associated loading patterns are given in Table A5.1.

.1 Step 1 - Classification of Various Critical Locations

Where deemed appropriate, the total applied stress range of the structural details classified in Step 1 may be checked against the permissible stress ranges as shown in Annex 5.

.2 Step 2 - Permissible Stress Range Approach

.3 Step 3 - Refined Analysis

Refined analyses are to be performed, as outlined in 1) or 2) below, for the structural details for which the total applied stress ranges obtained from Step 2 are greater than the permissible stress ranges, or for which the fatigue characteristics are not covered by the classified details and the associated S-N curves.

The fatigue life of structures is generally not to be less than 20 years, unless otherwise specified.

1) Spectral analysis.

   Alternatively, a spectral analysis may be performed, as outlined in 4.5.3 below, to directly calculate fatigue lives for the structural details in question.

2) Refined fatigue data.

   For structural details which are not covered by the detail classifications, proposed S-N curves and the associated SCFs, when applicable, may be submitted for consideration. In this regard, sufficient supporting data and background are also to be submitted for review. The refined SCFs may be determined by finite element analyses.

4.5.3 Spectral Analysis

Where the option in 4.5.2.3.1) is exercised, a spectral analysis is to be performed in accordance with the following guidelines.

.1 Representative Loading Patterns

Several representative loading patterns are to be considered to cover the worst scenarios anticipated for the design service life of the installation with respect to hull girder local loads.

.2 Environmental Representation

Instead of the design wave loads specified in 2, a wave scatter diagram (such as Walden's Data for North Atlantic Environment) is to be employed to simulate a representative distribution of all of the wave conditions expected for the design service life of the installation. In general, the wave data is to cover a time period of not less than 20 years. The probability of occurrence for each combination of significant wave height and mean period of the representative wave scatter diagram is to be weighted, based on the transit time of the installation at each wave environment within anticipated shipping routes or specific sites. Detailed environmental data requirements are given in A.3.2.6.

.3 Calculation of Wave Load RAOs

The wave load RAOs with respect to the wave-induced bending moments, shear forces, motions, accelerations and hydrodynamic pressures can then be predicted by ship motion calculation for a selected representative loading condition.

.4 Generation of Stress Spectrum

The stress spectrum for each critical structural detail (spot) may be generated by performing a structural analysis, accounting for all the wave loads separately for each individual wave group. For this purpose, the 3D structural model and 2D models specified in 4.6 may be used for determining structural responses. The additional secondary and tertiary stresses are also to be considered.

Alternatively, for FPI conversions, in order to calculate the hot spot stress spectrum, load component spectral fatigue analysis (LC SFA) can be used provided the following are verified:

1) The loads components are to include the global load components (three cross-sectional forces and three cross-sectional moments) and the local load components (lightweight and deadweight inertial loads and external pressure).
2) The effects of each global load component are to be adequately separated from the effects of other global and local load components.
3) The number of external pressure strips is to be such as to adequately capture the external pressure variations in the transverse direction, especially where the analyzed hot spot is significantly affected by the local external pressure loads.
4) A balanced system of hydrodynamic loads from the seakeeping analysis is to be used where sectional forces and moments approach zero at the vessel ends when hydrodynamic loads are integrated over the entire vessel.
5) Across two web frame distances or 10 m, whichever is greater, on either side of the analyzed hot spot in the longitudinal direction, the tolerance on the total lightweight and deadweight masses of the finite element model is to be ±1% and the tolerance on the longitudinal, vertical, and transverse center of gravity of the loaded vessel is to be ±0,1% of the vessel's length, depth, and breadth, respectively. Outside of this range, the tolerance on the total lightweight and deadweight masses these tolerances can be relaxed.
6) Attention is to be paid to the accuracy of all cross-sectional force and moment transfer functions at the hot spot locations, especially to the existence of large shear force distribution gradients that may not have been captured during the hydrodynamic analysis. Large shear force distribution gradients can occur due to concentrated loads or due to partial redistribution of shear forces to transverse bulkheads.
7) When a partial finite element model is used, the analyzed hot spot is to be at least two web frame distances or 10 m, whichever is greater, away from the model boundaries.

.5 Cumulative Fatigue Damage and Fatigue Life

Based on the stress spectrum and wave scatter diagram established above, the cumulative fatigue damage and the corresponding fatigue life can be estimated by the Palmgren-Miner linear damage rule.

4.6 Calculation of Structural Responses

4.6.1 Methods of Approach and Analysis Procedures

Maximum stresses in the structure are to be determined by performing structural analyses, as outlined below. Guidelines on structural idealization, load application and structural analysis are given in Annex 7

The strength assessment of the hull structure for new build FPIs is based on a three cargo tank lengths finite element model about midships where the strength assessment is focused on the results obtained from structures in the middle tank. For an FPI conversion, as an alternative, a complete hull length or

full cargo block length finite element model including all cargo and ballast tanks in the hull structure can be used in lieu of the three cargo tank length model.

In the three tank length model the strength assessment is to be focused on the results obtained from the mid tank structure. However, the deck transverse, the side transverse, the vertical web on longitudinal bulkheads, the horizontal girder and the vertical web on transverse bulkheads and the cross ties are also to be assessed using the end tanks of the three tank length model analysis.

4.6.2 3D Finite Element Models

A simplified three-dimensional (3D) finite element model, is required to determine the load distribution in the structure.

The three hold length finite element model represents three bays of tanks within 0,4**L** amidships of the hull structure. The same 3D model may be used for hull structures beyond 0,4**L** amidships with modify-cations to the structural properties and the applied loads, provided that the structural configurations are such that they are considered as representative of the location under consideration.

The full length or cargo block length finite element model is used for the alternative method of analysis for FPI conversions.

4.6.3 Local Structural Models

Local 3D fine mesh model are required to:

- Determine the stress distribution in major supporting structures, particularly at intersections of two or more structural members and/or
- Examine stress concentrations such as at bracket toes of main supporting members, at openings in way of critical locations, at intersections of longitudinals with transverses and at cut outs.

4.6.4 Load Cases

When performing structural analysis, the combined load cases specified in 2.5.1 are to be considered. In general, the structural responses for the still-water conditions are to be calculated separately to establish reference points for assessing the wave-induced responses. Additional load cases may be required for special loading patterns and unusual design functions, such as sloshing loads, as specified in 2.6. For the three hold length analysis, additional load cases may also be required for hull structures beyond the region of 0,4**L** amidships.

4.7 Critical Areas

4.7.1 General

The strength and fatigue capacity of the following critical areas is to be verified:

- Typical connections of transverse web frames in Fig. 4.46
- Typical connections of horizontal girders on transverse bulkhead in Fig. 4.47
- Typical connections buttress structure in Fig. 4.48

4.7.2 Strength Evaluation

The allowable stress applicable to critical areas in 4.7.1 is defined as a percentage of the minimum specified yield stress, R_{eH}, times the strength reduction factor, S_m. Application of this allowable stress to rod and beam elements is based on the axial stress while von-Mises membrane stresses are employed for quadrilateral elements.

The allowable stress for fine mesh analysis is defined in Table 4.22 and depends on the mesh size. To calculate the local stress distribution in a main supporting member, it is often necessary to model details and discontinuities using various fine mesh sizes. In areas of high stress gradient, the allowable stresses are to be adjusted according to mesh sizes and are listed in Table 4.22.

The high stress FE results should be viewed in terms of the extent of the high stresses with respect to the mesh size and the structural arrangement in the high stress region.

Table 4.22 - Allowable Stresses for Various Finite Element Fine Mesh Sizes

Mesh Size	Stress Limit	Normal Steel (S_m = 1.000) (S_m = 0.980)	HT32 (S_m = 0.950)	HT36 (S_m = 0.908)
1 × LS [1]	1.00 × $S_m \cdot R_{eH}$	2400	3040	3269
$^1/_2$ × LS [1]	1.06 × $S_m \cdot R_{eH}$	2544	3222	3465
$^1/_3$ × LS [1]	1.12 × $S_m \cdot R_{eH}$	2688	3404	3661
$^1/_4$ × LS [1]	1.18 × $S_m \cdot R_{eH}$	2832	3587	3857
$^1/_5$ × LS ~ $^1/_{10}$ × LS [1]	1.25 × $S_m \cdot R_{eH}$	3000	3800	4086
Thickness [1, 2]	σ_u or 1.50 × $S_m \cdot R_{eH}$	4100	4500	4903

Notes :

1 *Stress limits greater than 1,00 × $S_m \cdot R_{eH}$ are to be restricted to small areas in way of structural discontinuities.*

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

3 *For intermediate mesh size, the stress limit may be obtained by linear interpolation.*

4 *LS = stiffener spacing.*

4.7.3 Fatigue Evaluation

The procedure for fatigue analysis of the critical details indicated in 4.7.1 will follow Section Annex 5 considering prior fatigue damage as a trading vessel, low cycle and high cycle fatigue damages as an FPI.

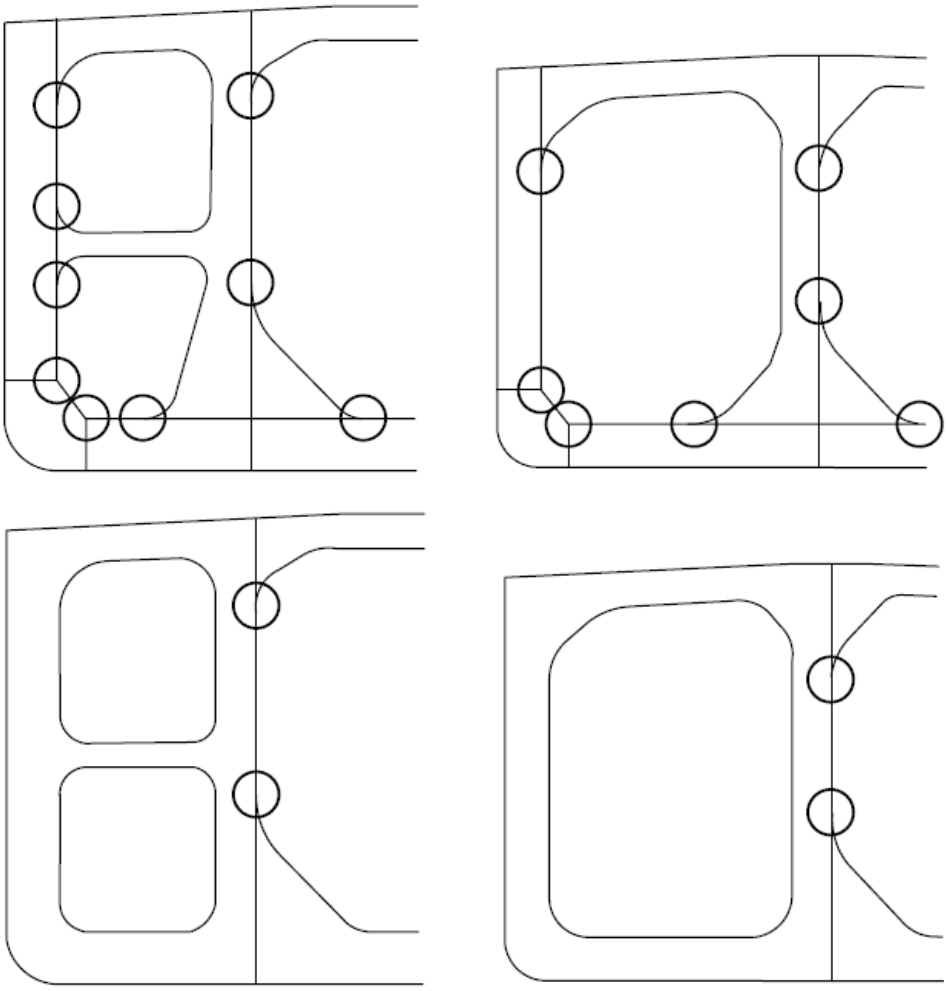


Fig 4.46 Critical Areas in Transverse Web Frame

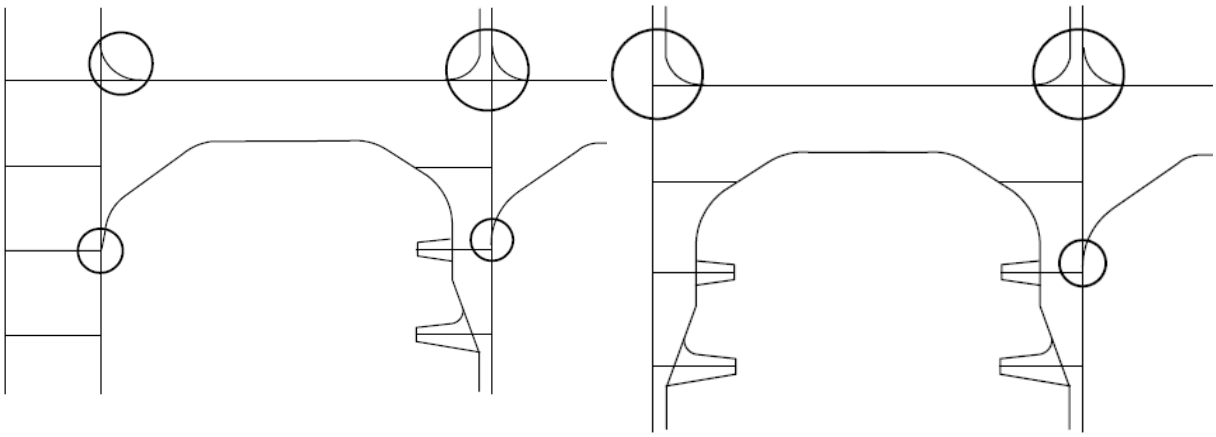


Fig 4.47 Critical Areas in Horizontal Girder on Transverse Bulkhead

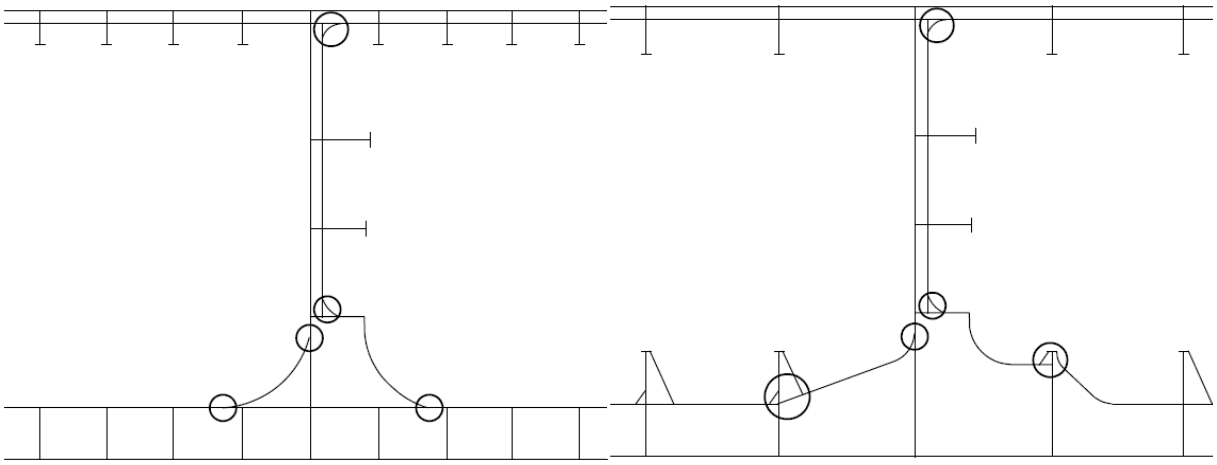


Fig. 4.48 Critical Areas of Buttress Structure

5. Hull Structure Beyond 0,4L Amidships

5.1 General Requirement

5.1.1 General

The structural configurations, stiffening systems and design scantlings of the hull structures located beyond 0.4 **L** amidships including the forebody, aft end and machinery spaces are to be in compliance with this Section of this Guidelines and D.2.9.

5.1.2 Structures within the Cargo Space Length

The scantlings of longitudinal structural members and elements in way of cargo spaces beyond 0,4**L** amidships may be gradually reduced toward 0,125**L** from the ends, provided that the hull girder section modulus complies with Rules for Hull (Pt.1 Vol.II), Sec.5, C.1.1 and that the strength of the structure satisfies the material yielding, buckling and ultimate strength criteria specified in 4.2 and 4.3.

The scantlings of main supporting members in way of the cargo space length beyond 0,4**L** amidships are to comply with the requirements of 3.6. Where the structural configuration is different from that amidships due to the hull form of the installation, additional evaluation is to be performed. The structural evaluation using the actual configuration is to be carried out to verify that the arrangement of openings necessary for access (1.3.11), ventilation (1.3.13), fabrication, etc. is satisfactory.

5.2 Forebody Side Shell Structure

In addition to the requirements specified in other relevant sections of the Rules, the scantlings of the structure forward of 0,4**L** amidships are also to satisfy the requirements in 5.2.1, 5.2.2 and 5.2.3 below.

The nominal design corrosion values in the forepeak tank may be taken as 1,5 mm in determining design scantlings.

5.2.1 Side Shell Plating

.1 Plating Forward of Forepeak Bulkhead

The net thickness of the side shell plating forward of the forepeak bulkhead is to be not less than t_1, t_2 and t_3, specified below.

$$t_1 = 0{,}73 \cdot \mathbf{a} \cdot \sqrt{k_1 \cdot \frac{p}{\sigma_1}} \quad [\text{mm}]$$

$$t_2 = 0{,}73 \cdot \mathbf{a} \cdot \sqrt{k_2 \cdot \frac{p}{\sigma_2}} \quad [\text{mm}]$$

$$t_3 = 0{,}73 \cdot \mathbf{a} \cdot k \cdot \sqrt{k_3 \cdot k_4 \cdot \frac{p_b}{\sigma_3}} \quad [\text{mm}]$$

for side shell and bow plating above LWL in the region from the forward end to the forepeak bulkhead

where

$\mathbf{a}$ = spacing of stiffeners, [mm]

k_1 = 0,342 for longitudinally and $0{,}50 \cdot k^2$ for transversely stiffened plating

k_2 = $0{,}50 \cdot k^2$ for longitudinally and 0,342 for transversely stiffened plating

k_3 = 0,50

k_4 = 0,74

k = $\dfrac{3{,}075 \cdot \sqrt{\alpha} - 2{,}077}{\alpha + 0{,}272}$, $(1 < \alpha < 2)$

= 1,0 $(\alpha > 2)$

α = aspect ratio of the panel (longer edge/shorter edge)

σ_1 = $0{,}65 \cdot S_m \cdot R_{eH}$, $[\text{N/cm}^2]$ in the longitudinal direction

σ_2 = $0{,}85 \cdot S_m \cdot R_{eH}$, $[\text{N/cm}^2]$ in the transverse (vertical) direction

σ_3 = $0{,}85 \cdot S_m \cdot R_{eH}$, $[\text{N/cm}^2]$

p = nominal pressure $| p_i - p_e |$, $[\text{N/cm}^2]$, as specified in Table 4.11, at the upper turn of bilge level amidships with the following modifications:

i) A_i is to be calculated at the forward or aft end of the tank, whichever is greater

ii) A_e is to be calculated at the center of the panel in accordance with 2.3.4.3, using L.C.7 with k_{fo} = 1,0 and x_o located amidships

iii) Be is to be calculated at 0,05 L from the FP in accordance with 2.3.4 ($p_s + k_u \cdot p_d$, full draft, heading angle = 0, k_u = 1.1)

p_b = maximum bow pressure = $k_u \cdot p_{bij}$

k_u = 1,1

p_{bij} = nominal bow pressure, as specified in 2.7.1, at the lowest point of the panel, $[\text{N/cm}^2]$

S_m and R_{eH}, as defined in 3.4.2.1.

.2 Plating between Forepeak Bulkhead and 0,125L from FP

Aft of the forepeak bulkhead and forward of 0,125**L** from the FP, the side shell plating is to be not less than as given in 5.2.1.1. with B_e calculated at 0,125**L** and the following permissible stress.

σ_1 = permissible bending stress in the longitudinal direction $[\text{N/cm}^2]$

= $0{,}50 \cdot S_m \cdot R_{eH}$ $[\text{N/cm}^2]$ for $\mathbf{L} \geq 190$ m

$$= \left[0{,}5+0{,}1\cdot\frac{190-\mathbf{L}}{40}\right]\cdot S_m\cdot R_{eH} \qquad [N/cm^2] \qquad \text{for } \mathbf{L} < 190 \text{ m}$$

σ_2 = $0{,}80 \cdot S_m \cdot R_{eH}$ $[N/cm^2]$ in the transverse (vertical) direction

.3 Plating between 0,3L and 0,125L from FP

The net thickness of the side shell plating between 0,3**L** and 0,125**L** from the **F.P** is to be determined from the equations in 3.3.2 and 5.2.1.2 above with B_e calculated at the longitudinal location under consideration. Between 0,3**L** and 0,25**L** from the **F.P**, the internal pressure need not be greater than that obtained amidships. The permissible stress f_1 between 0,3**L** and 0,2**L** from the **F.P** is to be obtained by linear interpolation between midship region (3.5.1) and the permissible stress f_1, as specified in 5.2.1.2.

5.2.2 Side Frames and Longitudinals

.1 Side Frames and Longitudinals Forward of 0,3L from FP

The net section modulus of side longitudinals and frames in association with the effective plating to which they are attached is to be not less than that obtained from the following equation:

$$W = \frac{M}{\sigma_{bi}} \qquad [cm^3]$$

$$M = 10^3 \cdot p \cdot \mathbf{a} \cdot \frac{\ell^2}{12} \qquad [N\text{-}cm]$$

where

p = nominal pressure $|\ p_i - p_e\ |$, $[N/cm^2]$, as specified in Table 4.11 with the following modifications:

i) A_i is to be calculated at the forward or aft end of the tank, whichever is greater. Between 0,3 **L** and 0,25 **L** aft of the FP, the internal pressure need not be greater than that obtained amidships.

ii) A_e is to be calculated at the center of the panel in accordance with 2.3.4.3 using L.C.7 with k_{fo} = 1,0 and x_o located amidships.

iii) B_e is to be calculated at the center of the panel in accordance with 2.3.4 ($p_s + k_u \cdot p_d$, full draft, heading angle = 0, k_u = 1,1), with the distribution of p_d, as shown in Fig. 4.49, at the side longitudinal and frame under consideration.

Longitudinal distribution of p_d may be taken as constant from the FP to forepeak bulkhead as per 5.2.1.1 and from 0,125**L** to the forepeak bulkhead as per 5.2.1.2 p_d is to be calculated in accordance with 2.3.4 between 0,3**L** and 0,125**L** from the FP as per 5.2.1.3.

σ_{bi} = $0{,}80 \cdot S_m \cdot R_{eH}$ $[N/cm^2]$, for longitudinals between 0,125**L** and 0,2**L** from the **F.P**

= $0{,}85 \cdot S_m \cdot R_{eH}$ $[N/cm^2]$, for longitudinals forward 0,125**L** from the **F.P**

= $0{,}85 \cdot S_m \cdot R_{eH}$ $[N/cm^2]$, for vertical frames (other than hold frames)

Between 0,3**L** and 0,2**L** from the FP, the permissible stress is to be obtained by linear interpolation between midship region and $0{,}80 \cdot S_m \cdot R_{eH}$

S_m and R_{eH} are as defined in 3.4.2.1.

s and ℓ are as defined in 3.4.3.

For side longitudinal/stiffener in the region forward of 0,0125**L** from the FP and above L_{WL}, the section modulus is not to be less than obtained from the above equation based on $p = p_b$, $f_b = 0,95 \cdot S_m \cdot R_{eH}$ and k = 16, where p_b is as defined in 5.2.1 above.

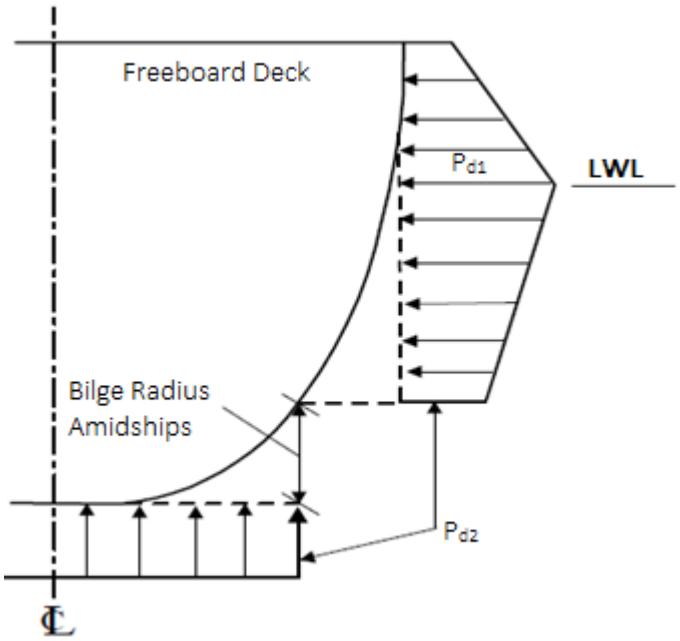


Fig. 4.49 - Transverse Distribution of p_d

5.2.3 Side Transverses and Stringers in Forebody

The requirements of the subparagraphs below apply to the region forward of the cargo spaces where single side skin construction is used.

.1 Section Modulus

The net section modulus of side transverse and stringer in association with the effective side shell plating is not to be less than obtained from the following equation:

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

1) **Longitudinally Framed Side Shell**

For side stringer

$$M = 10^3 \cdot c_1 \cdot c_2 \cdot p \cdot \mathbf{a} \cdot \ell_t \cdot \frac{\ell_s}{0,12} \quad [N\text{-}cm]$$

For side transverse, M is not to be less than M_1 or M_2, whichever is greater

$$M_1 = 10^3 \cdot c_3 \cdot p \cdot \mathbf{a} \cdot \ell_t^{\,2} \cdot \frac{1 - c_4 \cdot \phi}{0,12} \quad [N\text{-}cm]$$

$$M_2 = 850 \cdot p_1 \cdot \mathbf{a} \cdot \frac{\ell_{t1}^{\,2}}{0,12} \quad [N\text{-}cm]$$

where

c_1 = 0,125 + 0,875 · ϕ, but not less than 0,3

Coefficients c_2, c_3 and c_4 are given in the tables below.

Coefficient c_2

Number of Side Stringers Between Platforms (Flats)	No Stringer	One Stringer	More than One Stringer
Top Stringer	0,0	0,90	0,70
Stringers Between Top and Lowest Stringers			0,75
Lowest Stringer			0,80

Coefficient c_3

Number of Side Stringers Between Platforms (Flats)	No Stringer	One Stringer	More than One Stringer
Transverse above Top Stringer	0,85	0,55	0,55
Transverse Between Top and Lowest Stringers		–	0,64
Transverse Below Lowest Stringer		0,68	0,68

Coefficient c_4

Number of Side Stringers Between Platforms (Flats)	No Stringer	One Stringer	More than One Stringer
Transverses	0,0	0,75	0,80

p = nominal pressure, $|\ p_i - p_e\ |$, [kN/m^2], over the side transverses using the same load cases as specified in Table 4.11 for side transverses with the following modifications.

i) A_e is to be considered for case "a" and calculated in accordance with 2.3.4.3 using L.C.7 with k_{fo} = 1,0 and x_o located amidships

ii) B_e is to be calculated in accordance with 2.3.4 ($p_s + k_u \cdot p_d$, full draft, heading angle = 0, k_u = 1,0) with the distribution of pd as shown in Fig. 4.49

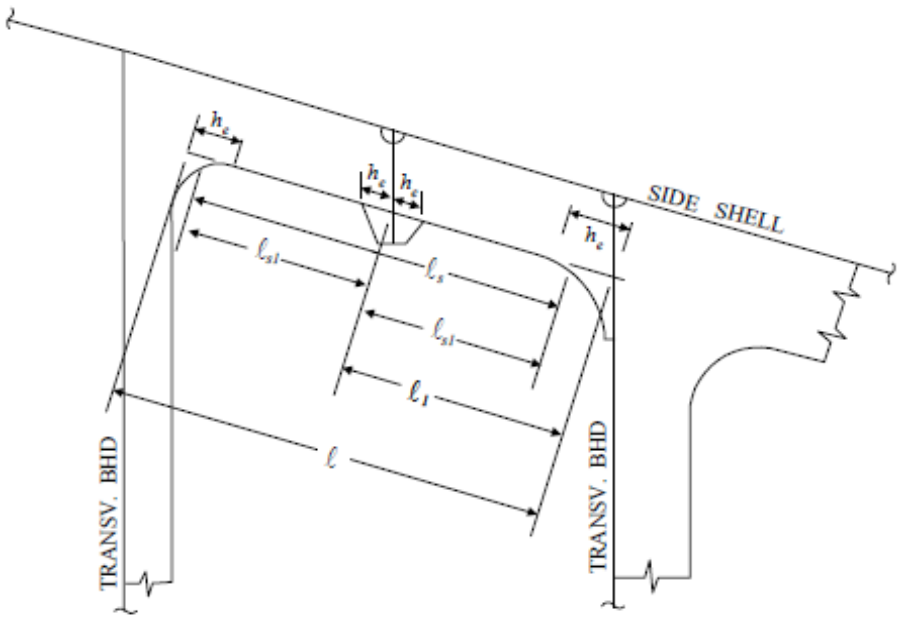
B_i, A_e and B_e may be taken at the center of the side shell panel under consideration.

p_1 = nominal pressure, $|\ p_i - p_e\ |$, [kN/m^2], using the same load cases as specified in Table 4.11 for side transverses with the following modifications.

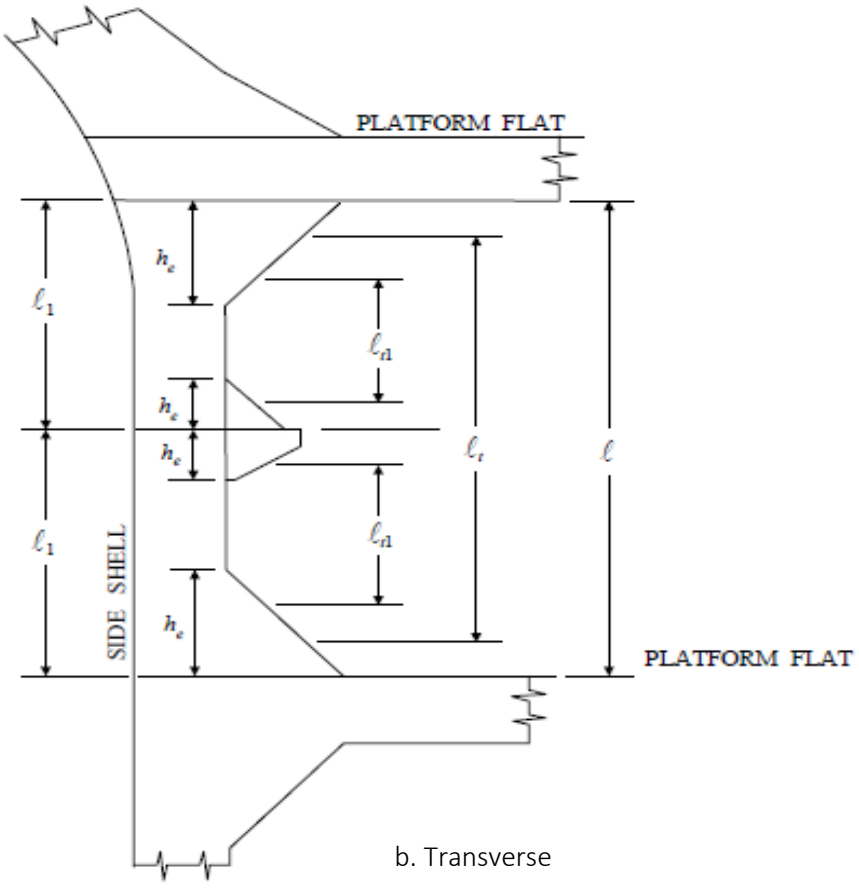
i) A_e is to be considered for case "a" and calculated in accordance with 2.3.4.3 using L.C.7 with k_{fo} = 1,0 and x_o located amidships

ii) B_e is to be calculated in accordance with 2.3.4 ($p_s + k_u \cdot p_d$, full draft, heading angle = 0, k_u = 1,0) with the distribution of p_d as shown in Fig. 4.49

B_i, A_e and B_e, calculated at the midspan ℓ_{s1} (between side stringers or between side stringer and platform, flat as shown in Fig. 4.50) of the side transverse under consideration..



a. Stringer



b. Transverse

Fig. 4.50 Definition of Spans

For side transverses

a = sum of half distances, [m], between side transverse under consideration and adjacent side transverses or transverse bulkhead

For side stringers

a = $0,45 \cdot \ell_s$

$$\phi = \frac{1}{1+\alpha}$$

$$\alpha = 1{,}33 \cdot \left(\frac{I_t}{I_s}\right) \cdot \left(\frac{\ell_s}{\ell_t}\right)^3$$

I_t = moment of inertia, in cm^4 (with effective side plating), of side transverse. It is to be taken as an average of those at the middle of each span ℓ_{t1} between side stringers or side stringer and platform (flat), clear of the bracket

I_s = moment of inertia, [cm^4] (with effective side plating), of side stringer at the middle of the span l_s, clear of the bracket

ℓ_t, ℓ_s = spans, [m], of the side transverse (ℓ_t) and side girder (ℓ_s) under consideration, as shown in Fig. 4.50

ℓ_{t1} = span, [m], of side transverse under consideration between stringers, or stringer and platform (flat), as shown in Fig. 4.31 B

When calculating α, if more than one side transverse or stringer is fitted and they are not identical, average values of I_t and I_s within side shell panel (panel between transverse bulkheads and platforms, flats) are to be used.

σ_b = permissible bending stress [N/cm^2]

= $0{,}75 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1.

The bending moment for side transverse below stringer (or below the platform if no stringer is fitted) is not to be less than 80% of that for side transverse above stringer (or above platform if no stringer is fitted).

2) **Transversely Framed Side Shell**

For side transverse:

$$M = 10^3 \cdot c_1 \cdot p \cdot a \cdot \ell_t \cdot \frac{\ell_s}{0{,}12} \quad \text{[N-cm]}$$

For side stringer, M is not to be less than M_1 or M_2, whichever is greater

$$M_1 = 10^3 \cdot c_2 \cdot p \cdot a \cdot \ell_s^{\,2} \cdot \frac{1 - c_3 \cdot \phi_1}{0{,}12} \quad \text{[N-cm]}$$

$$M_2 = 1100 \cdot p_1 \cdot a \cdot \frac{\ell_{s1}}{0{,}12} \quad \text{[N-cm]}$$

where

c_1 = $0{,}10 + 0{,}7 \cdot \phi_1$, but not to be taken less than 0,085

If no side transverses are fitted between transverse bulkheads

c_2 = 1,1

c_3 = 0

If side transverses are fitted between transverse bulkheads

c_2 = 0,8

c_3 = 0,8

p = nominal pressure, $|\ p_i - p_e\ |$, [kN/m^2], over the side stringers using the same load cases as specified in Table 4.11 for side transverses in lower wing tank. A_{ti}, A_e and B_e may be taken at the center of the side shell panel under consideration with the following modifications:

i) Ae is to be calculated in accordance with 2.3.4.3 using L.C.7 with k_{fo} = 1,0 and x_o located amidships

ii) B_e is to be calculated in accordance with 2.3.4. ($p_s + k_u \cdot p_d$, full draft, heading angle = 0, k_u = 1,0) with the distribution of p_d as shown in Fig. 4.49

p_1 = nominal pressure, $|p_i - p_e|$, [kN/m^2], using the same load cases as specified in Table 4.11 for side transverses in lower wing tank, with A_{ti}, A_e and B_e calculated at the midspan ℓ_{s1} (between side transverses or between side transverse and transverse bulkhead, as shown in Fig. 4.50 (a)) of the side stringer under consideration, with the following modifications :

For side stringers

i) A_e is to be calculated in accordance with 2.3.4.3 using L.C.7 with k_{fo} = 1,0 and x_o located amidships

ii) B_e is to be calculated in accordance with 2.3.4. ($p_s + k_u \cdot p_d$, full draft, heading angle = 0, k_u = 1,0) with the distribution of pd as shown in Fig. 4.49

a = sum of half distances, [m], between side stringer under consideration and adjacent side stringers or platforms (flats)

For side transverses

a = 0,45 . ℓ_t

$\phi_1 = \dfrac{\alpha}{1+\alpha}$

ℓ_{s1} = span, [m], of the side stringer under consideration between side transverses or side transverse and transverse bulkhead, as shown in Fig. 4.50 (a)

σ_b = permissible bending stress, [N/cm^2]

= 0,75 · S_m · R_{eH} [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1.

ℓ_t, ℓ_s and α are as defined in .1) above.

.2 Sectional Area of Web

The net sectional area of the web portion of the side transverse and side stringer is not to be less than obtained from the following equation:

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

1) Longitudinally Framed Side Shell

For side stringer:

$$Q = 500 \cdot c_1 \cdot p \cdot \ell_s \quad [N]$$

For side transverse, Q is not to be less than Q_1 or Q_2, whichever is greater:

$$Q_1 = 425 \cdot c_2 \cdot p \cdot \ell_s \cdot \left(1.0 - c_3 \cdot \phi - 2 \cdot \frac{h_e}{\ell}\right) \quad [N]$$

$$Q_2 = 850 \cdot c_2 \cdot p_1 \cdot \mathbf{a} \cdot (0.5 \cdot \ell_1 - h_e) \quad [N]$$

Where:

Coefficients c_1, c_2 and c_3 are given in the tables below.

Coefficient c_1

Number of Side Stringers Between Platforms (Flats)	No Stringer	One Stringer	More than One Stringer
Stringers	0,0	0,52	0,40

Coefficient c_2

Number of Side Stringers Between Platforms (Flats)	No Stringer	One Stringer	More than One Stringer
Transverse above Top Stringer	1,0	0,9	0,9
Transverse Between Top and Lowest Stringers		-	0,95
Transverse Below Lowest Stringer		1,0	1,0

Coefficient c_3

Number of Side Stringers Between Platforms (Flats)	No Stringer	One Stringer	More than One Stringer
Transverses	0,0	0,.5	0,60

ℓ = span, [m], of the side transverse under consideration between platforms (flats), as shown in Fig. 4.50 (b)

ℓ_1 = span, [m], of the side transverse under consideration between side stringers or side stringer and platform (flat), as shown in Fig. 4.50 (b)

h_e = length, [m], of the end bracket of the side transverse, as shown in Fig. 4.50 (b)

To obtain Q_1, h_e is equal to the length of the end bracket at the end of span ℓ of side transverse, as shown in Fig. 4.50 (b).

To obtain Q_2, h_e is equal to the length of the end bracket at the end of span ℓ_1 of side transverse, as shown in Fig. 4.50 (b).

τ_s = permissible shear stress, [N/cm^2]

= $0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1.

p, p_1, ϕ and **a** are as defined in 5.2.3.1.1) above.

The shear force for the side transverse below the lowest stringer (or below the platform if no stringer is fitted), is not to be less than 110% of that for the side transverse above the top stringer (or above the platform if no stringer is fitted).

2) Transversely Framed Side Shell

For side transverse

$$Q = 425 \cdot c_1 \cdot p \cdot \ell \cdot \mathbf{a} \quad [N]$$

For side stringer, Q is not to be less than Q_1 or Q_2, whichever is greater.

$$Q_1 = 500 \cdot p \cdot \ell \cdot \mathbf{a} \cdot \left(1{,}0 - 0{,}6 \cdot \phi_1 - 2 \cdot \frac{h_e}{\ell}\right) \quad [N]$$

$$Q_2 = 10^3 \cdot p_1 \cdot \mathbf{a} \cdot (0{,}5 \cdot \ell_1 - h_e) \quad [N]$$

where

c_1 = 0,1 + 0,7 · ϕ_1, but not to be taken less than 0,2

ℓ = span, [m], of the side stringer under consideration between transverse bulkheads, as shown in Fig. 4.50 (a)

ℓ_1 = span, [m], of the side stringer under consideration between side transverses or side transverse and bulkhead, as shown in Fig. 4.50 (a)

h_e = length, [m], of the end bracket of the side stringer under consideration, as shown in Fig. 4.50 (a)

To obtain Q_1, h_e is equal to the length of the end bracket at the end of span ℓ of the side stringer, as shown in Fig. 4.50 (a).

To obtain Q_2, h_e is equal to the length of the end bracket at the end of span ℓ_1 of the side stringer, as shown in Fig. 4.50 (a).

τ_s = permissible shear stress [N/cm^2]

= 0,45 · S_m · R_{eH} [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1.

p, p_1, ϕ_1 and **a** are as defined in 5.2.3.1.1) above.

.3 Depth of Transverse/Stringer

The depths of side transverses and stringers, dw, are neither to be less than obtained from the following equations nor to be less than 2,5 times the depth of the slots, respectively.

1) Longitudinally Framed Shell

For side transverse:

If side stringer is fitted between platforms (flats)

d_w = (0,08 + 0,80 · α) ℓ_t for α ≤ 0,05

= (0,116 + 0,084 · α) ℓ_t for α > 0,05

and need not be greater than 0,2 · ℓ_t

If no side stringer is fitted between platforms (flats), d_w is not to be less than 0,2 · ℓ_t or 0,06 · **H**, whichever is greater.

For side stringer:

d_w = (0,42 – 0,9 · α) ℓ_s for α ≤ 0,2

= (0,244 – 0.0207 · α) ℓ_s for α > 0,2

α is not to be taken greater than 8,0 to determine the depth of the side stringer.

ℓ_t, ℓ_s and α are as defined in 5.2.3.1.1) above.

H is as defined in Rules for Hull (Pt.1 Vol.II), Sec.1, H.2.7

2) Transversely Framed Side Shell

For side stringer:

If side transverse is fitted between transverse bulkheads

$d_w = (0,08 + 0,80 \cdot \alpha_1)\ \ell_s$ for $\alpha_1 \leq 0,05$

$= (0,116 + 0,084 \cdot \alpha_1)\ \ell_s$ for $\alpha_1 > 0,05$

and need not be greater than $0,2 \cdot \ell_s$

If no side transverse is fitted between transverse bulkheads

$d_w = 0,2 \cdot \ell_s$

For side transverse:

$d_w = (0,277 - 0,385 \cdot \alpha_1)\ \ell_s$ for $\alpha_1 \leq 0,2$

$= (0,204 - 0,205 \cdot \alpha_1)\ \ell_s$ for $\alpha_1 > 0,2$

α_1 is not to be taken greater than 7,5 to determine the depth of the side transverse

where

$$\alpha_1 = \frac{1}{\alpha}$$

ℓ_t, ℓ_s and α are as defined in 5.2.3.1.1) above.

.4 Thickness

The net thickness of side transverse and stringer is not to be less than 9,5 mm

5.3 Transition Zone

In the transition zone between the forepeak and the No. 1 cargo tank region, due consideration is to be given to the proper tapering of major longitudinal members within the forepeak such as flats, decks, horizontal ring frames or side stringers aft into the cargo hold. Where such structure is in line with longitudinal members aft of the forward cargo tank bulkhead, this tapering may be introduced by fitting of large brackets. These brackets are to have a taper of 4:1.

5.4 Forebody Strengthening for Slamming

Where the hull structure is subject to slamming, as specified in 2.7, proper strengthening will be required as outlined below. For strengthening to account for bottom slamming, the requirements of this subsection apply to installations with a heavy ballast draft forward of less than 0,04L.

5.4.1 Bottom Slamming

.1 Bottom Plating

When bottom slamming, as specified in 2.7, is considered, the bottom structure in the region of the flat of bottom forward of 0,25L measured from the FP is to be in compliance with the following requirement.

The net thickness of the flat of bottom plating forward of 0,25 L measured from the FP is not to be less than t obtained from the following equation :

$$t = 0,73 \cdot a \cdot \sqrt{k_2 \cdot k_3 \cdot \frac{p_s}{\sigma}} \quad \text{[mm]}$$

where

a = spacing of longitudinal or transverse stiffeners [mm]

k_2 = $0,5 \cdot k^2$ for longitudinally stiffened plating

k_3 = 0,74

k = $\frac{3,075 \cdot \sqrt{\alpha} - 2,077}{\alpha + 0,272} \; (1 \leq \alpha \leq 2)$

= 1,0 ($\alpha > 2$)

α = aspect ratio of the panel (longer edge/shorter edge)

p_s = the design slamming pressure = $k_u \cdot p_{si}$

For determination of t, the pressure p_s is to be taken at the center of the supported panel.

p_{si} = nominal bottom slamming pressure [N/cm^2], as specified in 2.7.2.1.

k_u = slamming load factor = 1,1

The maximum nominal bottom slamming pressure occurring along the installation is to be applied to the bottom plating between the foremost extent of the flat of bottom and 0,125 **L** from the **F.P.** The pressure beyond this region may be gradually tapered to the longitudinal location where the nominal slamming pressure is calculated as zero.

σ = permissible bending stress, [N/cm^2]

= $0,85 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1.

.2 Bottom Longitudinals and Stiffeners

The section modulus of the stiffener, including the associated effective plating on the flat of bottom forward of 0,25**L** measured from the FP, is not to be less than obtained from the following equation :

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^3 \cdot p_s \cdot \mathbf{a} \cdot \frac{\ell^2}{16} \quad [N\text{-}cm]$$

where

p_s = design slamming pressure = $k_u \cdot p_{si}$

For determination of M, the pressure p_s is to be taken at the midpoint of the span ℓ.

p_{si} = nominal bottom slamming pressure, as specified in 2.7.2.1, [N/cm^2]

k_u = slamming load factor = 1,1

The maximum nominal bottom slamming pressure occurring along the installation is to be applied to the bottom stiffeners between the foremost extent of the flat of bottom and 0,125 **L** from the **F.P.**. The pressure beyond this region may be gradually tapered to the longitudinal location where the nominal slamming pressure is calculated as zero.

a = spacing of longitudinal or transverse stiffeners, [mm]

ℓ = unsupported span of the stiffener, [m]

σ_b = $0,9 \cdot S_m \cdot R_{eH}$ [N/cm^2] for transverse and longitudinal stiffeners in the region forward of 0,125 **L** measured from the **F.P.**

= $0,8 \cdot S_m \cdot R_{eH}$ [N/cm^2] for longitudinal stiffeners in the region between 0,125 **L** and 0,25 **L** measured from the **F.P.**

The effective breadth of plating be is as defined in 3.4.3.

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

.3 Bottom Floors

The arrangements and scantlings of floors are to be adequate for bottom slamming loads, as specified in 2.7.

The spacing of floors forward of amidships need not be less than the spacing amidships .

5.4.2 Bowflare Slamming

When bowflare slamming, as specified in 2.7.3, is considered, the side shell structure above the waterline in the region between 0,0125**L** and 0,25**L** from the **F.P.** is to be in compliance with the following requirements.

.1 Side Shell Plating

The net thickness of the side shell plating between 0,0125**L** and 0,25**L** from the FP is not to be less than t_1 or t_2, whichever is greater, obtained from the following equations :

$$t_1 = 0,73 \cdot \mathbf{a} \cdot \sqrt{k_1 \cdot \frac{p}{\sigma_1}} \quad \text{[mm]}$$

$$t_2 = 0,73 \cdot \mathbf{a} \cdot \sqrt{k_2 \cdot \frac{p}{\sigma_2}} \quad \text{[mm]}$$

where

p_s = maximum slamming pressure = $k_u \cdot p_{ij}$

p_{ij} = nominal bowflare slamming pressure, as specified in 2.7.3.1, at the lowest point of the panel, [N/cm^2]

k_u = slamming load factor = 1,1

τ_1 = $0,85 \cdot S_m \cdot R_{eH}$ [N/cm^2] for side shell plating forward of 0,125**L** from the **F.P.**

= $0,75 \cdot S_m \cdot R_{eH}$ [N/cm^2] for side shell plating in the region between 0,125**L** and 0,25**L** from the **F.P.**

τ_2 = $0,85 \cdot S_m \cdot R_{eH}$ [N/cm^2]

k_1 = 0,342 for longitudinally stiffened plating

= 0,5 for transversely stiffened plating

k_2 = 0,5 for longitudinally stiffened plating

= 0,342 for transversely stiffened plating

a, S_m and R_{eH} are as defined in 5.4.1.1 above.

.2 Side Longitudinals and Stiffeners

The section modulus of the stiffener, including the associated effective plating, is not to be less than obtained from the following equation :

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^3 \cdot p_s \cdot \mathbf{a} \cdot \frac{\ell^2}{16} \quad [N\text{-}cm]$$

where

ℓ = unsupported span of the stiffener [m]

p_s = maximum slamming pressure [N/cm^2], as defined in 5.4.2.1, at the midpoint of the span ℓ

a and σ_b are as defined in 5.4.1.1 above.

The effective breadth of plating, b_e, is as defined in 3.4.3.

.3 Side Transverses and Side Stringers

The net section modulus and sectional area requirements for side transverses and side stringers, as specified in 5.2.3, are to be met with the bow flare slamming pressure, as specified in 2.7.3.2, for the region between 0,0125**L** and 0,25**L** from the **F.P**.

5.5 Forebody deck structure

The deck plating, longitudinals, girders and transverses forward of 0,25 **L** from the **F.P.** are to meet the requirements specified in 3.5 and 3.6 with the deck pressure, $p = p_g$, where pg is the nominal green water loading given in 2.7.4 and the permissible stresses as specified below.

5.5.1 Deck Plating

The net thickness of deck plating is to be not less than t_1 and t_2, as specified in 3.5.2, with the following modifications:

$\sigma_1 = 0{,}50 \cdot S_m \cdot R_{eH}$ [N/cm^2] for main deck within 0,1**L** from the **F.P**.

$\sigma_1 = 0{,}60 \cdot S_m \cdot R_{eH}$ [N/cm^2] for forecastle deck

$\sigma_2 = 0{,}80 \cdot S_m \cdot R_{eH}$ [N/cm^2]

where

S_m = strength reduction factor obtained from 3.4.2

R_{eH} = minimum specified yield point of deck plating material

The permissible stress, σ_1, for main deck between 0,25 **L** and 0,1 **L** from the FP is to be obtained by linear interpolation between midship region ($\sigma_1 = 0{,}15 \cdot S_m \cdot R_{eH}$ as in 3.5.2) and the permissible stress at 0,1 **L** from the FP, as specified above.

$$t_3 = 0{,}3 \cdot \mathbf{a} \cdot \sqrt{\frac{S_m \cdot R_{eH}}{E}} \quad [mm] \qquad \text{for main deck within } 0{,}1\mathbf{L} \text{ from the } \mathbf{F.P.}$$

The net thickness, t_3, between 0,30 **L** and 0,1 **L** from the FP is to be obtained by linear interpolation between midship region and the t_3 above. t_3 in midship region is defined as:

$$t_3 = c \cdot \mathbf{a} \cdot \sqrt{\frac{S_m \cdot R_{eH}}{E}} \quad [mm] \qquad (3.5.2)$$

where

$c = 0{,}5 \cdot (0{,}6 + 0{,}0015 \cdot \mathbf{L})$

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

The net thickness of deck plating should not be less than the minimum gross thickness specified in Rules for Hull (Pt.1, Vol.II) Sec. 7 minus the nominal corrosion value specified in 1.1.4.2

Finally, the net thickness of deck plating is not to be less than 85% of the net thickness requirement based on nominal green water load, p_g, calculated for North Atlantic environment.

5.5.2 Deck Longitudinals

The net section modulus is not to be less than obtained from 3.5, with the following modifications.

$\sigma_b = 0{,}70 \cdot S_m \cdot R_{eH}$ [N/cm²] for main deck longitudinals within 0,1**L** from the FP and forecastle deck longitudinals

$\sigma_b = 0{,}80 \cdot S_m \cdot R_{eH}$ [N/cm²] for main deck beams forward of the foremost hatch opening (No. 1 hatch) and forecastle deck beams

The permissible bending stress, σ_b, for main deck longitudinals between 0,25**L** and 0,1**L** from the FP is to be obtained by linear interpolation between midship region (see 3.5.3) and the permissible stress at 0,1**L** from the FP, as specified above.

Finally, the net section modulus of deck longitudinals is not to be less than 85% of the net section modulus requirement based on nominal green water load, pg, calculated for North Atlantic environment.

5.5.3 Deck Transverse and Deck Girders

The deck girders and transverses forward of 0,2**L** from the FP are to be verified based on appropriate analysis (e.g., grillage analysis) and should meet the requirements specified in the following with the deck pressure, $p = p_g$, where pg is the nominal green water loading given in 2.7.4 and the permissible stresses as specified below.

Permissible bending stress for net thickness

$\sigma_b = 0{,}70 \cdot S_m \cdot R_{eH}$ [N/cm²]

Permissible shear stress for net thickness

$$\sigma_b = 0,45 \cdot S_m \cdot R_{eH} \quad [N/cm^2]$$

The required section modulus of members such as girders, transverse etc., is to be obtained on an effective width of plating basis in accordance with Rules for Hull (Pt.1, Vol.II) Sec. 3, E

Finally, the net section modulus and sectional area of deck girders and transverses is not to be less than 85% of those required based on nominal green water load, pg, calculated for North Atlantic environment.

6. Application to Single Hull Ship-Type Installations

6.1 General

Where due to the nature of the cargo, single hull construction is permitted, the design criteria and evaluation procedures specified in 1. may also be applied to single hull ship-type installations with modifications as outlined in this Section.

6.1.1 Nominal Design Corrosion Values

Except as modified by the following, the nominal design corrosion values given in Table 4.8 are applicable to the corresponding structural elements of single hull ship-type installations based on the proposed usage of the individual space.

For bottom plating and contiguously attached structures, the nominal design corrosion values to be used are:

Wing Ballast Tanks	
Bottom Plating	1,00 mm
Bottom Longitudinals, Transverses and Girders (Web and Flange)	1,50 mm
Center or Wing Cargo Tanks	
Bottom Plating	1,00 mm
Bottom Longitudinals, Transverses and Girders (Web and Flange)	1,00 mm

Consideration may be given for modifying the nominal design corrosion values, depending upon the degree of cargo corrosiveness.

6.1.2 Load Criteria

The load criteria and load cases specified in 2.1 through 2.7 are generally applicable to single hull ship-type installations by considering the double bottom and wing ballast tanks, such as shown in Fig. 4.8 and 4.25, as null, except that the load patterns are specified in Table 4.23 for bottom and side shell structures.

6.1.3 Strength Criteria

.1 Shear Strength

For single hull ship-type installations with two or more longitudinal bulkheads, the net thickness of side shell and longitudinal bulkhead plating is not to be less than that specified in 3.3, wherein the shear distribution factor, D_s and D_i, and local load correction, R_i, may be derived either from direct calculations or from Annex 8.

.2 Plating and Longitudinals/Stiffeners

The strength requirements for plating and longitudinals/stiffeners specified in 3.4 through 3.9 and 5 are directly applicable to single hull ship-type installations by determining the internal pressure in accordance with the actual tank arrangement.

6.2 Main Supporting Structures

6.2.1 Bottom Transverses

.1 Section Modulus of Bottom Transverses

The net section modulus of the bottom transverse, in association with the effective bottom plating, is not to be less than obtained from the following equation (see also 3.1.2).

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^4 \cdot c \cdot p \cdot \mathbf{a} \cdot \ell_b^2 \quad [N\text{-}cm]$$

where

$c = 0{,}83 \cdot \alpha^2$ for center tank

$= 1{,}4$ for wing tank

$\alpha = \frac{\ell_g}{\ell_b} \cdot \sqrt[4]{\frac{I_b}{I_g} \cdot \frac{\mathbf{a_g}}{\mathbf{a}}} \le 1{,}0$ for ship-type installations with bottom girder

$= 1{,}0$ for ship-type installations without bottom girder

ℓ_b = span of the bottom transverse [m], as indicated in Fig. 4.51; the length is to be not less than 0,125**B** or one-half the breadth of the tank, whichever is the greater

ℓ_g = span of the bottom girder [m], as indicated in Fig. 4.51

a = spacing of the bottom transverse [m]

$\mathbf{a_g}$ = spacing of the bottom girder [m]

I_b, I_g = moments of inertia [cm^4], of the bottom transverse (I_b) and the bottom girder (I_g) with effective plating to which they are attached (clear of bracket)

p = nominal pressure [kN/m^2], at the mid-span of the bottom transverse, as specified in Table 4.23

σ_b = permissible bending stress

$= 0{,}70 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1.

B = installation breadth, [m]

.2 Web Sectional Area of Bottom Transverse

The net sectional area of the web portion of the bottom transverse is not to be less than obtained from the following equation:

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

The shear force, Q, [N], can be obtained from the following equation (see also 3.1.2).

$$Q = 10^3 \cdot \left[p \cdot \mathbf{a} \cdot \left(K_b \cdot \ell_s - h_e \right) + c \cdot \mathbf{H} \cdot B_c \cdot \mathbf{a} \right] \quad [N]$$

where

K_b = $0,5 \cdot \alpha$ for center tank
= 0,5 for wing tank

c = 0 for center tank
= 0,15 for wing tank without cross ties
= 0,06 for wing tank with one cross tie
= 0,03 for wing tank with two cross ties

ℓ_s = span of the bottom transverse [m], as indicated in Fig. 4.51

h_e = length of the bracket of bottom transverse [m], as indicated in Fig. 4.51

H = installation depth [m]

B_c = breadth of the center tank [m]

P, **a** and α are as defined in 6.2.1.1.

τ_s = permissible shear stress [N/cm^2]
= $0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1.

6.2.2 Bottom Girders

.1 Section Modulus of Bottom Girders

The net section modulus of the bottom girder, in association with the effective bottom plating, is not to be less than obtained from the following equation (see also 3.1.2).

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^3 \cdot c \cdot p \cdot \mathbf{a_g} \cdot \ell_g^2 \quad [N\text{-}cm]$$

where

c = α^2

α = $\left(\frac{\ell_b}{\ell_g} \right) \cdot \sqrt[4]{\frac{I_g}{I_b} \cdot \frac{\mathbf{a}}{\mathbf{a_g}}} \leq 1,0$

p = nominal pressure, [kN/m^2], at the mid-span of the bottom girder, as specified in Table 4.23

ℓ_b, ℓ_g, l_g, l_b, **a** and $\mathbf{a_g}$ are as defined in 6.2.1.1.

$$\sigma_b = 0,70 \cdot S_m \cdot R_{eH} \quad [N/cm^2]$$

S_m and R_{eH} are as defined in 3.4.2.1

.2 Web Sectional Area of Bottom Girder

The net sectional area of the web portion of the bottom girder is not to be less than obtained from the following equation :

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

The shear force, F [N], can be obtained from the following equation (see 3.1.2).

$$Q = 10^3 \cdot c \cdot p \cdot \mathbf{a_g} \cdot \left(0,5 \cdot \ell_s - h_e\right) \quad [N]$$

where

ℓ_s = span of the bottom girder, [m], as indicated in Fig. 4.51

h_e = length of bracket of bottom girder, [m], as indicted in Fig. 4.51

$\mathbf{a_g}$, c, p are as defined in 6.2.1.1.

τ_s = permissible shear stress

= $0,45 \cdot S_m \cdot R_{eH}$ $[N/cm^2]$

S_m and R_{eH} are as defined in 3.4.2.1.

Table 4.23 Design Pressure for Local and Supporting Structures

A. Plating & Longitudinals/Stiffeners

The nominal pressure, $p = |p_i - p_e|$, is to be determined from load cases "a" & "b" below, whichever is greater, with $k_u = 1.10$ and $k_c = 1.0$ unless otherwise specified in the table

Structural Members/ Components	Case "a" - At fwd end of the tank				Case "b" - At mid tank/fwd end of tank			
	Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients		Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients	
			p_i	p_e			p_i	p_e
1. Bottom Plating & Long'l	2/3 design draft/0°	Full center and wing tanks	A_i	A_e	Design draft/0°	Midtank of empty center and wing tanks	–	B_e
2. Side Shell Plating & Long'l	2/3 design draft/60°	Starboard side of full wing tank	B_i	A_e	Design draft/60°	Midtank of empty wing tank	–	B_e

B. Main Supporting Members

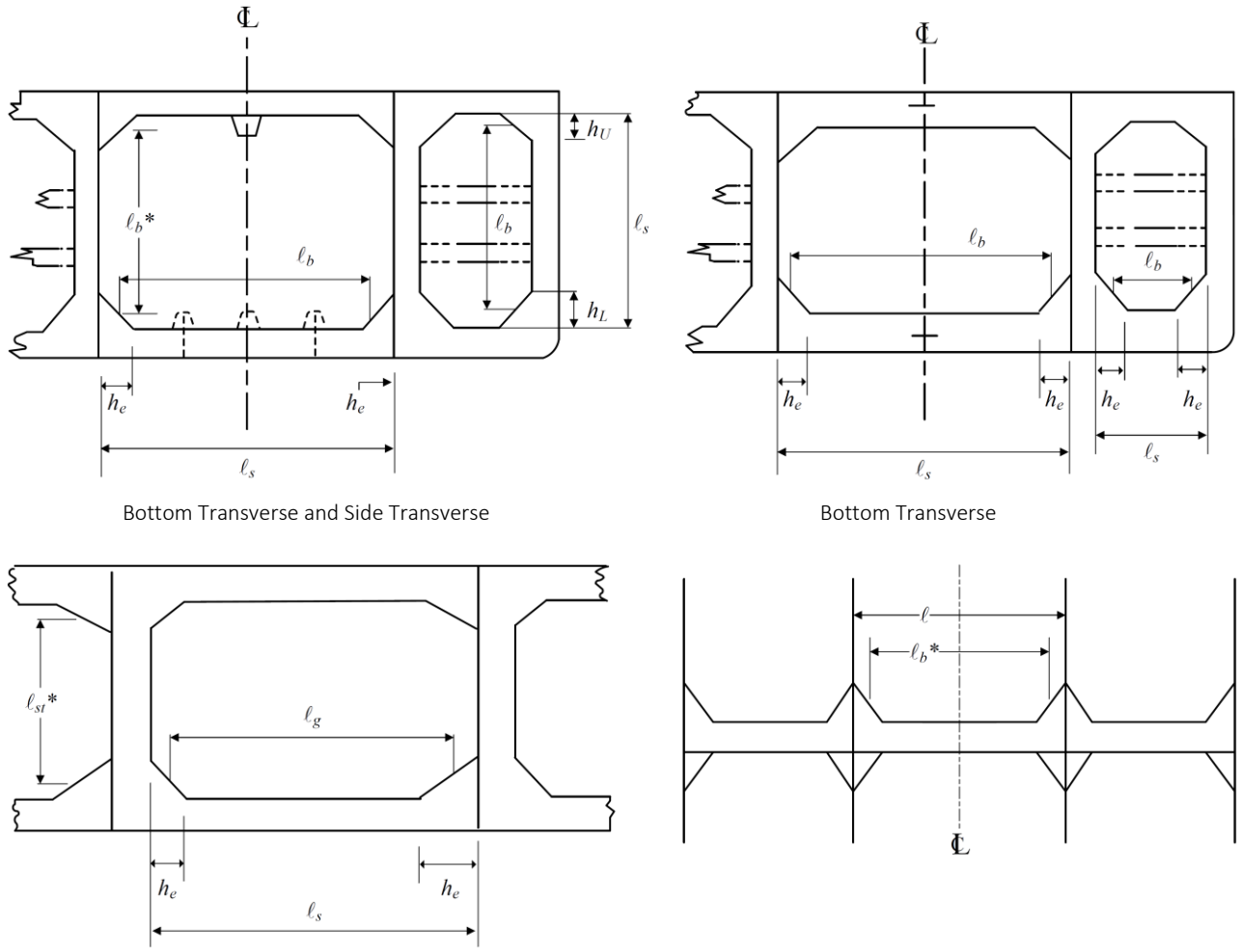
The nominal pressure, $p = |p_i - p_e|$, is to be determined at the midspan of the structural member at starboard side of installation from load cases "a" & "b" below, whichever is greater, with $k_u = 1.0$ and $k_c = 1.0$ unless otherwise specified in the table

Structural Members/ Components	Midtank for Transverses				Midtank for Transverses			
	Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients		Draft/Wave Heading Angle	Location and Loading Pattern	Coefficients	
			p_i	p_e			p_i	p_e
3. Bottom Transverse & Girder	2/3 design draft/0°	Full center and wing tanks	A_i	A_e	Design draft/0°	Midtank of empty center and wing tanks	–	B_e
4. Side Transverses	2/3 design draft/60°	Wing tanks full	B_i	–	Design draft/60°	Midtank of empty wing tank	–	B_e
5.*Deck Transverses with cross ties in wing tanks (Fig. 4.47)	2/3 design draft/60°	Wing tanks full, Center tank empty	C_1	–	2/3 design draft/60°	Center tank full, wing tank empty	C_1	–

** See note 5*

Notes :

1 *For calculating p_i and p_e, the necessary coefficients are to be determined based on the following designated groups:*
   a) *For p_i*
      A_i: $w_v = 0,75$, $w_{fwd\ bhd} = 0,25$, $w_{aft\ bhd} = -0,25$, $w_t = 0,0$, $c_\varphi = -1,0$, $c_e = 0,0$
      B_i: $w_v = 0,4$, $w_{fwd\ bhd} = 0,2$, $w_{aft\ bhd} = -0,2$, $w_t(starboard) = 0,4$, $w_t(port) = -0,4$, $c_\varphi = -0,7$, $c_e = 0,7$
   b) *For p_e*
      A_e: $k_{fo} = 1,0$, $k_u = 1,0$, $k_c = -0,5$
      B_e: $k_{fo} = 1,0$
2 *For structures within 0,4 **L** amidships, the nominal pressure is to be calculated for a tank located amidships. The longest cargo and ballast tanks in the region should be considered as located amidships*
3 *In calculation of the nominal pressure, ρg of the liquid cargoes is not to be taken less than 0,1025 kgf/cm^2-m for structural members 1 and 2 and is not to be taken less than 0,09 kgf/cm^2-m for cargo tanks and 0,1025 kgf/cm^2-m for ballast tanks for structural members 3 and 4.*
4 *For all other structures, Table 4.11 is applicable*
5 *Case-a is applied for deck transverse in wing tanks and case-b is applied for deck transverse in center tank*



* *Where both lower and upper ends of the vertical web are fitted with a bracket of the same or larger size on the opposite side, the span ℓ_b or ℓ_{st} may be taken between the toes of the effective lower and upper brackets.*

Fig. 4.51 Spans of Transverses and Girders

6.2.3 Side Transverses

.1 Section Modulus of Side Transverses

The net section modulus of the side transverse, in association with the effective side plating, is not to be less than obtained from the following equation (see also 3.1.2)

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^4 \cdot c \cdot p \cdot a \cdot \ell_b^2 \quad [N\text{-}cm]$$

where

ℓ_b = span of side transverse [m], as indicated in Fig. 4.51

a = spacing of side transverse [m]

p = nominal pressure [kN/m^2], at the mid-span ℓ_b of the side transverse, as specified in Table 4.23

σ_b = permissible bending stress [N/cm^2]

= $0,70 \cdot S_m \cdot R_{eH}$ [N/cm^2]

c is given in Table 4.24. S_m and R_{eH} are as defined in 3.4.2.1.

For ship-type installations without cross ties, the section modulus of the side transverse, as required above, is to extend at least up to $0,6 \cdot \ell_b$ from the lower end of the span. The value of the bending moment, M, used for the calculation of the required section modulus of the remaining part of the side transverse may be reduced, but not more than 20%.

In the case of one cross tie, the section modulus of the lower (upper) side transverse, as required above, is to extend to the cross tie.

In the case of two cross ties, the section modulus of the lower (upper) side transverse, as required above, is to extend to the lower (upper) cross tie and may be linearly interpolated between the cross ties.

Table 4.24 Coefficient c for Side Transverse

Arrangement of Cross Ties	For Upper Side Transverse	For Lower Side Transverse
No Cross Tie	0,75	
One Cross Tie in Wing Tank	0,19	0,33
Two Cross Ties in Wing Tank	0,13	0,20

.2 Web Sectional Area of Side Transverses

The net sectional area of the web portion of the side transverse is not to be less than obtained from the following equation :

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

The shear force, Q, [N], for the side transverse can be obtained from the following equation (see also 3.1.2):

– For the upper part of the transverse

$$Q = 10^3 \cdot \mathbf{a} \left[K_U \cdot \ell_s \left(P_U \cdot \ell_s + P_L \right) - h_U \cdot P_U \right] \quad [N]$$

– For the lower part of the transverse

$$Q = \max \left[10^3 \cdot \mathbf{a} \left[K_L \cdot \ell_s \left(P_U \cdot \ell_s + P_L \right) - h_L \cdot P_L \right] ; 350 \cdot \mathbf{a} \cdot K_L \cdot \ell_s \left(P_U + P_L \right) \right] \quad [N]$$

In no case is the shear force for the lower part of the transverse to be less than 120% of that for the upper part of the transverse.

where

ℓ_s = span of the side transverse [m], as indicated in Fig. 4.51

a = spacing of the side transverse [m]

P_U = nominal pressure, p, [kN/m^2], at the mid-length of the upper bracket (h_U/2), as specified in Table 4.23

P_L = nominal pressure, p, [kN/m^2], at the mid-length of the lower bracket (h_L/2), as specified in Table 4.24

h_U = length of the upper bracket [m], as indicated in Fig. 4.51

h_L = length of the lower bracket [m], as indicated in Fig. 4.51

τ_s = permissible shear stress [N/cm^2]

= $0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

K_U and K_L are given in Table 4.25.

S_m and R_{eH} are as defined in 3.4.2.1.

For ship-type installations without cross ties, the sectional area of the lower side transverse, as required above, is to extend up to $0,15 \cdot \ell$ from the toe of the lower bracket or $0,3\ \ell_s$ from the lower end of the span, whichever is greater.

In the case of one cross ties, the sectional area of the lower (upper) side transverse as required above, is to extend to the cross tie.

In the case of two cross ties, the sectional area of the lower (upper) side transverse as required above, is to extend to the lower (upper) cross tie and may be linearly interpolated between the cross ties.

Table 4.25 Coefficients K_U and K_L for Side Transverses

Arrangement of Cross Ties	K_U	K_L
No Cross Tie	0,16	0,30
One Cross Tie in Wing Tank	0,09	0,21
Two Cross Ties in Wing Tank	0,075	0,16

6.2.4 Deck Transverses - Loading Pattern 1

The net section modulus of deck transverses, in association with the effective deck plating, is not to be less than obtained from the following equation (see also 3.1.2).

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

For deck transverses in wing tanks:

$$M = \left(10^4 \cdot c_1 \cdot \varphi \cdot p \cdot \mathbf{a} \cdot \ell_t^2 + \beta_s \cdot M_s \right) \geq M_0 \quad [N\text{-}cm]$$

For deck transverses in center tanks:

$$M = \left(10^4 \cdot c_1 \cdot \varphi \cdot p \cdot \mathbf{a} \cdot \ell_t^2 + \beta_b \cdot M_b \right) \geq M_0 \quad [N\text{-}cm]$$

where

$M_s = 10^4 \cdot c_2 \cdot p_s \cdot \mathbf{a} \cdot \ell_s^2$

$M_b = 10^4 \cdot c_2 \cdot p_b \cdot \mathbf{a} \cdot \ell_b^2$

$M_0 = 10^4 \cdot c_3 \cdot \varphi \cdot p \cdot \mathbf{a} \cdot \ell_t^2$

p = nominal pressure [kN/m^2], at the mid-span of the deck transverse under consideration, as specified in Table 4.23, Item 5

p_s = corresponding nominal pressure [kN/m^2], at the mid-span of the side transverse (Table 4.11, Item 16)

p_b = corresponding nominal pressure [kN/m^2], at the mid-span of the vertical web on longitudinal bulkhead (Table 4.11, Item 16)

c_1 = 0,42 for tanks without deck girder

= $0,42 \cdot \alpha^2$ for tanks with deck girders, min. 0,05 and max. 0,42

$\alpha = \frac{\ell_g}{\ell_t} \cdot \sqrt[4]{\frac{\mathbf{a_g}}{\mathbf{a}} \cdot \frac{I_T}{I_g}}$

ℓ_g = span of the deck girder [m], as indicated in Fig. 4.31B-c

ℓ_t = span of the deck transverse [m], as indicated in Fig. 4.31A, but is not to be taken as less than 60% of the breadth of the tank

I_g, I_t = moments of inertia [cm^4], of the deck girder and deck transverse, clear of the brackets, respectively

$\mathbf{a_g}$ = spacing of the deck girders [m]

$\mathbf{a}$ = spacing of the deck transverses [m]

When calculating α, if more than one deck girder is fitted, the average values of $\mathbf{a}_g$, ℓ_g and I_g are to be used when the girders are not identical.

$\varphi = 1 - 5 \cdot \left(\frac{h_a}{\ell_t}\right) \alpha^{-1}$ to be not less than 0,6 for cargo tanks with deck girders

$= 1 - 5 \cdot \left(\frac{h_a}{\ell_t}\right)$ to be not less than 0,6 for cargo tanks without deck girders

h_a = distance, [m], from the end of the span to the toe of the end bracket of the deck transverse, as indicated in Fig. 4.38

$\beta_s = 0,9 \cdot \left(\frac{\ell_s}{\ell_t}\right) \cdot \left(\frac{I_t}{I_s}\right)$, but is not to be taken less than 0,10 and need not be greater than 0,65

$\beta_b = 0.9 \cdot \left(\frac{\ell_b}{\ell_t}\right) \cdot \left(\frac{I_t}{I_b}\right)$, but is not to be taken less than 0,10 and need not be greater than 0,50

ℓ_s, ℓ_b = spans [m], of side transverse and vertical web on longitudinal bulkhead, respectively, as indicated in Fig. 4.31A

I_s, I_b = moments of inertia [cm^4], clear of the brackets, of side transverses and vertical web on longitudinal bulkhead, respectively

σ_b = permissible bending stress [N/cm^2]

= $0,70 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1. c_2 is given in Table 4.26 below.

c_3 = 0,83 for tanks without deck girders

= $1,1 \cdot c_1$ for tanks with deck girders

Where no cross ties or other effective supporting arrangements are provided for the wing tank vertical webs, the deck transverses in the wing tanks are to have section modulus not less than 70% of that required for the upper side transverse.

Table 4.26 Coefficient c_2 For Deck Transverse

Arrangement of Cross Ties	Center Tank	Wing Tank
No Cross Tie	0,4	
One Cross Tie in Wing Tank	0,13	0,37
Two Cross Ties in Wing Tank	0,05	0,12

.2 Web Sectional Area of Deck Transverses

The net sectional area of the web portion of deck transverses is not to be less than obtained from the following equation:

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

$$Q = 10^3 \left[c_1 \cdot p \cdot \mathbf{a} \cdot \left(0.5 \cdot \ell_1 - h_e \right) + c_2 \cdot \mathbf{H} \cdot B_c \cdot \mathbf{a} \right] \quad [N]$$

where

c_1 = 1,30 for tanks without deck girder

= $\mathbf{0,90} \cdot \sqrt{\alpha}$ for tanks with deck girder, min. 0,50 and max. 1,0

c_2 = 0 for center tank

= 0,045 for wing tank

ℓ = span of the deck transverse, [m], as indicated in Fig. 4.31A

h_e = length of the bracket, [m], as indicated in Fig. 4.31A-c and d and Fig. 4.38

H = depth of the tanker, [m], as defined in Rules for Hull (Pt. 1, Vol. II), Sec. H.2.7

B_c = breadth of the center tank, [m]

p, **a** and α are as defined in 6.2.4.1.

τ_s = permissible shear stress, [N/cm^2]

= $0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH} are as defined in 3.4.2.1.

Area A is not to be less than the area obtained based on 3.6.6 and 3.6.7.

6.2.5 Deck Transverses – Loading Pattern 2

.1 Section Modulus of Deck Transverses

In addition to satisfying the net section modulus requirements of 6.2.4.1, the net section modulus of a deck transverse that is loaded with reactions (forces and moments) from the topside structure, is to be obtained from the following equation:

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$M = 10^5 \cdot (M_p + M_g + M_s)$ [N-cm] for deck transverses in wing tanks

$M = 10^5 \cdot (M_p + M_g + M_b)$ [N-cm] for deck transverses in center tanks

where

M_p = bending moment due to reactions from topside structure

= $\left| (M_v + M_m)\, \sigma_t \right|$

M_v = $\ell_t \sum_n P_n (k_{1n} + k_{2n})$

M_m = $\sum_n M_n (k_{3n} + k_{4n})$

P_n = reaction deck force number n, [kN], applied to the deck transverse in tank under consideration, see Fig. 4.37

M_n = reaction deck moment number n, [kN-m], applied to the deck transverse in tank under consideration, see Fig. 4.37

n = 1, 2,….., N_v to obtain bending moment M_v

= 1, 2,….., N_m to obtain bending moment M_m

N_v = number of reaction forces at deck transverse under consideration, (in tank under consideration)

N_m = total number of reaction moments at deck transverse under consideration, (in tank under consideration)

ℓ_t = span of the deck transverse under consideration [m], as defined in Fig. 4.31A

k_{1n} = $(1 - \bar{a}_n)^2 \left[\bar{a}_n - \bar{z} \left(1 + 2\bar{a}_n \right) \right]$

k_{2n} = 0 if $\bar{z} \le \bar{a}_n$

= $(\bar{z} - \bar{a}_n)$ if $\bar{z} > \bar{a}_n$

k_{3n} = $(1 - \bar{a}_n)(3 \cdot \bar{a}_n - 1 - 6 \cdot \bar{a}_n \cdot \bar{z})$

k_{4n} = 0 if $\bar{z} \le \bar{a}_n$

= 1 if $\bar{z} > \bar{a}_n$

$\bar{a}_n$ = $\dfrac{a_n}{\ell_t}$

$\bar{z}$ = $\dfrac{z}{\ell_t}$, $(0 \le \bar{z} \le 1)$

a_n = distance [m], from a point of application of reaction (force P_n or moment M_n) to the end of the deck transverse span ℓ_t, as shown in Fig. 4.37

z = coordinate (measured from the end of the span P_t) [m] of the section of the deck transverse under consideration, as shown in Fig. 4.37

For the toe of the deck transverse end brackets, $\bar{z} = h_a/\ell_t$ and $\bar{z} = 1 - h_a/\ell_t$

h_a = distance [m], from the end of the span to the toe of the end bracket of the deck transverse, as shown in Fig. 4.38.

Note:

For a wide topside bracket, the vertical load on a deck transverse can be considered uniformly distributed with pressure qn = Pn/c, and the concentrated bending moment can be substituted by force couples.

$$P_m = \frac{M_n}{k \cdot c} \quad [kN]$$

where

P_n, M_n = concentrated force and moment obtained from FE analysis of topside structure

c = width of the topside bracket

k = shape bracket factor, and may be taken as 0,8, unless otherwise specified

Bending moment at the toe of the end brackets due to green water pressure, M_g:

$$M_g = 0{,}1 \cdot c_3 \cdot \varphi \cdot P_{gi} \cdot \mathbf{a} \cdot \ell_t^2 \quad [kN\text{-}m]$$

where

P_{gi} = nominal green water pressure imposed on the deck [kN/m^2], as defined in 2.7.4.

a = spacing [m], of the deck transverses

c_3 = 0,83 for tanks without deck girders

= 1,1 · c_1 for tanks with deck girders

φ = $1 - 5\left(\frac{h_a}{\alpha \cdot \ell_t}\right)$ for cargo tanks with deck girders, 0,6 minimum

= $1 - 5\left(\frac{h_a}{\ell_t}\right)$ for cargo tanks without deck girders, 0,6 minimum

h_a = distance [m], from the end of the span to the toe of the end bracket of the deck transverse, as indicated in Fig. 4.38.

ℓ_t = span of the deck transverse [m], as indicated in 4.31A, but is not to be taken as less than 60% of the breadth of the tank, except for ship-type vessels with a non-tight centerline bulkhead (4.31A-b), for which the span is not to be taken as less than 30% of the breadth of the tank.

c_1 for tanks without deck girders:

= 0,30 for 4.31A-c with non-tight centerline bulkhead

= 0,42 or all other cases

c_1 for tanks with deck girders:

= 0,30 · α^2 for 4.31A-b with a non-tight centerline bulkhead, 0,05 min. and 0,30 max.

$= 0,42 \cdot \alpha^2$ for 4.31A-a or 4.30A-b with an oil-tight centerline bulkhead, 0,05 min. and 0,42 max.

$\alpha = \left(\frac{\ell_g}{\ell_t}\right) \cdot \sqrt[4]{\left(\frac{a_g}{a}\right)\left(\frac{I_t}{I_g}\right)}$

ℓ_g = span of the deck girder [m], as indicated in 4.31B-c of these Guidance

I_g, I_t = moments of inertia [cm^4], of the deck girder and deck transverse with effective deck plating, clear of the end brackets, respectively

a_g = spacing of the deck girder [m], as shown in 4.31A.

a = spacing of the deck transverses [m]

When calculating α, if more than one deck girder is fitted, average values of a_g, ℓ_g and Ig are to be used when the girders are not identical.

Bending moments due to pressure on side transverse and vertical web of longitudinal bulkhead:

$$M_s = k_s \cdot \beta_s \cdot c_2 \cdot p_s \cdot a \cdot \ell_b^2$$

$$M_b = k_b \cdot \beta_b \cdot c_2 \cdot p_b \cdot a \cdot \ell_b^2$$

where

k_s = 0,1 and k_b = 0,1, unless otherwise specified.

ℓ_s, ℓ_b = spans [m], of side transverse and vertical web on longitudinal bulkhead, respectively, as indicated in 4.31A. Where a cross tie is fitted and is located at a distance greater than 0,7 a or 0,7 b from the deck transverse, the effective span of the side transverse or the vertical web may be taken as that measured from the deck transverse to the cross tie and all coefficients determined as if there were no cross tie.

p_s = nominal pressure [kN/m^2], at the mid-span of side transverse when wing tank is empty, adjacent tanks full (Table 4.23, item 4)

p_b = nominal internal cargo pressure [kN/m], at the mid-span of the vertical web on longitudinal bulkhead when center tank is empty, adjacent tanks full (Table 4.11, item 13)

$\beta_s = 0,9 \cdot \left[\left(\frac{\ell_s}{\ell_t}\right)\left(\frac{I_t}{I_g}\right)\right]$ 0,10 min. and 0,65 max.

$\beta_b = 0,9 \cdot \left[\left(\frac{\ell_b}{\ell_t}\right)\left(\frac{I_t}{I_b}\right)\right]$ 0,10 min. and 0,50 max.

I_s, I_b = moments of inertia [cm^4], clear of the brackets, of side transverse and vertical web on longitudinal bulkhead, respectively

c_2 are given in Table 4.26.

σ_t = 1 for tanks without deck girders

σ_t = $\max\left\{1 - \left(\frac{0,67}{1 + 2 \cdot \delta}\right); 0,7\right\}$ for tanks with deck girders

δ = $\left(\frac{\ell_g}{\ell_t}\right)^3 \cdot \left(\frac{I_t}{I_g}\right)$

σ_b = permissible bending stress [N/cm^2]

= $0,70 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH} as defined in 3.4.2.1

.2 Web Sectional Area of Deck Transverse

In addition to satisfying the net web sectional area requirements of 6.2.4.2, the net sectional area of the web portion of the deck transverse, that is loaded with reactions (forces and moments) from the topside structure, is to be obtained from the following equation:

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

where

Q = $10^3 \cdot (Q_p + Q_g + c_2 \cdot \mathbf{a} \cdot \mathbf{H} \cdot B_c)$ [N]

Q_p = $\left|(Q_v + Q_m) \cdot \sigma_1\right|$

Q_v = $\sum_n \left[P_n (1 - \bar{a}_n)^2 (2 \cdot \bar{a}_n + 1) + \Delta Q\right]$

Q_m = $6 \cdot \sum_n \bar{a}_n (1 - \bar{a}_n) \cdot \frac{M_n}{\ell_t}$

Q_g = $c_1 \cdot p_{gi} \cdot \mathbf{a} \cdot (0,50 \cdot \ell + h_e)$

ΔQ = 0 if $\bar{z} \le \bar{a}_n$

= $-P_n$ if $\bar{z} > \bar{a}_n$

σ_1 = $1 - \left[\frac{0,5}{(1 + 4 \cdot \delta)}\right]$

c_1 = 1,30 for tanks without deck girder

= $0,90 \cdot \sqrt{\alpha}$ for tanks with deck girder, min. 0,50 and max. 1,0

c_2 = 0 for center tank

= 0,045 for wing tank

ℓ = span of the deck transverse [m], as indicated in Fig. 4.31A

h_e = length of the bracket [m], as indicated in Fig. 4.31A and B and Fig. 4.38 of these Guidelines

$\mathbf{H}$ = depth of a vessel [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.7.

B_c = breadth of the center tank [m]

τ_s = permissible shear stress [N/cm^2]

= $0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

P_n, M_n, p_{gi}, ℓ_t, **a**, $\bar{\bar{a}}_n$, $\bar{\bar{z}}$, α, δ, S_m and R_{eH} are as defined in 6.2.5.1, above .

6.2.6 Longitudinal Bulkhead Vertical Webs

.1 Section Modulus of Vertical Web on Longitudinal Bulkhead

The net section modulus of the vertical web, in association with the effective longitudinal bulkhead plating, is to be not less than obtained from the following equation (see also 3.1.2) :

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^4 \cdot c \cdot p \cdot \mathbf{a} \cdot \ell_b^2 \quad [N\text{-}cm]$$

where

ℓ_b = span of vertical web [m], as indicated in Fig. 4.51. Where both lower and upper ends of the vertical web are fitted with a bracket of the same or larger size on the opposite side, the span ℓ_b may be taken between the toes of the effective lower and upper brackets.

a = spacing of vertical webs [m]

p = nominal pressure [kN/m^2], at mid-span ℓ_b of the vertical web, as specified in Table 4.11.

σ_b = permissible bending stress [N/cm^2]

= $0,70 \cdot S_m \cdot R_{eH}$ [N/cm^2]

c is given in Table 4.27.

S_m and R_{eH} are as given in 3.4.2.1.

For ship-type installations without cross ties, the section modulus of the vertical web, as required above, is to extend at least up to $0,6\ell$ from the lower end of the span. The value of the bending moment M, used for the calculation of the required section modulus of the remaining part of vertical web, may be reduced, but not more than 20%.

In the case of one cross tie, the section modulus of the lower (upper) vertical web, as required above, is to extend to the cross tie.

In the case of two cross ties, the section modulus of lower (upper) vertical web, as required above, is to extend to the lower (upper) cross tie and may be linearly interpolated between cross ties.

Table 4.27 Coefficient c for Vertical Web on Longitudinal Bulkhead

Arrangement of Cross Ties	For Upper Vertical Web	For Lower Vertical Web
No Cross Tie	0,75	
One Cross Tie in Wing Tank	0,19	0,33
Two Cross Ties in Wing Tank	0,13	0,20

.2 Web Sectional Area of Vertical Web on Longitudinal Bulkhead

The net sectional area of the web portion of the vertical web is not to be less than obtained from the following equation:

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

The shear force, Q, [N], for the vertical web can be obtained from the following equation (see also 3.1.2):

– for upper part of web

$$Q = 10^3 \cdot \mathbf{a} \left[K_U \cdot \ell \left(P_U + P_L\right) - h_U \cdot P_U\right]$$

– for lower part of web

$$Q = \max \{10^3 \cdot \mathbf{a} \left[K_L \cdot \ell \left(P_U + P_L\right) - h_L \cdot P_L\right] ; 350 \cdot \mathbf{a} \cdot K_L \cdot \ell \left(P_U + P_L\right) \}$$

In no case is the shear force for the lower part of the web to be less than 120% of that for the upper part of the vertical web.

where

ℓ = span of the vertical web [m], as indicated in Fig. 4.31B-a

a = spacing of the vertical webs [m]

P_U = nominal pressure, p, [kN/m^2], at the mid-length of upper bracket (h_U/2), as specified in Table 4.11

P_L = nominal pressure, p, [kN/m^2], at the mid-length of the lower bracket (h_L/2), as specified in Table 4.11

h_U = length of the upper bracket [m], as indicated in Fig. 4.31B-a

h_L = length of the lower bracket [m], as indicated in Fig. 4.31B-a

τ_s = permissible shear stress [N/cm^2]

= $0,45 \cdot S_m \cdot R_{eH}$ [N/cm^2]

K_U and K_L are given in Table 4.28. S_m and R_{eH} are as defined in 3.4.2.1.

For ship-type installations without cross ties, the sectional area of lower vertical webs, as required above, is to extend up to $0,15\ell$ from the toe of the lower bracket or $0,3\ell$ from the lower end of the span, whichever is greater.

In the case of one cross tie, the sectional area of the lower (upper) vertical web, as required above, is to extend to the cross tie.

In the case of two cross ties, the sectional area of the lower (upper) vertical web, as required above, is to extend to the lower (upper) cross tie and may be linearly interpolated between the cross ties.

Table 4.28 Coefficients K_U and K_L for Vertical Web on Longitudinal Bulkhead

Arrangement of Cross Ties	K_U	K_L
No Cross Tie	0,16	0,30
One Cross Tie in Wing Tank	0,09	0,21
Two Cross Ties in Wing Tank	0,075	0,16

6.2.7 Horizontal Girder on Transverse Bulkhead

.1 Section Modulus of Horizontal Girder on Transverse Bulkhead

The net section modulus of the horizontal girder is to be not less than obtained from the following equation (see also 3.1.2).

$$W = \frac{M}{\sigma_b} \quad [cm^3]$$

$$M = 10^4 \cdot c \cdot p \cdot \mathbf{a} \cdot \ell_b^2 \quad [kN\text{-}cm]$$

where

ℓ_b = span of the horizontal girders [m], as indicated in Fig. 4.51. Where both ends of the horizontal girder are fitted with a bracket of the same or larger size on the opposite side, the span ℓ_b may be taken between the toes of the effective brackets.

a = sum of the half lengths [m], of the frames supported on each side of the horizontal girder

p = nominal pressure [kN/m^2], calculated at the mid-span of the horizontal girder under consideration, as specified in Table 4.11

σ_b = permissible bending stress [N/cm^2]

= $0,70 \cdot S_m \cdot R_{eH}$ [N/cm^2]

S_m and R_{eH}, as defined in 3.4.2.1.

c = 0,83 in wing tanks of vessels for transverse bulkhead without vertical webs

= 0,63 in center tanks of vessels for transverse bulkhead without vertical webs

= $0,73 \cdot \alpha^2$ for $\alpha < 0,5$ in center tanks of vessels for transverse bulkhead with vertical webs

= $0,467 \cdot \alpha^2 + 0,0657$ for $0,5 \le \alpha \le 1,0$ in center tanks of vessels for transverse bulkhead with vertical webs

= $0,1973 \cdot \alpha + 0,3354$ for $\alpha > 1,0$ in center tanks of vessels for transverse bulkhead with vertical webs

c is not to be taken less than 0,013 and need not be greater than 0,73.

$$\alpha = 0,9 \cdot \frac{\ell_{st}}{\ell_b} \cdot \sqrt[4]{\frac{I}{I_v} \cdot \frac{s_v}{\mathbf{a}}}$$

if more than one vertical web is fitted on the bulkhead, average values of ℓ_{st}, s_v and I_v are to be used when these values are not the same for each web.

ℓ_{st} = span of the vertical webs [m] (Fig. 4.51).

s_v = spacing of the vertical webs [m]

I, I_v = moments of inertia [cm^4], of the horizontal girder and the vertical web clear of the end brackets

.2 Web Sectional Area of the Horizontal Girder on Transverse Bulkhead

The net sectional area of the web portion of the horizontal girder is to be not less than obtained from the following equation:

$$A = \frac{Q}{\tau_s} \quad [cm^2]$$

$$Q = 10^3 \cdot a \cdot c \cdot p\,(0{,}5 \cdot \ell - h_e) \quad [N]$$

where

c = 0,80 for transverse bulkheads without vertical webs

= $0{,}72 \cdot \sqrt{\alpha}$ in center tanks of vessels for transverse bulkheads with vertical webs for $\alpha \geq 0{,}70$

= $0{,}452 \cdot \sqrt{\alpha}$ in center tanks of vessels for transverse bulkheads with vertical webs for $\alpha \geq 0{,}70$ if depth of centerline vertical web is the same or larger than that of horizontal girder under consideration

= $0{,}887 \cdot \alpha - 0{,}02$ in center tanks of vessel for transverse bulkheads with vertical webs for $\alpha < 0{,}7$, min. 0,1 and max. 0,8

= $0{,}554 \cdot \alpha - 0{,}02$ in center tanks of vessel for transverse bulkheads with vertical webs for $\alpha < 0{,}7$, min. 0,1 and max. 0,8 if depth of centerline vertical web is the same or larger than that of horizontal girder under consideration

ℓ = distance [m], between longitudinal bulkheads, as indicated in Fig. 4.51

a = sum of the half lengths [m], on each side of the horizontal girder, of the frames supported

h_e = length of the bracket [m], as indicated in Fig. 4.51

p and α are as defined in 6.2.7.1.

τ_s = permissible shear stress [N/cm²]

= $0{,}45 \cdot S_m \cdot R_{eH}$ [N/cm²]

S_m and R_{eH} are as defined in 3.4.2.1.

The equations in 6.2.7.1 and 6.2.7.2 are not applicable to horizontal girders in wing cargo tanks of vessels where vertical webs exist. In that case, the load effects may be determined from 3D structural analysis as specified in 3.1.2.

6.2.8 Other Main Supporting Members

The strength and stiffness requirements specified in 3.6 and 3.8 for deck girders, vertical webs and horizontal girders on transverse bulkheads and cross ties are applicable to single hull ship-type installations.

6.2.9 Proportions

The following minimum requirements for web depth are supplemental to those given in 3.6.6.

20%	for bottom transverses without bottom girder
14%	for bottom transverses with one girder
8%	for bottom transverses with three girders
20%	for bottom girders
12,5%	for side transverses

6.3 Strength Assessment

6.3.1 General

The failure criteria and strength assessment procedures specified in 4. are generally applicable to single hull ship-type installations, except for the special considerations outlined in 6.3.2 below.

6.3.2 Special Considerations

For assessing buckling and fatigue strength in accordance with 4.3 and 4.5, due consideration is to be given to the buckling characteristics of large stiffened panels of the side shell and bottom structures, as well as the realistic boundary conditions of side and bottom longitudinals at transverse bulkheads for calculating the total stress range with respect to fatigue strength.

D. Ship -Type Installations Under 150 meters in Length

1. Introduction

1.1 General

1.1.1 Classification

See Section 1, A.

1.1.2 Application

.1 Structural Arrangement

The requirements contained in this section are intended to apply to longitudinally framed, all- welded tank installations having proportions in accordance with:

- In general, these Guidelines are valid for steel vessels not exceeding 150 m in length, **L**, and having a breadth, **B**, not exceeding one-fifth of the length, **L**, nor 2,5 (2,0 for steel vessels under 90 m) times the depth, H_s, to the strength deck.

Vessels beyond these proportions will be specially considered.

- machinery aft and
- two or more continuous longitudinal bulkheads.

Where the arrangement differs from that described, the scantlings may require adjustment to provide equivalent strength.

.2 Installations of Similar Type and Arrangement

The requirements are also intended to apply to other installations of similar type and arrangement.

Double hull ship-type installation:

A monohull having full depth wing water ballast tanks or other non-cargo spaces and full-breadth double bottom water ballast tanks or other non-cargo spaces within cargo area to prevent liquid cargo outflow in stranding/collision. The size and capacity of these wing/double bottom tanks or spaces are to comply with MARPOL 73/78 and national Regulations, as applicable.

Double side, single bottom ship-type installation:

A monohull having full depth wing water ballast tanks or other non-cargo spaces and single bottom structure.

Single hull ship-type installation:

A monohull that does not have double side and double bottom spaces fitting the definition of Double hull ship-type installation.

.3 Engineering Analysis

It is recommended that compliance with the following requirements be accomplished through a detailed investigation of the magnitude and distribution of the imposed longitudinal and transverse forces by using an acceptable method of engineering analysis. The following paragraphs are to be used as a guide in determining scantlings. Where it can be shown that the calculated stresses using the loading conditions specified in 2.7.3 are less than those stated to be permissible, consideration will be given to scantlings alternative to those recommended by this Section.

1.1.3 Detail Design of Internal Members

The detail design of internals is to follow the guidance given in Rules for Hull (Pt.1, Vol.II), Sec.3, H. See also Annex 5.

1.1.4 Breaks

Special care is to be taken throughout the structure to provide against local stresses at the ends of the oil spaces, superstructures, etc. The main longitudinal bulkheads are to be suitably tapered at their ends, and effective longitudinal bulkheads in the poop are to be located to provide effective continuity between the structure in way of and beyond the main cargo spaces. Where the break of a superstructure lies within the midship 0,5**L**, the required shell and deck scantlings for the midship 0,4**L** may be required to be extended to effect a gradual taper of structure, and the deck stringer plate and sheer strake are to be increased. See 2.2.2 and 2.3.1. Where the breaks of the forecastle or poop are appreciably beyond the midship 0,5**L**, the requirements of 2.2.2 and 2.3.1 may be modified.

1.1.5 Variations

Ship-type installations of special type or design differing from those described in the following will be specially considered on the basis of equivalent strength.

1.1.6 Loading Guidance

Loading guidance is to be as required by Rules for Hull (Pt.1, Vol.II), Sec.5, A.4.

1.1.7 Higher-strength Materials

In general, applications of higher-strength materials for installations intended to carry oil in bulk are to meet the requirements of this section, but may be modified generally as outlined in Rules for Hull (Pt.1, Vol.II), Sec.2, B.

1.1.8 Pressure-Vacuum Valve Setting

Where pressure-vacuum valves of cargo oil tanks are set at a pressure in excess of the pressure appropriate to the length of the installation [see 4.C.1.1.10], the tank scantlings will be specially considered. Particular attention is to be given to a higher pressure setting of pressure-vacuum valves as may be required for the efficient operation of cargo vapor emission control systems, where installed.

1.1.9 Protection of Structure

For the protection of structure, see Rules for Hull (Pt.1, Vol.II), Sec.38.

1.1.10 Aluminum Paint

Paint containing aluminum is not to be used in cargo tanks, on tank decks in way of cargo tanks, in pump rooms and cofferdams, or in any other area where cargo vapor may accumulate, unless it has been shown by appropriate tests that the paint to be used does not increase the fire hazard.

1.1.11 Tank Design Pressures

The requirements of this section are for tanks intended for the carriage of liquid cargoes with specific gravities not greater than 1,05. Where the specific gravity is greater than 1,05, the design heads, h, are to be increased by the ratio of specific gravity to 1,05. See also Rules for Machinery Installations (Pt.1, Vol.III), Sec.15 with regard to pressure-vacuum valve setting and liquid level control.

1.2 Special Requirements for Deep Loading

Where an installation is intended to operate at the minimum freeboard allowed by the **ICLL**, for Type-A installations, the conditions in 1.2.1 through 1.2.5 are to be complied with.

1.2.1 Machinery Casings

Machinery casings are normally to be protected by an enclosed poop or bridge, or by a deckhouse of equivalent strength. The height of such structure is to be at least 1,8 m for installations up to and including 75 m in length, and 2,3 m for installations 125 m or more in length. The minimum height at intermediate lengths is to be obtained by interpolation. The bulkheads at the forward ends of these structures are to be of not less scantlings than required for bridge-front bulkheads. (See Rules for Hull (Pt.1, Vol.II), Sec.16, C) Machinery casings may be exposed, provided that they are specially stiffened and there are no openings giving direct access from the freeboard deck to the machinery space. A door complying with the requirements of Rules for Hull (Pt.1, Vol.II), Sec.21, S. may, however, be permitted in the exposed machinery casing, provided that it leads to a space or passageway which is as strongly constructed as the casing and is separated from the engine room by a second door complying with Rules for Hull (Pt.1, Vol.II), Sec.21, S. The sill of the exterior door is not to be less than 600 mm, and of the second door not less than 230 mm.

1.2.2 Access

Satisfactory arrangements are to be provided to safeguard the crew in reaching all parts used in the necessary work of the installation. See Rules for Hull (Pt.1, Vol. II), Sec.21, R.

1.2.3 Hatchways

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

1.2.4 Freeing Arrangements

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

1.2.5 Flooding

For reference only, attention is called to the requirement of the **ICLL**, that tankers over 150 m in freeboard length (see Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.2) to which freeboards less than those based solely on Table B are assigned must be able to withstand the flooding of certain compartments.

1.2.6 Ventilators

Ventilators to spaces below the freeboard deck are to be specially stiffened or protected by superstructures or other efficient means. See also Rules for Hull (Pt.1, Vol.II), Sec. 21, G.

1.3 Arrangement

The arrangements of the installation are to comply with the requirements in **Annex 1 to MARPOL 73/78** from Ships, with regard to segregated ballast tanks (Regulation 13), their protective locations (Regulation 13E - where the option in Regulation 13F (4) or (5) is exercised), collision or stranding considerations (Regulation 13F), hypothetical outflow of oil (Regulation 23), limitations of size and arrangement of cargo tanks (Regulation 24) and slop tanks [Regulation 15 (2)(c)]. A valid International Oil Pollution Certificate issued by the Administration may be accepted as an evidence for compliance with these requirements.

1.3.1 Subdivision

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

1.3.2 Cofferdams

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

1.3.3 Gastight Bulkheads

Gastight bulkheads are to be provided for the isolation of all cargo pumps and piping from spaces containing stoves, boilers, propulsion machinery, electric apparatus or machinery where sources of ignition are normally present. These bulkheads are to comply with the requirements of Rules for Hull (Pt.1, Vol. II), Sec.11.

1.3.4 Cathodic Protection

.1 Anode Installation Plan

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

.2 Magnesium and Magnesium Alloy Anodes

Magnesium and magnesium alloy anodes are not to be used.

.3 Aluminum Anodes

Aluminum anodes may be used in cargo tanks of ship-type installations, only in locations where the potential energy does not exceed 275 N-m. The height of the anode is to be measured from the bottom of the tank to the center of the anode, and its weight is to be taken as the weight of the anode as fitted, including the fitting devices and inserts.

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

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

.4 Anode Attachment

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

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

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

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

1.3.5 Ports in Pump Room Bulkheads

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

1.3.6 Location of Cargo Oil Tank Openings

Cargo oil tank openings, including those for tank cleaning, which are not intended to be secured gastight at all times during the normal operation of the installation are not to be located in enclosed spaces. For the purpose of this requirement, spaces open on one side only are to be considered enclosed. See also 1.3.11.

1.3.7 Structural Fire Protection

The applicable requirements of Rules for Hull (Pt.1, Vol.II), Sec.22 are to be complied with.

1.3.8 Allocation of Spaces

.1 Tanks Forward of the Collision Bulkhead

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

.2 Double Bottom Spaces and Wing Tank Spaces

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

1.3.9 Access to Upper Parts of Ballast Tanks on Double Hull Ship-Type Installations

Where the structural configuration within the ballast tank is such that it will prevent access to upper parts of tanks for required close-up examination [see Rules for Classification and Surveys (Pt.1, Vol.I), Sec.4.I.C] by conventional means, such as a raft on partly filled tank, permanent means of safe access is to be provided. The details of access are to be submitted for review.

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

1.3.10 Access to All Spaces in the Cargo Area

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

For access through horizontal openings, hatches or manholes, the access is to be of a size such as to allow a person wearing a self-contained, air-breathing apparatus and protective equipment (see Rules for Mobile Offshore unit (Pt.5, Vol.VI), Sec.10, C.8) to ascend or descend any ladder without obstruction and also to provide a clear opening to facilitate the hoisting of an injured person from the bottom of the space. In general, the minimum clear opening is not to be less than 600 mm x 600 mm.

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

For installations less than 5000 tons deadweight, smaller dimensions than above may be approved, provided that the ability to remove an injured person can be demonstrated to the satisfaction of the Surveyor.

1.3.11 Duct Keels or Pipe Tunnels in Double Bottom

Duct keels or pipe tunnels are not to pass into machinery spaces. Provision is to be made for at least two exits to the open deck, arranged at a maximum distance from each other. One of these exits may lead to the cargo pump room, provided that it is watertight and fitted with a watertight door complying with the requirements of Rules for Hull (Pt.1, Vol.II), Sec.11, A and in addition with the following:

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

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

For the requirements of ventilation and gas detection in duct keels or pipe tunnels, see Rules for Machinery Installations (Pt.1, Vol.III), Sec.15.

1.3.12 Ventilation

Holes are to be cut in every part of the structure where, otherwise, there might be a chance of gases being "pocketed". Special attention is to be paid to the effective ventilation of pump rooms and other working spaces adjacent to the oil tanks. In general, floor plating is to be of an open type not to restrict the flow of air. See Rules for Machinery Installations (Pt.1, Vol.III), Sec.15, B. Efficient means are to be provided for clearing the oil spaces of dangerous vapors by means of artificial ventilation or steam. For the venting of the cargo tanks, see Rules for Machinery Installations (Pt.1, Vol.III), Sec.15, B.

1.3.13 Pumping Arrangements

See applicable requirements in Rules for Machinery Installations (Pt.1, Vol.III), Sec.15.

1.3.14 Electrical Equipment

See Rules for Electrical Installations (Pt.1, Vol.IV), Sec.15.

1.3.15 Testing

Requirements for testing are contained in Rules for Classification and Surveys (Pt.1, Vol.I), Annex A.2, E.1.8. This Rules are to be applied as far as applicable.

1.3.16 Machinery Spaces

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

2. Hull Structure

2.1 Hull Girder Strength

2.1.1 Normal-strength Standard

The longitudinal hull girder strength is to be not less than required by the equations given in Rules for Hull (Pt.1, Vol.II), Sec.5, C.

2.1.2 Still-water Bending Moment Calculations

For still-water bending moment calculations, see Rules for Hull (Pt.1, Vol.II), Sec.5, A.3.

2.2 Shell Plating

2.2.1 Amidships

Shell plating within the midship 0,4**L** is to be of not less thickness than is required for longitudinal hull girder strength, or than that obtained from 2.2.1.1 through 2.2.1.3.

.1 Bottom Shell Thickness

The thickness t of the bottom shell plating is not to be less than obtained from 1) and 2).

1) $t = a\dfrac{L + 8{,}54}{42 \cdot L + 2318}$ [mm]

where

a = frame spacing [mm], but is not to be taken as less than:

= $\min\{864; (88\% \cdot (2{,}08 \cdot L + 438)\}$ [mm]

L = length of installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1

Where the bottom hull girder section modulus W_A is greater than required by Rules for Hull (Pt.1, Vol.II), Sec.5, C.1 and C.2, and still-water bending moment calculations are submitted, the thickness of bottom shell may be obtained from the above equation multiplied by the factor, R_b. Special consideration will be given to installations constructed of higher-strength steel.

$R_b = \sqrt{\dfrac{W_R}{W_A}}$ is not to be taken less than 0,85

where

W_R = hull girder section modulus required by Rules for Hull (Pt.1, Vol.II), Sec.5, C.1 and C.2 [cm^2-m]

W_A = bottom hull girder section modulus of installation [cm^2-m], with the greater of the bottom shell plating thickness obtained when applying R_n or R_b

2) $t = 0{,}006 \cdot a \cdot \sqrt{0{,}7 \cdot T + 0{,}02 \cdot (L - 50)} + 2{,}5$ [mm]

Where the bottom hull girder section modulus, W_A, is greater than required by Rules for Hull (Pt.1, Vol.II), Sec.5, C.1 and C.2, and still-water bending moment calculations are submitted, the thickness of bottom shell may be obtained from the above equation multiplied by the factor, R_n. Special consideration will be given to installations constructed of higher-strength steel.

$R_n = \sqrt{\dfrac{1}{\dfrac{\sigma_p}{\sigma_t} \cdot \left(1 - \dfrac{W_R}{W_A}\right) + 1}} \geq 0{,}85$

where

σ_p = nominal permissible bending stress [kN/cm^2]

= 17,5 [kN/cm^2]

σ_t = $K \cdot P_t \cdot \left(\dfrac{a}{t}\right)^2$ [kN/cm^2]

K = 0,34, for longitudinal framing

P_t = $(0{,}638 \cdot H + T) \cdot \alpha$ [kN/cm^2]

α = $1{,}005 \times 10^{-3}$

t = bottom shell plating thickness required by the equation in 2) above [mm]

H = wave parameter defined [m]:

= $(5{,}48 \cdot L^2 + 16\,045 \cdot L) \cdot 10^{-6} + 3{,}703$ [m]

W_R and W_A are as defined in 1) and **L**, **a** and **T** are as defined in 2.2.1.2.2).

$\frac{W_R}{W_A}$ is not to be taken as less than 0,70.

.2 Side Shell Thickness

The thickness t of the side shell plating is not to be less than obtained from 1) and 2).

1) $t = 0{,}01 \cdot L \left(6{,}5 + \frac{21}{H_c}\right)$ [mm]

2) $t = 0{,}052 \cdot a \sqrt{0{,}7 \cdot T + 0{,}02 \cdot L} + 2{,}5$ [mm]

where

L = length of installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1.

T = molded draft to the summer load line [m], as defined Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.9.

H_c = molded depth [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.8.

a = spacing of bottom longitudinals or spacing of side longitudinals or vertical side frames [m]

.3 Shell Thickness

Where a double bottom is fitted and is not to be used for the carriage of cargo oil, the bottom shell thickness may be in accordance with Rules for Hull (Pt.1, Vol.II), Sec.6.B, and if a double skin is provided and is not to be used for the carriage of cargo oil, the side shell thickness may be in accordance with Rules for Hull (Pt.1, Vol.II), Sec.6, C.

2.2.2 Sheer Strake

The thickness of the sheer strake is to be not less than the thickness of the side-shell plating, nor less than required by 2.3.1.2. The thickness is to be increased 25% in way of breaks of superstructures, but this increase need not exceed 6,5 mm. See 1.1.4.

2.2.3 Keel Plate

The thickness of the flat plate keel is to be not less than that required for the bottom shell plating at that location increased by 1,5 mm, except where the submitted docking plan (see Rules for Hull (Pt.1, Vol.II), Sec.8, E) specifies all docking blocks be arranged away from the keel.

2.2.4 Flat of Bottom Forward

Where the heavy weather ballast draft forward is less than 0,04**L**, the plating on the flat of bottom forward of $x/L \geq 0{,}5$ is to be not less than required in Rules for Hull (Pt.1, Vol.II), Sec.6, E.2. For this assessment, the heavy weather ballast draft forward is to be determined by using segregated ballast tanks only.

2.2.5 Plating Outside Midship 0,4 L

The bottom and side shell, including the sheer strake beyond the midship 0,4**L**, is generally to be in accordance with the requirements of Rules for Hull (Pt.1, Vol.II), Sec.6, B and C and is to be gradually reduced from the midship thickness to the end thickness.

2.2.6 Installations under 76 m

In installations under 76 m in length, the thickness of the bottom shell is to be obtained from Rules for Hull (Pt.1, Vol.II), Sec.6, B.1.1.

2.2.7 Bilge Keels

Bilge keels are to comply with Rules for Hull (Pt.1, Vol.II), Sec.6, F.2.

2.3 Deck Plating

2.3.1 Amidships

The strength deck within the midship 0,4 **L** is to be of not less thickness than is required to provide the deck area necessary for longitudinal strength in accordance with 2.1; nor is the thickness to be less than determined by the following equations for thickness of deck plating.

.1 $$t = 0{,}0016 \cdot a\sqrt{L - 53} + 0{,}32 \cdot \frac{L}{H_C} - 2{,}5 \quad \text{[mm]}$$

.2 $$t = \frac{a\,(30{,}48 + L)}{4981 + 40 \cdot L} \;;\; L < 150 \text{ m} \quad \text{[mm]}$$

where

t = plate thickness [mm]

a = spacing of deck longitudinals [mm]

L = length of installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1.

H_C = molded depth [m], as defined in Rules for Hull (Pt.1, Vol.II) Sec.1, H.2.8.

The thickness of the stringer plate is to be increased 25% in way of breaks of superstructures, but this increase need not exceed 6,5 mm. see 1.1.4. The required deck area is to be maintained throughout the midship 0,4**L** of the installation or beyond the end of a superstructure at or near the midship 0,4**L** point. From these locations to the ends of the installation, the deck area may be gradually reduced in accordance with:

- The deck sectional area at 0,15**L** from the ends may be one-half of the amidships deck area.
- In way of a superstructure beyond the amidship 0,4**L**, the strength deck area may be reduced to approximately 70% of the deck area required at that location if there were no superstructure.

Where bending moment envelope curve are used to determine hull girder section modulus, the foregoing requirements for strength deck area may be modified in accordance with Rules for Hull (Pt.1, Vol.II), Sec.3, H.2. Where so modified, the strength deck area is to be maintained a suitable distance from superstructure breaks and is to be extended into the superstructure to provide adequate structural continuity

2.3.2 Installations under 76 m

In installations under 76 m in length, the thickness of deck plating is to be obtained from Rules for Hull (Pt.1, Vol.II), Sec.7.

2.4 Bulkhead Plating

2.4.1 Plating Thickness

The plating is to be of not less thickness than is required for deep-tank bulkheads by Rules for Hull (Pt.1, Vol.II), Sec.12, where h is measured from the lower edge of the plate to the top of the hatch or to a point located 1,22 m above the deck at side amidships, whichever is greater. The upper strakes are to be increased above these requirements to provide a proper margin for corrosion. It is recommended that the top strake of a complete longitudinal bulkhead be not less than 9,5 mm in installations of 91,5 m length, and 12,5 mm in installations of 150 m length, and that the strake below the top strake be not less than 9,5 mm in installations of 122 m length and 10,5 mm in installations of 150 m in length, with intermediate thicknesses for intermediate lengths. See also 1.1.11.

2.5 Long or Wide Tanks

2.5.1 Oiltight Bulkheads

In installations fitted with long tanks, the scantlings of oiltight transverse bulkheads in smooth-sided tanks are to be specially considered when the spacing between tight bulkheads, nontight bulkheads or partial bulkhead exceeds 12 m in the case of corrugated-type construction, or 15 m in the case of flat-plate type of construction. Special consideration is to be given to the scantlings of longitudinal oiltight bulkheads forming the boundaries of wide tanks. Where the length of the smooth-sided tanks exceeds 0,1**L** or the breadth exceeds 0,6**B**, nontight bulkheads are to be fitted, unless calculations are submitted to prove that no resonance due to sloshing will occur in service.

Alternatively, reinforcements to the bulkheads and decks, without nontight bulkheads, may be determined by an acceptable method of engineering analysis.

2.5.2 Nontight Bulkheads

Nontight bulkheads are to be fitted in line with transverse webs, bulkheads or other structures with equivalent rigidity. They are to be suitably stiffened. Openings in the nontight bulkhead are to have generous radii and their aggregate area is not to exceed 33%, nor be less than 10% of the area of the nontight bulkhead. Plating is to be of not less thickness than that required by Table 4.30. Section moduli of stiffeners and webs may be one half of the requirements for watertight bulkheads in Rules for Hull (Pt.1, Vol.II), Sec.12, B.3. Alternatively, the opening ratio and scantlings may be determined by an acceptable method of engineering analysis.

2.6 Double Bottom Structure

2.6.1 General

Where a double bottom is fitted, it is generally to be arranged with a centerline girder, or equivalent, and, where necessary, with full depth side girders similar to Rules for Hull (Pt.1, Vol.II), Sec.8, B. The arrangements and scantlings of the double bottom structure as given in Rules for Hull (Pt. 1, Vol.II), Sec.8, B may be used, except where modified by this section. Increases in scantlings may be required where tanks other than double bottom tanks are designed to be empty with the installation in a loaded condition. Alternatively, consideration will be given to arrangements and scantlings determined by an acceptable method of engineering analysis, provided that the stresses are in compliance with 2.7. Where ducts forming

a part of the double bottom structure are used as a part of the piping system for transferring cargo oil or ballast, the structural integrity of the duct is to be safeguarded by suitable relief valves or other arrangement to limit the pressure in the system to the value for which it is designed.

2.6.2 Floors and Girders

In general, the thickness of floors and girders is to be as required by Rules for Hull (Pt.1, Vol.II), Sec.8, B, Where tanks adjacent to the double bottom are designed to be empty with the installation in a loaded condition, the floors and girders in the double bottom are to be specially considered. Where the heavy weather ballast draft forward is less than 0,04**L** the fore-end arrangement of floors and side girders is to comply with Rules for Hull (Pt.1, Vol.II), Sec.6, E.

2.6.3 Inner Bottom

The thickness of the inner-bottom plating is to be not less than required by Rules for Hull (Pt.1, Vol.II), Sec.8, B, with a head to 1,22 m above the deck at side amidships or to the top of the hatch, whichever is greater.

2.6.4 Inner-bottom Longitudinals

Scantlings for inner-bottom longitudinals are to be not less than required in 2.8.2, using c = 1,00. Where effective struts are fitted between inner-bottom and bottom longitudinals, the inner-bottom longitudinals are not to be less than required in 2.8.2, using c = 0,55, or 85% of the requirement in Rules for Hull (Pt.1, Vol.II), Sec.9, B for bottom longitudinals, whichever is greater.

2.6.5 Bottom Longitudinals

Scantlings for bottom longitudinals are to be not less than required by Rules for Hull (Pt.1, Vol.II), Sec.9, B. Where effective struts are fitted between bottom and inner-bottom longitudinals, the bottom longitudinals are to be not less than 90% of the inner-bottom longitudinal requirement in 2.8.2, using c = 0,55, or the requirement in Rules for Hull (Pt.1, Vol.II), Sec.9, B, whichever is greater.

Where the heavy weather ballast draft forward is less than 0,04**L**, the flat of bottom-forward longitudinals are to be not less than required by Rules for Hull (Pt.1, Vol.II), Sec.6, E and 9,B.

2.7 Deep Supporting Members

2.7.1 General

Webs, girders and transverses which support longitudinal frames, beams or bulkhead stiffeners, generally are to be in accordance with the following paragraphs. It is recommended that deep girders be arranged in line with webs and stringers to provide complete planes of stiffness. In installations without a longitudinal centerline bulkhead or effective centerline supporting member, a center vertical keel having sufficient strength to serve as one line of support is to be provided where centerline keel blocks are used in drydocking operations.

2.7.2 Section Modulus

Each member is to have a section modulus, W, [cm^3], not less than that obtained from the following equation:

$$W = \frac{M}{\sigma} \qquad [cm^3]$$

where

M = maximum bending moment along the member between the toes of the end brackets as computed by an acceptable method of engineering analysis [kN-cm]

σ = permissible maximum bending stress [N/cm^2], as determined from the following table.

Values of σ (Normal strength Steel)

	kN/cm^2
Transverse members	13,9
Longitudinal members	9,3
Note: *Local axial loads on webs, girders or transverses are to be accounted for by reducing the maximum permissible bending stress*	

In addition, the following equation is to be used in obtaining the required section modulus W.

$$W = 4{,}74 \cdot c \cdot h \cdot \mathbf{a} \cdot \ell_b^2 \qquad [cm^3]$$

c for bottom and deck transverses as shown in Fig. 4.52.

= 2,00 for bottom girders, vertical webs on transverse bulkheads, horizontal girders and stringers

= 2,50 for deck girders

c for side transverses and vertical webs on longitudinal bulkheads

= 1,50 without struts

= 0,85 with one horizontal strut

= 0,65 with two horizontal struts

= 0,55 with three horizontal struts

= Where a centerline longitudinal bulkhead is fitted, the value of c for side-shell transverses and vertical webs on longitudinal wing bulkheads will be subject to special consideration.

Where no struts or other effective supporting arrangements are provided for the wing-tank vertical transverses, the deck transverses in the wing tanks are to have section modulus values not less than 70% of that for the vertical side transverses. In no case are the deck transverses in the wing tank to have less than 70% of the section modulus for the corresponding members in the center tanks.

a = spacing of transverses, or width of area supported [m]

h = bottom transverses and girders of the depth of the installation, **H**, [m]. See also 1.1.11.

= side transverses and vertical webs on longitudinal bulkheads, vertical webs on transverse bulkheads and horizontal girders and stringers, the vertical distance, in m from the center of the area supported to a point located 1,22 m above the deck at side amidships in installations 61 m in length, and to a point located 2,44 m above the deck at side amidships in installations 122 m in length and above; for intermediate lengths, intermediate points may be used. The value of h is to be not less than the vertical distance from the center of the area supported to the tops of the hatches, [m]. See also 1.1.11.

= deck transverses and girders [m], is to be measured as indicated above for side transverses, etc., except that in no case is it to be less than 15% of the depth of installation.

ℓ_b = span of the member, [m], measured between the points of support as indicated in Fig. 4.52. Where effective brackets are fitted, the length ℓ_b is to be measured as indicated in Fig. 4.53a and Fig. 4.53b; nor is the length for deck and bottom transverses in wing tanks to be less than 0,125**B** or one-half the breadth of the wing tank, whichever is the greater. Where a centerline longitudinal bulkhead is also fitted, this minimum length will be specially considered.

2.7.3 Local Loading Conditions

In addition to withstanding the loads imposed by longitudinal hull girder shearing and bending action, the structure is to be capable of withstanding the following local loading conditions without exceeding the permissible bending and average shearing stresses stated in 2.7.2 and 2.7.4.

- Center tank loaded; wing tanks empty; $^1/_3$ summer load line draft
- Center tank empty; wing tanks loaded; $^1/_3$ summer load line draft
- Center and wing tanks loaded; $^1/_3$ summer load line draft

Note:

For loaded tanks, the head h is to be measured to a point located 2,44 m above the deck at side, except in the case of installations less than 122 m in length, as explained in 2.7.2. See also 1.1.11

In addition, where the arrangement of the installation involves tanks of relatively short length, or tanks designated as permanent ballast tanks, it is recommended that the following appropriate loading conditions also be investigated:

- Center tank loaded; wing tanks empty; summer load line draft
- Center tank empty; wing tank loaded; summer load line draft

In all cases, the structure is to be reviewed for other realistic loading conditions associated with the installation's intended service.

2.7.4 Web Portion of Members

The net sectional area of the web portion of the member, including effective brackets where applicable, is not to be less than that obtained from the following equation.

$$A = \frac{Q}{\tau} \quad [cm^2]$$

where

Q = shearing force at the point under consideration [kN]

τ = allowable average shearing stress in the web of the supporting member [N/cm^2], as determined from Table 4.29.

For longitudinal supporting members, the value of τ is to be 80% of the value shown in Table 4.29.

Where individual panels exceed the limits given in Table 4.29, detailed calculations are to be submitted in support of adequate strength against buckling.

The thickness of the web portions of the members is not to be less than given in Table 4.30 for minimum thickness. Reduced thickness may be considered for higher strength materials if the buckling and fatigue strength is proven adequate.

It is recommended that compliance with the foregoing requirement be accomplished through a detailed investigation of the magnitude and distribution of the imposed shearing forces by means of an acceptable method of engineering analysis. Where this is not practicable, the following equations may be used as Guidelines in approximating the shearing forces.

$$Q = c \cdot \mathbf{a} \cdot \mathbf{H} \left(K \cdot \ell_s - h_e \right)$$ for bottom transverses

$$Q = c \cdot \mathbf{a} \left[K_L \cdot \ell_s \cdot h - h_e \left(h + \frac{\ell_s}{2} - \frac{h_e}{2} \right) \right]$$ for lower side transverses or vertical transverses on longitudinal bulkheads

$$Q = c \cdot \mathbf{a} \left[K_U \cdot \ell_s \cdot h - h_e \left(h - \frac{\ell_s}{2} + \frac{h_e}{2} \right) \right]$$ for upper side transverses or vertical transverses on longitudinal bulkheads

where

c = 10,05

a = spacing of transverses [m]

H = depth of installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.7,

B = breadth of installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.6.

ℓ_s = span of transverse [m], as indicated in Fig. 4.54

h_e = effective length or height of bracket [m], as indicated in Fig. 4.54. In no case is h_e to be greater than $0,33 \cdot \ell_s$

h = vertical distance [m], as defined in 2.7.2, for the particular member in question. See also 1.1.11.

K = bottom members, K is as shown in Fig. 4.54 for the point under consideration

K_L = lower side transverses or vertical transverses on longitudinal bulkheads

= 0,65 without struts

= 0,55 with one strut

= 0,43 with two struts

= 0,38 with three or more struts

K_U = upper side transverses or vertical transverses on longitudinal bulkheads

= 0,35 without struts

= 0,25 with one strut

= 0,20 with two struts

= 0,17 with three or more struts

Where a centerline longitudinal bulkhead is fitted, the tabulated values of K_L and K_U will be specially considered.

The net sectional area of the lower side transverse, as required by the foregoing paragraphs, should be extended up to the lowest strut, or to $0,33\ \ell_s$, whichever point is the higher. The required sectional area of the upper side transverse may be extended over the upper $0,33\ \ell_s$ of the member.

2.7.5 Proportions

Webs, girders and transverses are to be not less in depth than required by the following, where the required depth of member is expressed as a percentage of the span.

12,5% for side and deck transverses, for webs and horizontal girders of longitudinal bulkheads, and for stringers.

20% for deck and bottom centerline girders, bottom transverses, and webs and horizontal girders of transverse bulkheads.

The depth of side transverses and vertical webs is to be measured at the middle of ℓ_b, as defined in 2.7.2, and the depth may be tapered from bottom to top by an amount not exceeding 8 mm per 100 mm. In no case are the depths of members to be less than three (3) times the depth of the slots for longitudinals. The thickness of webs is to be not less than required by 2.7.4, nor is it to be less than the minimum thickness given in Table 4.30.

2.7.6 Brackets

Brackets are generally to be of the same thickness as the member supported, are to be flanged at their edges and are to be suitably stiffened.

2.7.7 Stiffeners and Tripping Brackets

.1 Web Stiffeners

Stiffeners are to be fitted for the full depth of the deep supporting member at the following intervals, unless specially approved based on the structural stability of deep supporting members:

Location	Interval
Bottom	every longitudinal
Side	every second longitudinal
Bulkhead	every second stiffener
Deck	every third longitudinal

Special attention is to be given to the stiffening of web plate panels close to change in contour of web or where higher strength steel is used.

The moment of inertia, I, of the above stiffener, with the effective width of plating not exceeding **a** or $0,33 \cdot \ell$, whichever is less, is not to be less than the following equations:

$$I = 0.,9 \cdot \ell \cdot t^3 \left(\frac{\ell}{a}\right)^3 \quad [cm^4] \quad \text{for } \frac{\ell}{a} \leq 2,0$$

$$I = 0,38 \cdot \ell \cdot t^3 \left(\frac{\ell}{a}\right)^2 \quad [cm^4] \quad \text{for } \frac{\ell}{a} > 2,0$$

where

ℓ = length of stiffener between effective supports [cm]

t = required thickness of web plating [cm], but need not be greater than $\frac{a}{80}$

a = spacing of stiffeners [cm]

Web stiffeners are to be attached to the deep webs, longitudinals and stiffeners by continuous fillet welds.

Where depth/thickness ratio of the web plating exceeds 200, a stiffener is to be fitted parallel to the flange at approximately one-quarter depth of the web from the face plate. Special attention is to be given to providing for compressive loads.

.2 Tripping Bracket

Tripping brackets, arranged to support the flanges, are to be fitted at intervals of about 3 m, close to change of section, and in line with or as near as practicable to the flanges of struts.

2.7.8 Slots and Lightening Holes

Slots and lightening holes, where cut in webs, are to be kept well clear of other openings. The slots are to be neatly cut and well rounded. Lightening holes are to be located midway between the slots and at about one-third of the depth of the web from the shell, deck or bulkhead. Their diameters are not to exceed one-fourth the depth of the web. In general, lightening holes are not to be cut in those areas of webs, girders and transverses where the shear stresses are high. Similarly, slots for longitudinals are to be provided with filler plates or other reinforcement in these same areas. Where openings are required in high shear stress areas, they are to be effectively compensated. Continuous fillet welds are to be provided at the connection of the filler plates to the web and of the filler plate to the longitudinals.

2.7.9 Sruts

Where one or more struts are fitted as an effective supporting system for the wing-tank members, they are to be spaced so as to divide the supported members into spans of approximately equal length. The value of W for struts is obtained from the following equation:

$$W = 10,5 \cdot b \cdot h \cdot a \qquad [kN]$$

where

b = mean breadth [m], of the area supported

h = vertical distance [m], from the center of the area supported to a point located 1,22 m above the deck at side amidships in installations 61 m in length and to a point located 2,44 m above the deck at side amidships in installations 122 m in length and above; for intermediate lengths, intermediate points may be used. The value of h is not to be less than the vertical distance [m], from the center of the area supported to the tops of the hatches.

The permissible load of struts, W_a, is to be determined by the following equation and is to be equal to or greater than the calculated W as determined above.

$$W_a = \left(k - n\frac{\ell}{r}\right) A \qquad [kN]$$

where

k = 12,09 normal strength steel

= 16,11 HT32

= 18,12 HT36

ℓ = unsupported span of the strut [cm]

r = least radius of gyration [cm]

A = cross sectional area of the strut [cm]

n = 0,0444 ordinary strength steel

= 0,0747 HT32

= 0,0900 HT36

Special attention is to be paid to the end connections for tension members, as well as to the stiffening arrangements at their ends, to provide effective means for transmission of the compressive forces into the webs. In addition, horizontal stiffeners are to be located in line with and attached to the first longitudinal above and below the ends of the struts.

2.8 Frames, Beams and Bulkhead Stiffeners

2.8.1 Arrangement

The sizes of the longitudinals or stiffeners as given in this paragraph are based on the transverses or webs being regularly spaced. Longitudinals or horizontal stiffeners are to be continuous or attached at their ends to effectively develop their sectional area. This requirement may be modified in the case of stiffeners on transverse bulkheads. Longitudinals and stiffeners are to be attached to the transverses or webs to effectively transmit the loads onto these members. Consideration is to be given to the effective support of the plating in compression when selecting the size and spacing of longitudinals.

2.8.2 Structural Sections

.1 Section Modulus

Each structural section for longitudinal frames, beams or bulkhead stiffeners, in association with the plating to which it is attached, is to have a section modulus W not less than obtained from the following equation:

$$W = 7{,}8 \cdot c \cdot h \cdot \mathbf{a} \cdot \ell^2 \quad [cm^3]$$

where

c = 1,40 for bottom longitudinals

= 0,95 for side longitudinals

= 1,25 for deck longitudinals

= 1,00 for vertical frames

= 1,00 for horizontal or vertical stiffeners on transverse bulkheads and vertical stiffeners on longitudinal bulkheads

= 0,90 for horizontal stiffeners on longitudinal bulkheads.

h = distance [m], from the longitudinals, or from the middle of ℓ for vertical stiffeners, to a point located 1,22 m above the deck at side amidships in installations of 61 m length, and to a point located 2,44 m above the deck at side amidships in installations of 122 m length and above; at intermediate lengths, h is to be measured to intermediate heights above the side of the installation. The value of h for bulkhead stiffeners and deck longitudinals is not to be less than the distance, [m], from the longitudinal, or stiffener to the top of the hatch. See also 1.1.11.

a = spacing of longitudinals or stiffeners [m]

ℓ = length between supporting points [m]

The section modulus W of the bottom longitudinals may be obtained from the above equation multiplied by R_1 where,

a) The bottom hull girder section modulus, W_A, is greater than required by Rules for Hull (Pt.1, Vol.II), Sec.5, C.1 and C.2, at least throughout 0,4**L** amidships,

b) Still-water bending moment calculations are submitted, and

c) Adequate buckling strength is maintained.

The bottom longitudinals with this modified section modulus are to meet all other Rule requirements.

$$R_1 = \frac{7{,}69}{\left[7{,}69 + \sigma_p \left(1 - \frac{W_R}{W_A}\right)\right]} \qquad \text{but is not to be taken less than 0,69}$$

where

σ_p = nominal permissible bending stress, as given in Rules for Hull (Pt.1, Vol.II), Sec.5, C.1

W_R = hull girder section modulus required by Rules for Hull (Pt.1, Vol.II), Sec.5, C.1 and C.2, [cm^2-m]

W_A = bottom hull girder section modulus, [cm-m], with the longitudinals modified as permitted above.

Where the heavy weather ballast draft forward is less than 0,04**L**, the flat of bottom forward longitudinals are not to be less than required by Rules for Hull (Pt.1, Vol.II), Sec.6, E and 9.B

.2 Web Thickness

In addition to the requirements in Rules for Hull (Pt.1, Vol.II), Sec.3, F.2.3, the thickness of web portion is to be not less than the thickness given in Table 4.30, reduced by 1,0 mm.

2.8.3 Bilge Longitudinals

Longitudinals around the bilge are to be graded in size from that required for the lowest side longitudinals to that required for the bottom longitudinals.

2.8.4 Installations under 76 m

In installations under 76 m in length, the coefficient c for use in the above equation for bottom longitudinals may be reduced to 1,30.

2.9 Structure at Ends

Beyond the cargo spaces, the scantlings of the structure may be as required in way of the oil spaces or dry spaces. The deck beams, longitudinal and transverse are to be as required in Rules for Hull (Pt.1, Vol.II), Sec.10.

The transition from longitudinal framing to transverse framing is to be effected in as gradual a manner as possible, and it is recommended that a system of closely spaced transverse floors be adopted in way of the main machinery.

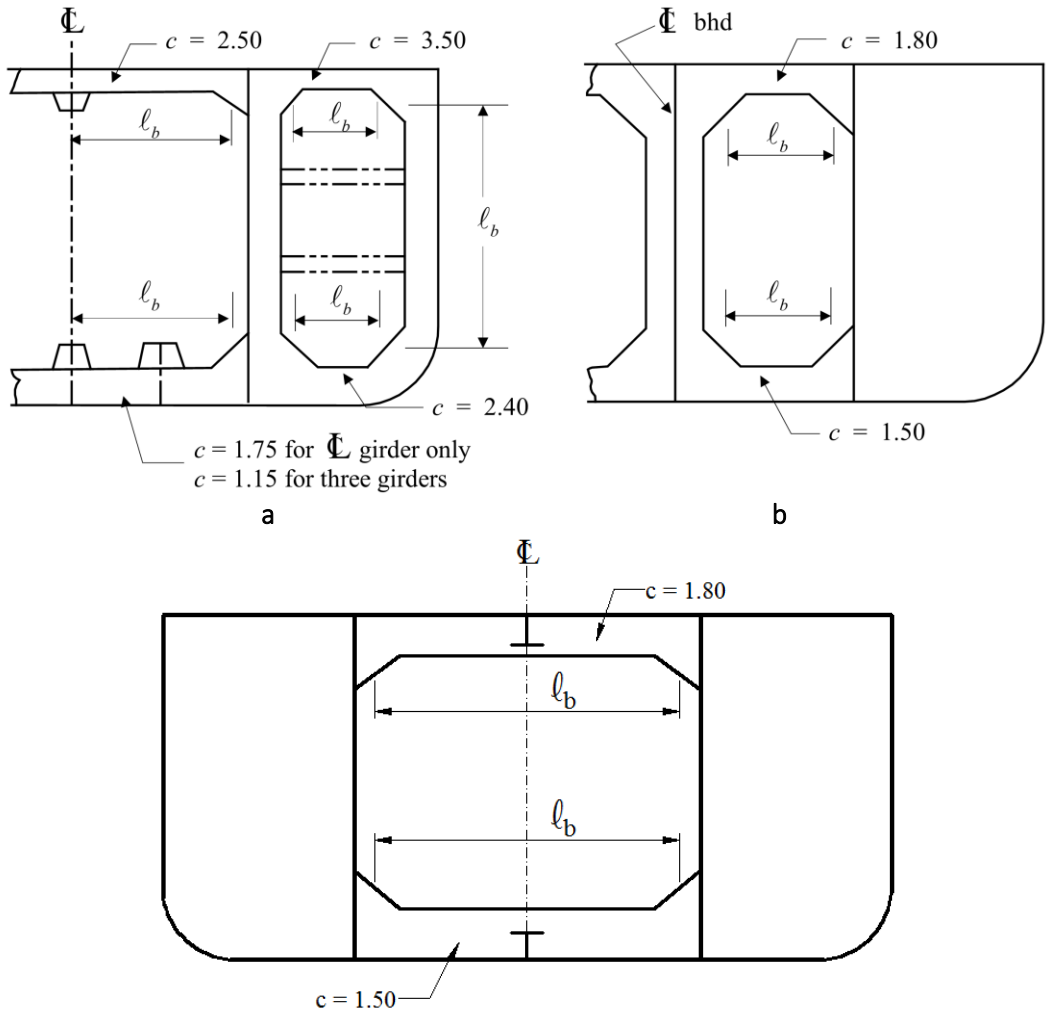


Fig. 4.52 Coefficients and Lengths for Transverses

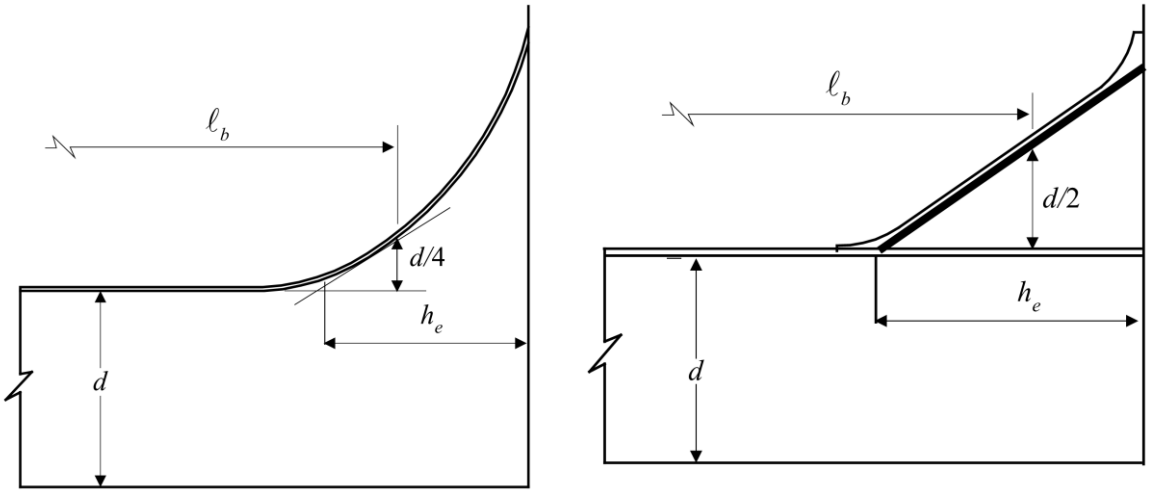


Fig. 4.53 Lengths with Brackets

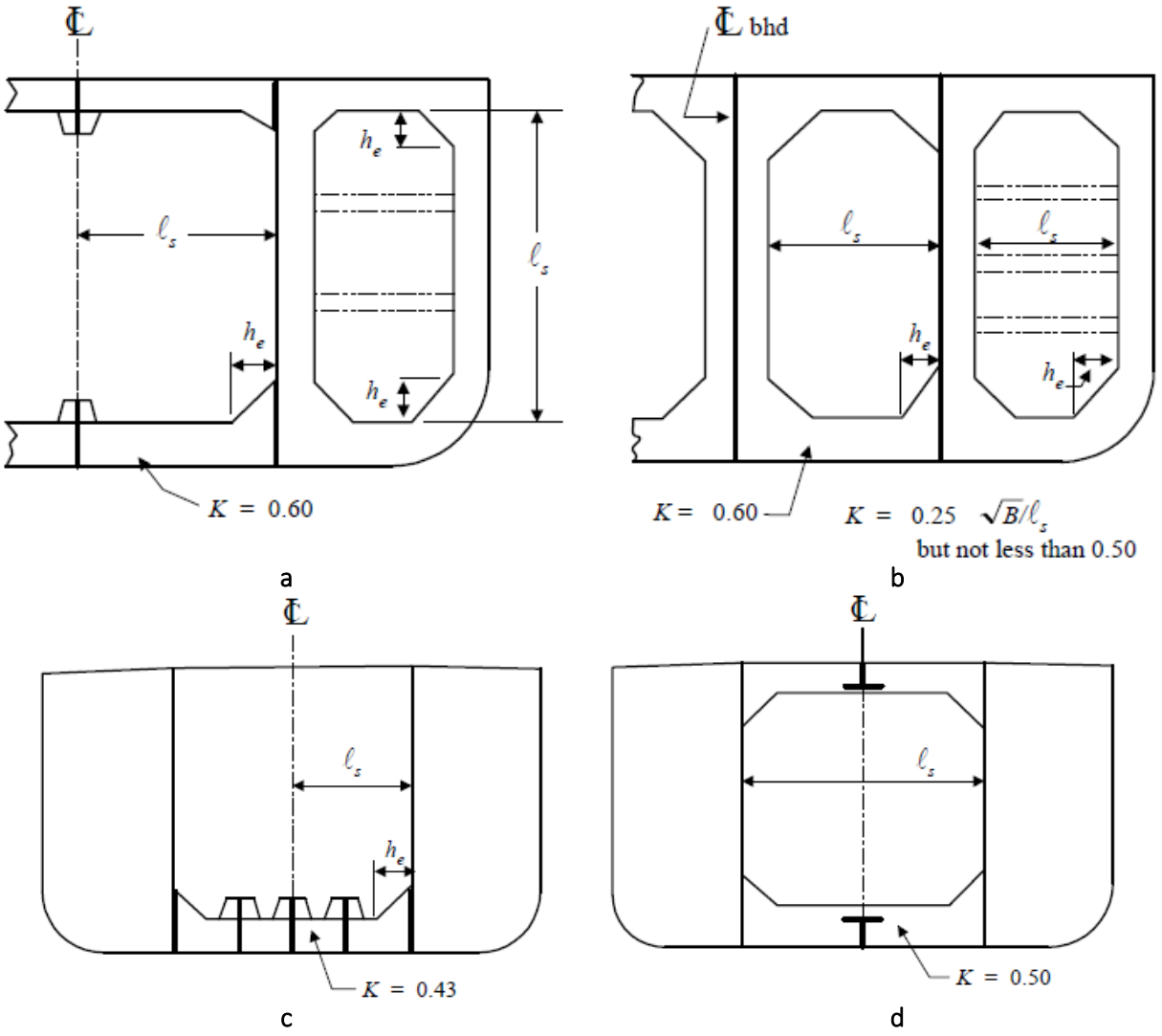


Fig. 4. 54 Spans of Members and Effective Lengths or Heights of Brackets

Table 4.29 - Values of q for Ordinary Strength Steel

a/t	kN/cm²
80 and less	8,5
160 maximum	5,4
a = *spacing of stiffeners or depth of web plate [mm], whichever is the lesser* *t* = *thickness of web plate [mm]*	

Table 4.30 - Minimum Thickness for Web Portions of Members

L meters	t mm
61	8,5
82	9
118	10
150	11
L *is the length of the installation [m], as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1. For installations of lengths intermediate to those shown in the table, the thickness is to be obtained by interpolation.*	

3. Cargo Oil and Associated Systems

See Rules for Hull (Pt.1, Vol.II), Sec.24, Rules for Machinery Installations (Pt.1, Vol.III), Sec.15 and Rules for Electrical Installations (Pt.1, Vol.IV), Sec.15.

Section 5 Other Installation Types

A. Column-Stabilized Installations 5–1
B. Tension Leg Platforms 5–18
C. Spar Installations 5–41

A. Column-Stabilized Installations

1. General Requirements

1.1. General Requirements

The design and construction of column-stabilized type installations are to be based on the applicable requirements of the Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.5, B. However, the design criteria, as given in the Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.5, B, can be modified to reflect the different structural performance and demands expected of a mobile installation, compared to an installation positioned at a particular site on a long-term basis. In addition, the applicable criteria contained in the Load Line, SOLAS and MARPOL Conventions issued by the International Maritime Organization are to be considered. It is further suggested that the local authorities having jurisdiction where the installation is to operate be contacted to obtain any further criteria that are applicable to the Floating Installation.

1.2. Definitions

A column stabilized floating production installation consists of hull, topside deck and position mooring system. The hull may consist of pontoons, columns and bracing members. The tops of the columns are connected to a column top frame or a topside deck forming the global strength of the hull. For the hull with a column top frame, the topside deck is not integrated as part of the global strength of the hull. The topside deck is noted as "Non-integrated Deck" in these Guidelines. The topside deck integrated with the hull to form the global strength of the hull is noted as "Integrated Deck" in these Guidelines.

The installation depends upon the buoyancy of columns or caissons for flotation and stability. Lower hulls or footings are normally provided at the bottom of the columns for additional buoyancy and the most common arrangements are either twin pontoons connected by braces or a ring (continuous) pontoon. The topside deck structure can be of an enclosed hull type or an open space truss frame construction. The topside deck structure is interconnected with the stability columns of the hull to form the installation's overall strength.

1.3 Loading Criteria

1.3.1 Loads

An installation's modes of operation in pre-service (loadout, transportation, installation) and in-service (in-place) conditions should be investigated using anticipated loads, including gravity loads together with relevant environmental loads due to the effects of wind, waves, currents, and, where deemed necessary by the Owner or designer, the effects of earthquake, temperature, fouling, ice, etc.

These loads are to include, as applicable, but should not be limited to, the following loads:

1) *Environmental loads*. Loads due to wind, waves, and current are to be considered. Directionality of wind, waves, and current may be considered if accurate data is available. Where there is no accurate data available, the directionality of wind, waves, and current that generates the most severe local

and global load effects are to be used for design. Adequate headings for the environment are to be analyzed such that the most critical heading for the environment has been covered.

2) *Hydrostatic pressures and buoyancy*. Hydrostatic pressures and buoyancy are to be considered for all submerged structural members.

3) *Gravity*. Gravity of the structure and equipment steel and the variables in the topside deck structure and hull are to be considered.

4) *Inertia loads*. Inertia loads due to motions of the column-stabilized installation are to be considered.

5) *Operational loads*. Loads induced by operations of drilling and production are to be considered.

6) *Mooring and riser loads*. Loads due to mooring and riser systems are to be considered.

7) *Marine operation loads*. Loads encountered during transportation and installation are to be taken into account in the design. These loads include loads exposed during transport (wet or dry), launch, or float-off.

8) *Slamming*. Wave slamming loads are to be considered for members such as pontoons, columns, braces, and members forming the underside of the topside deck structure that are subject to wave slamming during transportation and operation. Breaking wave slamming loads are also to be considered, if applicable.

Combinations of these loads that produce the most severe local and global effects on the installation, as determined by the operational and installation requirements of the in-service and pre-service conditions, should be used.The global effects that are critical to the installations global strength are given in 2.3.1.2 1).

A loading plan is to be prepared to show the maximum uniform and concentrated loadings to be considered for the decks of the topside deck structure for each mode of operation. In the preparation of this plan, the following loadings are to be considered as minimums.

– Crew spaces (walkways, general traffic area, etc.)

  4510 N/m^2 or 0,64 m head

– Work areas

  9020 N/m^2 or 1,28 m head

– Storage areas

  13000 N/m^2 or 1,84 m head.

1.3.2 Environmental Conditions

A column-stabilized installation is to be designed to withstand a specified extreme storm in the Design Environmental Condition and operate in the Design Operating Condition. The environmental conditions required are defined in Section 6, B.1.1.2 and Section 6, B.1.1.3 and the environmental criteria required for these design conditions are defined in Section 2, B.4. Additionally, the column-stabilized installation is to be designed for all operations in pre-service conditions such as loadout, transportation, and installation. The environmental conditions for loadout and installation are to be specified by the designers or Owners. The environmental condition for transportation is to be of a 10-year return event of the selected transit route, unless a weather routing plan is to be implemented for the voyage.

In the design of the column-stabilized installation in-service and pre-service strength, the following environmental conditions are to be considered:

– **Design Environmental Conditions (DEC)**. Please refer to Section 6, B.1.1.2. For structural strength design, environmental conditions that produce responses having a minimum return period of 100 years are to be used.

- **Design Operating Conditions (DOC).** Please refer to Section 6, B.1.1.3. For structural design, environmental conditions that produce responses having a minimum return period of 1 year are to be used.
- **Calm Conditions**. Environmental conditions such that the effects of wind, waves and current are insignificant and can be ignored. Where such a situation exists, the design case is permitted to use calm conditions.

1.4 Global Performance Analyses

1.4.1 General

Global performance analyses of a column-stabilized installation are aimed at determining the global effects of environmental loads on the overall installation and its components, such as mooring lines, risers, etc. The key function of the analyses is to establish that the column-stabilized installation meets all of the pre-service and in-service requirements. It is suggested that global response analysis be performed for each of the most critical design phases. The following aspects are to be included in the global performance analyses:

1) Installation motions in six degrees of freedom
2) Mooring line tensions, including the maximum and minimum tensions and mooring line fatigue loads for mooring component design
3) Equivalent design wave heights and periods for the global structural analysis
4) Hull hydrodynamic pressure loads for global structural analysis
5) Installation accelerations for the determination of inertia loads
6) Deck clearance - please refer to 1.4.4.

Global analyses with various loading conditions are required because complex motion characteristics of the column-stabilized installation will have different impacts on different structural components. Therefore, the topside deck structure, hull, moorings and risers are to be included in these analyses. Several analytical methods with varying degrees of complexity may be used to achieve this goal. Loading and response predictions for the topside deck structure and hull, and those for the moorings and risers can be performed either separately or in an integrated form. Methods and models employed in the analyses are to account for the relevant nonlinear and motion coupling effects. Due to numerical efficiency and limitations of each method, frequency domain analyses are usually performed for all of the load cases. For those cases that are determined to be critical to the column-stabilized installation global performance or to have highly nonlinear effects, a time-domain analysis should be performed. For the detailed discussion of various available global analysis methods of column-stabilized installations, refer to API RP 2SK.

1.4.2 Frequency Domain Analyses

Frequency domain analyses include those in six degrees of freedom of the column-stabilized installation in both the wave frequency and the low frequency domains.

In order to evaluate the first-order installation and mooring responses, linear wave theory is usually employed in the wave frequency analysis. However, an alternative method may be applied to evaluate the effects of finite amplitude waves. The low frequency analysis is also to be carried out to evaluate the effects caused by wind dynamics and wave drift forces. The damping levels used in the analyses are to be properly determined and documented.

1.4.3 Time Domain Analyses

Time domain analysis is a preferable approach to include the nonlinear effects in global response analyses of the column-stabilized installation. These nonlinear effects include hull drag forces, finite wave amplitude

effects, nonlinear restoring forces from moorings and risers, and coupling effects of hull, moorings, and risers in deep waters. In time domain analysis, a relevant wave spectrum is to be transferred to random time series for simulating irregular wave elevations and kinematics.

For deep water applications, a time domain analysis of fully coupled motions of installation, moorings, and risers may be required for the load cases that are shown to govern the column-stabilized installation's global performance. When strong nonlinear responses are expected, a time domain mooring analysis is to be performed and submitted for review. In an area with a strong current extending deep into the ocean, possible VIV effects are to be assessed and documented.

1.4.4 Deck Clearance or Air Gap

Unless topside deck structures are satisfactorily designed for wave impact, reasonable clearance between the bottom of the topside deck structures and the wave crests is to be ensured for all afloat modes of operation, taking into account the predicted motion of the installation relative to the surface of the sea.

A clearance is to be maintained between the lowest point of the topside deck and the wave crest. The deck clearance is normally determined by an appropriate model test. Alternatively, the deck clearance can also be determined by a detailed hydrodynamic analysis that accounts for relative motions between the column- stabilized installation and waves. The following items are to be considered to determine the deck clearance:

1) Various environmental headings
2) All motions due to wind, waves, and current
3) Nonlinearity of wave profile
4) Wave diffraction and run-up
5) Tide and water level effects

Deck clearance is also to be checked at various points on the underside of the topside deck for all of the critical environmental conditions.

The deck clearance or air gap analysis establishes the elevation of topside deck structure in still water condition so that the bottom of topside deck structure is not subjected to wave impact in Design Environmental Conditions (DEC), unless the topside deck structure bottom is designed for such loading.

Where topside deck structural members are designed for passage of waves or if wave impact on the underside of the topside deck structure is anticipated, local strengthening of these members is required. Structures and equipment subject to wave run-up or green water are to be designed for the associated forces.

Guidance on air gap and horizontal wave impact analysis is provided in Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.5, B.2.6

Where the negative air gap near peripheral sides of the upper structure is identified, windows are not to be installed within the horizontal wave impact zone measured up to the elevation of 1,3 times of the relative maximum wave elevation. However, side scuttles provided with hinged inside deadlights may be installed in this zone. Deadlights are to be capable of being closed and secured watertight to resist the horizontal wave impact pressure at the position where the side scuttle is installed.

1.4.5 Model Testing

Model testing for deriving some of the design parameters, such as deck clearance and nonlinear effects, is recommended as the final check of column-stabilized installation designs if innovative components emerge

in the design. Relevant environmental conditions are to be covered in the model testing. The primary objectives of model tests are listed below:

1) To determine the responses of a particular design, such as to calibrate low-frequency damping coefficients.
2) To verify analysis tools for prediction of system responses or simply to correlate the analysis results.
3) To derive design information as a substitute for numerical analysis.

2. Structures

2.1 Structural Design

The structural design criteria specified in this Section is presented in the Working Stress Design (WSD) format, also known as the Allowable Stress (or Strength) Design (ASD) format. For alternative structural design criteria, see Rules for Structure (Pt.5, Vol.II), Sec.3, B.1.

The design of the installation is to be based on the applicable portions of the Rules for Mobile Offshore Units (Pt.5, Vol.VI). Where the conditions at the installation site are less than those for a mobile installation that are the bases of the Rules for Mobile Offshore Units (Pt.5, Vol.VI), the design criteria for various components of the installation structure may be reduced to reflect these differences. However, when the installation site conditions produce more arduous demands, it is mandatory that the design criteria be increased appropriately.

2.1.1 Scantlings

Installation's scantlings, including topside deck structure, columns, braces, and pontoons are to be designed in accordance with 2.2.

2.1.2 Deckhouses

Deckhouses such as living quarters, utility buildings, etc., which are not an integral part of the upper deck structure are to have sufficient strength for their size, function, and location, with due consideration given to the environmental conditions to which the installation may be exposed. Special considerations should be given to deckhouses which act as foundations for vital machinery or equipment.

2.1.3 Helicopter Deck

The design of the helicopter deck is to comply with the requirements of Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.4, E.

2.1.4 Protection of Openings in Decks and Columns

All openings in decks or column tops, hatch covers and companionway sills are to comply with Section 4, D.1.2. Portlights or other similar openings are not to be fitted in columns.

2.1.5 Guards and Rails

Guards and rails are to comply with the requirements of Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.3, H.

2.2 Scantling Design of the Hull Structure

The initial scantling design of the hull is to be based on the applicable portions of the Rules for Mobile Offshore Units (Pt.5, Vol.VI) and Rules for Hull (Pt.1, Vol.II). The aspects that are not covered by these Rules

are to be based on the recognized codes and standards. For curved shells, the minimum scantlings of shell plating and ring girders are to be determined on the basis of established shell analysis methods, using the heads given in 2.2.1 and safety factors appropriate to the method employed. As a minimum, a detailed local analysis is to be performed, with failure modes meeting the criteria in 2.3.1.6.

2.2.1 Hull - Pontoons, Columns, and Braces

Pontoons, columns, and braces may be considered either as framed or unframed shells. Ring girders, bulkheads, or other suitable diaphragms are to be adequate to maintain shape and stiffness under all anticipated loadings in association with established analysis methods.

.1 Scantlings of Framed Shells

Where the components of braces, columns, or pontoons incorporate stiffened plating, the minimum scantlings of plating, stiffeners, girders, etc., for shells and interior boundary bulkheads and flats may be determined in accordance with the requirements for tanks, as given in 2.2.3 in association with the following.

1) **Tank Space**. Where the internal space is a tank, the head, h, is to be taken to a point located at two-thirds of the distance from the top of the tank to the top of the overflow, or to a point 0,91 m above the top of the tank, whichever is greater. For tanks intended to carry contents with a specific gravity in excess of 1,05, the head is to be suitably increased by a factor equal to the ratio of the specific gravity to 1,0.
2) **Void Compartment Spaces**. Where the internal space is a void compartment, the head is to be taken to the maximum permissible draft of the installation in service.
3) **Areas Subject to Wave Immersion**. For all areas subject to wave immersion, the minimum head is to be 6,1 m.
4) **Minimum Scantlings**. In general, the scantlings of boundaries are not to be less than those required by 2.2.2, in association with a head to the maximum damaged waterline.

.2 Scantlings of Unframed Shells

Where braces, columns, or pontoons do not incorporate framing members, the minimum scantlings of shell plating and ring girders are to be determined on the basis of established shell analysis methods using the heads given in .1 and safety factors appropriate to the methods employed. Interior boundary bulkheads and flats are to be considered on the basis of framed shells, as given in .1.

.3 Additional Structural Requirements for Scantlings

Scantlings of braces, columns, and pontoons as determined above are minimum requirements for hydrostatic loads. Where wave and current loadings are superimposed, the scantlings of the local structure of the shell are to be increased as necessary, to meet the strength requirements of 2.3.1.6.

2.2.2 Watertight Boundary Formula

.1 Plating

The plating thickness of watertight boundaries is not to be less than that obtained from the following equation:

$$t = \mathbf{a} \cdot c_k \frac{\sqrt{k \cdot h}}{290} + 1{,}5 \quad [\text{mm}]$$

but not less than 6 mm or $\frac{\mathbf{a}}{200} + 2{,}5$ [mm], whichever is greater.

where

t = thickness [mm]

a = spacing of stiffeners [mm]

c_k = $\dfrac{3{,}075 \cdot \sqrt{\alpha} - 2{,}077}{\alpha + 0{,}272}$ for $1 \le \alpha \le 2$

= 1,0 for $\alpha > 2$

α = aspect ratio of the panel (longer edge/shorter edge)

k = $\dfrac{235}{R_{eH}}$

R_{eH} = specified minimum yield point or yield strength [N/mm^2]

h = distance [m], from the lower edge of the plating to a point defined in 2.2.1

.2 Stiffeners and Beams

The section modulus, W, of each bulkhead stiffener or beam on a watertight flat, in association with the plating to which it is attached, is not to be less than that obtained from the following equation:

$$W = 7{,}8 \cdot k_s \cdot f \cdot c \cdot h \cdot \mathbf{a} \cdot \ell^2 \quad [cm^3]$$

where

k_s = $\dfrac{489{,}55}{R_{eH} + 2 \cdot \dfrac{U}{3}}$

c = 0,56 for stiffeners with ends attached

= 0,60 for stiffeners with no end attachment

h = distance [m], from the middle of ℓ to a point defined in 2.2.1

a = spacing of stiffeners [m]

ℓ = length of stiffeners [m], where brackets are fitted with a slope of approximately 45 degrees and thickness given in Table 5.1, the length of ℓ may be measured to a point on the bracket equal to 25% of the length of the bracket.

R_{eH} = specified minimum yield strength [N/mm^2]

U = specified minimum tensile strength of the higher-strength material [N/mm^2]

.3 Girders and Webs

The section modulus, W, of each girder or web is not to be less than that obtained from the following equation:

$$W = 4{,}7 \cdot k_s \cdot h \cdot \mathbf{a} \cdot \ell^2 \quad [cm^3]$$

where

h = distances [m], from the middle of the area supported to a point defined in 2.2.1

a = sum of half lengths [m], (on each side of girder or web), of the stiffeners or beams supported

ℓ = length [m], between supports, where brackets are fitted at shell, deck or bulkhead supports, and the brackets are in accordance with Table 5.1 and have a slope of approximately 45 degrees, the length ℓ may be measured to a point on the bracket located at the distance from the toe equal to 25% of the length of the bracket.

k_s = factor defined in 2.2.2.2

Table 5.1 Thickness and Flange Width of Brackets and Knees

The thickness of brackets is to be increased in cases where the depth at throat is less than two-thirds of the knee.

Depth of Longer Arm [mm]	Thickness [mm]		Flange Width [mm]
	Plain	Flanged	
150	6,5		
175	7,0		
200	7,0	6,5	30
225	7,5	6,5	30
250	8,0	6,5	30
275	8,0	7,0	35
300	8,5	7,0	35
325	9,0	7,0	40
350	9,0	7,5	40
375	9,5	7,5	45
400	10,0	7,5	45
425	10,0	8,0	45
450	10,5	8,0	50
475	11,0	8,0	50
500	11,0	8,5	55
525	11,5	8,5	55
550	12,0	8,5	55
600	12,5	9,0	60
650	13,0	9,5	65
700	14,0	9,5	70
750	14,5	10,0	75
800		10,5	80
850		10,5	85
900		11,0	90
950		11,5	90
1000		11,5	95
1050		12,0	100
1100		12,5	105
1150		12,5	110
1200		13,0	110

2.2.3 Tank Boundary Formula

.1 Plating

Plating is to be the thickness derived from the following equation:

$$t = \mathbf{a} \cdot c_k \frac{\sqrt{k \cdot h}}{254} + 2{,}5 \quad [mm]$$

but not less than 6.5 mm or $\frac{\mathbf{a}}{150} + 2{,}5$ mm, whichever is greater.

where

t = thickness [mm]

a = spacing of stiffeners [mm]

c_k = $\frac{3{,}075 \cdot \sqrt{\alpha} - 2{,}077}{\alpha + 0{,}272}$ for $1 \le \alpha \le 2$

= 1,0 for $\alpha > 2$

α = aspect ratio of the panel (longer edge/shorter edge)

k = $\frac{235}{R_{eH}}$

R_{eH} = specified minimum yield point or yield strength [N/mm^2]

h = distance [m], from the lower edge of the plating to a point defined in 2.2.1

When the specific gravity of the liquid contents of a tank is greater than 1,05, the head, h, specified above is to be increased by a factor equal to the ratio of the specific gravity to 1,0.

.2 Stiffeners and Beams

The section modulus, W, of each bulkhead stiffener or beam on a flat, in association with the plating to which it is attached, is not to be less than that obtained from the following equation:

$$W = 7{,}8 \cdot k_s \cdot c \cdot h \cdot \mathbf{a} \cdot \ell^2 \quad [cm^3]$$

where

c = 0,9 for stiffeners having clip attachments to decks or flats at the ends or having such attachments at one end with the other end supported by girders

= 1,0 for stiffeners supported at both ends by girders

h = distance [m], from the middle of ℓ to a point defined in 2.2.1

a = spacing of stiffeners [m]

ℓ = length [m], between supports; where brackets are fitted at shell, deck or bulkhead supports, and the brackets are in accordance with Table 5.1 and have a slope of approximately 45 degrees, the length, ℓ, may be measured to a point on the bracket located at a distance from the toe equal to 25% of the length of the bracket.

k_s = factor defined in 2.2.2.2

.3 Girders and Webs

The section modulus, W, of each girder or web is not to be less than that obtained from the following equation:

$$W = 7{,}05 \cdot k_s \cdot h \cdot \mathbf{a} \cdot \ell^2 \quad [cm^3]$$

where

h = distances [m], from the middle of the area supported to a point defined in 2.2.1

a = sum of half lengths [m] (on each side of girder or web), of the stiffeners or beams supported

ℓ = length [m], between supports, where brackets are fitted at shell, deck or bulkhead supports, and the brackets are in accordance with Table 5.1 and have a slope of approximately 45 degrees, the length, ℓ, may be measured to a point on the bracket located at the distance from the toe equal to 25% of the length of the bracket.

k_s = factor defined in 2.2.2.2

2.3 Engineering Analysis of the Installation's Primary Structure

2.3.1 Hull, Integrated Deck and Top Column Frame

.1 General

Documents necessary to verify the structural strength of the installation, including yielding, buckling, and fatigue of the hull, integrated deck, top column frame and main intersections of primary structural components of the hull, integrated deck, top column frame are to be submitted for review. The criteria in this Subsection relate to the analyses required to verify the scantlings selected in the basic design in 2.2. The results of analysis that are required in this Subsection cannot be used to reduce the scantlings established from 2.2. Depending on the specific features of the offshore installations, additional analyses to verify and help design other portions of the installation structural components will be required. Such additional analyses include those for the topside deck structural components supporting deck-mounted equipment/machinery and the installation structure interface with the position mooring and riser systems. Analysis criteria for interface structures are given in 2.4.

.2 Global Strength Analysis

The primary structural components of the hull, integrated deck, top column frame are to be analyzed using the loading and environmental conditions stipulated below. Conditions representative of all modes of operation are to be considered to determine critical cases. Calculations for critical conditions are to be submitted for review. The analyses are to be performed using recognized calculation methods and fully documented and referenced.

Design conditions are to be developed in accordance with Section 2, B.3, "Design Conditions" and Section 2, B.4, "Environmental Conditions". Table 5.2 below shows the required environmental events and safety factors to be considered for each design condition in the global strength analysis:

Table 5.2 - Required Environmental Events and Safety Factors

Design Conditions	Environmental Events	Safety Factors
Loadout	Calm or specified by designer or Owner	1,67
Ocean Transit (Dry Tow)	10 year return storm for the selected route condition or specified by designer or Owner if weather routing plan is to be implemented for the voyage	1,25
Field Transit (Wet Tow)	1 year return storm for the selected route condition or specified by designer or Owner	1,25
In-place Design Operating	1 year return storm (minimum)	1,67
In-place Design Environmental	100 year return storm	1,25
In-place Damaged	1-year return storm	1,25

1) Critical Responses for Global Strength.

The global strength of the installation is to be designed for withstanding the maximum global effects (noted in this Guidelines as "critical responses") induced by the loads specified in 1.3.1. The critical responses that control the installation strength design are prying/squeezing loads, deck inertia loads, torsional moments, and longitudinal shear forces between pontoons. The critical responses that control the integrated deck and top column frame strength design are the deck inertia loads. As indicated in Table 5.2, the in-place intact strength is to be designed for these critical responses with a return period of 100 years in the Design Environmental Condition (DEC).

The highest wave may not always produce the most critical responses. So that the most critical responses are captured, a sufficient number of design cases are to be used, considering the following permutations:

A) Variation in environmental conditions and headings

B) Variation in variables (deck payloads)

C) Variation in ballasting distributions

D) Variation in riser arrangements

.3 Major Joint Analysis - Analysis for Main Intersections of Primary Structures

Since it is difficult to adequately capture the details of the main intersections in the global strength model, local FEM analyses are to be used, as required, to design these areas. These main intersections include connections of pontoon to pontoon, column to pontoon, and column to topside deck structure. For twin-pontoon column stabilized installations, special attention should be given to brace connections to braces, columns, pontoons, and topside deck structure.

.4 Fatigue Analysis

Fatigue analysis is to be performed to verify adequate strength against fatigue failure within its design life. The fatigue analysis is to consider the loading history of the column-stabilized installation including transport and in-place conditions. Special attention is to be given to the major joints mentioned above. Attention is also to be given to the designs of structural notches, cutouts, brackets, toes, and abrupt changes of structural sections where they are prone to fatigue damages.

.5 Structural Redundancy Analysis

The hull structural redundancy analysis is required to verify that there is adequate redistribution of stress in the damaged condition defined in Table 5.2. The damaged conditions are to consider loss of one compartment buoyancy and loss of one brace for twin-pontoon column stabilized installations.

For integrated deck and top column frame constructed with open space trusses, the redundancy analysis is also required for the damaged condition with loss of one primary member in association with a factor of safety of 1,0.

.6 Acceptance Criteria

The total assessment of the structure and details is to be performed against the design conditions in Table 5.2 and failure modes of material yielding, buckling, ultimate strength and fatigue. The acceptance criteria of each mode are given as follows.

1) **Material Yielding**. For the hull, integrated deck and top column frame the yielding criteria based on the safety factors in Table 5.2 are to be used for bar and beam elements. For plate structures the allowable von Mises equivalent stress is to be 0,7 of the yield strength for the Design Operating and Loadout Conditions, and 0,9 of the yield strength for the Design Environmental, Transit and Damaged Conditions.

   If local detail FE model analysis (localized highly stressed area, 50 mm x 50 mm element size. In no case is the plate element size required to be less than the plate thickness) is provided, the allowable von Mises equivalent stress of $0,97S_m R_{eH}$ may be used for the Design Operating and Loadout Conditions, and $1,25 S_m R_{eH}$ for the Design Environmental, Transit and Damaged Conditions.

   Note:

   The yield strength is to be based on the specified minimum yield point or yield stress as defined in Rules for Materials (Pt.1, Vol.V) and Rules for Welding (Pt.1, Vol.VI) for higher strength material or 72 percent of the specified minimum tensile strength, whichever is the lesser. S_m is the strength reduction factor as defined in Section 4, C.3.4.2.1

2) **Buckling and Ultimate Strength**. For the hull, integrated deck and top column frame the criteria specified in Guidance for Buckling and Ultimate Strength Assessment for Offshore Structures (Pt.5, Vol.C) are to be used. Alternatively, the criteria specified in the API Bulletin 2U and 2V and other recognized standards acceptable to BKI can be used. The safety factors are to be based on Table 5.2.

3) **Fatigue**. For the hull, including the main intersections defined in 2.3.1.3, the fatigue damages can be calculated using the Offshore S-N curves for environment in air, in seawater with cathodic protection, and free corrosion, as specified in Guidance for the Fatigue Assessment of Offshore Structures (Pt.5, Vol.B), Sec.3. The S-N curves are applicable to thicknesses that do not exceed the reference thickness of 22 mm. For members of greater thickness, thickness correction is to be applied with an exponent of 0,25. Other recognized standards equivalent to BKI requirements are also acceptable.

   The fatigue life is determined by safety factors and the design life of the column-stabilized installation. Safety factors depend on the inspectability, repairability, redundancy, the ability to predict failure damage, as well as the consequence of failure of the structure. Minimum safety factor requirements are listed in Table 2.1.

   For existing installations, the remaining fatigue life of the installation is to be assessed and the supporting calculations are to be submitted for review. Special consideration is to be given to the effects of corrosion and wastage on the remaining fatigue life of existing structures.

   Any areas determined to be critical to the structure are to be free of cracks, and the effects of stress risers is to be determined and minimized. Critical areas may require special analysis and survey.

2.3.2 Non Integrated Deck

The design of non-integrated deck is to be based on applicable sections of the Rules for Facilities Offshore Installations (Pt.5, Vol.XII) and B.3.3.2.

2.4 Analysis and Design of Other Major Structures

The analysis and design criteria to be applied to the other pertinent features of the installation structural design are to conform to recognized practices acceptable to BKI. For installations, there will be a need to consider in the hull and topside deck structure design the interface between the mooring system and the installation, the interface between the riser system and the installation, and the effects of structural support reactions from deckhouses and deck-mounted equipment/machinery. The criteria to be applied for these cases are presented below.

2.4.1 Hull Interface with Riser System (Riser Porches, Supports, and Guides)

The riser porches, guides, and supports, including the hull backup structures (the reinforcements for the hull), are to be designed for the maximum anticipated riser loads with a safety factor of 1,25 in the Design Environmental Condition (DEC) and with a safety factor of 1,67 in the Design Operating Condition (DOC).

Fatigue strength is to be designed to meet the requirements in 2.3.1.6.3), taking into account the effects of both local drag and inertia loads on the risers and the global motions of the installation.

2.4.2 Hull Interface with Mooring System (Fairlead, Chain Stopper, and Winch Foundations)

Each individual foundation and back-up structure of the fairlead, chain jack, and winch is to be designed for the breaking strength of the mooring line with a safety factor of 1,25. The foundation and back-up structure for multiple fairleads, chain jacks, or winches is to be designed for the maximum anticipated mooring loads with a safety factor of 1,25 in the Design Environmental Condition (DEC) and with a safety factor of 1,67 in the Design Operating Condition (DOC).

Fatigue strength is to be designed to meet the requirements in 2.3.1.6.3), taking into account the effects of both local drag and inertia loads on the moorings and the global motions of the installation.

2.4.3 Topside Deck Structure Interface with Deckhouses and Deck Mounted Equipment/Machinery

The topside deck structure may require reinforcements to resist the reaction forces from equipment/ machinery foundations or deck modules. The reinforcements of the topside deck structure are referred to as backup structures. The forces to be resisted by the backup structures of the topside deck structure are to be designed for the maximum anticipated gravity, functional, and environmental loads together with the inertia loads induced by the installation motions with a safety factor of 1,25 in the Design Environmental Condition and 1,67 in the Design Operating Condition. If deemed necessary, the fatigue strength is to meet the requirements of 2.3.1.6.3). Special attention should also be given to the following interface structures:

.1 Lifeboat Platform

The strength of a lifeboat platform is to be designed to meet the following requirement:

- The most adverse combination of list and trim of 20° with Safe Working Load (total weight of lifeboat, passengers and supplies) with allowable stresses equal to Ultimate Tensile stress divided by a factor of 4,5.

.2 Crane Pedestal and Foundation

The crane pedestal is to be designed in accordance with the recognized standard that the crane is certified to, such as Guidelines for Loading Gear on Seagoing Ships and Offshore Installations (Pt.4, Vol.3) or API Spec. 2C.

2.5 Materials and Welding

2.5.1 Hull and Topside Deck Structure

Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.3, C are to be used to establish the welding requirements for the hull. The weld type and size are to be shown on the scantling drawings or in the form of a welding schedule, and are to comply with the Rules that govern the steel selection. Special attention is to be given to the weld details for fatigue sensitive areas, if necessary. Weld improvements by means of toe grinding and weld profiling are to be used if required by fatigue analysis results.

Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.3, B is to be used for the material selections for the hull and topside deck structure. The hull and topside deck structure are grouped into the following material application categories for the purpose of material grade selection :

Special Application Structure	• External shell structure in way of main intersections of columns, topside deck structure, pontoons, braces, mooring foundations, and riser porches • Portions of topside deck structure which receive major concentrated loads • Intersections of topside deck structure's main truss members • External brackets, portions of bulkheads, flats, and frames which receive concentrated loads at main intersections of columns, topside deck structure, pontoons, braces, mooring foundations, and riser porches • "Through" material used at main intersections of columns, topside deck structure, pontoons, braces, mooring foundations, and riser porches, which provide proper alignment and adequate load transfer
Primary Application Structure	• External shell structure of columns, pontoons, braces, topside deck structure (barge hull), and riser porches • Topside deck structure's main truss members • Bulkheads, flats, and framing which provide local reinforcement or continuity of structure in way of main intersections, except where the structure is considered special application • Bulkheads, girders, decks that are designed to provide global strength to the installation
Secondary Application Structure	• Internal structure, including bulkheads and girders in columns, topside deck structure, and pontoons, except where the structure is considered primary or special applications • Decks of topside deck structure, except where the structure is considered primary or special applications

2.5.2 Corrosion Protection and Control

A corrosion protection and control system utilizing anodes and coating in accordance with the recognized industry standards such as API and NACE (National Association of Corrosion Engineering) is to be provided. The design life of the corrosion protection and control system is to be the design life of the installation. In the splash zone, corrosion allowance is to be added to the external shell plating. When reinforced coatings are installed (such as glass flake reinforced epoxy or thermally sprayed aluminium) which have satisfactory service experience in the splash zone, the corrosion allowance may be reduced or eliminated subject to BKI review.

3. Stability

3.1 Stability

3.1.1 Transit Voyage Stability

Stability during wet tow to location is to comply with Coastal and Flag State requirements. If personnel will be on board during the tow, the stability is to meet the criteria for column-stabilized units in the Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.6 at all transit drafts in association with wind speeds to be agreed with BKI based on the environmental parameters and procedures associated with the tow route.

During the installation phase (ballasting and deballasting on site), the installation is to have a positive metacentric height (GM) after correction for free surface effects. When evaluating GM, the effect of free surface from partially filled tanks during the ballasting/deballasting sequence is to be considered.

3.1.2 On-Site Stability

All installations are to have positive metacentric height (GM) in calm water equilibrium position for all afloat conditions after correction for free surface effects. The minimum GM used in design is to be specified by the designer and included in the operations manual.

Installations are to comply with the intact and damage stability criteria of Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.6, A using the site-specific wind or 50 knots (25,7 m/s), whichever is greater. Height profile is to be taken from the MODU Rules or other recognized standard.

1) Wind speed for normal operations V_n – the 1-year, 1-minute average wind in the DOC as defined in C.3.2
2) Wind speed for storm survival V_s – the 100-year, 1-minute average wind in the DEC as defined in C.3.2
3) Wind speed for damage conditions V_d – the 1-year 1-minute average wind in the DOC as defined in C.3.2

The design wind velocities are to be selected by the designer and submitted with the design documentation.

3.1.3 Lightweight and Center of Gravity

The inclining test required by Section 2, C.1.2 is to be carried out while the installation is floating at a draft where pontoons are submerged. Braces or other structures should not affect the waterplane properties at any point during the test.

Alterations in the lightweight data during service (e.g., new equipment, structural modifications) are to be recorded in the operation manual and be taken into account in daily operation.

3.1.4 Watertight and Weathertight Integrity

Watertight and weathertight integrity are to be established in accordance with Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.6, B.

3.1.5 Penetrations

Penetrations are to comply with Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.6, B.1.3.

Cable penetrations are to be installed in accordance with the manufacturer's specifications and procedures. Evidence of prototype testing at the water pressure of the watertight boundary under consideration is to be provided.

During installation of deck and bulkhead watertight and fire-rated cable penetrations, the attending Surveyor is to confirm that the installer is familiar with and has access to the manufacturer's installation procedures for stuffing tubes, transit devices or pourable materials.

After installation, all watertight and fire-rated cable penetrations are to be visually examined. Watertight cable penetrations are to be tested as required by Rules for Classification and Surveys (Pt.1, Vol. I), Table A2.3.

4. Machinery and Systems

4.1 Marine Piping Systems

Marine piping systems are those systems (such as bilge, ballast, fuel oil and tank venting) that are required to conduct marine operations and are not associated with process facilities. Marine piping systems are to comply with Rules for Machinery Installations (Pt 5, Vol. IV), Sec.13 and Rules for Facilities on Offshore Installations (Pt.5, Vol.XII) Sec.3, E as applicable.

4.2 Electrical Systems

Electrical systems are to comply with Rules for Electrical Installations (Pt.5, Vol.V), Sec.3.and Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, F. Where the Flag Administration permits, the minimum number of required main power sources may be reduced to one. For area classification requirements, refer to Section 7, A.9.

4.3 Fire Fighting Systems and Equipment

Fire fighting systems and equipment for installation service functions not associated with the process facilities are to be in accordance with Rules for Machinery Installations (Pt 5, Vol.VI), Sec.10, C. Fire fighting systems and equipment for protection of hydrocarbon process and associated systems are to be in accordance with Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, H.

4.4 Machinery and Equipment

Machinery and equipment not associated with the process facilities are to be in accordance with the applicable requirements of Rules for Machinery Installations (Pt.5, Vol.IV) and Rules for Machinery Installations (Pt.1, Vol.III), Sec.7 and 11 , as applicable. Machinery and equipment forming a part of the hydrocarbon processing facilities are to be in accordance with the applicable requirements of Rules for Facilities on Offshore Installations (Pt.5, Vol.XII). (See Section 4, A.3.1.8 of this Guidelines regarding machinery and equipment foundations.)

4.5 Hydrocarbon Storage in Hull Tanks

If the Column-Stabilized Installation is designed to store hydrocarbons in hull tanks, criteria for hull storage of hydrocarbons are to meet flag and coastal state requirements and applicable international requirements. The designs for scantlings and strength for such storage tanks are to be in accordance with

Section 5, A.2.1. See Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, E.3.5 for the storage facility arrangement requirements.

4.6 Additional Plans and Data to be Submitted

The following information is to be submitted and appropriate relevant information is to be provided in the Operating Manual:

1) Inspection plans for all compartments below the maximum immersion line.
2) Closure means for external openings whose lower edges are below the levels to which weathertight integrity is to be ensured, as shown by the diagrams submitted in accordance with Rules for Classification and Surveys (Pt. 5, Vol. I), defining their appropriate extent for each mode of operation afloat, for example, Normal Operating, Severe Storm Conditions and Transit Condition. (See Rules for Mobile Offshore Units (Pt. 5, Vol. VI), Sec. 6, A.2)
3) A plan identifying the disposition (open or closed) of all non-automatic closing devices and locations of all watertight and weathertight closures for each mode of operation afloat is to be submitted for review prior to the installation's delivery. Upon satisfactory review, the plan is to be incorporated into the Operating Manual. (See Rules for Classification and Surveys (Pt.5, Vol.I) and Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.6, B)
4) Means for detection of and recovery from flooding of compartments that lie partly or completely below the operating or survival drafts and are adjacent to the sea or contain salt water piping or pumping equipment. (See Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.6.4.2)
5) The estimated time to deballast the installation from operating to survival draft. (See Rules for Machinery Installations (Pt.5, Vol.IV), Sec.13)
6) Means of preventing progressive flooding via sounding tubes, tank vents and overflows, ventilating systems, trunks, etc., from compartments within the assumed damaged areas. (See Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.6, A.3.3)
7) Means of detecting flooding of and means of water removal from void spaces not connected to the bilge or ballast systems if applied. (See Rules for Machinery Installations (Pt.1, Vol.III), Sec.11, N)
8) Means of closure and evacuation of water from chain lockers.
9) The remaining or "residual" range of stability resulting from the damaged condition and the type and location of appropriate closures to prevent downflooding. (See Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.6, A.4.2)
10) Means of sounding tanks. (See Rules for Machinery Installations (Pt.5, Vol.IV), Sec.13, E)
11) A description of the ballast piping and control system describing the items listed below. (See Rules for Machinery Installations (Pt.5, Vol.IV), Sec.13)
    A) Redundancy of pumps, valves and controls and alternate means of valve operation.
    B) Valve operating and indicating means.
    C) Means of manual and remote operation of ballast pumps and valves.
    D) Communication means between ballast control spaces and pump rooms, including those means of communication that are independent of the ship's service communication system.
    E) Means of determining the failure of critical ballast system components and means to overcome their failure.

B. Tension Leg Platforms

1. General Requirements

1.1 General

The design and construction of a Tension Leg Platform (TLP) are to be based on all applicable requirements of the Rules for Mobile Offshore Units (Pt.5, Vol.VI), Rules for Fixed Offshore Installations (Pt.5, Vol.VII) and API RP 2T. However, the design criteria, as given in the Rules for Mobile Offshore Units (Pt.5, Vol.VI) and Rules for Fixed Offshore Installations (Pt.5, Vol.VII) can be modified to reflect the different structural performance and demands expected of a TLP in offshore service. In addition, in the absence of equivalent Coastal State requirements, the applicable criteria contained in the Load Line, SOLAS and MARPOL Conventions issued by the International Maritime Organization (IMO) may be considered. It is further suggested that the local authorities having jurisdiction where the installation is to operate be contacted to obtain any further criteria that are applicable to the TLP installations.

1.2 Definitions

A TLP consists of structural components of hull, column top frame, topside deck, tendon system and foundation system. The hull consists of buoyant pontoons and columns. The tops of the columns are connected to a column top frame or a topside deck forming the global strength of the hull. For the hull with a column top frame, the topside deck is not integrated as part of the global strength of the hull. This topside deck is noted as "Non-integrated Deck" in this Guidelines. The topside deck integrated with the hull to form the global strength of the hull is noted as "Integrated Deck" in this Guidelines.

Tendon System: A vertical mooring system that forms the link between the hull and the foundation for the purpose of mooring the TLP.

Foundation System: The foundations used to anchor the tendon legs to the seafloor.

1.3 Loading Criteria

1.3.1 Loads

The TLP's modes of operation in pre-service (loadout, transportation, installation) and in-service (in-place) conditions are to be investigated using anticipated loads, including gravity loads together with relevant environmental loads due to the effects of wind, waves, current and other phenomena such as earthquake, temperature, fouling, ice, etc., depending upon the specific installation site.

The TLP is to be designed for the loading conditions that produce the most severe local and global effects on the structure, as determined by the most severe operational or installation requirements.

Applied loading combinations considered for structural design are to include, as applicable, but not be limited to, the following loads:

1) *Environmental loads*. Loads due to wind, waves and current are to be considered. Directionality of wind, waves and current may be considered if accurate data is available. Where there is no accurate data available, the directionality of wind, waves and current that generates the most severe local and global load effects are to be used for design. Adequate headings for the environment are to be analyzed such that the most critical heading for the environment has been covered.
2) *Hydrostatic pressures and buoyancy*. Hydrostatic pressures and buoyancy are to be considered for all submerged structural members.
3) *Gravity*. Gravity of the structure and equipment steel and the variables in the topside deck and hull are to be considered.

4) *Inertia loads*. Inertia loads due to motions of the TLP are to be considered.
5) *Operational loads*. Loads induced by operations of drilling and production are to be considered.
6) *Tendon and riser loads*. Loads due to tendon and riser systems are to be considered, as applicable.
7) *Marine operation loads*. Loads encountered during transportation and installation are to be taken into account in the design. These loads include loads exposed during transport (wet or dry), launch or float-off and during ballasting and deballasting operations when the topside deck is being installed and during tendon installation procedure.
8) *Slamming*. Wave slamming loads are to be considered for members such as pontoons, columns, top column frame members and members forming the underside of the topside deck that are subject to wave slamming during transportation and operation.

1.3.2 Environmental Conditions

The TLP is to be designed to withstand a specified extreme storm in the Design Environmental Condition and operate in the Design Operating Condition. The environmental conditions required are defined in Section 6, B.1.1.2 and Section 6, B.1.1.3. and the environmental criteria required for these design conditions are defined in Section 2, B.4. Additionally, the TLP is to be designed for all operations in pre-service conditions such as loadout, transportation and installation. The environmental conditions for loadout and installation are to be specified by the designers or Owners. The environmental condition for transportation is to be of a 10-year return event of the selected transit route, unless a weather routing plan is to be implemented for the voyage.

In the design of the TLP in-service and pre-service strength, the following environmental conditions are to be considered:

- **Design Environmental Conditions (DEC)**. Please refer to Section 6, B.1.1.2. For structural strength design, environmental conditions that produce the responses having a minimum return period of 100 years are to be used.
- **Design Operating Conditions (DOC).** Please refer to Section 6, B.1.1.3. For structural design, environmental conditions that produce TLP responses having a minimum return period of 1 year are to be used.
- **Reduced Extreme Conditions (REC***)*. Environmental conditions that have a low probability of being exceeded when the hull is damaged or a tendon is removed/flooded. For structural strength design, joint statistics may be used to determine a return period which, combined with the probability of damage, produces a risk level equal to that of the Design Environmental Conditions (DEC).
- **Calm Conditions.** Environmental conditions such that the effects of wind, waves and current are insignificant and can be ignored. Where such a situation exists, the design case is permitted to use calm conditions.

In assessing the minimum tendon tension and topside deck clearance the following environmental condition should be considered:

- **Survival Environmental Conditions (SEC).** Environmental conditions that produce TLP responses having a minimum return period of 1000 years.

1.4 Global Performance Analyses

1.4.1 General

Global performance analyses of the TLP are aimed at determining the global effects of environmental loads on the overall platform and its components, such as tendons, risers, etc. The key function of the analyses is to establish that the TLP meets all of the pre-service and in-service requirements. It is suggested that

global response analysis be performed for each of the most critical design phases. The following aspects are to be included in TLP global performance analyses:

1) Platform motions in six degrees of freedom
2) Tendon tensions, including the maximum and minimum tensions and tendon fatigue loads for tendon design
3) Equivalent design wave heights and periods for the global structural analysis
4) Hull hydrodynamic pressure loads for global structural analysis
5) Platform accelerations for the determination of inertia loads

Global analyses with various loading conditions are required because complex motion characteristics of the TLP will have different impacts on different structural components. Therefore, the deck, hull, tendons and risers are to be included in these analyses. Several analytical methods with varying degrees of complexity may be used to achieve this goal. Loading and response predictions for the deck and hull, and those for the tendons and risers can be performed either separately or in an integrated form. Methods and models employed in the analyses are to account for the relevant nonlinear and motion coupling effects. Due to numerical efficiency and limitations of each method, frequency domain analyses are usually performed for all of the load cases. For those cases that are determined to be critical to the TLP global performance or to have highly nonlinear effects, a time-domain analysis should be performed. For the detailed discussion of various available global analysis methods of TLP, refer to API RP 2T.

1.4.2 Frequency Domain Analyses

Frequency domain analyses include the wave frequency analysis in six degrees of freedom of the TLP system, and the low frequency analysis in surge, sway and yaw of the TLP system.

In order to evaluate the first-order platform and tendon responses, linear wave theory is usually employed in the wave frequency analysis. However, an alternative method may be applied to evaluate the effects of finite amplitude waves. In case where second-order sum-frequency effects are determined to be significant, the high frequency springing analyses are to be carried out to evaluate the springing responses of the platform and tendons. The low frequency analysis is also to be carried out to evaluate the slow drift effects caused by wind and wave drift. The damping levels used in the above analyses are to be properly determined and documented.

1.4.3 Time Domain Analyses

Time domain analysis is a preferable approach to evaluate the nonlinear effects in global response analyses of the TLP. These nonlinear effects include hull drag forces, finite wave amplitude effects, nonlinear restoring forces from tendons and risers, ringing (the high frequency vertical vibration of a TLP excited by impulsive loading) and springing (the high frequency vertical vibration of the TLP excited by cyclic loading at or near the resonant periods), and coupling effects of hull, tendons and risers in deep waters. In time domain analysis, a relevant wave spectrum is to be transferred to random time series for simulating irregular wave elevations and kinematics.

For deepwater applications, a time domain analysis of fully coupled motions of platform, tendons and risers may be required and documented for the load cases that are shown to govern the TLP global performance. When strong nonlinear responses are expected, a time domain ringing response analysis is to be performed and submitted for review.

In areas with a strong current extending deep into the ocean, possible VIV effects are to be assessed and documented.

1.4.4 Deck Clearance

A clearance meeting the following criteria is recommended to be maintained between the underside of the topside deck and the wave crest:

1) 1,524 m minimum in Design Environmental Conditions (DEC).
2) A reasonable clearance in Survival Environmental Conditions.

The deck clearance is normally determined by an appropriate model test. Alternatively, the deck clearance can also be determined by a detailed hydrodynamic analysis that accounts for relative motions between the TLP and waves. The following items are to be considered to determine the deck clearance:

1) Various environmental headings
2) Offset due to wind, waves and current
3) Nonlinearity of wave profile
4) Wave diffraction, run-up
5) Platform set-down
6) Tide and water level effects
7) Seabed subsidence

Deck clearance is also to be checked at various points on the underside of the topside deck.

Unless the recommended deck clearance can be maintained to avoid impact, the TLP including topside deck, hull, tendons and foundations should be designed for the anticipated local and global wave forces (including slamming) and resulting responses. Structures and equipment on the topside deck, which may subject to wave run-up or green water, should also be designed for the associated forces.

1.4.5 Model Testing

Model testing for deriving some of the design parameters, such as deck clearance and nonlinear effects, is recommended as the final check of TLP designs if innovative components emerge in the design. Relevant environmental conditions are to be covered in the model testing. The primary objectives of model tests are listed below:

1) To determine the responses of a particular design, such as to calibrate factors for ringing and springing.
2) To verify analysis tools for prediction of system responses or simply to correlate the analysis results.
3) To derive design information as a substitute for numerical analysis.

1.5 Corrosion Protection and Control

A corrosion protection and control system utilizing anodes and coating in accordance with the recognized industry standards such as API and NACE is to be provided. The design life of the corrosion protection and control system is to be the design life of the TLP. In the splash zone, corrosion allowance is to be added to the external shell plating.

2. Stability

2.1 Stability

2.1.1 Intact and Damaged Stability

Stability during wet tow to location is to comply with Coastal and Flag State requirements. If personnel will be on board during the tow, the stability is to meet the

criteria for column-stabilized units in the Rules for Mobile Offshore Units (Pt.5, Vol.VI) at all transit drafts in association with wind speeds to be agreed with BKI based on the environmental parameters and procedures associated with the tow route.

During the installation phase (ballasting and deballasting for tendon connection), the installation is to have a positive metacentric height (GM) after correction for free surface effects. When evaluating GM, the effect of free surface from partially filled tanks during the ballasting/deballasting sequence is to be considered.

Under in-place conditions, positive tendon tension is to be maintained to ensure integrity of the platform and tendons, and account for tendon slacking. The intact condition is to include the full range of possible center of gravity variations permitted by acceptable operating procedures during severe conditions.

The TLP is to maintain positive tendon tension in Design Operating Condition (DOC) after sustaining any one of the following flooding scenarios:

1) Any one compartment at or below the still water line, or
2) Damage is assumed to be 3 m wide and 3 m high with a horizontal penetration of 1,5 m inboard of the hull plating. This extent of damage is to be considered at all levels between 3 m below to 5 m above the waterline in consideration. No vertical bulkhead needs to be considered damaged unless the nearest vertical bulkhead is placed closer than 1/8 of the perimeter of the column at the waterline or 3 m, whichever is less, or
3) Any one tendon compartment.

The environmental condition is to be assumed as Design Operating Condition at the time of flooding. Positive tendon tension is to be demonstrated through analysis. Ballast pump capacity is to meet API RP 2T specifications.

The ability to compensate for damage incurred, by pumping out or ballasting other compartments, is not to be considered when determining whether positive tendon tension can be maintained.

2.1.2 Weight Control

An inclining test is to be conducted to accurately determine the platform weight and the position of the center of gravity. If integration of topsides takes place offshore, an alternative procedure may be applied using an inclining test or lightweight survey of the hull combined with weighing of the topside components to be installed.

A global weight verification plan is to be submitted. Procedures for the lightweight survey, each weighing, and permanent ballast measurement are to be submitted for approval and are to include estimates of weight and center of gravity. An BKI surveyor is to attend each activity.

When weighing components, these parts are to be as complete as possible with not more than 2% of the weight of the component remaining to be incorporated.

The result of each weight verification activity is to be compared to the estimated weight. When the measured weight is within ±1% of the estimated weight, the vertical center of gravity is to be the estimated value in the calculation. When it is outside the 1% tolerance, the vertical center of gravity is to be computed by taking the difference between the estimated and the measured weight and placing it at an indisputably conservative location.

Changes of onboard load conditions after the inclining test and during service are to be carefully accounted for. The operations manual is to provide guidance for the maintenance of a weight change log and

periodical correlation between calculated and measured tendon tension. The weight log and the records of the periodical correlations are to be kept onboard.

2.2 Watertight/Weathertight Integrity

A plan, identifying the disposition (open or closed) of all non-automatic closing devices and locations of all watertight and weathertight closures, and unprotected openings is to be submitted for review prior to the installation's delivery. Upon satisfactory review the plan is to be incorporated into the Operating Manual.

2.2.1 Weathertight Integrity

External closing appliances are to be in accordance with the requirement of the 1966 International Convention on Load Lines.

In all cases, external openings whose lower edges are below the levels to which weathertight integrity is to be ensured are to have weathertight closing appliances.

Openings fitted with appliances to ensure weathertight integrity are to effectively resist the ingress of water due to intermittent immersion of the closure.

2.2.2 Watertight Integrity

All internal and external openings whose lower edges are below the levels to which watertight integrity is to be ensured, as shown by the diagrams submitted in accordance with C.2.2, are to be fitted with appliances to ensure watertight integrity.

.1 Internal Openings

Internal openings fitted with appliances to ensure watertight integrity are to comply with the following.

1) Doors and hatches are to be of the quick-acting type and an indicating system (e.g., light signals) is to be provided showing personnel, both locally and at a normally manned central position, whether the doors or hatches in question are open or secured closed. In addition, a sign is to be posted near the opening to the effect that the closing appliance is to be secured closed and opened only during actual use. If sliding doors are fitted they are to be capable of being remotely controlled from a normally manned central position as well as being operable locally from both sides of the bulkhead.
2) Manholes fitted with bolted covers need not be dealt with as under 1).
3) The closing appliances are to have strength, tightness and means for securing which are sufficient to maintain watertightness under the water pressure of the watertight boundary under consideration

.2 External Openings

External openings are to comply with the following.

1) The lower edges of all openings, including air pipes, ventilators, ventilation intakes and outlets (regardless of closing appliances), non-watertight hatches and weathertight doors, are to be above the levels to which watertight integrity is to be ensured.
2) Manholes fitted with bolted covers need not be dealt with as under 1).
3) External openings fitted with appliances to ensure watertight integrity are normally to be secured closed and are to comply with the requirements of 2.2.2.1.

2.2.3 Penetrations

Where watertight bulkheads and flats are necessary for damage stability, they are to be made watertight throughout. Where individual lines, ducts or piping systems serve more than one compartment or are within the extent of damage, satisfactory arrangements are to be provided to preclude the possibility of progressive flooding through the system. Valves fitted at watertight boundaries are to be operable from above the top of the hull.

Cable penetrations are to be installed in accordance with the manufacturer's specifications and procedures. Evidence of prototype testing at the water pressure of the watertight boundary under consideration is to be provided.

During installation of deck and bulkhead watertight and fire-rated cable penetrations, the attending Surveyor is to confirm that the installer is familiar with and has access to the manufacturer's installation procedures for stuffing tubes, transit devices or pourable materials.

After installation, all watertight and fire-rated cable penetrations are to be visually examined. Watertight cable penetrations are to be tested as required by Rules for Classification and Surveys (Pt.1, Vol.I), Table A2.3.

3. Hull and Primary Structures

3.1 Structural Design

3.1.1 General

The design of the TLP is to be based on the applicable portions of the Rules for Mobile Offshore Units (Pt.5, Vol.VI) and Rules for Fixed Offshore Installations (Pt.5, Vol.VII). Where the conditions at the installation site are less than those for full ocean service that are the basis of the Rules for Mobile Offshore Unit (Pt.5, Vol.VI) and Rules for Fixed Offshore Installations (Pt.5, Vol.VII), the design criteria for various components of the TLP may be reduced to reflect these differences. However, when the installation site conditions produce more arduous demands, it is mandatory that the design criteria be increased appropriately. The TLP strength can be obtained by initially designing each component's scantlings for local load effects and, subsequently, verifying the initial scantlings for the global load effects.

This subsection provides requirements for the designs of initial scantlings and secondary structures. In 3.3 of this Guidelines provides requirements for verification of the initial scantlings.

3.1.2 Hull Scantlings

Scantlings of TLP structural components, including columns and pontoons, are to be designed in accordance with 3.2.

3.1.3 Modules and Buildings on the Topside Deck

The structural design of modules and buildings on the topside deck is to be in accordance with 3.3.2, wherever applicable. The relative deformations among module and building supports are to be included in the analysis if their effects on the module are significant.

The module and building supporting structures on the topside deck are to be analyzed and shown explicitly on the drawings so that the construction of the module and building supports can be consistent with those assumed in the structural analysis. Means are to be provided to verify that the module and building design reactions and conditions are identical with those used in the topside deck design.

The structural fire protection aspects of the design of topsides modules and buildings, including the arrangement of the hydrocarbon process area, are to be in accordance with Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, H.

The designs of piping system on the topside deck are to comply with Rules for Machinery Installations (Pt.5, Vol.IV), Sec.13 and applicable requirements of the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII).

3.1.4 Helicopter Deck

The design of the helicopter deck is to comply with the requirements of Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.4, E, and Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, H.5.5.

3.1.5 Protection of Openings on Top of Columns

All openings of the top of columns are to comply with Rules for Hull (Pt.1, Vol.II), Sec.1, H.6.7 and 17.

3.1.6 Guards and Rails

Guards and rails are to comply with the requirements of Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.3, H. The above mentioned section is to be used for the perimeters of the TLP. Alternative arrangements, such as a minimum 1,0 meter high and two tiers evenly spaced handrail with a kickboard, may be considered by the BKI, provided they are also acceptable to local authorities.

3.1.7 Machinery and Equipment Foundations

Foundations for machinery or equipment subject to high concentrated or cyclic loading, such as drilling facilities, cranes, tendon porches, riser porches, if applicable, are to be designed to provide satisfactory strength and fatigue resistance for the reaction forces specified by the manufacturer or the maximum anticipated loads during the design life of the TLP, in accordance with safety factors outlined in 3.3.1. The global load effects, TLP motion-induced inertia loads are also to be considered in addition to the reaction forces. The backup structures, reinforcements on hull or topside deck, are also to be designed for the same loads and safety factors, as a minimum.

3.1.8 Appurtenances

Main appurtenances attached to the exterior of the hull are to be evaluated, taking into account the effects of both local drag and inertia loads. Responses resulting from these loads, together with any appropriate consideration of global action of the TLP, are to be considered with respect to yield, buckling and fatigue strength. The backup structures are also to be designed for the same loads and safety factors, as a minimum.

3.1.9 Temporary Structures

Structures built for temporary use in the pre-service conditions are not subjected to BKI review. However, the arrangements and details of these structures are to be submitted for reference to verify the adequacy of the local and global strength of the hull and topside deck to support these temporary structures during operation in the pre-service condition. The backup structures are to be designed for the safety factors outlined in 3.3.1.

3.2 Scantling Design of the Hull Structure

The initial scantling design of the hull is to be based on the applicable portions of Rules for Hull (Pt.1, Vol.II) and Rules for Structures (Pt.5, Vol.II). The aspects that are not covered by these Rules are to be based on the recognized codes and standards. For curved shells, the minimum scantlings of shell girders are to be determined on the basis of established shell analysis methods, using the heads given in 3.2.1 and safety

factors appropriate to the method employed. As a minimum, a detailed local analysis is to be performed, with failure modes meeting the criteria in 3.3.1.6.

3.2.1 Hull - Pontoons and Columns

Pontoons and columns may be considered either as framed or unframed shells. Ring stiffeners, bulkheads or other suitable diaphragms which are used are to be adequate to maintain shape and stiffness under all anticipated loadings in association with established shell analysis methods.

.1 Scantlings of Framed Shells

Where the components of columns or pontoons incorporate stiffened plating, the minimum scantlings of plating, framing, girders, etc., for shells and interior boundary bulkheads and flats may be determined in accordance with the requirements for tanks, as given in 3.2.3, in association with the following.

1) Tank Space. Where the internal space is a tank, the head, h, is to be taken to a point located at two-thirds of the distance from the top of the tank to the top of the overflow, or to a point 0,91 m above the top of the tank, whichever is greater. For tanks intended to carry contents with a specific gravity in excess of 1,05, the head is to be suitably increased by a factor equal to the ratio of the specific gravity to 1,0.
2) Void Compartment Spaces. Where the internal space is a void compartment, the head is to be taken to the maximum permissible draft of the unit in service.
3) Areas Subject to Wave Immersion. For all areas subject to wave immersion, the minimum head is to be 6,1 m.
4) Minimum Scantlings. In general, the scantlings of boundaries are not to be less than those required by 3.2.2, in association with a head to the maximum damaged waterline.

.2 Scantlings of Unframed Shells

Where columns or pontoons do not incorporate framing members, the minimum scantlings of shell plating and ring stiffeners are to be determined on the basis of established shell analysis methods using the heads given in 3.2.1.1 and safety factors appropriate to the methods employed. Interior boundary bulkheads and flats are to be considered on the basis of framed shells, as given in 3.3.1.6.

.3 Additional Structural Requirements for Scantlings

Scantlings of columns and pontoons as determined above are minimum requirements for hydrostatic loads. Where wave and current loadings are superimposed, the scantlings of the local structure of the shell are to be increased as necessary, to meet the strength requirements of 3.3.1.6.

3.2.2 Watertight Boundary Formula

.1 Plating

The plating thickness of watertight boundaries is not to be less than that obtained from the following equation:

$$t = \mathbf{a} \cdot c_k \frac{\sqrt{k \cdot h}}{290} + 1{,}5 \quad [\text{mm}]$$

but not less than 6 mm or $\frac{\mathbf{a}}{200}$ + 2,5 mm, whichever is greater.

where

t = thickness [mm]

a = spacing of stiffeners [mm]

c_k = $\dfrac{3{,}075 \cdot \sqrt{\alpha} - 2{,}077}{\alpha + 0{,}272}$ for $1 \le \alpha \le 2$

= 1,0 for $\alpha > 2$

α = aspect ratio of the panel (longer edge/shorter edge)

k = $\dfrac{235}{R_{eH}}$

R_{eH} = specified minimum yield point or yield strength [N/mm^2]

h = distance [m], from the lower edge of the plating to a point defined in 3.2.1

.2 Stiffeners and Beams

The section modulus, W, of each bulkhead stiffener or beam on a watertight flat, in association with the plating to which it is attached, is not to be less than that obtained from the following equation :

$$W = 7{,}8 \cdot k_s \cdot c \cdot h \cdot \mathbf{a} \cdot \ell^2 \quad [cm^3]$$

$$k_s = \frac{49{,}92}{R_{eH} + 2 \cdot \frac{U}{3}}$$

where

c = 0,56 for stiffeners with ends attached

= 0,60 for stiffeners with no end attachment

h = distance, in m, from the middle of ℓ to a point defined in 3.2.1

a = the spacing of stiffeners [m]

ℓ = the length of stiffeners [m] ; where brackets are fitted with a slope of approximately 45 degrees and thickness given in Table 5.1, the length of ℓ maybe measured to a point on the bracket equal to 25% of the length of the bracket.

R_{eH} = specified minimum yield strength [N/mm^2]

U = specified minimum tensile strength of the higher-strength material [N/mm^2]

.3 Girders and Webs

The section modulus, WSM, of each girder or web is not to be less than that obtained from the following equation:

$$W = 4{,}7 \cdot k_s \cdot h \cdot \mathbf{a} \cdot \ell^2 \quad [cm^3]$$

where

h = distances [m], from the middle of the area supported to a point defined in 3.2.1

a = sum of half lengths [m], (on each side of girder or web), of the stiffeners or beams supported

ℓ = length [m], between supports, where brackets are fitted at shell, deck or bulkhead supports, and the brackets are in accordance with Table 5.1 and have a slope of

approximately 45 degrees, the length ℓ may be measured to a point on the bracket located at the distance from the toe equal to 25% of the length of the bracket.

k_s = factor defined in 3.2.2.2

3.2.3 Tank Boundary Formula

.1 Plating

Plating is to be the thickness derived from the following equation:

$$t = \mathbf{a} \cdot c_k \frac{\sqrt{k \cdot h}}{254} + 2,5 \quad [mm]$$

but not less than 6,5 mm or $\frac{\mathbf{a}}{150}$ + 2,5 mm, whichever is greater.

where

t = thickness [mm]

a = spacing of stiffeners [mm]

c_k = $\frac{3,075 \cdot \sqrt{\alpha} - 2,077}{\alpha + 0,272}$ for $1 \le \alpha \le 2$

= 1,0 for $\alpha > 2$

α = aspect ratio of the panel (longer edge/shorter edge)

k = $\frac{235}{R_{eH}}$

R_{eH} = specified minimum yield point or yield strength [N/mm^2]

h = distance [m], from the lower edge of the plating to a point defined in 3.2.1

When the specific gravity of the liquid contents of a tank is greater than 1,05, the head, h, specified above is to be increased by a factor equal to the ratio of the specific gravity to 1,0.

.2 Stiffeners and Beams

The section modulus, W, of each bulkhead stiffener or beam on a flat, in association with the plating to which it is attached, is not to be less than that obtained from the following equation :

$$W = 7,8 \cdot k_s \cdot c \cdot h \cdot \mathbf{a} \cdot \ell^2 \quad [cm^3]$$

where

c = 0,9 for stiffeners having clip attachments to decks or flats at the ends or having such attachments at one end with the other end supported by girders

= 1,0 for stiffeners supported at both ends by girders

h = distance [m], from the middle of ℓ to a point defined in 3.2.1.

a = spacing of stiffeners [m]

ℓ = length [m], between supports; where brackets are fitted at shell, deck or bulkhead supports, and the brackets are in accordance with Table 5.1 and have a slope of

approximately 45 degrees, the length, ℓ, may be measured to a point on the bracket located at a distance from the toe equal to 25% of the length of the bracket.

k_s = factor defined in 3.2.2.2.

.3 Girders and Webs

The section modulus, WSM, of each girder or web is not to be less than that obtained from the following equation:

$$W = 7{,}05 \cdot k_s \cdot c \cdot h \cdot \mathbf{a} \cdot \ell^2 \quad [cm^3]$$

where

h = distances [m], from the middle of the area supported to a point defined in 3.2.1

a = sum of half lengths [m], (on each side of girder or web), of the stiffeners or beams supported

ℓ = length [m], between supports, where brackets are fitted at shell, deck or bulkhead supports, and the brackets are in accordance with Table 5.1 and have a slope of approximately 45 degrees, the length, ℓ, may be measured to a point on the bracket located at the distance from the toe equal to 25% of the length of the bracket.

k_s = factor defined in 3.2.2.2

3.3 Structural Strength Analysis and Design of Primary Structures

3.3.1 Hull, Integrated Deck and Top Column Frame

.1 General

Documents necessary to verify the structural strength, including yielding, buckling and fatigue of the hull, integrated deck, column top frame and main intersections of primary structures are to be submitted for review. The criteria in this subsection relate to the analyses required to verify the scantlings selected in the basic design in 3.2. Except as provided in Rules for Mobile Offshore Units (Pt.5, Vol.VI), the results of analyses that are required in this subsection cannot be used to reduce the scantlings established from 3.2 of this Guidelines.

Depending on the specific features of the TLP, additional analyses to verify and help design other portions of the TLP structural components will be required. Such additional analyses include the hull interfaces with tendons, riser systems, machinery/equipment foundations and appurtenances. Analysis criteria for these additional hull structural components are given in 4.3.

.2 Global Strength Analysis

The primary structures of the hull, integrated deck and column top frame are to be analyzed using the loading and environmental conditions stipulated below. Conditions representing all modes of operation are to be considered to determine the critical cases. Calculations for critical conditions are to be submitted for review. The analyses are to be performed using recognized calculation methods and fully documented and referenced.

Table 5.3 below shows the required environmental events and safety factors to be considered for each design condition in the global strength analysis:

Table 5.3 - Required Environmental Events and Safety Factors

Design Conditions	Environmental Events	Safety Factors
Loadout	Calm or specified by designer or Owner	1,67
Ocean Transit (Dry Tow)	10 year return storm for the selected route condition or specified by designer or Owner if weather routing plan is to be implemented for the voyage	1,25
Field Transit (Wet Tow)	1 year return storm for the selected route condition or specified by designer or Owner	1,25
Deck Installation	Calm or specified by designer or Owner	1,67
In-place Design Operating	1 year return storm (minimum)	1,67
In-place Design Environmental	100 year return storm	1,25
In-place Damaged	1-year return storm	1,25

1) Critical Responses for Global Strength.

The global strength of the hull is to be designed to withstand the responses induced by the loads specified in 1.3.1. The responses of the hull induced by these loads that control the hull strength design are prying/squeezing loads, inertia loads and torsional moments. The responses that control the topside deck strength design are the accelerations induced by the waves in addition to those responses that control the hull. As indicated in Table 5.3, the in-place intact strength is to be designed for these responses with a 100-year return period in the Design Environmental Condition (DEC).

The highest wave may not always produce the most critical responses. To ensure that the most critical responses are captured, a sufficient number of design cases are to be used, considering the following permutations:

A) Variation in environmental conditions and headings

B) Variation in variables (deck payloads)

C) Variation in ballasting distributions

D) Variation in riser arrangements

.3 Major Joint Analysis - Analysis for Main Intersections of Primary Structures

Since the details of the main intersections are difficult to adequately capture in the global strength model, local FEM analyses are to be used, as required, to design these areas. These main intersections include connections of pontoon to pontoon, column to pontoon, column to topside deck, column to column top frame, and joints of column top frame and topside deck structures.

.4 Fatigue Analysis

Fatigue analysis is to be performed to ensure adequate strength against fatigue failure within the TLP's design life. The fatigue analysis is to consider all loading history of the TLP including transport and in-place conditions. Special attention is to be given to the major joints mentioned above.

Attention is also to be given to the designs of structural notches, cut-outs, attachments and abrupt changes of structural sections where they are prone to fatigue damages.

.5 Structural Redundancy Analysis

Redundancy analysis is required to ensure that there is adequate redistribution of stress in the damaged conditions defined in Table 5.3. The damaged conditions are also to consider loss of buoyancy in one compartment or removal of one tendon.

.6 Acceptance Criteria

The total assessment of the structure and details is to be performed against the design conditions in Table 5.3 and failure modes of material yielding, buckling, ultimate strength and fatigue. The acceptance criteria of each mode are given as follows.

1) **Material Yielding**.

For the hull, integrated deck and column top frame, the yielding criteria indicated in Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.4, C is to be used. The safety factors are to be based on Table 5.3 are to be used for bar and beam elements. For plated structures the allowable von Mises equivalent stress is to be 0,7 of the yield strength for the Design Operating, Loadout and Deck Installation Conditions and 0,9 of the yield strength for the Design Environmental, Transit and Damaged Conditions.

If local detail FE model analysis (localized highly stressed area, 50 mm x 50 mm element size. In no case is the plate element size required to be less than the plate thickness) is provided, the allowable von Mises equivalent stress of $0,97S_mR_{eH}$ may be used for the Design Operating, Loadout and Deck Installation Conditions, and $1,25S_mR_{eH}$ for the Design Environmental, Transit and Damaged Conditions.

The yield strength R_{eH} is to be based on the specified minimum yield point or yield stress, as defined in Rules for Materials (Pt.1, Vol.V), Sec.2, D.3 for higher strength material. S_m is the strength reduction factor as defined in Section 4, C.3.4.2.1

2) **Buckling and Ultimate Strength**.

For the hull, integrated deck and column top frame, the buckling criteria in API Bulletin 2V and 2U or other recognized standards are to be used. Alternatively, the criteria specified in the Guidance for Buckling and Ultimate Strength Assessment for Offshore Structures (Pt.5, Vol.C) or other recognized standards may be used. The safety factors are to be based on Table 5.3.

3) **Fatigue**.

For the hull, including the main intersections defined in 3.3.1.3, the fatigue damages can be calculated using the Offshore S-N curves for environment in air, in seawater with cathodic protection and free corrosion, as specified in Guidance for the Fatigue Assessment of Offshore Structures (Pt.5, Vol.B), Sec.3. The S-N curves are applicable to thicknesses that do not exceed the reference thickness of 22 mm. For members of greater thickness, thickness correction is to be applied with an exponent of 0,25. Other recognized standards equivalent to BKI requirements are also acceptable.

For integrated deck and column top frame, Offshore S-N curves and AWS S-N curves can be used.

The fatigue life is determined by safety factors and the design life of the TLP. Safety factors depend on the inspectability, repairability, redundancy, the ability to predict failure damage, as well as the consequence of failure of the structure. Minimum safety factor requirements are listed in Table 2.1.

Any areas determined to be critical to the structure are to be free from cracks, and stress concentration factors are to be determined and minimized. Critical areas may require special analysis and survey.

3.3.2 Non-integrated Deck

.1 General

The designs of non-integrated deck structural members, such as deck girders, columns, beams, braces, stiffeners, deck plating, etc., are to be based on the applicable sections of the Rules for Fixed Offshore Installations (Pt.5, Vol.VII). To this end, the loads on the structure, as indicated in 3.3.2.2, as applicable, are to be determined, and the resulting structural responses are not to exceed the safety criteria given in 3.3.2.4.

The use of design methods and associated safety criteria, other than those specifically covered in this section, is permitted where it can be demonstrated that the use of such alternative methods will result in a structure possessing a level of safety equivalent to or greater than that provided by the direct application of these requirements.

.2 Loading Conditions

Loadings which produce the most unfavourable effects on the non-integrated deck structure for the pre-service and in-service conditions are to be considered. The environmental conditions and applicable loads described in 1.3 are to be used to establish the design load cases for the in- service and pre-service conditions. The environmental events included in Table 5.3 are also to be considered for the deck design. For a given topside payload, the most critical responses for the topside deck may be the accelerations induced by the TLP's motions and the inclination- induced loads.

.3 Structural Analysis

A space frame analysis of the deck structure is to be performed to obtain the structural response. The structural model can be either the overall TLP with a detailed deck model or a standalone deck structural model. In the latter case, the boundary conditions of the model are to be properly simulated in the analysis. In modelling the deck structures, all relevant structural components are to be included. The nature of loads and loading combinations, as well as the local environmental conditions, are to be taken into consideration in the selection of design methods. Methods of analysis and their associated assumptions are to be compatible with the overall design principles. Linear, elastic methods (working stress methods) are generally employed in design and analysis. For the use of other methods, reference is to be made to Rules for Structures (Pt.5, Vol.II), Sec.3

.4 Allowable Stresses

The safety criteria are to be expressed in terms of appropriate basic allowable stresses, in accordance with requirements specified below:

1) For tubular members, stress limits are to be in accordance with the API RP 2A. The basic allowable stresses for the other type of members are to be obtained using the American Institute of Steel Construction (AISC) Manual of Steel Construction, ASD. For plated structures, the design is to be in accordance with API RP 2U and API RP 2V or other recognized industry standards.
2) Where stresses in members described in 1) are shown to be due to forces imposed by the Design Environmental Condition (DEC) acting in combination with dead and live loads, the basic allowable stresses cited in 1) may be increased by one-third, provided the resulting structural member sizes are not less than those required for the operating environment loading combined with dead and live loads without the one-third increase in allowable stresses.
3) The allowable stresses specified in 2) are to be regarded as the limits for stresses in all structural parts for the marine operations covered in 1.3.1, except for lifting, where the one-third increase in the basic allowable stress is not permitted. The one-third increase in the basic allowable stress is also not permitted in loadout operations. The lifting analysis is to adequately account for equipment

and fabrication weight increase with dynamic amplification factors recommended in API RP 2A. Other lift analysis methods can be considered on a case-by-case basis.

4) For any two- or three-dimensional stress field within the scope of the working stress formulation, the equivalent stress (e.g., the von Mises stress intensity) is to be used in the design. The allowable von Mises stress is to be 0.6 of the yield strength for the Design Operating Condition (DOC). A one-third increase in the allowable stress is allowed for the Design Environmental Condition (DEC). For highly localized areas, local yielding of the structure may be accepted, provided it can be demonstrated that such yielding does not lead to progressive collapse of the overall structure and that the general structural stability is maintained.

5) Whenever elastic instability, overall or local, may occur before the stresses reach their basic allowable levels, appropriate allowable buckling stresses govern.

.5 Fatigue Assessment

A detailed fatigue analysis is to be performed for deck structures. Rational fatigue analysis methods are acceptable if the forces and member stresses can be properly represented. The dynamic effects are to be taken into consideration if they are significant to the structural response. For the frame members of the deck, the S-N curves specified in the Guidance for the Fatigue Assessment of Offshore Structures (Pt.5, Vol.B) and API RP 2A are recommended. The Stress Concentration Factors (SCFs) for tubular joints can be calculated based on applicable empirical formulas. For the complex critical connections, the SCFs should be calculated by means of a fine mesh finite element analysis.

The results of the assessment are to indicate a minimum expected fatigue life of three times the design life of the structure where sufficient structural redundancy exists to prevent catastrophic failure of the structure of the member or connection under consideration. Where such redundancy does not exist or where the desirable degree of redundancy is significantly reduced as a result of fatigue damage, the result of a fatigue assessment is to indicate a minimum expected fatigue life of three or more times the design life of the structure. Table 2.1 provides general safety factor requirements for fatigue life. For the deck to hull connections, see 3.3.1.6.3).

Any areas determined to be critical to the structure are to be free from cracks, and stress concentration factors are to be determined and minimized. Critical areas may require special analysis and survey.

.6 Stresses in Connections

Connections of structural members are to be developed to ensure effective load transmission between connected members, to minimize stress concentration and to prevent excessive punching shear. Connection details are also to be designed to minimize undue constraints against overall ductile behaviour and to minimize the effects of post-weld shrinkage. Undue concentration of welding is to be avoided. The design of tubular joints is to be in accordance with the API RP 2A, including pinching shear. AISC Manual of Steel Construction, ASD can be used for the design of non-tubular joints.

4. Other Structures

4.1 Tendon System Design

4.1.1 General

The tendon system provides a vertical mooring system to the TLP by linking the TLP hull to the foundation system. The tendon system provides axial stiffness to control the heave natural period of the TLP and also provides sufficient axial strength to restrain the TLP motions under the environmental loading.

The tendon system may consist of a different number of tendons, depending on the platform configuration, loading conditions, intended service life requirement and redundancy requirement specified by the Owner.

Generally, the design life of the tendon is to be taken as the service life of the TLP. In special situations, the tendons may also be designed to be removable for maintenance and/or inspections.

Each tendon consists of a top section for attaching the tendon to the TLP hull-mounted tendon porches, a tendon main body to span the water column and a tendon bottom termination assembly for attaching the tendon to the foundation system. The main body of the tendon is generally made up of steel tubulars. Any other form of tendons such as solid rods, bars or wire ropes and any other materials such as non-metallic materials and composites that meet the service requirements may also be specially considered.

The tendon main body may consist of a number of tendon elements connected by tendon connectors. Tendon connectors can be mechanical couplings, welded joints or any other form of structural connection that meets the service requirements. The tendons may also have special components such as corrosion protection system components, tendon load and performance monitoring devices and VIV suppression devices. The term "tendon", as used here, refers to all of the components of the tendon system between the hull porch and the foundation system.

4.1.2 Loading Conditions

Loading conditions which produce the most unfavorable effects on the tendons for pre-service and in-service conditions are to be considered. The in-service condition analyses are to consider TLP intact and damaged conditions. The TLP intact condition analyses are to consider different TLP configurations such as drilling with rig, production with or without rig, different number of risers attached to the TLP, etc. TLP damaged condition analyses are to consider accidental flooding of a compartment in the platform or tendon and tendon removed condition. The environmental conditions described in 1.3 are to be used in these analyses. TLP analyses, as a minimum, are to consider loading conditions associated with the following:

1) Maximum tension
2) Minimum tension
3) Largest flex element rotational angle
4) Lifetime fatigue conditions
5) Hydrostatic collapse

4.1.3 Tendon Analysis Procedure

Tendon static loads may be determined from the equilibrium condition of the TLP. Tendon static loads arise from pretension, tide, platform offset due to wind and current and due to foundation installation position errors.

Tendon dynamic loads arise from platform motions under hydrodynamic loads and seismic motions and direct hydrodynamic forces acting on the tendons. Tendon dynamic loads may be determined by TLP global performance analysis described in 1.4 if the analysis is coupled, that is, the transverse (bending) response of the tendon is calculated simultaneously with the platform response. If the global performance analysis is uncoupled, that is, the tendons are represented by springs, then separate tendon analysis is to be carried out to evaluate the tendon responses along the length of the tendon. Procedures described in API RP 2T can be used for detailed tendon analysis.

4.1.4 Tendon Loads

For each loading condition, the maximum and minimum tendon tensions are to be evaluated. In general, the following factors are to be considered in the evaluation of the maximum and minimum tendon tensions.

1) Design pretension at mean water level
2) Variation in tendon tension due to tide and storm surge

3) Variation in tendon tension due to variations in load and ballast condition
4) Tension due to overturning moment from wind and current forces
5) Tension due to set down and slowly varying offset caused by wind, wave drift and current
6) Tension due to wave forces and wave-induced platform motions about the mean offset
7) Tension due to high frequency heave, pitch and roll oscillations (ringing and springing)
8) Tension due to vortex-induced responses.

For special situations, tendon loads arising from other sources such as thermal stresses may have to be considered.

Tendon loads include axial, bending, shear, torque, radial and hoop loads. While the tendon loads are primarily axial, other types of loads should also be evaluated, as appropriate, to assure adequacy of the design. Axial and bending stresses are to be combined in the evaluation of the maximum stresses in the tendon. Axial, bending and hoop stresses are to be considered in the evaluation of the adequacy of the tendons to withstand hydrostatic loads.

The minimum tendon bottom tension is to be positive for all intact conditions. For damage conditions, if the tendon minimum bottom tension is less than zero, both scenarios of tendon buckling and downstroke of the bottom flex element connector are to be evaluated. In addition, the tendon stresses resulting from reengagement of the bottom connector are to be evaluated. A static overload analysis may be required to show that the TLP does not rotate or heave to unlatch the tendons when a small overload is applied.

The tendon tension requirements under platform damaged conditions due to different flooding scenarios are described in 2.1.

4.1.5 Tendon Components

The adequacy of the tendon components such as top and bottom connectors, couplings, flex element, etc., are to be verified by detailed finite element analysis (FEA) and testing, where necessary, to support and validate the FEA. The loads for the finite element analyses are to be obtained from the tendon global analysis. Worst case analyses are to be run to quantify the effects of fabrication tolerances on fit-up and component stresses. Axisymmetric modelling may be used for FEA. Three-dimensional modelling is to be used to quantify three-dimensional effects in critically stressed areas, where appropriate. Von Mises equivalent stresses of net section stress and local bending stress are to be evaluated for critical sections. Peak stresses are to be evaluated for fatigue analysis of the components.

4.1.6 Installation Analyses

The effects which may be induced in the tendons during transportation, lifting and installation are to be considered in the design. If the tendons are pre-installed, analysis is to be carried out for the freestanding condition to verify structural stability and tendon interference.

4.1.7 Allowable Stresses

The allowable stresses of the tendons are to be in accordance with API RP 2T. The interaction between the net section stresses and local bending stresses is to be considered, where applicable.

The allowable stresses against hydrostatic buckling are to be in accordance with API RP 2A.

4.1.8 Fatigue Analysis

Fatigue damage calculations are to be carried out to verify the adequacy of the fatigue life of the tendon. The fatigue calculations are to consider all of the sea states expected over the lifetime of the tendons and any fatigue damage due to vortex-induced vibrations during the in-place and installation conditions.

Frequency domain or time domain analysis may be used to evaluate the tendon loads. The tendon fatigue loading is to consider total tendon stresses, including axial and bending stresses, due to wave frequency, low frequency and high frequency loads. Appropriate material S-N curves based on the lower bound of a two-sided 95 percent prediction interval are to be selected according to the material, welding detail and workmanship, level of quality control and level of cathodic protection. For the use of different S-N curves, please refer to the Guidance for the Fatigue Assessment of Offshore Structures (Pt.5, Vol.B). Appropriate stress concentration factors (SCF) for tendon pipe and components are to be determined based on parametric formulas or local finite element analyses considering local mismatch tolerances, geometry and loading.

For tendon receptacles and other components attached to the pile while it is driven, fatigue damage due to pile driving is also to be considered. Fatigue damage is to be accumulated using the linear Palmgren-Miner rule.

The minimum fatigue life of the tendon is to be ten (10) times the tendon service life.

4.1.9 Fracture Mechanics Calculations

The tendons are to have sufficient fracture toughness to prevent fracture unstable crack growth from surface, sub-surface or through-wall flaws under extreme design loads within a period less than five (5) times the tendon service life or tendon inspection period, whichever is less. Fracture mechanics analyses are to be performed in accordance with BS7910 or other equivalent standard to demonstrate that the smallest reliably detectable initial flaws will not grow by fatigue to a critical size for fracture failure within this period, where the preferred critical flaw is a through-thickness fatigue crack rather than a surface or sub-surface fatigue crack. Initial flaws of various aspect ratios and no threshold for fatigue crack growth ($\Delta K_{th} = 0$) are to be considered in these analyses.

4.1.10 Corrosion Protection

The tendons are to be protected from the effects of corrosion by the use of coatings and cathodic protection. The system is to be effective from the time the structure is initially installed. When the sea environment contains unusual contaminants, any special corrosive effects of such contaminants are also to be considered. For the design of coatings and cathodic protection systems, reference is to be made to the appropriate National Association of Corrosion Engineers (NACE) standards, such as SP0108 or SP0176 or other recognized standards.

4.2 Foundation

4.2.1 General

The primary function of the foundation system is to anchor the tendons to the seafloor. TLP foundation system may consist of individual piles directly attached to the tendons or template structures anchored by piles or a gravity base. TLP foundation design and site investigation requirements in general are to be in accordance with Rules for Structures (Pt.5, Vol.II), Sec.7. Detailed geological surveys, seafloor and sub-bottom geophysical surveys and geotechnical investigations are to be carried out for each TLP site. Special design considerations for foundation systems subject to tensile loading and in deep water sites are given in the following sections. Fabrication, transportation, installation and materials of foundation systems are also to be in accordance with Offshore Installation Rules.

4.2.2 Site Investigations

Requirements for site investigations are to be guided by the quality of data from prior site surveys and the consequence of foundation failure. For soil samples obtained from deep water sites, the measured properties under laboratory conditions may be different from in-situ values due to relief of hydrostatic pore

pressure and its associated effects on dissolved gases. Therefore, in-situ or special laboratory testing is required to determine soil properties for Deepwater sites. Since installation sites may be distant from areas for which extensive site data are available, regional and local site studies are to be carried out to adequately establish soil characteristics. A less extensive site investigation may be acceptable, provided that previous site investigation and experience are available.

TLP foundations experience upward static and dynamic loadings that are different from those typically experienced by the foundations of a jacket-type structure. In order to predict soil-structure interaction due to cyclic loading, soil tests are to be carried out to define the dynamic and cyclic behaviour of the soil. In addition, TLP foundations are subject to sustained tensile loads together with cyclic tensile load components, which can result in tensile creep of the foundation. Therefore, additional tests are to be carried out to determine long-term soil-pile response when subjected to these loadings. Consideration should be given to the performance of permeability and consolidation tests to assist in the evaluation of the soil-pile setup.

4.2.3 Foundation Design

The loadings used for the foundation design are to be obtained from the tendon analyses. The loads resulting from the extreme, normal, platform or tendon damaged and tendon removed conditions are to be considered in the foundation design. The application of the loads to the foundation system should also consider the foundation installation tolerances, as applicable.

The design of the foundation systems consisting of driven piles, in general, is to be in accordance with Rules for Structures (Pt.5, Vol.II), Sec.7. The axial capacity of piles subject to tension is to be equal to skin friction alone. In the evaluation of the axial capacity, consideration should be given to cyclic degradation about a sustained tension load, axial flexibility of the pile, the effects of sustained tension loading such as creep, group effects and the potential of near surface axial capacity reduction from gapping caused by lateral deflection, scouring or liquefaction.

Pile set-up analyses are to be carried out to evaluate the time required for the piles to gain the ultimate strength. The pile design penetration is to be determined based on the pile axial capacity at the completion of TLP installation. For the duration between the tendon hook up and completion of TLP installation, the adequacy of the piles capacity will be determined based on the project specifications.

TLP piles are subject to cyclic tensile loads during the life of the structure. Therefore, for TLP foundation systems, a fatigue analysis is to be carried out to evaluate the fatigue life. The fatigue analysis is to consider fatigue damage due to in-place loading, as well as fatigue damage during pile driving.

Pile installation analyses are to be carried out in accordance with API RP 2A. The effect of ocean currents on the freestanding portion of the pile and hammer are to be considered in these analyses.

The analysis of piled template structures and gravity-based structures is to be in accordance Rules for Structures (Pt.5, Vol.II), Sec.7, API RP 2T and API RP 2A.

The safety factors for TLP foundations are specified in Table 5.4.

Table 5.4 Safety Factors for Pile Foundation Design

Description	Safety Factors
Design Operating Condition	3,0
Design Environmental Condition	2,25
Tendon Removed with Reduced Extreme Condition	2,25
Foundation Fatigue Life w.r.t. Design Service Life	10

4.3 Analysis and Design of Other Major Structures

The analysis and criteria to be applied to the other pertinent features of the TLP structural design are to conform to recognized practices acceptable to BKI Head Office. For TLPs, there will be a need to consider in the hull and topside deck design: the interface between the tendon system and the hull, the interface between the riser system and the hull and the effects of structural support reactions from deck modules. The criteria to be applied for these cases are presented below.

4.3.1 Hull Interface with Riser System (Riser Porches, Supports and Guide)

The riser porches, guide and supports, including the hull backup structures (the reinforcements for the hull), are to be designed for the maximum anticipated riser loads with a safety factor of 1,25 in the Design Environmental Condition and with a safety factor of 1,67 in the Design Operating Condition.

Fatigue strength is to be designed to meet the requirements in 3.3.1.6.3), taking into account the effects of both local drag and inertia loads on the risers and the global motions of the TLP.

4.3.2 Hull Interface with Tendons (Tendon Porches)

The tendon porches, including the hull backup structures, are to be designed for the maximum anticipated tendon loads with a safety factor of 1,25 in the Design Environmental Condition and with a safety factor of 1.67 in the Design Operating Condition.

Fatigue strength is to be designed to meet the requirements in 3.3.1.6.3), taking into account the effects of both local drag and inertia loads on the tendons and the global motions of the TLP.

4.3.3 Topside Deck Interface with Deck Modules

The topside deck may require reinforcements to resist the reaction forces from equipment/machinery foundations or deck modules. The reinforcements of the topside deck are referred to as backup structures. The forces to be resisted by the backup structures of the topside deck are to be designed for the maximum anticipated load together with the inertia loads induced by the TLP motions with a safety factor of 1,25 in the Design Environmental Condition and with a safety factor of 1,67 in the Design Operating Condition. If deemed necessary, the fatigue strength is to meet the requirements of 3.3.1.6.3).

5. Materials and Welding

5.1 Materials and Welding

5.1.1 Hull Including Integrated Deck Structures

Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.3, C are to be used to establish the welding requirements for the hull. The weld type and sizing are to be shown on the scantling drawings or in the form of a welding schedule, and are to comply with the Rules that govern the steel selection. Special attention is to be given to the weld details for fatigue sensitive areas, if necessary. Weld improvements by means of toe grinding and weld profiling are to be used if required by fatigue analysis results.

Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.3, B is to be used for the material selections for the hull including integrated deck. The TLP hull structures are grouped into the following material application categories for the purpose of material grade selection:

Special Application Structure	Portions of topside deck which receive major concentrated loads Intersections of topside deck main truss members External brackets, portions of bulkheads, flats and frames which receive concentrated loads at main intersections of columns, topside deck, pontoons, column top frame, tendon porches and riser porches "Through" material used at main intersections of columns, topside deck, pontoons, column top frame, tendon porches and riser porches, which provide proper alignment and adequate load transfer "Through" material D7 at main intersections of columns, topside deck, pontoons, column top frame, tendon porches and riser porches, which provide proper alignment and adequate load transfer
Primary Application Structure	External shell structure of columns, pontoons, column top frame, tendon porches and riser porches Integrated topside deck main truss members – Bulkheads, flats and framing which provide local reinforcement or continuity of structure in way of main intersections, except where the structure is considered special application Bulkhead girders, decks that are designed to provide global strength to the TLP
Secondary Application Structure	Internal structure, including bulkheads and girders in columns, integrated topside deck, pontoons and top column frame, except where the structure is considered primary or special applications Decks of topside deck, except where the structure is considered primary or special applications

5.1.2 Non-integrated Deck Structures

Rules for Structures (Pt.5, Vol.II), Sec.3 can be used to establish the material selections and welding requirements for the truss deck of the topside. The deck structures are categorized into the following four groups, in association with the Charpy toughness test described in Rules for Structures (Pt.5, Vol.II), Table 4.6:

1) Deck lifting points, deck-to-hull cans
2) Major truss row girders, major truss row columns, major truss row bracing
3) Intermediate girders, intermediate bracing
4) Deck stringer beams, deck plating

Alternatively, Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.3, B may be used for material selections.

Note:

Items such as handrails, walkways, access platforms do not require the above material requirements.

6. Machinery and Systems

6.1 Marine Piping Systems

Marine piping systems are those systems that are required for maintaining the normal operations of a floating unit (such as power generation, bilge, ballast, tank vent and sounding, etc.). Systems installed in the hull are to be designed to minimize the requirements for equipment and machinery to be installed in hull compartments and to limit as much as possible systems requiring piping or cable runs in the TLP hull.

Marine piping systems are to be in accordance with the requirements of the Rules for Machinery Installations (Pt.5, Vol.IV), Sec.13, except as modified herein.

6.1.1 Bilge System

The design of bilge systems is to meet applicable requirements of Rules for Machinery Installations (Pt.5, Vol.IV), Sec.13. For the bilge suction sizing purposes, column-stabilized units and self-elevating units sizing criteria listed in Rules for Machinery Installations (Pt.5, Vol.IV), Sec.13 are applicable.

6.1.2 Ballast System

The system fitted is to provide the capability to ballast and deballast all ballast tanks. All pumps and valves are to be fitted with a remote means of operation situated above the uppermost watertight deck. The capabilities of the pumping system are to meet the requirements of APR RP 2T. The normal or emergency operation of the ballast system is not to introduce a greater risk of progressive flooding due to the opening of hatches, manholes etc. in watertight boundaries.

.1 Pumping Systems

Where ballast systems powered by pumping systems are installed, at least two ballast pumps are to be provided, one of which is to be permanently connected to the installation's ballast system. The second pump may be a spare held in reserve or an eductor type arrangement permanently connected to the system. If submersible ballast pumps are installed in each ballast tank, one spare pump must be stored onboard at all times.

.2 Compressed Air Systems

Where ballast systems powered by compressed air are installed, a satisfactory quantity of compressed air is to be available to the system at all times. If two compressors are installed, one compressor is to be powered by either the emergency switchboard or a dedicated engine. Each compressor is to be capable of providing 100% of the required capacity of compressed air, as defined in 1). If only one compressor is provided, this compressor is to be powered by either the emergency switchboard or a dedicated engine, and a quantity of stored compressed air equivalent to the required capacity called out in 1). is to be provided.

1) Quantity of Compressed Air. A quantity of air capable of bringing the installation from its worst case damage or accidental flooding condition, as defined by 2.1.1, to normal operating tension.

6.1.3 Vents and Sounds

Except for comparatively small compartments that are not fitted with a fixed means of drainage, vent pipes are to be fitted on all tanks, cofferdams, voids, tunnels and compartments which are not fitted with other ventilation arrangements.

The requirements for sounding are to comply with the Rules for Machinery Installations (Pt.5, Vol.IV), Sec.13. However, to prevent duplication of pipe runs, it would be acceptable to sound the void spaces through the vent lines. In the case of a sealed vent, a sounding plug would need to be provided to permit void space sounding.

6.1.4 Hydrocarbon Storage in Hull Tanks

If the TLP is designed to store hydrocarbons in hull tanks, criteria for hull storage of hydrocarbons are to meet flag and coastal state requirements and applicable international requirements. The designs for scantlings and strength for such storage tanks are to be in accordance with 3.2 and 3.3. See the Rules for Facilities Offshore Installations (Pt.5, Vol.XII), Sec.3, E.3.5 for the storage facility arrangement requirements.

6.2 Electrical Systems

The design criteria of electrical systems associated with marine systems (and drilling systems) are to be in accordance with applicable requirements described in Rules for Machinery Installations (Pt.5, Vol.IV) and Rules for Electrical Installations (Pt.5, Vol.V).

The design criteria of electrical systems strictly devoted to the hydrocarbon processing facilities are to be in accordance with applicable requirements described in Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3.

The design criteria of electrical systems associated with both marine systems and hydrocarbon processing facilities are to be in accordance with the applicable requirements described in Rules for Machinery Installations (Pt.5, Vol.IV) and Rules for Electrical Installations (Pt.5, Vol.V).

6.3 Fire Fighting Systems and Equipment

The fire fighting systems and equipment for the TLP service functions not associated with the process facilities are to be in accordance with Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.10, C. Fire fighting systems and equipment for protection of hydrocarbon process and associated systems, including fire pumps, are to be in accordance with Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, H.

6.4 Machinery and Equipment

Machinery and equipment not associated with the process facilities are to be in accordance with the applicable requirements of Rules for Machinery Installations (Pt.5, Vol.IV). Machinery and equipment forming a part of the hydrocarbon processing facilities are to be in accordance with the applicable requirements of Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, C. Machinery and equipment forming a part of the permanent drilling facility are to be in accordance with Rules for Machinery Installations (Pt.5, Vol.IV).

C. Spar Installations

1. General Requirements

1.1 General

A Spar is a deep draft installation consisting of a hull and a topside deck, where the topside deck sits on top of the hull. The hull can be divided into upper hull, mid-section and lower hull, as described in the following Subsection. The topside deck is a space frame truss deck that provides space for the production equipment, work over or drilling rig (if any), accommodations and marine support systems, and supports the loads of this equipment, including operational loads.

The design and construction of the hull are to be based on all applicable requirements of the Rules for Mobile Offshore Units (Pt.5, Vol.VI). The design and construction of topside deck are to be based on Pt.5, Offshore Technology. However, the structural performance and demand of a Rules for Mobile Offshore Units (Pt.5, Vol.VI) in ocean service are different from those of a Spar positioned at a particular site on a long-term basis. Therefore, the design criteria given in the MOU Rules can be modified to reflect the differences. In addition, in the absence of equivalent Coastal State requirements, the applicable criteria contained in the Load Line, SOLAS and MARPOL Conventions issued by the International Maritime Organization (IMO) may be considered. It is further suggested that the local authorities having jurisdiction where the installation is to operate be contacted to obtain any further criteria that are applicable to the Spar installations.

1.2 Definitions

1.2.1 Upper Hull – Hard Tank

The Upper Hull is also known as the Hard Tank, which serves to provide buoyancy to support the topside deck and provide spaces for variable ballast and in some cases for diesel oil, drill water, or methanol storage. The Spar Deck is the uppermost deck of the hard tank.

1.2.2 Mid-section – Truss Space Frame with Heave Plates or Free Flooded Cylindrical Column

The Mid-section connects the upper hull with the lower hull. The mid-section can be a truss space frame with heave plates or a cylindrical column. Normally, the cylindrical column mid-section is free flooded and the truss space frame is buoyant. The heave plates are a series of horizontal decks between each bay of the truss space frame that trap water mass providing added mass and hydrodynamic damping to limit heave motions and act as guides for the risers.

1.2.3 Lower Hull – Soft Tank (or Keel Tank)

The Lower Hull, also known as the Soft Tank (or Keel Tank), normally consists of a fixed ballast tank and, in the case of a truss Spar, a flotation tank. The fixed ballast tank provides temporary buoyancy during a horizontal wet tow and provides the needed ballast in upending by flooding the tank. After upending, the ballast water may be replaced by fixed ballast (a substance with a density higher than water) to lower the Spar center of gravity. The ballast in the fixed ballast tank results in a vertical center of gravity well below the center of buoyancy, which provides Spar with sound stability, as well as motion characteristics. The flotation tank is located adjacent to the fixed ballast tank to provide additional buoyancy for wet tow and ballast in upending.

1.3. Loading Criteria

1.3.1 Loads

The Spar's modes of operation in pre-service (load-out, transportation, installation) and in-service (inplace) conditions are to be investigated using anticipated loads, including gravity loads together with relevant environmental loads due to the effects of wind, waves, current and other phenomena such as earthquake, temperature, fouling, ice, etc., depending upon the specific installation site.

The Spar is to be designed for the loading conditions that produce the most severe local and global effects on the structure, as determined by the most severe operational or installation requirements. Applied loading combinations considered for structural design are to include, as applicable, but not limited to the following loads:

1) *Environmental Loads*. Loads due to wind, waves and current are to be considered. Directionality of wind, waves and current may be considered if accurate data is available. Where there is no accurate data available, the directionality of wind, waves and current that generates the most severe local and global load effects are to be used for design. Adequate headings for the environment are to be analyzed such that the most critical heading for the environment has been covered.
2) *Hydrostatic Pressures and Buoyancy*. Hydrostatic pressures and buoyancy are to be considered for all submerged structural members.
3) *Gravity and Inclination Induced Loads*. Gravity with appropriate components due to Spar heeling and trimming is to be considered.
4) *Inertia Loads*. Inertia Loads due to motions of the Spar are to be considered.
5) *Operational Loads*. Loads induced by operations of drilling, production, storage and offloading, as applicable, are to be considered.

6) *Mooring and Riser Loads*. Loads due to mooring and riser systems are to be considered.

7) *Marine Operation Loads*. Loads encountered during transportation and installation are to be taken into account in the design. These loads include loads exposed during transport (wet or dry), launch or float-off, upending, and during ballasting and deballasting operations when the deck is being installed.

8) *VIV Loads*. Vortex-Induced-Vibration (VIV) is incurred by vortex shedding behind slender bodies and the Spar hull itself in current. Loads and fatigue strength are to be fully assessed for structures and the mooring system subject to VIV effects.

9) *Green Water Loads on Spar Deck*. Green water effects are to be considered for the strength of affected structures on the top of the hull, as applicable.

10) *Slamming*. Wave slamming loads are to be considered for members subject to wave slamming during transportation and operation.

1.3.2 Environmental Conditions

The Spar is to be designed to withstand a specified extreme storm in the Design Environmental Condition and operate in the Design Operating Condition. The environmental conditions required for these conditions are defined in Section 6, B.1.1.2 and Section 6, B.1.1.3 and the environmental criteria required for these design conditions are defined in Section 2, B.4. Additionally, the spar is also to be designed for all operations in pre-service conditions such as load out, transportation and installation. The environmental conditions for load out and installation are to be specified by the designers or Owners. The environmental conditions for transportation is to be of a 10-year return event of the selected transit route, unless a weather routing plan is implemented for the voyage.

In the design of the Spar in-service and pre-service strength, the following environmental conditions are to be considered:

- **Design Environmental Conditions (DEC).** Please refer to Section 6, B.1.1.2. For structural strength design, environmental conditions that produce the responses having a minimum return period of 100 years are to be used.
- **Design Operating Conditions (DOC).** Please refer to Section 6, B.1.1.3. For structural design, environmental conditions that produce the responses having a minimum return period of 1 year are to be used.
- **Reduced Extreme Conditions (REC).** Environmental conditions that have a low probability of being exceeded when the hull is damaged. For structural strength design, joint statistics may be used to determine a return period which, combined with the probability of damage, produces a risk level equal to that of the Design Environmental Conditions (DEC).
- **Calm Conditions.** Environmental conditions such that the effects of wind, waves and current are insignificant and can be ignored. Where such a situation exists, the design case is permitted to use calm conditions.

1.4 Global Performance Analyses

1.4.1 General

Global performance analyses of a Spar are aimed at determining the global effects of environmental loads on the overall platform and its components. The principal scope of the analyses includes calculation of external loads for global structural analysis for in-place condition and critical pre-service conditions, as well as analysis/confirmation of:

1) Hydrodynamic loads, shear forces and bending moments for global strength analyses

2) The Spar in-place motions and accelerations, including those for the structural design of the deck structure and topside modules, hull appurtenances, and those for risers and mooring lines
3) The Spar freeboard and deck clearance.

The hydrodynamic models used in the global performance analysis may include:

1) Diffraction equation or simulated diffraction equation using Morison members for cylindrical sections
2) Morison equation for truss element and external hull appurtenances (with well documented drag coefficients C_d and inertia coefficients C_m)
3) Computational fluid dynamics, diffraction theory, and/or model test of multiple heave plate, or simulated using Morison members with C_d and C_m computed by CFD/Diffraction theory

Global motions of a Spar are quite different from traditional offshore floating structures due to the deep draft of the Spar. The vertical modes of motions, i.e., pitch, roll and heave of the Spar are important design parameters for deriving inertia loads and are to be included in the mooring analysis due to the increased line tensions induced by vertical motions of the Spar. Among these, the effects due to rotational modes are more pronounced. The static rotational modes of motions are due to the mean loads of wind, current and waves, while the low frequency rotational modes of motions are induced by the slowly varying low frequency waves, wind and current excitations. The motion responses of the Spar in six degrees of freedom are usually solved in a time domain analysis for the nonlinear effects described below. Hydrodynamic coefficients, except the drag coefficients used in a time-domain analysis, are usually taken from frequency domain wave diffraction/radiation calculations. For classic spars, C_d for heave will significantly impact the heave motions and needs to be carefully chosen, accounting for the potential damping, drag from the bottom as well as from the strakes and other hull appurtenances. Both industry-recognized software and in-house software may be used for the analyses. In-house software needs to be adequately calibrated against model tests or industry-recognized software.

1.4.2 Frequency Domain Analyses

Frequency domain analyses include the six degrees of freedom analysis of a Spar system in wave frequency range for motion Response Amplitude Operators (RAOs) and hydrodynamic coefficients such as wave exciting forces and moments, added masses and moments of inertia, and radiation damping. The hydrodynamic coefficients are to be passed to time domain analysis for the prediction of installation motions and mooring line tensions with the combined effects of wave frequency and low frequency excitations.

1.4.3 Time Domain Analyses

For a Spar, due to nonlinear effects and large displacements in surge/sway and pitch/roll motions, a time domain analysis is generally required in order to obtain more accurate loads and global motion responses for the design.

The nonlinear effects include hull drag forces, finite wave amplitude effects, nonlinear restoring forces from mooring lines and risers, Vortex-Induced Motions (VIM), dynamics of heave plates and coupling effects. For deep-water applications, a time domain analysis of fully coupled motions of the Spar hull, mooring lines and risers is desirable. The most probable maximum response is to be predicted using adequate simulations and appropriate distribution curves fitted to the simulation results or other recognized statistical techniques. The most critical SCR and/or TTR cases are to be included in the loading conditions of the analysis. Typically, it is recommended that at least five simulations with different seeds for a storm duration of three hours each are to be conducted. In the time domain analysis, relevant wave and wind spectra are to be transferred to random time series in order to simulate irregular wave elevations and wind gustiness.

1.4.4 Maximum Inclination

The maximum angles of inclination in the storm survival, operating, and damage conditions in applicable DOC or DEC environment (see 2.1.3.1) are to be established with consideration of the following:

1) Static and dynamic inclination limits of equipment and machinery on board the installation
2) Strength of the mooring system, risers and umbilicals

Inclinations may be determined based on model tests or analytical methods.

1.4.5 Deck Clearance

A clearance is to be maintained between the lowest point of the topside deck and the highest point on the wave surface. The clearance can be determined by an appropriate model test or a detailed hydrodynamic analysis that accounts for relative motions between the Spar and wave surfaces. The analysis is to be performed for various environmental headings and to include static heeling due to mean wind, wave, current loads (including long period oscillations), mooring and riser loads, nonlinearity of wave profile, wave diffraction, wave run-up, hull set down and tide elevation effects. The clearance is to be checked at various points on the underside of the topside deck for all of the relevant environmental conditions.

If wave impact on the underside of the lower deck is anticipated, local strengthening of these members is required. Structures and equipment subject to wave run-up or green water are to be designed for the associated forces.

1.4.6 Model Testing

Model testing can be used to calibrate analytical tools. It may also be an alternative for analytical tools. Whenever analytical tools have difficulties or a significant level of uncertainty in determining hydrodynamic properties such as wind and current drag force coefficients (C_d), heeling moments, etc., wind tunnel tests are preferred. In addition, wave basin testing may be carried out to evaluate the Spar performance, including deck clearance, in-place motion and mooring responses, VIM effects, horizontal tow, upending and vertical tow.

Adequate heading angles and wind profiles are to be considered in wind tunnel testing. For wave basin tests, a calibration analysis may be required to correlate the results obtained from the model tests with the software being used for different analyses.

1.5 Corrosion Protection and Control

A corrosion protection and control system utilizing anodes and coating, in accordance with the recognized industry standards such as API and NACE, is to be provided. The design life of the corrosion protection and control system is to be the design life of the Spar. In the splash zone, a corrosion allowance is to be added to the external shell plating.

2. Stability

2.1 Stability

2.1.1 Wet Tow

Stability during wet tow to location is to comply with Coastal State requirements.

2.1.2 Installation

After the upending and during the installation phase, the installation is to have a positive metacentric height (GM). If the installation is to accommodate personnel during the installation and commissioning the installation's stability are to fully comply with in-service stability specified on 2.1.3. The installation analysis is to be submitted for review.

2.1.3 In-Service Stability

The stability calculations are to reflect the actual configuration of the spar while afloat. Free flooding compartments are not accounted for in assessment of the installation's stability. In case the permanent ballast is installed in a free flooding compartment, the net weight of the permanent ballast (using the in water density) is to be included in the loading calculation.

.1 Environmental Loads

Installations are to comply with the intact and damage stability criteria presented below, using the site-specific wind or 50 knots (25,7 m/s), whichever is greater. Height profile is to be taken from the MOU Rules or other recognized standard.

1) Wind speed for normal operations V n – the 1-year, 1-minute average wind in the DOC as defined in 1.3.2
2) Wind speed for storm survival V s – the 100-year, 1-minute average wind in the DOC as defined in 1.3.2
3) Wind speed for survival after damage V d – the 1-year 1-minute average wind in the DOC as defined in 1.3.2
4) Current Speed – The current at surface associated with the adopted wind speed as defined above.

The design wind and current velocities are to be selected by the designer and submitted with the design documentation.

.2 Heeling Moment

Heeling moments represent an idealization of the total environmental force on the installation. For purposes of stability calculations they are taken as the moments, which result from wind forces on the installation at the speeds specified in 2.1.3.1 and calculated in accordance with Section 2, B.4.4.1.

For each draft of the designated range of operating drafts, the wind heeling moment is to be calculated assuming the installation in the upright position for all directions. The critical wind direction is the direction that produces the greatest wind heeling moment. The analysis will assume this determined critical wind heeling moment acting in all directions and constant over the range of inclination angles.

The lever for the heeling moment is to consider the wind center of pressure and the attachment point of the mooring lines. In case that the current force increases the heeling moment, the adverse effect of the current is to be considered in the heeling moment lever calculation. The current force on the hull is to be calculated as shown in Section 2, B.4.3.

Heeling force and center of pressure derived from wind tunnel tests on a representative model of the installation may be considered alternatively. The wind profile to be adopted for wind tunnel tests is defined on Section 2, B.4.5.1 or a more conservative profile.

.3 Stability Criteria

The installation is to meet stability requirements of this subparagraph for each mode of operation at all drafts in design. Other standards may be acceptable during abnormal operations, with due consideration

to the hazards associated with the operation. Such operations and standards are to be submitted for approval.

The installation is to have positive metacentric height (GM) in calm water equilibrium position and the vertical center of buoyancy is to be above the height of center of gravity in all conditions.

1) Intact Stability Criteria.

The area under the righting moment curve at 30 degrees is to reach a value of not less than 30% in excess of the area under the overturning moment curve to the same limiting angle. In all cases, the righting moment curve is to be positive over the entire range of angles from upright and all downflooding angles are to be greater than 30 degrees.

2) Damage Stability Criteria.

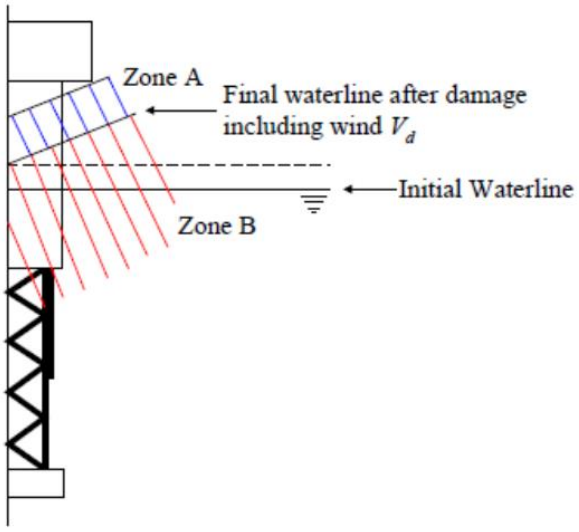
After damage by collision or accidental flooding as described in A) and B) respectively, the unit is to meet the following criteria:

The final waterline, after damage with a wind speed V_d, is not to exceed the level of watertight integrity and is to be 1,5 m below any unprotected opening that could lead to further flooding of the hull or the lowest point of the hull upper deck, whichever is lower.

A) *Collision Damage*. Damage is assumed to be 3 m wide and 3 m high with a horizontal penetration of 1,5 m inboard of the hull plating. This extent of damage is to be considered at all levels between 3 m below to 5 m above the waterline in consideration.

Where a watertight flat is located within this zone, the damage is to be assumed to have occurred in both compartments above and below the watertight flat in question.

The distance between effective watertight bulkheads or their nearest stepped portions which are positioned within the assumed extent of horizontal penetration is to be not be less than 3 m. Where there is a lesser distance, one or more of the adjacent bulkheads are to be disregarded.



Zona A: (Minimum 1,5 m above final waterline after damage with wind (V_d) – Zone of weathertight integrity

Zone B: (Below final waterline after damage with

Fig. 5.1 Zones of Weathertight and Watertight Integrity

B) *Accidental Flooding*. Any compartment at or below the waterline in consideration is to be assumed independently flooded, regardless of exposure and source of the assumed flooding.

When access openings are fitted on watertight divisions between compartments to provide access to one or more compartments, the compartments are to be assumed flooded

simultaneously. Multiple compartment flooding may be dispensed, provided the following measures are taken to avoid operations that can result in the accidental flooding of such compartments when the covers are removed:

- Warning (or Notice) plates, e.g., "Watertight Door (or Hatch) – Keep closed" are placed on the access opening covers.
- Instructions and warnings are provided in the operations manual.
- System locks are available to prevent unintentional ballasting operations, where either compartment designed for ballast tank.
- The compartment can be pumped or blown dry without removal of the access cover.

The operations manual is to include guidance for operating personnel in determining the cause of unexpected inclination or draft changes and assessing the potential effects of corrective measures on stability and buoyancy.

2.1.4 Lightweight and Center of Gravity

The lightweight and center of gravity of the installation are to be established by a combination of a hull lightweight survey, measurement of permanent ballast and weighing of the major components. There are to be at least two (2) separate measures of the permanent ballast.

A global weight verification plan is to be submitted. Procedures for the lightweight survey, each weighing, and permanent ballast measurement are to be submitted for approval and are to include estimates of weight and center of gravity. An BKI surveyor is to attend each activity.

When weighing components, these parts are to be as complete as possible with not more than 2% of the weight of the component remaining to be incorporated.

The result of each weight verification activity is to be compared to the estimated weight. When the measured weight is within ±1% of the estimated weight, the vertical center of gravity is to be the estimated value in the calculation. When it is outside the 1% tolerance, the vertical center of gravity is to be computed by taking the difference between the estimated and the measured weight and placing it at an indisputably conservative location.

Reports of the results of each weight verification activity are to be submitted for review. An overall lightweight calculation, considering all individual approved lightweight components, is to be submitted for review.

Alterations in the lightweight data during service (e.g., new equipment, structural modifications) are to be recorded in the operation manual and be taken into account in daily operation.

2.2 Watertight/Weathertight Integrity

A plan, identifying the disposition (open or closed) of all non-automatic closing devices and locations of all watertight and weathertight closures, and unprotected openings is to be submitted for review prior to the unit's delivery. Upon satisfactory review the plan is to be incorporated into the Operating Manual.

2.2.1 Weathertight Integrity

External openings whose lower edges are below the levels to which weathertight integrity is to be ensured are to have weathertight closing appliances. Openings fitted with appliances to ensure weathertight integrity are to effectively resist the ingress of water due to intermittent immersion of the closure.

2.2.2 Watertight Integrity

All internal and external openings whose lower edges are below the levels to which watertight integrity is to be ensured, as shown by the diagrams submitted in accordance with 2.2, are to be fitted with appliances to ensure watertight integrity.

.1 Internal Openings

Internal openings fitted with appliances to ensure watertight integrity are to comply with the following.

1) Doors and hatches are to be of the quick-acting type and an indicating system (e.g., light signals) is to be provided showing personnel, both locally and at a normally manned central position, whether the doors or hatches in question are open or secured closed. In addition, a sign is to be posted near the opening to the effect that the closing appliance is to be secured closed and opened only during actual use. If sliding doors are fitted they are to be capable of being remotely controlled from a normally manned central position as well as being operable locally from both sides of the bulkhead.
2) Manholes fitted with bolted covers need not be dealt with as under 1).
3) The closing appliances are to have strength, tightness and means for securing which are sufficient to maintain watertightness under the water pressure of the watertight boundary under consideration.

.2 External Openings

External openings are to comply with the following.

1) The lower edges of all openings, including air pipes, ventilators, ventilation intakes and outlets (regardless of closing appliances), non-watertight hatches and weathertight doors, are to be above the levels to which watertight integrity is to be ensured.
2) Manholes fitted with bolted covers need not be dealt with as under 1).
3) External openings fitted with appliances to ensure watertight integrity are normally to be secured closed and are to comply with the requirements of 2.2.2.1.

2.2.3 Penetrations

Where watertight bulkheads and flats are necessary for damage stability, they are to be made watertight throughout. Where individual lines, ducts or piping systems serve more than one compartment or are within the extent of damage, satisfactory arrangements are to be provided to preclude the possibility of progressive flooding through the system. Valves fitted at watertight boundaries are to be operable from above the top of the spar hull.

Cable penetrations are to be installed in accordance with the manufacturer's specifications and procedures. Evidence of prototype testing at the water pressure of the watertight boundary under consideration is to be provided.

During installation of deck and bulkhead watertight and fire-rated cable penetrations, the attending Surveyor is to confirm that the installer is familiar with and has access to the manufacturer's installation procedures for stuffing tubes, transit devices or pourable materials.

After installation, all watertight and fire-rated cable penetrations are to be visually examined. Watertight cable penetrations are to be tested as required by Rules for Classification and Surveys (Pt.1, Vol. I), Table A2.3.

3. Hull and Primary Structures

3.1 Structural Design

The structural design criteria specified in this Section is presented in the Working Stress Design (WSD) format, also known as the Allowable Stress (or Strength) Design (ASD) format. Alternative structural design criteria are provided in the Rules for Structures (Pt.5, Vol.II), Sec.3, B.

3.1.1 Scantlings

The design of the Spar is to be based on the applicable portions of the Rules for Mobile Offshore Units (Pt.5, Vol.VI). Where the conditions at the installation site are less than those for full ocean service that are the basis of the Rules for Mobile Offshore Units (Pt.5, Vol.VI), the design criteria for various components of the Spar may be reduced to reflect these differences. However, when the installation site conditions produce more arduous demands, it is mandatory that the design criteria be increased appropriately. The Spar strength can be obtained by initially designing each component's scantlings for local load effects and subsequently verifying the initial scantlings for the global load effects.

This subsection provides requirements for the designs of initial scantlings and secondary structures. Requirements for verification of the initial scantlings are provided in 3.3.

3.1.2 Scantling Design of the Hull Structure

Scantlings of the hull are to be designed in accordance with 3.2.

3.1.3 Modules and Buildings on the Topside Deck

The structural design of modules and buildings on the topside deck is to be in accordance with 3.3.2, wherever applicable. The relative deformations among module and building supports are to be included in the analysis if their effects on the module are significant.

The module and building supporting structures on the topside deck are to be analyzed and shown explicitly on the drawings so that the construction of the module and building supports can be consistent with those assumed in the structural analysis. Means are to be provided to verify that the module and building design reactions and conditions are identical with those used in the topside deck design.

The structural fire protection aspects of the design of topsides modules and buildings, including the arrangement of the hydrocarbon process area, are to be in accordance with Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, H. The designs of the piping system on the topside deck are to comply with Rules For Machinery Installations (Pt.5, Vol.IV), Sec.13 and applicable requirements of the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII).

3.1.4 Helicopter Deck

The design of the helicopter deck is to comply with the requirements of Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.4, E.

3.1.5 Protection of Spar Deck Openings

All openings on the Spar deck are to comply with Rules for Hull (Pt.1, Vol.II), Sec.1, H.6.7 and 17.

3.1.6 Guards and Rails

Guards and rails are to comply with the requirements of Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.3, H. The above mentioned section is to be used for the perimeters of the Spar, including the hull,

topside deck and centre well on the Spar deck. Alternative arrangements, such as a minimum 42-inch high and two tier evenly spaced handrail with a kickboard, may be considered by BKI, provided they are also acceptable to the local authority.

3.1.7 Machinery and Equipment Foundations

Foundations for machinery or equipment subject to high concentrated or cyclic loading, such as mooring winches, fairleads, chain stoppers, riser guides, riser tensioner supports, crane and drilling facilities, if applicable, are to be designed to provide satisfactory strength and fatigue resistance for the reaction forces specified by the manufacturer or the maximum anticipated loads during the entire service life of the Spar, in accordance with safety factors outlined in 3.3.1. The global load effects and Spar motion-induced inertia loads are also to be considered in addition to the reaction forces. The backup structures and reinforcement on hull or topside deck are also to be designed for the same loads and safety factors, as a minimum.

3.1.8 Vortex Shedding Strakes

Vortex shedding strakes are designed to reduce the VIM effects on the Spar hull. Yield, buckling and fatigue strengths of vortex shedding strakes are to be checked, taking into account the effects of local drag and inertia loads together with the effects of global motions.

3.1.9 Appurtenances

Main appurtenances attached to the exterior of the hull are to be evaluated, taking into account the effects of local drag and inertia loads together with any appropriate consideration of global action of the Spar and the VIM effect. The backup structures are also to be designed for the same loads and safety factors, as a minimum.

3.1.10 Temporary Structures

Structures built for temporary use in the pre-service conditions are not subjected to BKI review. However, the arrangements and details of these structures are to be submitted for reference to verify the adequacy of the local and global strength of the hull and topside deck to support these temporary structures during operation in the pre-service condition. The backup structures are to be designed for the safety factors outlined in 3.3.1.

3.2 Scantling Design of the Hull Structure

The initial scantling design of the hull is to be based on the applicable portions of the Rules for Hull (Pt.1, Vol.II) and Rules for Structures (Pt.5, Vol.II). The aspects that are not covered by these Rules are to be based on the recognized codes and standards. For curved shells, the minimum scantlings of shell girders are to be determined on the basis of established shell analysis methods, using the heads given in 3.2.1 and safety factors appropriate to the method employed. As a minimum, a detailed local analysis is to be performed, with failure modes meeting the criteria in 3.3.1.6.

3.2.1 Hull Structure

.1 Upper Hull – Hard Tank

Where the external components of the hard tank, such as external shell, centre well bulkheads and top (Spar deck) and bottom decks, incorporate stiffened plating, the minimum scantlings of plating, stiffeners, girders, etc. may be determined in accordance with the requirements for tanks as given in 3.2.1.5, in association with the following heads:

1) **Tank Spaces.**

Where the internal space is a tank space, the head, h, is to be taken:

A) To a point located at two-thirds of the distance from the top of the tank to the top of the overflow,

B) To a point 0,91 m above the top of the tank, or

C) To a point representing the maximum permissible operating draft, including offset operation draft.

For tanks intended to carry contents with a specific gravity in excess of 1,05, the head, h, is to be increased by a factor equal to the ratio of the specific gravity to 1,0.

2) Void Compartment Spaces.

Where the internal space is a void compartment or a tank without liquid in it, the head is to be taken to a point representing the maximum permissible operating draft.

A) *Areas Subject to Wave Immersion*. For all areas subject to wave immersion, the minimum head is to be 6,1 m.

B) *Minimum Scantlings*. The scantlings of the external boundary are also to be designed as watertight boundary using 3.2.1.4, in association with

– A head to the maximum damaged waterline, or

– A head to a point representing the installation draft.

Where the interior boundaries of the hard tank, such as radial bulkheads and other bulkheads and flats that separate two tank spaces, incorporate stiffened plating, the minimum scantlings of plating, stiffeners, girders, etc. may be determined in accordance with the requirements for the tank spaces of the hard tank, as given in 3.2.1.5.

Where the interior boundaries of the hard tank, such as radial bulkheads and other bulkheads and flats that separate two void spaces, incorporate stiffened plating, the minimum scantlings of plating, stiffeners, girders, etc., may be determined in accordance with the requirements for watertight bulkheads and flats, as given in 3.2.1.4, in association with a head to the maximum damaged waterline.

.2 Mid-Section – Free Flooded Column and Truss Space Frame with Heave Plates

1) Free Flooded Column

Where the external components of the mid-section incorporate stiffened plating, the minimum scantlings of plating, stiffeners, girders, etc. may be determined in accordance with the requirements for tank bulkheads and flats as given 3.2.1.5, in association with the maximum anticipated hydrostatic and hydrodynamic pressures during the wet tow and in the in-place conditions.

2) Truss Space Frame with Heave Plates

The scantlings of the chords and braces of the truss frame may be initially determined in accordance with API RP 2A for the hydrostatic collapse requirements, in association with the installation and maximum operating drafts.

Where the components of the heave plates incorporate stiffened plating, the minimum scantlings of plating, framing, girders, etc., may be determined in accordance with the requirements for tank bulkheads and flats, as given in 3.2.1.5, in association with the maximum anticipated pressures in wet tow, upending and in the in-place conditions.

.3 Lower Hull – Fixed Ballast and Flotation Tank

Where the components of the fixed ballast and flotation tanks incorporate stiffened plating, the minimum scantlings of plating, stiffeners, girders, etc., may be determined in accordance with the requirements for tank bulkheads and flats, as given in 3.2.1.5, in association with the following:

1) The maximum anticipated hydrostatic pressures in wet tow and upending, and

2) Equivalent hydrostatic head due to fixed ballast weight.

.4 Watertight Boundary Formula

1) Plating

The plating thickness of watertight boundaries is not to be less than that obtained from the following equation:

$$t = \mathbf{a} \cdot c_k \frac{\sqrt{k \cdot h}}{290} + 1{,}5 \quad [mm]$$

but not less than 6 mm or $\frac{\mathbf{a}}{200} + 2{,}5$ [mm], whichever is greater.

where

t = thickness [mm]

a = spacing of stiffeners [mm]

$c_k = \frac{3{,}075 \cdot \sqrt{\alpha} - 2{,}077}{\alpha + 0{,}272}$ for $1 \le \alpha \le 2$

$= 1{,}0$ for $\alpha > 2$

α = aspect ratio of the panel (longer edge/shorter edge)

$k = \frac{235}{R_{eH}}$

R_{eH} = specified minimum yield point or yield strength [N/mm^2]

h = distance [m], from the lower edge of the plating to a point defined in 3.2.1.1 through 3.2.1.3

2) Stiffeners and Beams.

The section modulus, W, of each bulkhead stiffener or beam on a watertight flat, in association with the plating to which it is attached, is not to be less than that obtained from the following equation:

$$W = 7{,}8 \cdot k_s \cdot c \cdot h \cdot \mathbf{a} \cdot \ell^2 \quad [cm^3]$$

$$k_s = \frac{49{,}92}{R_{eH} + 2 \cdot \frac{U}{3}}$$

where

c = 0,56 for stiffeners with ends attached

= 0,60 for stiffeners with no end attachment

h = distance [m], from the middle of ℓ to a point defined in 3.2.1.1 through 3.2.1.3

a = spacing of stiffeners [m]

ℓ = length of stiffeners [m]; where brackets are fitted with a slope of approximately 45 degrees and thickness given in Table 5.1, the length of ℓ maybe measured to a point on the bracket equal to 25% of the length of the bracket.

R_{eH} = specified minimum yield strength [N/mm^2]

U = specified minimum tensile strength of the higher-strength material [N/mm^2]

3) **Girders and Webs.**

The section modulus, W, of each girder or web is not to be less than that obtained from the following equation:

$$W = 4{,}7 \cdot k_s \cdot h \cdot \mathbf{a} \cdot \ell^2 \quad [cm^3]$$

where

h = distances [m], from the middle of the area supported to a point defined in 3.2.1.1 through 3.2.1.3

a = sum of half lengths [m] (on each side of girder or web), of the stiffeners or beams supported

ℓ = length [m], between supports, where brackets are fitted at shell, deck or bulkhead supports, and the brackets are in accordance with Table 5.1 and have a slope of approximately 45 degrees, the length ℓ may be measured to a point on the bracket located at the distance from the toe equal to 25% of the length of the bracket.

k_s = factor defined in 3.2.1.4.2)

.5 **Tank Boundary Formula**

1) **Plating**

Plating is to be the thickness derived from the following equation:

$$t = \mathbf{a} \cdot c_k \frac{\sqrt{k \cdot h}}{254} + 2{,}5 \quad [mm]$$

but not less than 6,5 mm or $\frac{\mathbf{a}}{150} + 2{,}5$ [mm], whichever is greater.

where,

t = thickness [mm]

a = spacing of stiffeners [mm]

$c_k = \frac{3{,}075 \cdot \sqrt{\alpha} - 2{,}077}{\alpha + 0{,}272}$ for $1 \le \alpha \le 2$

$= 1{,}0$ for $\alpha > 2$

α = aspect ratio of the panel (longer edge/shorter edge)

$k = \frac{235}{R_{eH}}$

R_{eH} = specified minimum yield point or yield strength [N/mm^2]

h = distance [m], from the lower edge of the plating to a point defined in 3.2.1.1 through 3.2.1.3

When the specific gravity of the liquid contents of a tank is greater than 1,05, the head, h, specified above, is to be increased by a factor equal to the ratio of the specific gravity to 1,0.

2) Stiffeners and Beams

The section modulus, SM, of each bulkhead stiffener or beam on a flat, in association with the plating to which it is attached, is not to be less than that obtained from the following equation:

$$W = 7{,}8 \cdot k_s \cdot c \cdot h \cdot \mathbf{a} \cdot \ell^2 \quad [cm^3]$$

where

c = 0,9 for stiffeners having clip attachments to decks or flats at the ends or having such attachments at one end with the other end supported by girders

= 1,0 for stiffeners supported at both ends by girders

h = distance [m], from the middle of ℓ to a point defined in in 3.2.1.1 through 3.2.1.3

a = spacing of stiffeners [mm]

ℓ = length [m], between supports; where brackets are fitted at shell, deck or bulkhead supports, and the brackets are in accordance with Table 5.1 and have a slope of approximately 45 degrees, the length ℓ may be measured to a point on the bracket located at a distance from the toe equal to 25% of the length of the bracket.

k_s = factor defined in 3.2.1.4.2)

3) Girders and Webs

The section modulus, W, of each girder or web is not to be less than that obtained from the following equation:

$$W = 7{,}05 \cdot k_s \cdot c \cdot h \cdot \mathbf{a} \cdot \ell^2 \quad [cm^3]$$

where:

h = distances [m], from the middle of the area supported to a point defined in 3.2.1.1 through 3.2.1.3

a = sum of half lengths [m] (on each side of girder or web), of the stiffeners or beams supported

ℓ = length [m], between supports, where brackets are fitted at shell, deck, or bulkhead supports, and the brackets are in accordance with Table 5.1 and have a slope of approximately 45 degrees, the length, ℓ, may be measured to a point on the bracket located at the distance from the toe equal to 25% of the length of the bracket.

k_s = factor defined in 3.2.1.4.2)

3.3 Structural Analysis and Design of Primary Structures

3.3.1 Hull Structure

.1 General

Documents necessary to verify the structural strength, including yielding, buckling and fatigue of the hull are to be submitted for review. The criteria in this subsection relate to the analyses required to verify the scantlings selected in the basic design in 3.2. Except as provided in the MOU Rules, the results of analyses that are required in this subsection cannot be used to reduce the scantlings established from 3.2.

Depending on the specific features of the spar, additional analyses to verify and help design other portions of the Spar structural components will be required. Such additional analyses include the hull interfaces with

the topside deck, position mooring and riser systems. Analysis criteria for these additional structural components are given in 4.1

.2 Global Strength Analysis

Global strength analysis is to be performed in accordance with the design conditions and required safety factors outlined in this Subparagraph. The objective is to verify the scantlings selected in the basic design in 3.2 against the global stresses induced by the global motions, environmental loads and gravity loads.

The global strength analysis is to be performed for the in-service and pre-service conditions, ensuring that the strength of the hull is adequate. The environmental conditions and loads described in 1.3 are to be used to establish the design load cases for the in-service and pre-service conditions.

The in-service condition includes in-place intact and in-place damaged conditions. The in-place intact condition includes Design Operating Conditions (DOC) and Design Environmental Conditions (DEC), as defined in 1.3.2. The in-place damaged condition includes design cases such as loss of one mooring line or one compartment flooded.

The pre-service condition includes load out, transportation (both wet and dry tows) and installation (topside deck mating and hull upending) conditions. Some structural component design could be governed by transport, upending and installation loads.

Table 5.5 below shows the required environmental events and safety factors to be considered for each design condition in the global strength analysis:

Table 5.5 Required Environmental Events and Safety Factors

Design Conditions	Environmental Events	Safety Factors
Loadout	Calm or specified by designer or Owner	1,67
Ocean Transit (Dry Tow)	10 year return storm for the selected route condition or specified by designer or Owner if a weather routing plan is implemented for the voyage	1,25
Field Transit (Wet Tow)	1 year return storm for the selected route condition or specified by designer of Owner	1,25
Upending	Calm or specified by designer or Owner	1,67
Topsides Installation	Calm or specified by designer or Owner	1,67
In-place Design Operating	1 year return storm (minimum)	1,67
In-place Design Environmental	100 year return storm	1,25
In-place Damaged	1-year return storm	1,25

1) Critical Responses for Global Strength

The global strength of the hull is to be designed to withstand the responses induced by the loads specified in 1.3.1. The responses of the hull induced by these loads that control the hull strength design are the global bending moments and shears. As indicated in Table 5.5, the in-place intact strength is to be designed for responses with a 100-year return period in the Design Environmental Condition.

Special attention is to be given to the low frequency loads and the heeling and trimming induced loads in calculating these responses.

The highest wave may not always produce the most critical responses. To ensure that the most critical responses are captured, a sufficient number of design cases is to be used considering the following permutations:

A) Variation in environmental conditions and headings

B) Variation in variables (topside deck payloads)

C) Variation in ballasting distributions

D) Variation in riser arrangements

.3 Main Intersections (Major Joints)

The details of the main intersections are difficult to adequately capture in the global strength model. To design these areas, local FEM analyses are to be used, as required. These main intersections include connections of hard tank to topside legs, hard tank to truss and truss to soft tank (or keel tank). For the truss space frame of the mid-section, the design of unstiffened tubular joints, stiffened tubular joints and transition joints is to comply with Rules for Structures (Pt.5, Vol.II) or API RP 2A.

.4 Fatigue

Fatigue analysis is to be performed to ensure adequate strength against fatigue failure within the Spar's design life. The fatigue analysis is to consider all loading history of the Spar, including transport and in-place conditions.

Attention is to be given to the low frequency loads and global motions induced by these loads, which are important to fatigue damages at the main intersections of connections between topside deck to hard tank, hard tank to mid-section, mid-section to soft tank (or keel tank) and truss joints.

Attention is also to be given to the designs of structural notches, cut outs, attachments and abrupt changes of structural sections which are prone to fatigue damages.

.5 Structural Redundancy Analysis

Redundancy analysis is required to ensure that there is adequate redistribution of stress in the damaged conditions defined in Table 5.5. The damaged conditions are to consider loss of one compartment buoyancy or one mooring line.

.6 Acceptance Criteria

The total assessment of the structure and details is to be performed against the design conditions specified in Table 5.5 and failure modes of material yielding, buckling and ultimate strength, and fatigue. The acceptance criteria of each mode are given as follows.

1) **Material Yielding**.

For the hull, the yielding criteria indicated in Rules Mobile Offshore Units (Pt.5, Vol.VI), Sec.4, C are to be used. For the truss space frame of the mid-section, the yielding criteria in Chapter 3 of API RP 2A are to be used. The safety factors in Table 5.5 of these Rules are to be used for bar and beam elements. For plated structures the allowable von Mises equivalent stress is to be 0,7 of the yield strength for the Design Operating, Loadout, Upending and Topsides Installation Conditions, and 0,9 of the yield strength for the Design Environmental, Transit and Damaged Conditions.

If local detail FE model analysis (localized highly stressed area, 50 mm x 50 mm element size. In no case is the plate element size required to be less than the plate thickness) is provided, the allowable von Mises equivalent stress of $0,97 \cdot S_m \cdot R_{eH}$ may be used for the Design Operating, Loadout, Upending, and Topsides Installation Conditions, and $1,25 \cdot S_m \cdot R_{eH}$ for the Design Environmental, Transit and Damaged Conditions.

The yield strength ReH is to be based on the specified minimum yield point or yield stress, as defined in Rules for Materials (Pt.1, Vol.V), Sec.2, D.3 for higher strength material. Sm is the strength reduction factor as defined in Section 4, C.3.4.2.1

2) **Buckling and Ultimate Strength**

For the hull, the buckling criteria in API Bulletin 2V and 2U are to be used. Alternatively, the criteria specified in the Guidance for Buckling and Ultimate Strength Assessment for Offshore Structures (Pt.5, Vol.C) or other recognized standards may be used. For the truss space frame of the midsection, the buckling criteria in Chapter 3 of API RP 2A are to be used. The factors of safety are to be based on Table 5.5.

3) Fatigue

For the hull, including the hard tank connections to the truss space frame mid-section, the topside deck legs and the soft tank (or keel tank) connections to the truss space frame mid-section, the fatigue damages can be calculated using Offshore S-N curves for environment in air, in seawater with cathodic protection and in seawater free corrosion, as specified in the Guidance for the Fatigue Assessment of Offshore Structures (Pt.5, Vol.B). The S-N curves are applicable to thicknesses that do not exceed the reference thickness of 22 mm. For members of greater thickness, thickness correction is required with an exponent of 0,25. Other recognized standards equivalent to BKI requirements are also acceptable.

For the truss space frame mid-section, the API RP 2A S-N curves can be used.

The fatigue life is determined by safety factors and the design life of the Spar. Safety factors depend on the inspectability, reparability, redundancy, the ability to predict failure damage, as well as the consequence of failure of the structure. Minimum safety factor requirements are listed in Table 2.1.

Any areas determined to be critical to the structure are to be free from cracks, and stress concentration factors are to be determined and minimized. Critical areas may require special analysis and survey.

3.3.2 Topside Deck

.1 General

The designs of topside deck structural members such as deck girders, columns, beams, braces, stiffeners, deck plating, etc., are to be based on the applicable portions of the Offshore Installation Rules. To this end, the loads on the structure, as indicated in 3.3.2.2, as applicable, are to be determined, and the resulting structural responses are not to exceed the safety criteria given in 3.3.2.4.

The use of design methods and associated safety criteria, other than those specifically covered in this section, is permitted where it can be demonstrated that the use of such alternative methods will result in a structure possessing a level of safety equivalent to or greater than that provided by the direct application of these requirements.

.2 Loading Conditions

Loadings which produce the most unfavourable effects on the topside deck structure for the pre-service and in-service conditions are to be considered. The environmental conditions and applicable loads described in 1.3 are to be used to establish the design load cases for the in-service and pre-service conditions. The environmental events included in Table 5.5 are also to be considered for the deck design. For a given topside payload, the most critical responses for the topside deck may be the accelerations induced by the Spar's motions and the inclination-induced loads.

.3 Structural Analysis

A space frame analysis of the deck structure is to be performed to obtain the structural response. The structural model can be either the overall Spar with a detailed deck model or a standalone deck structural model. In the latter case, the boundary conditions of the model are to be properly simulated in the analysis. In modelling the deck structures, all relevant structural components are to be included. The nature of loads and loading combinations, as well as the local environmental conditions, are to be taken into consideration in the selection of design methods. Methods of analysis and their associated assumptions are to be

compatible with the overall design principles. Linear, elastic methods (working stress methods) are generally employed in design and analysis. For the use of other methods, reference is to be made to Rules for Structure (Pt.5, Vol.II).

.4 Allowable Stresses

The safety criteria are to be expressed in terms of appropriate basic allowable stresses in accordance with requirements specified below:

1) For tubular members, stress limits are to be in accordance with the API RP 2A. The basic allowable stresses for the other type of members are to be obtained using the American Institute of Steel Construction (AISC) Manual of Steel Construction, ASD. For plated structures, the design is to be in accordance with API RP 2U and API RP 2V or other recognized industry standards.

2) Where stresses in members described in 1) are shown to be due to forces imposed by the Design Environmental Condition (DEC) acting in combination with dead and live loads, the basic allowable stresses cited in 1) may be increased by one-third, provided the resulting structural member sizes are not less than those required for the operating environment loading combined with dead and live loads without the one-third increase in allowable stresses.

3) The allowable stresses specified in 2) are to be regarded as the limits for stresses in all structural parts for the marine operations covered in 1.3.1, except for lifting, where the one-third increase in the basic allowable stress is not permitted. The one-third increase in the basic allowable stress is also not permitted in load out operations. The lifting analysis is to adequately account for equipment and fabrication weight increase with dynamic amplification factors recommended in API RP 2A. Other lift analysis methods can be considered on a case by case basis.

4) For any two- or three-dimensional stress field within the scope of the working stress formulation, the equivalent stress (e.g., the von Mises stress intensity) is to be used in the design. The allowable von Mises stress is to be 0,7 of the yield strength for the Design Operating Condition (DOC) and 0,9 of the yield strength for the Design Environmental Condition (DEC). For highly localized areas, local yielding of the structure may be accepted, provided it can be demonstrated that such yielding does not lead to progressive collapse of the overall structure and that the general structural stability is maintained.

5) Whenever elastic instability, overall or local, may occur before the stresses reach their basic allowable levels, appropriate allowable buckling stresses govern.

.5 Fatigue Assessment

A detailed fatigue analysis is to be performed for deck structures. Rational fatigue analysis methods are acceptable if the forces and member stresses can be properly represented. The dynamic effects are to be taken into consideration if they are significant to the structural response. For the frame members of the deck, the S-N curves specified in the Guidance for the Fatigue Assessment of Offshore Structures (Pt.5, Vol.B) and API RP 2A are recommended. The Stress Concentration Factors (SCFs) for tubular joints can be calculated based on applicable empirical formulas. For the complex critical connections, the SCFs should be calculated by means of a fine mesh finite element analysis.

The results of the assessment are to indicate a minimum expected fatigue life of two or more times of the design life of the structure where sufficient structural redundancy exists to prevent catastrophic failure of the structure of the member or connection under consideration. Where such redundancy does not exist or where the desirable degree of redundancy is significantly reduced as a result of fatigue damage, the result of a fatigue assessment is to indicate a minimum expected fatigue life of three or more times the design life of the structure Table 2.1 provides general safety factor requirements for fatigue life. For the deck to hull connections, see 3.3.1.6.3).

Any areas determined to be critical to the structure are to be free from cracks, and stress concentration factors are to be determined and minimized. Critical areas may require special analysis and survey.

.6 Stresses in Connections

Connections of structural members are to be developed to insure effective load transmission between connected members to minimize stress concentration and to prevent excessive punching shear. Connection details are also to be designed to minimize undue constraints against overall ductile behaviour and to minimize the effects of post-weld shrinkage. Undue concentration of welding is to be avoided. The design of tubular joints is to be in accordance with the API RP 2A, including pinching shear. AISC Manual of Steel Construction, ASD can be used for the design of non-tubular joints.

4. Other Structures

4.1 Analysis and Design of Other Major Structures

The analysis and criteria to be applied to the other pertinent features of the Spar structural design are to conform to recognized practices acceptable to BKI. For Spars, the following needs to be considered in the Spar structural design: the interface between the position mooring system and hull, and the interface between hull and the riser system. The criteria to be applied for these cases are presented below.

4.1.1 Hull Interface with Mooring System (Fairlead, Chain Stopper and Winch Foundations)

Each individual foundation and back-up structure of the fairlead, chain jack and winch is to be designed for the breaking strength of the mooring line with a safety factor of 1,25. The foundation and back-up structure for multiple fairleads, chain jacks or winches is to be designed for the maximum anticipated mooring loads with a safety factor of 1,25 in the Design Environmental Condition (DEC) and with a safety factor of 1,67 in the Design Operating Condition (DOC).

Fatigue strength is to be designed to meet the requirements in 3.3.1.6.3), taking into account the effects of both local drag and inertia loads on the mooring lines and the global motions of the Spar.

4.1.2 Hull Interface with Riser System (Riser Guides and Riser Supports)

The riser foundation and guide and back-up structures are to be designed for the maximum anticipated riser loads with a safety factor of 1,25 in the Design Environmental Condition (DEC) and with a safety factor of 1,67 in the Design Operating Condition (DOC).

Contacts between hull and riser buoyancy components may cause cyclic impact loads to the hull. Fatigue due to the cyclic impacts is to be adequately considered in the design.

5. Materials and Welding

5.1 Hull Structures

Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.3, C are to be used to establish the welding requirements for the hull. The weld type and sizing are to be shown on the scantling drawings or in the form of a welding schedule and are to comply with the Rules that govern the steel selection. Special attention is to be given to the weld details for fatigue-sensitive areas. Weld improvements by means of toe grinding and weld profiling are to be used, if required by fatigue analysis results.

Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.3, B is to be used for the material selections for the hull. The Spar hull structures are grouped into the following material application categories for the purpose of material grade selection:

Special Application Structure	– Hard tank-to-topside deck leg connection – Hard tank-to-truss connection – Truss-to-soft tank (or keel tank) connection – Heave plate-to-truss connection – Truss tubular joint cans – Chain jack foundation structure – Fairlead foundation structure – Riser support foundation structure – Riser guide-to-hull connection
Primary Application Structure	– All inner and outer hull shell plating – Hull top deck and bottom deck, including main girders – All radial hull bulkheads – All hull ring frames and longitudinal girders – All truss chords and braces – Heave plate plating and girders – Soft tank (or keel tank) plating and girders – All struts
Secondary Application Structure	– All hull, heave plate and soft tank (or keel tank) stiffeners – All internal hull flats – All internal bulkheads in soft tank (or keel tank) – All other structures

5.2 Topside Deck Structures

Rules For Materials (Pt.1, Vol.V) and Rules For Welding (Pt.1, Vol.VI) can be used to establish the material selections and welding requirements for the truss deck of the topside. The deck structures are categorized into the following four groups, in association with the Charpy toughness test described in Rules for Structures (Pt.5, Vol.II),Table 4.6.

1) Deck lifting points, deck-to-hull cans
2) Major truss row girders, major truss row columns, major truss row bracing
3) Intermediate girders, intermediate bracing
4) Deck stringer beams, deck plating

Alternatively, Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.3, B may be used for material selections.

Note:

Items such as handrails, walkways and access platforms do not require the above material requirements

6. Machinery and Systems

6.1 Marine Piping Systems

Marine piping systems are those systems that are required for maintaining the normal operations of a floating unit (such as power generation, bilge, ballast, tank vent and sounding, etc.). Systems installed in the hull are to be designed to minimize the requirements for equipment and machinery to be installed in hull compartments and to limit as much as possible systems requiring piping or cable runs in the Spar hull.

Marine support systems are to be in accordance with the requirements of the Rules for Machinery Installations (Pt.5, Vol.IV), Sec.13, except as modified herein.

6.1.1 Bilge System

It is acceptable to omit a fixed bilge pumping system, as required by Rules for Machinery Installations (Pt.5, Vol.IV), Sec.13, for void spaces in the Spar hull and to use portable pumps lowered into spaces through

manholes for bilge pumping capabilities. At least two (2) portable pumps with hoses and accessories, capable of draining any void space, are to be available on-board at all times. For the bilge suction sizing purposes, column-stabilized units and self-elevating units sizing criteria listed in Rules for Machinery Installations (Pt.5, Vol.IV), Sec.13 are applicable.

6.1.2 Ballast System

The system fitted is to provide the capability to ballast and deballast all ballast tanks when the unit is upright or listed up to five degrees in any direction. All pumps and valves are to be fitted with a remote means of operation situated above the uppermost watertight deck. The normal or emergency operation of the ballast system is not to introduce a greater risk of progressive flooding due to the opening of hatches, manholes, etc., in watertight boundaries.

.1 Pumping Systems

Where ballast systems powered by pumping systems are installed, at least two ballast pumps are to be provided, one of which is to permanently connected to the installation's ballast system. The second pump may be a spare held in reserve or an eductor type arrangement permanently connected to the system. If submersible ballast pumps are installed in each ballast tank, one spare pump must be stored onboard at all times.

.2 Compressed Air Systems

Where ballast systems powered by compressed air are installed, a satisfactory quantity of compressed air is to be available to the system at all times. If two compressors are installed, one compressor is to be powered by either the emergency switchboard or a dedicated engine. Each compressor is to be capable of providing 100% of the required capacity of compressed air, as defined in 1). If only one compressor is provided, this compressor is to be powered by either the emergency switchboard or a dedicated engine, and a quantity of stored compressed air equivalent to the required capacity called out in 1) is to be provided.

1) Quantity of Compressed Air. A quantity of air capable of bringing the installation from its worst case damage or accidental flooding condition, as defined by 2.1.1, to normal operating draft and inclination is to be provided.

6.1.3 Vents and Sounds

Except for comparatively small compartments that are not fitted with a fixed means of drainage, vent pipes are to be fitted on all tanks, cofferdams, voids, tunnels and compartments which are not fitted with other ventilation arrangements. The vent opening for a hull void space on a Spar hull may be normally sealed off at the spar deck level by means of a blank, provided the venting arrangement of the Spar hull satisfies the conditions listed below:

1) The hull void spaces are below the waterline under all operating conditions. Above waterline void spaces may be considered if they are designed for pressure fluctuations due to thermal load and if fitted with a rupture disk. The set pressure of the rupture disk is to be lower than the void design pressure
2) The hull void space is not classified as a hazardous area. Hazardous voids may be considered if they are designed for pressure fluctuations due to thermal load and fitted with a rupture disk. The set pressure of the rupture disk is to be lower than the void design pressure. Areas around vents fitted with rupture disks are to comply with appropriate hazardous area requirements.
3) The hull void space is not fitted with a permanently installed bilge or drainage system.
4) Each void space is fitted with a high bilge water level alarm or a high pressure alarm.

5) The blank is to be installed after commissioning the Spar hull below the water line and after giving due consideration for temperature stabilization of the void space atmosphere with outside.

6) The blank is installed in readily accessible position so that the same can be removed for ventilation purposes during routine inspection and/or de-watering period.

7) The hull void space does not contain pressurized piping. When pressurized pipe must be routed through the void space, a burst disk designed to rupture at pressure/vacuum not exceeding the void space's design pressure/vacuum will be installed at the vent pipe outlet instead of a blank. For such instances, a blind flange or similar device is not acceptable as a blanking device. Additionally, the vent terminal will be provided with a gooseneck and fitted with a ball check valve (or equivalent).

The requirements for sounding are to comply with the Rules for Machinery Installations (Pt.5, Vol.IV), Sec.13. However, to prevent duplication of pipe runs, it would be acceptable to sound the void spaces through the vent lines. In the case of a sealed vent, a sounding plug would need to be provided to permit void space sounding.

6.1.4 Hydrocarbon Storage in Hull Tanks

If the Spar is designed to store hydrocarbons in hull tanks, criteria for hull storage of hydrocarbons are to meet flag and coastal state requirements and applicable international requirements. The designs for scantlings and strength for such storage tanks are to be in accordance with 3.2 and 3.3. For the storage facility arrangement requirements, see Rules for Facilities Offshore Installations (Pt.5, Vol.XII), Sec.3, E.3.5

6.2 Electrical Systems

The design criteria of electrical systems associated with marine systems (and drilling systems) are to be in accordance with applicable requirements described in Rules for Machinery Installations (Pt.5, Vol.IV) and Rules for Electrical Installations (Pt.5, Vol.V).

The design criteria of electrical systems strictly devoted to the hydrocarbon processing facilities are to be in accordance with applicable requirements described in Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3.

The design criteria of electrical systems associated with both marine systems and hydrocarbon processing facilities are to be in accordance with the applicable requirements described in Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3.

6.3 Fire Fighting Systems and Equipment

The fire fighting systems and equipment for the Spar service functions not associated with the process facilities are to be in accordance with Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.10, C. Fire fighting systems and equipment for protection of hydrocarbon process and associated systems, including fire pumps, are to be in accordance with Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, H.

6.4 Machinery and Equipment

Machinery and equipment not associated with the process facilities are to be in accordance with the applicable requirements of Rules for Machinery Installations (Pt.5, Vol.IV). Machinery and equipment forming a part of the hydrocarbon processing facilities are to be in accordance with the applicable requirements of Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, C. Machinery and equipment forming a part of the permanent drilling facility are to be in accordance with Rules for Machinery Installations (Pt.5, Vol.IV).

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Section 6 Position Mooring Systems

A. General 6–1
B. Mooring Systems Design 6–1
C. Mooring System Component 6–21
D. Mooring System Analysis 6–29

A. General

The position mooring system includes the mooring, anchoring and dynamic positioning (if any) systems. The purpose of the position mooring system is to keep the Floating Installation on station at a specific site.

Typically, there are two types of position mooring systems: conventional spread mooring and single point mooring, as defined in Section 2, A.4.2 and A.4.3. Thruster-assisted systems are defined in Section 2, A.4.4. For mooring systems incorporating synthetic ropes, additional design considerations are defined in API RP 2SM Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Rope for Offshore Mooring.

If dynamic positioning systems installed for position mooring purposes will be subject to approval in accordance with the requirements of Rules for Dynamic Position Systems (Pt.4, Vol.II).

Where Floating Installations are equipped with thrusters to assist the mooring system, the thrusters are subject to approval in accordance with Rules for Machinery Installations (Pt.1, Vol.III), Sec.14.C. The contribution of the thrusters in the mooring system design will be reviewed on a case-by-case basis.

B. Mooring Systems Design

This Sub-Section provides requirements related to the design of a mooring system for the class notations described in Section 1, A.3.1. This Section includes design criteria for the mooring systems and the methodology for evaluation and verification of the mooring systems.

1. Environmental Criteria

1.1 Design Environmental Condition

1.1.1 General

For a position mooring system, where applicable, the following environmental conditions are to be considered:

1) Design Environmental Condition (DEC). The extreme condition with a specific combination of wind, waves and current for which the system is to be designed.
2) Design Operating Condition (DOC). The limiting environmental condition that would require suspension of normal operations.
3) Design Installation Condition (DIC). The limiting environmental condition that would require suspension of installation operations.

1.1.2 Design Environmental Condition (DEC)

The DEC is to be one of the following combinations that results in the most severe loading case:

1) 100-year waves with associated wind and current.
2) 100-year wind with associated waves and current.

3) 100-year current with associated waves and wind.

   In areas where the maximum mooring system responses are governed by squalls, 100-year squalls with the following combination are also to be included for the DEC:

4) 100-year squalls with associated wind seas and 1-year current.

In areas with high current, additional design environmental load cases may need to be considered.

The 100-year waves are normally characterized by a significant wave height with a spectral shape type and a range of associated peak wave periods.

A minimum return period of 100 years for the DEC is required for Floating Installations. A minimum return period of 50 years will be specially considered if it is accepted by the Coastal State. Any environmental combinations with return periods shorter than that of the 100-year DEC which may induce larger mooring load responses are also to be used in the design.

For a Floating Installation with a Disconnectable notation (see Section 1, A.3.1), the Disconnecting Environmental Condition (DISEC) of the mooring system is the limiting extreme environmental condition at which the installation is to be disconnected from the mooring system. The DISEC condition is not to be taken as less severe than the environmental condition based on 10-year return period. In tropical revolving storm areas, the 100-year "sudden" tropical cyclone (hurricane or typhoon) which may form near the site of the installation may be considered instead of a fully developed storm for this evaluation. The permanent mooring system (i.e., the mooring system alone (without the installation)), is to be designed to withstand an environmental condition based on a 100-year return period. An acceptable monitoring system is to be provided for tracking environmental conditions or mooring line tensions in order to assist in the decision to disconnect the installation from the mooring system.

1.1.3 Design Operating Condition (DOC)

The return period associated with the DOC shall be the larger of:

1) the value as specified by the Operator, or
2) one year.

1.1.4 Design Installation Condition (DIC)

Specific limits on environmental conditions affecting safe operation during the installation phases described in Section 2, D are to be established and documented.

1.1.5 Fatigue Environmental Condition

For the long term fatigue analysis, a set of environmental states, such as wave scatter diagram data of wave height/period joint occurrence distribution, are to be specified, to cover the range of conditions and allow the calculation of fatigue damage with adequate accuracy.

1.2 Environmental Data

1.2.1 General

The environmental conditions for various design conditions described in 1.1 are to be submitted with adequate data for the specific site of operation. Statistical data and mathematical models that describe the range of expected variations of environmental conditions are to be employed. All data used are to be fully documented with the sources and estimated reliability of data noted.

An environmental report describing methods employed in developing available data into design criteria is to be submitted in accordance with Section 1, C.2. Probabilistic methods for short-term, long-term and

extreme-value prediction are to employ statistical distributions appropriate to the environmental phenomena being considered, as evidenced by relevant statistical tests, confidence limits and other measures of statistical significance. Hindcasting methods and models are to be fully documented.

For areas where the design is governed by special weather events, which may not be well represented by typical return period statistics, such as squalls, such special weather events are also to be taken into consideration when determining the environmental conditions.

Generally, data and analyses supplied by recognized consultants will be accepted as the basis of design. Relevant published design standards and data, if available, may be cited in documentation.

1.2.2 Waves

Extreme wave events of Design Environmental Condition (DEC) and Design Operation Condition (DOC) are to be provided, including both winter storms and tropical cyclones (hurricanes or typhoons) where applicable. The environmental report is to provide the following wave statistics for the site of installation:

1) Significant wave height
2) A range of associated wave periods is to be considered for each specified significant wave height
3) Long period swell and direction, where applicable
4) Wave spectral shape formulation
5) Wave height/period joint occurrence distribution (wave scatter diagram data with equal annual probability of occurrence for each data point)
6) Long-term wave statistics by direction

For each design sea state, a long-crested sea without spectral energy spreading is normally considered in the mooring analysis.

1.2.3 Wind

The wind conditions for various design conditions are to be established from collected wind data and are to be consistent with other environmental parameters assumed to occur simultaneously. In general, the wind speed is to be based on a return required for the DECs.

The environmental report is to present wind statistics for the site of installation and operation. The statistics are to be based on the analysis and interpretation of wind data by a recognized consultant. The report is to include a wind rose or table showing the frequency distributions of wind velocity and direction and a table or graph showing the recurrence period of extreme winds.

The percentage of time for which the operational phase limiting wind velocity is expected to be exceeded during a year and during the worst month or season is to be identified. Extreme wind events of Design Environmental Condition (DEC) and Design Operation Condition (DOC) of following are to be provided where applicable. The following wind statistics for the site of installation are to be provided:

1) Wind speed of 1-minute average at 10m above sea level
2) Steady wind speed of 1-hour mean wind at 10m above sea level
3) Suitable wind gust spectrum
4) Long-term wind direction statistics

1.2.4 Squall

A squall is a strong transient wind event characterized by sudden rapid increases in wind speed and sudden shifts in wind direction. The environmental report is to present squall statistics for the site of installation and operation. The statistics are to be based on the analysis and interpretation of squall data by a

recognized consultant. Extreme squall events of Design Environmental Condition (DEC) of the following are to be provided where applicable.

1) Squall events and it's time history of wind speed and wind direction
2) Statistics of squall direction. The squall direction is defined as the direction at which the wind speed is peaked

When the information on extreme squall events of Design Environment Condition with a 100-year return period are not available, the following method can be used to determine the characteristics of a 100-year squall.

.1 100-year Squalls.

100-year squalls can be established by scaling the wind speeds of selected squall events as given in below. The maximum wind speed of a squall event is to be scaled to the wind speed associated with 100-year return period of a given metocean site.

$$V_{100}(t_i) = \frac{V_{100}}{V_{max}} V(t_i) \qquad [m/s]$$

Where,

$V_{100}(t_i)$ = wind speed at time *i* of scaled 100-year squall, [m/s]

$V(t_i)$ = wind speed at time *i* of squall record, [m/s]

V_{100} = wind speed with 100-year return period, [m/s]

V_{max} = maximum wind speed of a squall record, [m/s]

.2 Squall Direction

The wind direction of one minute mean of a squall time record can be in any direction. The direction of a squall in this Guidelines is defined as the wind direction corresponding to the maximum wind speed in a squall time record. If there is no information on squall direction, it can be assumed that the squall can come from any direction. The critical squall directions given in 1.2.6 should be considered in mooring analysis.

1.2.5 Current

For the extreme current events of Design Environmental Condition (DEC) and Design Operation Condition (DOC), the following data is to be provided where applicable. The following current statistics for the site of installation are to be presented:

1) Current speed and directional variation through the water depth
2) Long-term current direction statistics

The vector sum of the currents may include following components:

1) Tidal currents (associated with astronomical tides)
2) Circulation currents (loop and eddy currents)
3) Storm-generated currents
4) Soliton currents

1.2.6 Angular Separation of Wind, Current and Waves

For single point mooring systems, which allow the installation to weathervane, both collinear and non-collinear directions among wind, current and waves are to be considered. Proper angular separation for

the DEC of wind, current and waves is to be determined based on the site-specific environmental study. If this information is not available, the following two angular combinations for non-collinear environments can be considered as a minimum:

- Wind and current are collinear and both at 30 degrees to waves.
- Wind at 30 degrees to waves and current at 90 degrees to waves. For wave condition dominated design, the angular separation between current and waves may be reduced from 90 degrees, but is to be no less than 45 degrees.

Fig. 6.1 illustrates one example of wind, wave and current directions.

For spread mooring systems with limited change in installation heading angles (less than 20 degrees) under design environmental loads, the collinear environments of wind, current and waves, which are generally controlling, can be used in design.

For each design sea state, a long-crested sea without spectral energy spreading in direction is normally considered in the mooring analysis.

For a squall-dominated environment, the following conditions are to be considered.

Squall directions, as well as current and wave directions of site specific information can be used for the mooring analysis. If such information is not available, below guidelines can be followed.

For a spread mooring system, a co-linear condition, (squall, current and waves are in same direction), can be considered. Mooring analysis should include following directions as minimum:

1) Squall direction in each mooring line group
2) Squall direction is beam-on a moored unit

For a single point mooring, in addition to the co-linear condition, following additional conditions are also to be considered.

1) Current and waves are collinear and both at 30 degrees to squall.
2) Waves at 30 degrees to squall and current at 90 degrees to squall.
3) Waves at 180 degrees, current 90 degrees, squall initial direction (direction at the initial time step of a squall) in 0-degree, 30-degree and 60-degree from stern, respectively

The initial squall direction for the analysis case considered should be shifted accordingly as follows.

$$\theta_i(t_0) = \theta(t_0) - \theta(t_{max}) - \beta_i \qquad [°]$$

where,

$\theta_i(t_0)$ = initial squall direction for the analysis case *i*, [°]

$\theta(t_0)$ = initial squall direction at first time step, [°]

$\theta(t_{max})$ = squall direction defined as at the maximum wind speed of a squall, [°]

β_i = specified direction for analysis case *i*, such as the direction of a mooring line group, etc.

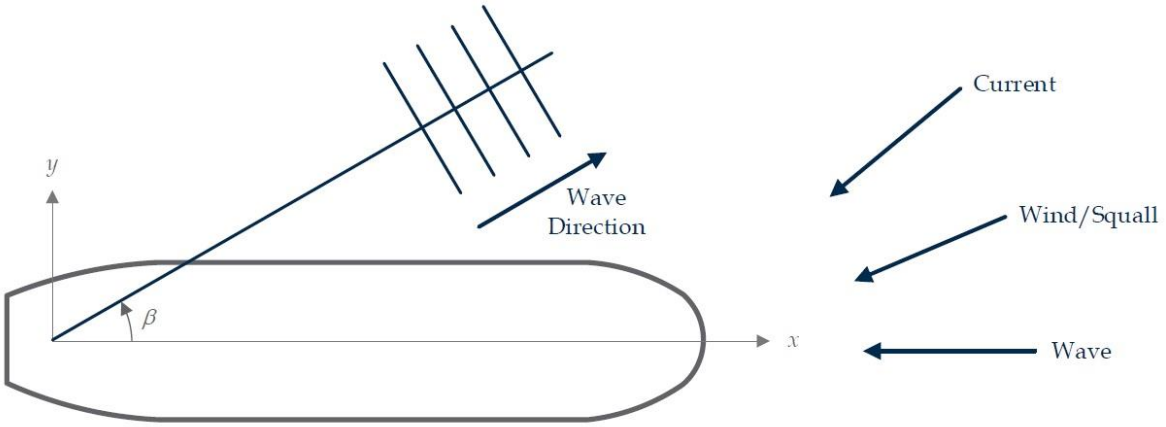

Fig. 6.1 Direction of Wave Wind and Current Illustration

1.2.7 Water Depth

The design water depth for the mooring system is to account for sea level variations due to tides, storm surges, and seafloor subsidence, if applicable.

Tidal data is to be based on astronomical tides and storm surge. The astronomical tidal extremes and tidal means for the mooring site are to be established. Sufficient data is to be submitted to establish the validity of the tide data. Tide levels may preferably be determined from records of a tide gauge in the vicinity of the site or from published tide tables for a location in the vicinity of the site. If the location from which the tide data is obtained is from a remote mooring site, a transformation of the tide data to the mooring site is to be performed by a recognized consultant.

The seasonality of extreme tidal variations should be considered when considering the combination of astronomical tide and storm surge.

The maximum storm surge for the mooring site is to be established if the mooring is in a coastal or estuary location. Sufficient data is to be submitted to establish the validity of this storm surge.

Maximum storm surge may preferably be determined from tide records taken near the location. Ifthe location from which the tide data is obtained is remote from the mooring site, a transformation of the tide data to the mooring site is to be performed by a recognized consultant. Storm surge hindcasts for design (extreme) storms performed by a recognized consultant may be submitted.

1.2.8 Seiche

The location of the mooring site in relation to seiche nodal points is to be investigated by a recognized consultant if the site is in a basin or other area known for seiche action. Seiche is defined as a standing wave in a basin or partially enclosed body of water due to wind, waves, atmospheric pressure, or earthquake. Mooring sites located at or near seiche nodal points may be influenced by currents not otherwise predicted. If the mooring site is at or near a seiche nodal point, currents induced by seiche are to be reflected in the operating current and maximum current, and the influence of the period of the current on the dynamic response of the moored vessel is to be considered.

1.2.9 Temperatures and Ice

Where drift ice may be a hazard to a mooring or to a vessel navigating to or moored at a mooring or to floating hoses at a mooring, an analysis of the nature and degree of this hazard is to be submitted.

When air temperature and precipitation, spray, or tidal action may combine to cause substantial ice formation on the mooring, an analysis of the degree to which ice may form and how this ice may affect the performance of the mooring is to be submitted.

The structure, equipment, hoses/flexible risers, component parts and their respective material which may be affected by low temperatures are to be examined.

1.2.10 Marine Growth

The type and accumulation rate of marine growth at the design site can affect mass, weight, hydrodynamic diameters, and drag coefficients of floating structure members and mooring lines. Marine growth is to be taken into consideration for permanent mooring systems not subject to any regular marine growth removal.

Note:

Marine growth is dependent on the location. If no data is available the following data from NORSOK N-003 shall be used:

	56-59°N		59-72°N	
Water depth (m)	Thickness (mm)	Density ρ_{mg} (kg/m^3)	Thickness (mm)	Density ρ_{mg} (kg/m^3)
Above +2	0	-	0	-
-15 to +2	100	1300	60	1325
-30 to -15	100	1300	50	1325
-40 to -30	100	1300	40	1325
-60 to -40	50	1300	30	1100
-100 to -60	50	1300	20	1100
Below -100	50	1300	10*	1100
*) Cold water corals can build up local colonies with no limitation regarding size in water depths between 100 and 800 m. Cold water corals are assumed not to occur for temperatures below 2 deg Celcius, i.e. for the Norwegian continental shelf it may be assumed that these occur in water depths between 100m and 450m. The density of the marine growth should be taken as 1300 kg/m3 in the whole water depth range where cold water corals can be found.				

Mass of marine growth:

$$M_{growth} = \frac{\pi}{4}\left[\left(D_{nom} + 2\Delta T_{growth}\right)^2 - D_{nom}^2\right]\rho_{growth} \cdot \mu \qquad [kg/m]$$

Submerged weight of marine growth:

$$W_{growth} = M_{growth}\left[1 - \frac{\rho_{seawater}}{\rho_{growth}}\right]\frac{9{,}81}{1000} \qquad [kN/m]$$

where,

ρ_{growth} = *density of marine growth [kg/m^3]*

$\rho_{seawater}$ = *density of seawater [kg/m^3]*

D_{nom} = *nominal chain or wire rope diameter [m]*

ΔT_{growth} = *marine growth surface thickness [m]*

μ = *2,0 for chain, 1,0 for wire rope.*

Increasing the drag coefficient due to margine growth:

$$C_{D\,growth} = C_D \left[\frac{D_{nom} + 2 \cdot \Delta T_{growth}}{D_{nom}} \right]$$

where,

C_D = *stud chain: 2,6*

studless chain: 2,4 with respect to chain diameter

C_D = *stranded rop : 1,8*

spiral rope without sheathing: 1,6

spiral ropes with sheathing : 1,2

Other methods for determining the increased drag coefficients due to marine growth may be accepted.

1.3 Mooring Location

1.3.1 Site Chart

A complete chart of the mooring area is to be submitted. This chart is to show depth soundings and obstructions within the swing circle, the maneuvering area, and where applicable, the approach channel from deep water or an established navigation channel. The chart may be based on local charts published by government agencies or on hydrographic surveys conducted by a recognized consultant. In the case of charts based on hydrographic surveys, a survey report is to be submitted describing the surveying method, equipment, and personnel employed to conduct the survey.

The exact location and water depth of the mooring base and each anchor point, is to be indicated on the chart. If the mooring is associated with other SPMs in the area, or with a pumping or control platform, these features are to be indicated on the chart. All other features and water use areas which may present potential navigational hazards are to be identified. All existing and planned navigation aids such as lights, buoys, and shore markers which will be used in conjunction with the mooring are to be indicated and identified on the chart.

1.3.2 Swing Circle

The radius of the swing circle is the sum of the horizontal excursion of the mooring systems from its center position under operating hawser load and minimum tide, the horizontal projection of the length of the hawser under operating hawser load, the length overall of the largest vessel for which the mooring system is designed, with an additional safety allowance of 30 m.

1.3.3 Water Depth Requirement

The determination of the required water depth is to be based upon calculations, data from model tests or full scale trials, designers' experience, or other available sources of information.

The designer is to submit evidence to demonstrate to the satisfaction of BKI that in determining the required water depth, the following factors have been considered:

1) Vessel’s dimensions and other relevant characteristics
2) Wave height, wave period, and compass direction with respect to the vessel
3) The prevailing wind and astronomical tides
4) The expected vessel's heaving, rolling and pitching and vessel under keel clearance of at least 1 meter.
5) The consistency of the sea bottom material or the character of any protrusion from the sea bottom

6) The level of accuracy of the depth survey data
7) Predicted variation of seabed profile due to sediment transport during the design life, where applicable.

1.3.4 Soil Condition

In general, site investigation is to be in accordance with Rules for Structures (Pt.5, Vol.II), Sec.3, A. Soil data is to be taken from the vicinity of the foundation system site. An interpretation of this data is to be submitted by a recognized geotechnical consultant. To establish the soil characteristics of the site, foundation system borings or probings are to be taken at all foundation locations to a suitable depth. This depth is to be of at least the anticipated depth of any piles or anchor penetrations plus a consideration for the soil variability. As an alternative, sub-bottom profile runs may be taken and correlated with at least two borings or probings in the vicinity of anchor locations and an interpretation may be made by a recognized geotechnical consultant to adequately establish the soil profile at all anchoring locations.

2. Mooring System Design Requirement

2.1 Design Requirement

2.1.1 Functional Requirement

A mooring system is to be designed to restrict the offset of a floating installation within prescribed limits, as well as to maintain the directionality when the structure's orientation is important for safety or operational considerations. The limiting criteria for offset and orientation are generally established either by the owner of the floating structure/unit or directly derived from design requirements including those related to:

1) Safety of personnel
2) Stability of the floating structure
3) Serviceability of the floating structure, and intended operations
4) Drilling riser and production riser requirements
5) Access to and clearances with respect to nearby installations
6) Any other special positioning requirement

Other mooring system design requirements, to include:

1) Contact of connectors with soil
2) Contact of synthetic rope with soil
3) Uplift at anchor where applicable
4) Clashing of mooring lines
5) Synthetic rope minimum tension, where applicable

2.1.2 Strength and Fatigue Capacity Requirement

The mooring system and its components are to be designed to withstand environmental and other external forces under the environmental conditions specified in 1.1. They are to be designed with consideration given to the following limit states.

1) *Ultimate Limit States (ULS).* The mooring system and its components are to be designed to have adequate strength to withstand the load resulted from extreme environmental conditions.
2) *Fatigue Limit States (FLS).* The mooring system and its components, where applicable, are to be designed to have adequate capacity to withstand the cyclic load due to exposure environments.

3) *Accidental limit state (ALS).* The mooring system and its components, where applicable, are to be designed to have adequate capacity to withstand the load resulting from extreme environmental conditions when the mooring system loses any one of the mooring lines, or thrusters for thruster assisted mooring systems.

2.2 Design Analysis

The design requirements given in 2.1 for the excursion/offset of a moored offshore installations and the strength and fatigue capacity of the mooring line components can be evaluated by engineering analysis with methodologies provided in this section. Other industry guidelines may be used provided those methods can achieve the same level of, or better results, than the methods in this section.

The detailed analysis considerations and procedures are provided in D.

1) *Quasi-Static Method*

   In this approach, the load on the mooring lines are calculated by statically offsetting the structure by wave-induced motions. Dynamic actions on the mooring lines associated with mass, damping and fluid acceleration are not considered. Various conditions, such as the type of floating structures and mooring systems, mooring line configuration, and water depth are to be considered when selecting this method to evaluate the effect on the mooring load predictions.

2) *Dynamic Analysis Method*

   Dynamic analysis includes the effects due to added mass, damping, fluid acceleration and relative velocity between the mooring system and the fluid.

Both frequency domain and time domain analyses methods can be used for mooring analysis. In the time domain method, nonlinear effects, such as line stretch, line stiffness, and nonlinear wave frequency load can be included in the analysis. For the mooring systems subject to squalls, time domain analysis methods are be used to account for the variations of wind speed and directions.

In the frequency domain method, on the other hand, the loads, mooring line stiffness and responses are assumed linear as the linear principle of superposition is used. Methods of approximating nonlinear effects in the frequency domain and their limitations are to be investigated so that the analysis results are not compromised.

2.3 Loading and Mooring System Conditions

The mooring system analysis is to be carried out to cover various loading conditions of the moored floating installations for the environmental conditions specified in 1. The design limit states specified in 2.1 are to be verified through mooring analysis.

2.3.1 Loading Conditions of Moored Floating Installations

The loading conditions for mooring analysis are to be selected from the loading manual or operations manual which could result in maximum mooring line load or maximum offset of the moored floating structures. The following loading conditions, where applicable, are to be included:

1) Full load condition
2) Minimum load condition
3) Intermediate load condition
4) Survival load condition
5) Largest vessel intended to dock with the floating installations through hawsers, or other vessel of a smaller size if the smaller vessel is apt to impose higher load.

2.3.2 Mooring System Condition

The following mooring system conditions, where applicable, are to be included in the mooring analysis as minimum.

1) *Intact Design*

A condition with all components of the system intact and exposed to an environment as described by the design environmental condition (DEC).

2) *One Line Damage*

A condition with any one mooring line broken at the design environmental condition (DEC) that would cause maximum mooring line load for the system. The mooring line subjected to the maximum load in intact extreme conditions when broken might not lead to the worst broken mooring line case. The designer should determine the worst case by analyzing several cases of broken mooring line, including lead line broken and adjacent line broken cases (or thruster or propeller if the mooring is thruster-assisted).

For a disconnectable mooring system with quick release system, the mooring analysis for a broken line case may not be required. For unusual (non-symmetric) mooring pattern, mooring analysis for the broken line case for the disconnectable environmental condition may be required.

For a system utilizing the SALM concept, the case with one broken mooring line is not relevant. A case considering loss of buoyancy due to damage of a compartment of the SALM structure should be analyzed for position mooring capability.

3) *One Line Damage Transient*

A condition with one mooring line broken (usually the lead line) in which the moored installation exhibits transient motions (overshooting) before it settles at a new equilibrium position. The transient condition can be an important consideration when proper clearance is to be maintained between the moored installation and nearby structures. An analysis for this condition under the design environmental condition (DEC) is required. The effect of increased line tensions due to overshoot upon failure of one mooring line (or thruster or propeller if mooring is power-assisted) should also be considered.

2.4 Summary of Mooring Analysis Conditions

The analysis of a mooring system includes the determination of environmental forces and the extreme response of the moored installations (excursion/offset), mooring line load, and hawser load, in the Design Environmental Condition (DEC).

Calculations of the maximum mooring system loading are to consider various relative directions of the wind, wave and current forces. The environmental conditions specified in 1.1 are to be used in the mooring analysis. Table 6.1 provides the summary of mooring analysis conditions.

Table 6.1 Mooring Analysis Condition

Environmental Condition	Mooring System Condition	Limit State
DEC	Intact	ULS
DEC	Intact	FLS
DEC	One line damage (steady)	ULS
DEC	One line damage (transient)	ULS

3. Mooring System Design Criteria

3.1 Offset of Moored Floating Installations

The offset limits of the moored floating installations is to be established based on the clearance requirements and limitations on equipment such as umbilicals, risers and gangways, and other operations requirements.

The offsets are to be calculated following the procedures provided in D. which covers the offsets induced by wind, wave and current.

When the offset is calculated using a frequency domain approach, the maximum offset can be obtained by combining the mean offset plus maximum displacement due to combined wave frequency and low frequency vessel motions as following.

$S_{max} = S_{mean} + S_{\ell f(max)} + S_{wf(sig)}$ or

$S_{max} = S_{mean} + S_{\ell f(sig)} + S_{wf(max)}$; whichever is greater

where

S_{mean} = mean installation offset due to wind, current and mean (steady) drift force

$S_{\ell f(sig)}$ = significant single amplitude low frequency motion

$S_{wf(sig)}$ = significant single amplitude wave frequency motion

The maximum values of low frequency motion, $S_{\ell f(max)}$, and wave frequency motion, $S_{wf(max)}$, are typically calculated by multiplying the corresponding significant single amplitude values by a factor C that is to be calculated as follows:

$$C = \frac{1}{2}\sqrt{2\ln N}$$

$$N = \frac{T}{T_a}$$

where

T = specified storm duration (seconds), minimum of 10,800 seconds (i.e., 3 hours). For areas with longer storm duration (e.g., a monsoon area), a higher value of T may need to be considered.

T_a = average response zero up-crossing period (seconds).

For low frequency components, T_a can be taken as the natural period, T_n, of the installation with mooring system. T_n can be estimated from the installation mass (or mass moment of inertia for yaw motion), *m* (including added mass or mass moment of inertia for yaw motion), and mooring system stiffness, *k*, for lateral and yaw motions at the installation's mean position and equilibrium heading as follows :

$$T_n = 2\pi\sqrt{\frac{m}{k}}$$

The quantities *m* and *k* are to be in consistent units. Other parameters affecting the low frequency motions, such as system stiffness and damping forces, are to be calibrated and the supporting data submitted to BKI for review.

The formula given for the calculation of *C* is based on a narrow band Gaussian process with Rayleigh distributed peaks. It may not always yield conservative predictions of maximum value. For non-Rayleigh peak distributions, alternative approaches such as model tests or time domain simulation for the specified storm duration can be used.

For transient motions after a mooring line breakage or thruster system failure before it settles at a new equilibrium position, the maximum offset can be calculated by:

$$S_{max} = S_{mean} + S_{\ell f(max)} + S_{wf(sig)} + S_t$$

Where S_t is maximum transient motion (overshoot) with respect to the equilibrium position at intact condition to new mean position after one line damage or thruster system failure.

When the offset is calculated using a time domain approach, where the offset including all components is solved simultaneously, the maximum offset, including all components, can be obtained from the resulting time histories. The time domain simulation is to be long enough to establish stable statistical peak values. Typically, responses in the storm duration are to be simulated several times, and statistical fitting techniques should be used to establish the expected maximum response.

Alternatively, the maximum excursion can be determined through model tests.

3.2 Mooring Line Tension

The mooring line tension limit is to be established based on the minimum breaking strength (MBS) of the mooring line components and corresponding safety factors given in Table 6.3. MBS is defined as the breaking strength guaranteed by the mooring component manufacturer.

Mooring line tension is to be calculated according to the procedures denoted in D.

When the line tension is calculated using a frequency domain approach, the maximum line tension can be obtained by combining the mean line tension plus maximum line tension due to combined wave frequency and low frequency excitations:

$$T_{max} = T_{mean} + T_{\ell f(max)} + T_{wf(sig)} \quad \text{or}$$

$$T_{max} = T_{mean} + T_{\ell f(sig)} + T_{wf(max)} \quad \text{whichever is greater.}$$

where

T_{mean} = mean mooring line tension due to wind, current and mean (steady) drift force.

$T_{\ell f(sig)}$ = significant single amplitude low frequency tension.

$T_{wf(sig)}$ = significant single amplitude wave frequency tension.

For transient motions after a mooring line breakage or thruster system failure before it settles at a new equilibrium position, the maximum mooring line tension can be calculated by:

$$T_{max} = T_{mean} + T_{\ell f(max)} + T_{wf(sig)} + T_t$$

where T_t is maximum mooring line tension due to transient motion (overshoot) with respect to the equilibrium position at intact condition to new mean position after one line damage or thruster system failure.

The maximum values of low frequency tension, $T_{\ell f(max)}$, and wave frequency tension, $T_{wf(max)}$, are to be calculated in the same procedure as that of obtaining the motions at wave frequency and low frequency described in 3.1.

The maximum mooring line tension can also be obtained using a time domain approach or a model test approach similar to the application for obtaining the offset described in 3.1.

3.3 Mooring Line Fatigue

The mooring line fatigue life is to be established based on mooring line fatigue capability, fatigue load and corresponding safety factors given in Table 6.4.

3.3.1 Fatigue Capacity

The fatigue capacity of chain, wire rope, fiber rope, connecting links, and other mooring system components is, in general, represented by corresponding T-N curves, where the tension range, T, is usually non-dimensionalized by dividing a suitable reference breaking strength, and N is the permissible number of cycles.

The T-N curve can be described by following equation and should be obtained based on fatigue test data and a regression analysis.

$$NT^M = K$$

Where,

N = number of permissible cycles corresponding to tension range ratio T

T = ratio of tension range (double amplitude) to reference MBS

M = slope of the T-N curve

K = intercept of T-N curve

Table 6.2 provides recommended values for the slope and intercept of the fatigue design T-N curves for wire ropes, chains, polyester rope and connecting links.

Table 6.2

Component	M	K
Common stud-link	3,00	1000
Common studless link	3,00	316
Six/multi-strand wire rope (corrosion protected)	4,09	$10^{(3,20 - 2,79\ Lm)}$
Spiral strand wire rope (corrosion protected)	5,05	$10^{(3,25 - 3,43\ Lm)}$
Polyester rope	5,20	25000
Note : *Lm : ratio of mean tension to MBS of the wire rope*		

When using the T-N curve with Table 6.2, following factors are to be considered.

1) The T-N curves are applicable for tension-tension fatigue assessment.
2) The reference MBS common or connecting links is equal to the MBS of ORQ (Oil Rig Quality) common chain link of the same diameter.
3) The reference breaking strength for wire rope is equal to its MBS. The wire rope curves are mean load dependent, and a mean load of 30% MBL is assumed in general for catenary mooring.
4) For the effects of corrosion and wear when determining the reference breaking strength of R3, R4, and R4S common or connecting links, the diameter is to be taken equal to the nominal diameter minus half of the corrosion and wear allowance.
5) The presence of studs introduces a number of possible fatigue issues that cannot be detected by inspection (i.e., loose studs, stud weld cracks, sharp corners at stud footprint, corrosion between stud and link, and defects hidden behind the stud). The equation for stud-link chain is not valid for

links with loose studs. Consequently, it is important to consider all factors affecting fatigue resistance in the selection of chain type.

6) The T-N curves for the wire ropes are only appropriate for the wire ropes protected from corrosion by, for example, galvanizing, polymeric sheathing, blocking compound, or zinc filler wires. When using wire rope as part of permanent mooring systems, the design service life, inspection, and change-out strategy is to be considered.

3.3.2 Fatigue Damage

The fatigue life of mooring lines can be assessed using the T-N curve approach which gives the number of cycles to failure, *N*, for a specific tension range, *T*. The fatigue damage ratio, D_i, for a particular sea state, *i,* is estimated in accordance with the Miner's Rule, as follows :

$$D_i = \frac{n_i}{N_i}$$

where

n_i = number of cycles within the tension range interval, i, for a given sea state.

N_i = number of cycles to failure at tension range, i, as given by the appropriate T-N curve.

The cumulative fatigue damage, D, for all of the expected number of sea states, *NN* (identified in a wave scatter diagram), is to be calculated as follows :

$$D = \sum_{i=1}^{NN} D_i$$

$$D_T \cdot SF \leq 1{,}0$$

where

D_T = total accumulated damage from all anticipated sources over the life cycle of the station keeping system

= DL + any fatigue damage arising from other sources

D = annual fatigue damage calculated, $years^{-1}$

L = design service life, in years

SF = fatigue safety factor, see Table 6.4

The detailed analysis procedures for the tension ranges are provided in D.

3.3.3 Bending Tension Fatigue

Combined bending-tension of wire ropes and chains generally occurs at locations such as fairleads, bending shoes, chain stoppers, hawser pipes, bend-limiting devices, and adjacent to clump weights and mid-water buoys. At these locations, tension-tension fatigue damage is aggravated by the presence of bending. Bending effects on wire rope and chain fatigue are to be considered in connection with the following conditions:

1) Wire rope that passes over pulleys or fairleads

2) Chain that experiences in-plane bending (IPB) and out-of-plane bending (OPB) due to constrained interlink rotation under tension, such as chains on a chain wheel (fairlead), in a chain hawser pipe, or at a chain stopper

Free bending at wire rope terminations can induce significant fatigue damage and reduce fatigue life. Bend-limiting devices should be incorporated at such locations. Such devices should be designed to smoothly transfer forces from the termination to the rope over the full range of structure draft and offset conditions.

Sheaves used in position mooring system are to be provided with sheave to rope diameter ratio of 40-60 to minimize tension-bending fatigue.

When chain links subject to constraint by chain hawse, chain stopper or bending shoes, out-of plane bending, in-plane bending, and tension-tension (OPB/IPB/TT) are to be considered in the fatigue damage assessment. Various methods, including finite element analysis method and chain testing, may be used to determine the bending moments and stresses of the subject chain links. Annex 11 provides guidelines for the assessment method of bending-tension fatigue including OPB/IPB/TT.

For chain links permanently located on a seven-pocket fairlead where the interlink angles are constrained by the fairlead geometry, a minimum load factor of 1,15 can be used in the tension-tension fatigue analysis to take into account the bending effect of the chain links in lieu of direct bending effect analysis.

3.4 Mooring Line Design Factor of Safety

The mooring lines are to be designed with the minimum strength factors of safety specified in Table 6.3. The factor of safety is defined as the ratio of the minimum breaking strength to the maximum mooring line load. The safety factors for fatigue are given in Table 6.4. These factors of safety are dependent on the design conditions of the system, as well as the level of analyses methodology. Allowances for corrosion and abrasion of a mooring line given in Table 6.6 is also be taken into consideration for the calculation of the factor of safety.

The value of a mooring line diameter used in the mooring analysis is to be the nominal value (i.e., without deduction for corrosion and wear).

The mooring chain's minimum breaking strength (MBS) is to include allowance for corrosion and wear as given in Table 6.6. For the fatigue strength assessment, a half of the corrosion and wear allowance associated with the design life can be used in determining the reference breaking strength of the chain lines.

Table 6.3 Strength Factor of Safety for Mooring Lines

Mooring System Condition		Environmental Condition	Factor of Safety	
			Quasi – Static	Dynamic Analysis
Permanent Mooring - Floating Installations	All Intact	(DEC)	2,00	1,67
	One broken Line (at New Equilibrium Position)	(DEC)	1,43	1,25
	One broken Line (Transient)	(DEC)	1,18	1,05
Fiber Rope Mooring Line Component[1]	All Intact	(DEC)	NA	1,82
	One broken Line	(DEC)	NA	1,43

Note :

[1] *Applicable to those products that are newly introduced to the mooring application, not applicable to polyester ropes where many years' experience has been gained.*

Table 6.4 Fatigue Factor of Safety for Mooring Lines

Mooring Component Fatigue Life w.r.t Design Service Life		
Inspectable areas	(DEC)	3,00
Non-Inspectabele[1] and Critical Areas[2]	(DEC)	10,00

Note:

1 *Non-inspectable means that the detailed physical conditions of the component, such as changes of geometry and etc., cannot not obtained reliably. It may depend on the locations of the component and the inspection techniques.*

2 *The failure of the component could immediately and directly affect the position keeping capability of the mooring system, such as a mooring line link.*

3.5 Mooring Anchor

3.5.1 Anchor Holding Capacity

The anchoring system includes drag anchors, pile anchors, plate anchors, suction piles and dynamically installed piles. In general, they can be categorized as anchors that have vertical load capacity and that have no or very limited vertical load capacity. The holding capacity of an anchor in a particular soil condition represents the maximum pull-out force that can be resisted by the anchor. Empirical method, limit equilibrium method, plastic limit analysis method or advanced numerical method may be used to predict the anchor behavior in soft to medium stiff clay.

However, all the methods need to be calibrated against well controlled and instrumented anchor test data. The type and design of anchors are to be submitted for review, together with the documentation for estimating their holding capacity in various types of soil. The details on the anchors of different types provide in C.

3.5.2 Factor of Safety of Anchor Holding Capacity for Permanent Mooring Systems

The factor of safety for anchors is defined as anchor holding capacity divided by maximum anchor load from mooring dynamic analysis. Table 6.5 provides the factors of safety for drag anchors, plate anchors, suction piles, pile anchors, and dynamically installed piles.

Table 6.5 Factor of Safety for Anchor Holding Capacities

		Factor of Safety
Drag Anchors		
All Intact	(DEC)	1.50
One Broken Line	(DEC)	1.00
Plate Anchors and Dynamically Installed Piles		
All Intact	(DEC)	2.00
One Broken Line	(DEC)	1.50
Suction Piles, Driven Pile Anchor and Gravity Anchors		
All Intact-Lateral	(DEC)	1,6
All Intact-Axial	(DEC)	2,0
One Broken Line-Lateral	(DEC)	1,2
One Broken Line-Axial	(DEC)	1,5
TLP Piles		
Refer to API RP 2T as applicable		

The following method can be used for lateral/axial or combined factor of safety:

If $\theta \le \theta_{lateral}$ $FOS = FOS_{lateral}$

If $\theta \ge \theta_{axial}$ $FOS = FOS_{axial}$

If $\theta_{lateral} \le \theta \le \theta_{axial}$ $FOS = FOS_{lateral} + \frac{\theta - \theta_{lateral}}{\theta_{axial} - \theta_{lateral}} * (FOS_{axial} - FOS_{lateral})$

where,

FOS = factor of safety (FOS)

$FOS_{lateral}$ = lateral FOS from Table 6.5

FOS_{axial} = axial FOS from Table 6.5

θ = angle of mooring line from horizontal at anchor attachment point

$\theta_{lateral}$ = load angle, measured from horizontal, below which the ultimate capacity is controlled by the lateral capacity. The lateral capacity is defined as the capacity under purely horizontal loads

θ_{axial} = load angle, measured from horizontal, above which the ultimate capacity is controlled by the axial capacity. The axial capacity is defined as the capacity under purely vertical loads.

θ_{axial} and $\theta_{lateral}$ could be obtained from either numerical simulations or laboratory tests. If the information is missing for θ_{axial} and $\theta_{lateral}$, FOS_{axial} is to be used for a conservative design.

3.5.3 Drag Anchor Uplift

For drag anchors, the mooring line length should in general be sufficient to prevent anchor uplift under the design environmental condition. This requirement is especially important for anchors in sand and hard soil where anchor penetration is shallow. For soft clay conditions, a small angle for the damaged case with one broken line may be considered by BKI on a case-by-case basis.

Uplift of drag anchors may be permitted if it can be demonstrated that the anchor has sufficient vertical resistance for the soil condition under consideration.

3.6 Mooring between Vessel and Installation

When hawsers are used as the connecting links, they are to be designed using the following factors of safety on the breaking strength of the weakest part. The strength of ropes or hawsers is to be determined in accordance with, and certified to, the latest version of OCIMF Prototype Rope Testing. The breaking strength of spliced rope is to be established by appropriate testing. The breaking strength of the hawser is to be the lower value of the hawser in wet or dry condition.

- With one fairlead: F.S. = 1,67
- With multiple fairleads: F.S. = 2,50

Where the vessel is moored to the installation or mooring terminal using hawsers running through more than two (2) fairleads on the vessel, the hawser loads are to be calculated as if there are only two (2) fairleads.

The hawser manufacturer is to comply with the OCIMF Quality Control and Inspection during the Production of Hawsers.

Note:

The above mentioned OCIMF references are available in the volume entitled, OCIMF Guidelines for the Purchasing and Testing of SPM Hawsers.

When a rigid mooring structure is used as the mooring structure between the vessel and the installation, the connecting structures are to comply with Rules for Mobile Offshore Units (Pt.5, Vol.VI), Sec.5, B.2.4

3.7 Allowance for Corrosion and Wear

3.7.1 Allowances for corrosion and wear of a mooring line are to be included in the design. For chain, a corrosion and wear allowance is provided by an appropriate increase in the link diameter. The increase should be determined by a site-specific assessment dependent upon several parameters such as seawater temperature, dissolved inorganic nitrogen (DIN) level, the locations of the links, splash zone, submerged catenary, or bottom zones and etc. If site specific study for corrosion and wear rate is not available, the corrosion and wear allowances given in Table 6.6 are to be considered in the design.

Table 6.6 Chain Corrosion and Wear Allowance

Chain Location	Corrosion and Wear allowance on Criteria Diameter (mm/year)[5]	
	Low DIN Level [3]	High DIN Level [4]
Splash zone[1]	0,2 ~ 0,4	0,8
Mid-catanery[2]	0,1 ~ 0,2	0,3
Touch down zone	0,2 ~ 0,4	0,4

Note :

1 *Splash zone: the chain links that are periodically in and out of the water when the unit is at its operating depth. In general, this zone is between 5 m above and 4 m below the waterline.*

2 *Mid-catenary: mooring line below the splash zone and always above the touch down point.*

3 *DIN level smaller than 1 mgN/L*

4 *DIN level close to 7 mgN/L, such as in West Africa*

5 *Higher corrosion allowance should be considered if pitting corrosion associated with Microbiologically Influenced Corrosion (MIC) is suspected*

Corrosion of wire rope at connections to sockets may be excessive due to the galvanized wire acting as an anode for adjacent components. In such case, it is recommended that either the wire be electrically solated from the socket or that the socket be isolated from the adjacent component. Additional corrosion protection can be achieved by adding sacrificial anodes to this area.

Additional allowance may be considered for locations where wear is a predominant factor for degradation of mooring chain.

3.7.2 The mooring chain's minimum breaking strength (MBS) which forms the basis for the mooring calculations shall be adjusted for the reduction in capacity due to corrosion and wear according to the corrosion allowance given in Table 6.6. In reality, when corrosion happens, the geometry of the chain link is not changed. Hence when identifying the minimum breaking strength (MBS) of a corroded chain link, it is not acceptable to use the MBL catalogue value for the reduced diameter. When determining the minimum breaking strength (MBS) of corroded chain links, MBS_{corr}, this should be based on reduction of the cross sectional area:

$$MBS_{corr} = MBS \cdot \left(\frac{D_{corr}}{D_{new}} \right)^2$$

where,

D_{corr} = corroded chain diameter

D_{new} = new (un-corroded) chain diameter

Alternatively, more sophicasticated FEA may be conducted to identify the reduced minimum breaking strength due to corrosion.

3.8 Clearence

3.8.1 General

Where required, the clearances between a floating vessel, its mooring components, and other marine installations is to be determined for design and operation environmental conditions. For local coastal water, the owner/designer is to consider the local regulatory requirements for the clearance which may be more stringent than class requirements.

3.8.2 Mooring Line Crossing Mooring Line

Where a mooring line crosses another mooring line, a minimum vertical clearance of 10 m under the intact condition is to be maintained if one of the mooring lines at the crossing is grounded. The minimum clearance is to be increased to 20 m if both lines are suspended at the crossing.

3.8.3 Horizontal Distance between Installations

A horizontal clearance between a floating structure, including its mooring lines, and any other installations for all relevant conditions is not to be less than of 10 m. The clearance requirement may be reduced if an appropriate risk assessment is performed.

3.8.4 Clearance between a Drag Anchor and Other Installations

If an installation lies in the dragging path between the anchor and the floating unit, the final anchor position is to allow at least 300 m drag before contacting the installation. Otherwise the anchor is to be at least 100 m from the marine installation. Anchors are not allowed to drag over pipelines or other critical subsea infrastructures in general.

4. Mooring Line Monitoring

Where required, the design of the mooring system is to include suitable arrangements and/or equipment for the crew to periodically verify that each mooring leg remains intact. Suitable arrangements might include, but are not necessarily limited to, mooring line load monitoring arrangements, inclinometers, laser measuring devices, FPSO excursion monitoring systems (GPS), submersible cameras, etc. Noting that these arrangements will have to operate for the life of the vessel, the design should take into account such things as:

- Robustness and reliability
- Serviceability and maintainability
- Validation and periodic verification/testing

Such systems are not required to constantly monitor or detect mooring line failures, nor is it a requirement that they should alarm on the failure of a mooring leg. However, as a minimum, there should be adequate procedural arrangements in place for the crew to periodically check the integrity of the lines.

Note:

Mooring legs can be visually checked on certain types/designs of mooring systems. For example, mooring lines on External Turret and some Spread Moored designs can be visually observed and checked without the need for any additional equipment. Where this is not possible, the design is to include such equipment and systems as may be necessary so that the crew can periodically verify that all of the mooring lines remain intact.

C. Mooring System Component

1. General

The anchors, mooring lines, shackles and other associated connecting equipment should be designed, manufactured and tested in accordance with the published BKI requirements. In instances where BKI does not have published requirements, the equipment will be reviewed for compliance with applicable recognized industry standards.

Complete details and supporting calculations, including fatigue analysis where applicable, of the structural and mechanical components used in position mooring systems (e.g., connecting links, shackles, chain stoppers, fairleads, etc.), which transmit the mooring loads, are to be submitted.

All mooring system components such as anchors, anchor chains or wires, anchor chain accessories such as shackles or links, and anchor wire-rope accessories such as sockets or links, are to be manufactured and tested in the presence of and to the satisfaction of the Surveyor in accordance with approved plans.

2. Mooring Line

Mooring line components such as wire rope, chain, connecting link, synthetic fiber rope and in-line buoys are to be designed that is compatible with the design conditions of the mooring system.

2.1 Mooring Wire Rope

Mooring wire ropes and end sockets are to meet the material, design, manufacture, and testing requirements specified in industry recognized standard, such as API Spec 9A and RP 9B.

Wire rope manufacturers should provide users torque/twist data for the allowable tension range as part of the wire rope basic properties. Contact of wire rope in the dip or thrash zone may cause excessive wear in the rope/jacket or excessive free bending at the socket. This condition should be avoided for permanent moorings under normal operating environments.

2.2 Synthetic Fiber Mooring Rope

Requirements for synthetic fiber rope for mooring system can be found in the industry recognized standard, such as API RP 2SM

2.3 Mooring Chain and Accessories

Mooring chain and accessories are to be manufactured according to the Rules for Materials (Pt.1, Vol.V), Sec.13, C For buoyancy tanks, the requirements in ASME Boiler and Pressure Vessel Code can be used.

2.4 Other Components

In general, the structural and mechanical components used in position mooring systems (e.g., connecting links, shackles, chain stoppers, fairleads, etc.), which transmit the mooring loads, are to be designed to the Minimum Breaking Strength (MBS) of the mooring line. The computed stress obtained from FE analysis is to be limited to minimum specified yield strength. Local stress due to large contact pressure obtained from FE analysis is to be limited to three times the minimum specified yield strength.

The fatigue life, where applicable, for inspectable and repairable structural and mechanical components used in position mooring systems is not to be less than 3 times the service life. For those that cannot be readily inspected and repaired, the fatigue life is to be at least 10 times the service life.

The attachments to the hull or structure are to be such as to withstand the stresses imposed when the mooring line is loaded the Minimum Breaking Strength (MBS) of the mooring line or maximum allowable mooring line load. Allowable stress is to comply with Rules for Single Point Mooring (Pt.1, Vol.IX), Sec.3, C.4.

3. Anchor

Different types of foundation systems used for floating installations are drag anchors, pile anchors, plate anchors, suction piles and dynamically installed piles. Gravity boxes, grouted piles, and templates may also be used and are considered to be within the scope of classification. The safety factors for the anchore`s holding capacity are specified in Table 6.5

The type and design of anchors are to be submitted for review, together with documentation estimating their holding power in various types of soil.

The following is to be considered in the evaluation of the anchor holding capacity:

1) Cyclic, creep and soil set-up effects of the soil strength.
2) Soil disturbance due to padeye and chain.
3) If the reference site is within a seismic zone, potential of soil liquefaction and its impact.
4) The effect of the inverse catenary line on the anchor loading directions is to be considered. An upper bound and a lower bound inverse catenary is be considered to establish the worst-case anchor loading.

Suitable anchor stowage arrangements are to be provided to prevent movement of the anchors during transit. When the unit is kept on position solely by DP units and the anchors are not used, anchors are not to be stored in the bolsters unless they are designed for the extreme design environmental conditions.

3.1 Drag Anchor

For a mooring system with drag anchors, the mooring line length should be sufficiently long such that there is no angle between the mooring line and the seabed at any design condition, as described in Section 2, B.3.1. For soft clay condition, a small angle for the damaged case with one broken line may be considered by the BKI on a case-by-case basis.

Drag anchor holding power depends on the anchor type, as well as the condition of the anchor deployed in regard to penetration of the flukes, opening of the flukes, depth of burial, stability of the anchor during dragging, soil behavior of the flukes, etc. The designer should submit to the BKI the performance data for the specific anchor type and the site-specific soil conditions for the estimation of the ultimate holding capacity (UHC) of an anchor design. Because of uncertainties and the wide variation of anchor characteristics, exact holding power is to be determined after the anchor is deployed and test loaded.

The maximum load at anchor, F_{anchor}, is to be calculated, in consistent units, as follows :

$$F_{anchor} = P_{line} - W_{sub} \cdot WD - F_{friction} \quad [kN]$$

$$F_{friction} = f_{s\ell} \cdot L_{bed} \cdot W_{sub} \quad [kN]$$

where

P_{line} = maximum mooring line tension [kN]

WD = water depth [m]

$f_{s\ell}$ = frictional coefficient of mooring line on sea bed at sliding

L_{bed} = length of mooring line on seabed at the design storm condition, not to exceed 20 percent of the total length of a mooring line [m]

W_{sub} = submerged unit weight of mooring line [kN/m]

Note:

The above equation for F_{anchor} is strictly correct only for a single line of constant, W_{sub}, without buoys or clump weights. Appropriate adjustments will be required for other cases.

The coefficient of friction $f_{s\ell}$ depends on the soil condition and the type of mooring line. For soft mud, sand and clay, the following values (from API RP 2SK) of $f_{s\ell}$ along with the coefficient of friction at start f_{st} for wire rope and chain may be considered representative:

	Coefficient of Friction, f	
	Starting (f_{st})	Sliding (f_{sl})
Chain	1,00	0,70
Wire Rope	0,60	0,25

3.2 Driven Pile Anchor

Driven pile anchors are capable of withstanding uplift and lateral forces at the same time. Analysis of the pile as a beam column on an elastic foundation is to be submitted to BKI for review. The analyses for different kinds of soil using representative soil resistance and deflection (p – y) curves are described in the Rules for Structures (Pt.5, Vol.II), API RP 2SK, API RP 2A and API RP 2T, as applicable. Where required, the fatigue analysis of the pile is to be submitted for review.

3.2.1 Allowable Yielding Stresses for Pile Anchor

Where required, pile analysis in accordance with API RP 2A can be applied to the piles with diameter to thickness ratios (D/t) of less than 100. For cylindrical piles with D/t ratios exceeding 100, it is recommended that a detailed structural finite element model be developed for the global structural anchor analysis to verify that the anchor wall structure and appurtenances have adequate strength in highly loaded areas. Supplementary calculations may be necessary for members or appurtenances subjected to local loading.

The von Mises stress is to be limited to:

$\sigma_{eqv} \leq 0{,}9\sigma_{yield}$ for one line damage

$\sigma_{eqv} \leq 0{,}67\sigma_{yield}$ for intact

where,

σ_{yield} = yield stress of the considered structural component, [kN/m^2]

For highly localized stresses, the local yielding of the structure may be accepted provided it can be demonstrated that such yielding does not lead to progressive collapse of the overall structure and that the general structural stability is maintained.

It is recommended that pile foundations be designed to comply with the appropriate sections of API RP 2A. A pile driving record or pile grouting record is to be taken and submitted for each pile. The method of installation of the piles and the equipment employed is to be included in the pile driving record.

3.2.2 Fatigue Assessment of Pile Anchors

Where required, the design fatigue life is to be at least 10 times of the intended service life. For driven pile anchors fatigue analysis is to be reviewed to evaluate the adequacy of the fatigue life considering both driving and in-place conditions. The critical locations, such as in way of padeye, girth welds, should be selected for the fatigue assessment based on the finite element results or calculated based on parametric equations taking into account fabrication tolerances. "In-Air" S-N curves may be used to calculate the pile driving fatigue damage, while in-place fatigue damage should be based on "Free Corrosion" S-N curves given in the Guidance for the Fatigue Assessment of Offshore Structures (Pt.5, Vol.B). Fatigue analyses of the suction piles should be carried out in accordance with the Guidance for the Fatigue Assessment of Offshore Structures (Pt.5, Vol.B) using appropriate S-N curves provided in the Guidance.

3.3 Plate Anchor

Plate anchors can be used in a taut leg mooring system with approximately a 35 to 45 degree angle between the seabed and the mooring lines. These anchors are designed to withstand both the vertical and horizontal loads imposed by the mooring line.

Plate anchors can be drag embedded plate anchors or direct embedded plate anchors, according to different installation methods. Vertically Loaded Anchors (VLAs) are one type of plate anchors. It is important that the anchor's penetration depth can be established during the installation process. After penetrating into the designated depth, a plate anchor gets its high ultimate pull-out capacity by having its fluke oriented nearly perpendicular to the applied load.

The structural and geotechnical holding capacity design of the plate anchors are to be submitted for review. This is to include the ultimate holding capacity and the anchor's burial depth beneath the seabed. Additionally, the fatigue analysis of the anchor and the connectors joining the Plate anchors to the mooring line is to be submitted for review.

3.4 Suction Pile

3.4.1 General

Suction pile anchors are caisson foundations that are penetrated to the target depth by pumping out the water inside of the pile to create underpressure within the pile. They typically consist of a stiffened cylindrical shell with a cover plate at the top and an open bottom and they generally have larger diameters and are shorter in length than driven piles. These piles can be designed to have either a permanent or retrievable top depending on the required vertical holding capacity. The padeye for the mooring line connection can be at the top or at an intermediate level depending on the design of the suction pile.

Suction pile anchors are capable of withstanding uplift and lateral forces. Due to the geometry of the suction piles, the failure modes of the soils may be different than what are applicable for long slender driven piles.

Geotechnical holding capacity and structural analyses for the suction piles are to be submitted to verify the adequacy of the suction piles to withstand the in-service and installation loads. Additionally, fatigue analysis of the suction piles are to be submitted to verify the adequacy of the fatigue life of the critical locations. The criteria given in 3.2.1 and 3.2.2 are applicable to suction piles.

Installation analyses are to be submitted to verify that the suction piles can be penetrated to the design penetration and that the suction piles can be retrieved, if necessary. It is suggested that a ratio of at least 1,5 between the force that would cause uplift of the soil-plug inside of the pile and the effective pile installation force be considered in the penetration analysis.

3.4.2 Stability Analysis of Suction Pile

The buckling strength of the suction pile is to be checked in accordance with API Recommended Practice 2A, or the Guidance for Buckling and Ultimate Strength Assessment for Offshore Structures (Pt.5, Vol.C).

3.5 Dynamically Installed Piles

Dynamically installed piles are finned piles designed to be released from height above the seabed and reach velocities of 20 to 35 m/s at the seabed before self-embedment. They may be stabilized with multiple fins at the trailing edge.

The installation procedures of dynamically installed piles are to be submitted for BKI review and are to include all the necessary data for the Surveyor to inspect onboard, such as coordinates of piles installation, designed penetration depth, acceptable tolerances for pile position, actual penetration depth, inclination angle and azimuth.

Geotechnical holding capacity and structural analysis for the piles is to be submitted to verify the adequacy of the piles to withstand the in-service load. The geotechnical analysis and structural assessment may be performed in accordance with recognized standard. Fatigue assessment are to be submitted to demonstrate the adequacy of the mooring line attachment components for the expected service life of the mooring system. The criteria given in 3.2.1 and 3.2.2 are applicable to dynamically installed piles.

3.6 Gravity Anhors

Where the anchoring system uses gravity boxes, resistance against sliding, uplifting, and overturning of the gravity boxes are to be analyzed. The forces due to environmental, gravity and mooring are to be taken into account appropriately. Scour effects on the gravity boxes are to be considered in the design.

4. Chain Stoppers

The chain stoppers are to be so designed that no additional bending to the chain links is imposed and the links are evenly supported. Findings and recommendations from Chain Out of Plane Bending JIP (Joint Industry Project) can be used to minimize the OPB.

The strength analysis is to include the most unfavorable direction of the mooring line.

The chain stoppers are to be tested in accordance with the submitted specifications and to the satisfaction of the attending Surveyor.

Position mooring systems without chain stoppers will be specially considered.

5. Fairleads and Sheaves

Fairleads and sheaves are to be designed to prevent excessive bending and wear of the mooring lines. Sharp edges at the interface structures with the mooring line are to be avoided.

Sheaves used in position mooring system are to be provided with sheave to rope diameter ratio of 40-60 to minimize tension-bending fatigue. 7 to 9 pocket wildcat sheaves are recommended for chain. Other constructions which provide similar or better support may be considered.

The strength analysis is to include the most unfavorable direction of the mooring line.

Corrosion allowance or suitable cathodic protection is to be considered for underwater fairleads.

The fairleads are to be tested to the satisfaction of the attending Surveyor.

6. Winches and Windlasses

The design of mooring winches and windlasses is to provide for adequate dynamic braking capacity to control normal combinations of loads from the anchor, anchor line and anchor handling vessel during the deployment of the anchors at the maximum design payout speed of the winch or windlass. Winch and windlass foundations and adjacent hull structures are to be designed to withstand an anchor line load at the winch or windlass at least equal to the rated breaking load of the anchor line.

For a winch intended for mooring line hook-up and future retensioning activities, the equipment is to be in compliance with recognized industry standards. The manufacturer needs to submit details to demonstrate compliance with the industry standards, either in the form of certificates issued by recognized certification bodies or by submitting details and calculations to BKI for review and approval.

Each winch or windlass is to be provided with two independent, power operated brakes and each brake is to be capable of holding a static load in the anchor line of at least 50 percent of the anchor line's rated breaking strength. One of the brakes may be replaced by a manually operated brake.

On loss of power to the winches or windlasses, the power operated braking system is to be automatically applied and be capable of holding against 50 percent of the total static braking capacity of the windlass.

The details requirements for mooring winches and windlass including their controls are defined in Rules for Machinery Installations (Pt.5, Vol.IV), Sec.8, A and C.

7. Quality Control

Quality control details of the manufacturing process of the individual mooring system components are to be submitted. Components are to be designed, manufactured and tested in accordance with recognized standards insofar as possible and practical. Equipment so tested is to, insofar as practical, be legibly and permanently marked with the Surveyor's stamp and delivered with documentation which records the results of the tests.

8. Control Stations

Where applicable, the control station is to include the following:

1) Means to indicate anchor line tensions and to indicate wind speed and direction.
2) Reliable means to communicate between locations critical to the anchoring operation.
3) Each winch or windlass is to be capable of being controlled from a position which provides a good view of the operation. Means are to be provided at the individual winch or windlass control positions to monitor anchor line tension, winch or windlass power load and to indicate the amount of anchor line paid out.

9. Single Point Mooring Systems

This Subsection provides the requirements for the components that facilitate the weathervaning of the single point mooring systems, such as CALMs, SALMs, turrets and yokes, and which are not covered in mooring components, such as mooring lines and anchors.

For the onboard electrical installations related to the single point mooring systems, they are to comply with the requirements of Rules for Single Point mooring (Pt.5, Vol.IX), Sec.4, C.

9.1 Design Loadings

The design of structural and mechanical components is to consider the most adverse combination of loads, including, but not limited to, those listed below, and is to be submitted for review:

1) Dead Loads
2) Dynamic Loads due to motions
3) Mooring Loads
4) Fatigue Loads
5) Riser Loads

9.2 Structural Components

In general, structural components are to be designed to a recognized code or standard. The structural and buoyancy elements of CALMs and SALMs are to comply with the requirements of the Rules for Single Point Mooring (Pt.5, Vol.IX). Minimum mooring turret and yoke arm scantlings are to comply with Rules for Mobile Offshore Units (Pt.5, Vol.VI) (also see Section 4, A.4.2 of this Guidelines for single point mooring foundation strength criteria)

9.3 Mechanical Components

Mechanical components of an SPM usually include the Product Distribution Unit (PDU), bearings, driving mechanisms and various types of connectors. Where applicable, those components can be designed in accordance to the following standards and codes:

– Product Distribution Unit	ASME Boiler and Pressure Vessel Code AISC Steel Code ANSI B31.3 (for Pipe Swivels)
– Bearings	ABMA Codes (American Bearing Manufacturers Association ASME 77-DE-39
– Connectors: driving mechanisms	ASME Boiler and Pressure Vessel Code AISC Steel Code API Standards as applicable

Ancillary mechanical components, such as structural connectors, uni-joints, chain jacks, turret retrieval mechanisms, hoists, winches, and quick connect/disconnect devices are to be designed in accordance with applicable industry standards, codes, and published recommended practices.

9.4 Turret System

A turret mooring system is one type of station keeping system for a floating installation and can either be installed internally or externally. Both internal and external turret mooring systems allow the installation to weathervane around the turret. The mooring lines are fixed to the sea bottom by anchors or piles.

In an internal turret system, the turret is supported by a system of bearings. The loads acting on the turret pass through the bearing system into the installation. Typically, a roller bearing is located near the installation deck level, and a radial sliding bearing is located near the keel of the installation. For an external turret mooring system, the installation is extended to attach the turret mooring system at the end of the installation.

The loads acting on an internal turret system include those basic loads induced by the mooring lines, risers, gravity, buoyancy, inertia and hydrostatic pressure. Other loads, such as wave slam and loads resulting from misalignment and tolerance that may have effect on the turret are also be considered in the design. In establishing the controlling turret design loads, various combinations of installation loading conditions ranging from the full to minimum storage load conditions, wave directions, and both collinear and

noncollinear environments are to be considered. The mooring loads and loads applied to the external turret structure are transferred through the bearing system into the installation. The load range and combinations to be considered and analysis methods are similar to those stated for an internal turret mooring system, with additional consideration of environmentally-induced loads on the turret structure.

A structural analysis using finite element method is required to verify the sufficient strength of the turret structure. The allowable von Mises stress of the turret structure is to be 0,7 of the yield strength for the operational intact mooring design conditions. The von Mises stress allowed for the design storm intact mooring design conditions and for the design storm one-line broken mooring condition are 0,9 and 1,0 of the yield strength, respectively, to verify the turret structure mooring attachment locations and supporting structure.

Note:

The yield strength is to be based on the specified minimum yield point or yield stress as defined in Rules for Welding (Pt.1, Vol.V) for higher strength material or 72 percent of the specified minimum tensile strength, whichever is the lesser.

The buckling strength check for the turret structures is to be performed using the criteria in Section 4, API Bulletin 2U, 2V or other applicable industry standards. A fatigue evaluation of the turret system using a spectral method or other proven approaches is called for to determine the fatigue lives for the turret components. Fatigue life of the turret is not to be less than three times the design life for inspectable areas and 10 times for no-inspectable areas.

9.5 Turret/Installation Structural Interface loads

The installation structure in the way of the turret mooring system interface is to be capable of withstanding forces (obtained as the maximum of all the design conditions considered) from the systems and is to be suitably reinforced.

Mooring forces transmitted to the installation's supporting structure by the turret mooring system are to be determined by an acceptable engineering analysis. The transmission and dissipation of the resulting mooring forces into the installation's structure are to be determined by an acceptable engineering method, such as finite element analysis. The loads acting on the installation's supporting structures due to the turret system are mainly transmitted through the upper and lower bearings. The loading conditions are chosen to cause the most unfavorable loads and the load combinations that may occur. The derivation of mooring loads is to be determined as described in 9.4, "Turret Mooring". The structural model used in the finite element analysis for the installation's supporting structure is to extend to a reasonable distance of the installation to minimize the effects due to the boundary conditions.

9.6 Submerged Buoy Structure

9.6.1 Buoys Connected to Floating Installations

The submerged buoy structure that forms part of the positioning mooring system for a floating installation is to be capable of withstanding the design forces during the following design conditions:

1) Design Environmental Condition (DEC) defined in B.1
2) Disconnecting Environmental Condition (DISEC) defined in B.1 (if applicable)
3) Design Installation Condition (DIC) defined in B.1

The design of the submerged buoy structure is to consider the most adverse combination of loads, including, but not limited to, those listed below.

1) Risers and mooring loads

2) Swivel stack load
3) Bearings load
4) Hook-up or pull-in loads
5) Inertia loads
6) Loads induced by the holding device and contact points with the hull when connected to the floating installation
7) Hydrostatic pressure
8) Accidental flooding of a single compartment when not connected to the floating installation

Where required, the fatigue life of the submerged buoy is to be at least 10 times the service life of the unit.

A suitable protective coating with sacrificial anodes is to be provided for the submerged buoy.

9.6.2 Buoys Disconnected from Floating Installations

This condition is defined as the condition in which the buoy is not connected to the floating installation and is submerged in water with risers and mooring lines attached to the buoy.

For a permanently moored unit, the maximum submerged depth of the buoy is to be determined considering the dynamic motion induced for the worst anticipated environment during the proposed submerged period, prior to connecting to the floating installation. The selected environment is to be based on the site metocean data and agreed to by BKI. The selected environmental condition is not to less severe than that defined for the DIC.

For a disconnectable unit, the maximum submerged depth of the buoy is to be determined considering the dynamic motion induced for the DEC.

Structural adequacy for an accidental flooding condition with a single compartment damaged is to be studied. Alternative acceptance criteria for this accidental flooding condition can be considered on a case-by-case basis.

A submerged buoy with accidental flooding of a single compartment is to have sufficient buoyancy for supporting the mooring, riser system and any ballast when not connected to the floating installation. Stability is to comply with Rules for Single Point Mooring (Pt.5, Vol.IX), Sec.3, C.6, where applicable.

D. Mooring System Analysis

1. General

This Subsection provides analysis procedures for the verification of the mooring system to the design requirements specified in B.

Depending on the level of sophistication and analysis objectives, quasi-static and dynamic analysis methods may be used. Both frequency and time domain approaches are acceptable. The designer should determine the extreme offset and line tension in a manner consistent with the chosen method of analysis.

For deepwater operations with many production risers, the mooring system analysis should take into account the riser loads, stiffness and damping due to significant interactions between the floating structure, mooring system and riser system.

The analysis in general includes:

1) Environment load prediction including:

A) Wind load
B) Current load
C) Wave load
D) Vortex induced motion load where applicable

2) Motion response of moored floating installation including:
   A) Equilibrium position of the floating structures (mean offset and heading)
   B) Maximum offset of the floating structure
3) Mooring line response including:
   A) Mean tension
   B) Maximum tension
   C) Fatigue life
4) Anchor holding capacity analysis, where applicable

Other phenomena such as subsea landslides, seiche, abnormal composition of air and water, humidity, salinity, ice drift and icebergs may require special considerations.

2. Environmental Load

The design of a mooring system requires the establishment of environmental loads considering the following parameters:

1) Air and sea temperatures
2) Tides and storm surges
3) Currents
4) Waves
5) Ice and Snow
6) Wind

Other phenomena such as loop currents, tsunamis, submarine slides, seiche, abnormal composition of air and water, humidity, salinity, ice drift and icebergs may require special considerations.

Wind tunnel and towing tank tests on the project-specific submerged hulls and superstructures are preferred in determining current and wind loads. Alternatively, the following calculation procedures can be applied.

The design environmental conditions in terms of return period and environment data are given in B.1.1 and B.1.3.

The design of a mooring system requires the establishment of wind, wave and current load are provide in Section 2, B.4.3 through B.4.8.

2.1 Vortex Induced Motion

Where a floating installation is susceptible to vortex induced motion (VIM), the load on the mooring system due to VIM is to be analyzed.

Vortex-induced motions, transverse to and in line with the current, contribute to the offset of the floating installation and hence result in mooring line load. The occurrence of VIM also increases the mean drag force in the current direction. These effects may need to be taken into account for the strength and fatigue design of the mooring system.

2.1.1 Occurrence of VIM

Significant VIM can occur if a natural frequency of the moored system lies in the vicinity of the vortex shedding frequency of a major cylindrical component of the platform.

The vortex shedding frequency in steady flow can be calculated by:

$$f_s = S_t \frac{V_c}{D}$$

where,

f_s = vortex shedding frequency, [Hz]

S_t = Strouhal number

V_c = current velocity, [m/s]

D = member diameter, [m]

The occurrence of significant VIM is related to the non-dimensional reduced velocity V_r:

$$V_r = \frac{V_c}{Df_s}$$

where,

V_r = reduce velocity

2.1.2 VIM Prediction

The VIM analysis is to predict the amplitude of the VIM and the corresponding drag coefficients. The analysis is to include the following:

1) Range of reduced velocity
2) In-line and transverse VIM response amplitude as a function of reduced velocity
3) Drag coefficient as a function of VIM response amplitude
4) VIM response trajectory or envelope

Model testing can be used for the VIM predictions and numerical analysis may provide preliminary assessment of VIM. A VIM model testing is to be well planned and consider the following:

1) Geometric scaling
2) Dynamic scaling
3) Hydrodynamic scaling
4) Modeling of appurtenances
5) Mooring stiffness characteristics
6) Degrees of freedom
7) Current direction and profile
8) Directional resolution
9) Damping from moorings, floating unit, et al.
10) Blockage (wall) effect
11) Length of response record

Further guidance for VIM prediction is given in Annex 12

3. Mooring System Analysis

3.1 General

Mooring system analysis is to be performed to predict extreme responses for mooring line tensions, anchor loads, and vessel offsets under the design environments and other external loads. The responses are then checked against allowable values so that the system has adequate strength against loading and sufficient clearance to avoid interference with other structures. The mooring analysis should consider the following as a minimum:

1) Environmental load including wind, wave and current load
2) Environmental load induced motions/excursions and mooring line load
3) Vortex induced motions and mooring line load where applicable
4) Squall induced motions and mooring line load where applicable

Active control of the mooring system by mooring line adjustment may be performed for certain operations.

However, active mooring line adjustment should not be considered in the mooring analysis for maximum design conditions.

3.2 Analysis Model

A moored system is a dynamic system that is subjected to steady forces of wind, current and mean wave drift force, as well as wind and wave-induced dynamic forces. Calculations of the maximum mooring system loading are to consider the various relative wind, wave and current forces.

Depending on the level of sophistication and analysis objectives, quasi-static and dynamic analysis methods may be used. Frequency domain, time domain or combined time and frequency domain approaches are acceptable. The designer is to determine the extreme offset and line tension in a manner consistent with the chosen method of analysis. For the final design of a permanent mooring system, the dynamic analysis method is to be employed to account for mooring line dynamics. In deep water and high current areas the current load on mooring lines and risers, which imposed additional loading on the floating vessel, is to be included in the global analysis.

Where applicable, when a quasi-static analysis method is used, the tension in each anchor line is to be calculated at the maximum excursion for each design condition. The excursion is to include the steady state and dynamic responses of the unit of following:

1) Steady mean excursion due to the defined wind, current and mean wave drift forces;
2) Maximum surge/sway excursions of the unit due to first-order wave excitations
3) The effects of second order wave-induced motions are to be included for units when the magnitudes of such motions are considered important.

For a single point mooring system, the vessel may experience large low frequency yaw motions. These yaw motions may affect vessel and mooring system responses, and therefore should be accounted for in time or frequency domain simulations as well as in model testing. Care should be taken on the limitation of frequency domain method where variation of yaw angle from the equilibrium position cannot be captured.

The motion amplitude is highly dependent on the stiffness of the mooring system and damping. They are to be properly modeled in the analysis.

Polyester ropes as well as other fiber ropes are made of materials with visco-elastic properties, so their stiffness characteristics are not constant and vary with the load duration and magnitude, the number and

frequency of load cycles, and the loading history. In general, polyester mooring lines become stiffer after a long time in service. Historical loading above a certain level may result in a permanent increase of the rope length and a softer mooring system if no re-tensioning is performed. Because of this complex rope behavior, it is not possible to develop models that represent the precise stiffness characteristics of the rope.

Currently the industry relies on simplified models that capture the most important characteristics and at the same time yield conservative prediction of line tensions and vessel offsets. Guidance on modeling stiffness of polyester ropes and other fiber ropes are provided in the API RP 2SM Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Rope for Offshore Mooring.

The mooring system analysis should take into account the riser loads, stiffness and damping due to the interactions between the mooring system and riser system, unless it can be demonstrated that disregarding some or all riser effects will produce same or more conservative mooring design. Some of the floating production units are equipped with steel catenary risers or midwater flowlines arranged in asymmetric patterns, which may impose large riser or flowline loads on the mooring system. In this case the riser or flowline loads are to be carefully evaluated and properly accounted for.

The effect of water depth should be considered where applicable.

3.3 Initial System Balance and Equilibrium Position

The mean equilibrium position of the moored units is calculated from static balance between the mean environmental load, buoyancy, weight of the floating unit and mooring lines, and the mooring system's restoring force. A stable equilibrium position should be determined before carrying out further dynamic analysis, especially for the analysis in frequency domain. Riser effects are to be considered where their stiffness is relatively high.

3.4 Response to Wave Frequency Force

3.4.1 Frequency Domain Analysis Method

In the frequency domain analysis method, all the parameters are linearized due to the use of the linear principle of superposition. Methods to approximate non-linear effects in the frequency domain and their limitations should be investigated so that the solutions for the intended operation are not compromised.

Frequency domain analysis is to use the equilibrium position based on the environmental mean loads and restoring forces of the mooring lines.

In the frequency domain method, the wave frequency responses can be calculated separately from the low frequency responses. The analysis is to obtain:

1) Motion, velocity and acceleration RAOs of floating units
2) RAOs of mooring line tensions
3) Statistical values of the responses, such as standard deviation, significant or maximum responses based on the probability distributions of the peak responses

The wave frequency responses can be combined with low frequency responses to obtain the maximum response value according to the method given in B.3.

3.4.2 Time Domain Analysis Method

In the time domain analysis approach, all nonlinear effects including line stretch, line geometry, fluid loading, and others nonlinear effects can be modeled.

In this approach, the combined mean, low, and wave frequency response of the floating unit is solved in a time domain. The dynamic equations describing the floating unit, mooring lines, risers, and other forces are all included in a single time domain simulation. The time domain simulation analysis is to obtain:

1) Response time histories of all parameters (floating unit offsets, mooring line tensions, etc.)
2) Extreme values of the responses through statistical analysis using response time history data. The time domain simulation should be long enough to establish stable statistical peak values.

3.5 Response to Second-Order Low Frequency Force

In general, the same methodology for the wave frequency responses is applicable to the analysis of second order low frequency responses.

In the low frequency analysis, the mooring stiffness and low frequency damping are to be properly modeled and included in the analysis. The prediction of low frequency damping is complicated. The resources of low frequency damping may include:

1) Viscous damping of the floating unit
2) Wave drift damping of the unit
3) Mooring system damping
4) Riser system damping

The basis for the low frequency damping used in the analysis is to be documented.

3.6 Response to Squalls

3.6.1 Ambient Environment and Initial Condition.

If there is no specific site information available regarding the equilibrium position (location and heading), the equilibrium position may be determined based on the 1-year return environment of wind waves, swell and current. The equilibrium position determined is to be used as the initial floater's position for the analysis subject to squalls.

3.6.2 Yaw Damping

For a turret mooring system, yaw damping is an important parameter when subject to squalls. However, determination of yaw damping may be difficult. In the absence of better information, the linearized yaw damping coefficient for the turret provided in API 2SK and given below can be used.

$$C_{Rz} = \frac{1}{3} C_y \left(a^3 + b^3\right)/(a+b) \qquad \text{[Nm/(Rad/s)]}$$

where,

C_{RZ} = linear yaw damping coefficient

C_y = linear sway damping, [N/(m/s)]

A = length of vessel forward of turret, [m]

B = length of vessel aft of turret, [m]

3.6.3 Simulation of Responses to Squalls

Mooring systems subject to squall winds are to be analyzed using a time-domain simulation approach. The length of the simulation time depends on the squall records selected and is to cover the significant variations of the wind speed and wind directions. Squalls characteristics and the responses of mooring

systems to squalls are still ongoing research topic. Care is to be taken when selecting squalls for analysis. Among other factors, the following is to be taken into account:

1) Wind Speed. Wind speed is the most important parameter of a squall especially at the early stage of the squall when the turret moored unit is weathervaning, namely unit heading changing from initial to head-on condition. Squalls with high wind speeds are the most critical.
2) Rate of Speed Change. In general, the higher rate of speed change, the more critical of the squalls.
3) Rate of Wind Direction Change. The effect of the rate of wind direction change is to be considered with reference to the initial heading of the floating unit.
4) Duration of the Wind Speed. The longer duration of the high wind speed, the more critical the squalls.

Users should be aware of the latest development on squalls, and sensitivity study for the selected parameters may be necessary.

In the time domain simulation, a proper initial ramp up to the real wind speed may be considered to avoid the sudden transient response at the beginning of the analysis.

3.6.4 Extreme Value of Mooring Load and Offset

Regarding responses of mooring loads and offset to squall dominant conditions, the results can be separated into very slowly varying component due to slowly varying squall wind speed, and the frequent varying component mainly induced by waves and wind fluctuation. The statistics for the frequent varying component can be constructed for the maximum value calculation and combined with the very slowly varying component. The most probable maximum value can be used as the extreme value if the number of simulations provide reasonable probability distribute density function. If the simulation number is limited, the maximum value from the simulation results may be used. The methodology for the determination of extreme values is to be documented and submitted to BKI for review

3.7 Response to VIM

The following effects from VIM are to be included in the mooring analysis:

- Drag coefficient in the presence of VIM.
- Offset of floating units due to VIM
- Low-frequency oscillations in mooring line tensions due to VIM

To take these effects into account for strength and fatigue design of the mooring system, the following VIM-related design parameters are to be established:

- In-line and transverse VIM response amplitude (A/D) as a function of reduced velocity (V_r)
- Drag coefficient as a function of VIM response amplitude

These design parameters are to be based on a combination of project specific model test data, previous VIM design experience, and relevant field measurements.

Model testing has been the primary tool for VIM prediction because of the difficulties in obtaining fullscale measurement data and the lack of a sufficiently mature numerical approach. It is usual practice to perform well planned model testing to determine motion amplitudes and drag coefficients for the purposes of mooring design. However, all the model tests conducted to date can only accurately model certain parameters while approximating others. The confidence in model test results and VIM design parameters should be established through adherence to sound engineering principles and comparison with field measurements where available. The reliance on model testing, the limitations of model testing and limited validation with full-scale data are be recognized as potential sources of uncertainty in the design process.

The recommended practice is to develop the design parameters for a base case (the best estimate). Tension safety factors for intact and damaged conditions are to be met for the base case. A sensitivity study related to influential parameters on the design parameters is to be carried out to confirm the robustness of the mooring system (i.e., the risk of mooring failure in the event that estimates of certain influential parameters are inaccurate). The sensitivity check is also used to determine if, with some changes in system parameters the system would enter a VIM lock-in regime.

Mooring strength analysis for the VIM condition is normally conducted for an extreme current with associated wind and waves. The metocean criteria should specify current velocity, profile, and directions as well as the intensity and direction of the wind and wave conditions associated with the extreme current.

Recent experience suggests that consideration is also to be given to extreme wind and waves with associated current as these conditions may produce a larger VIM response.

Mooring tensions due to VIM are cyclic by nature and contribute to the fatigue damage of the mooring system. For long-term fatigue analysis under the VIM condition, current events can be represented by a number of discrete current bins, with each current bin consisting of a reference direction, a reference current velocity and profile, associated wave and wind conditions, and probability of occurrence. Fatigue damage for each current bin is evaluated, and the sum of fatigue damage due to VIM from all current bins is added to the fatigue damage due to wind and waves to determine the total in-place fatigue damage.

In the GOM, a typical loop/eddy current event can last more than one month. Instead of using a constant extreme design current for the whole event, current strength and direction variation based on field measurements for strong loop currents can be considered.

Annex 12 provides more information on the assessment of VIM.

3.8 Multiple Vessels Interaction

If floating installation are in close proximity to each other, the hydrodynamic interactions, wind and current shielding effects is also to be accounted for in analysis.

4. Fatigue Damage

4.1 General

The annual fatigue damage of a mooring line component is to be calculated as the sum of the annual fatigue damage from all the combined environmental parameters, or all sea states. Each sea state may consist of:

- Sea State Direction. Eight to twelve directions can be considered as representing the directional distribution of the long-term environment if no site specific information.
- Probability of occurrence of each sea state
- Mean offset and heading of the floating installation due to the effects of the sea state, with associated wind and current

4.2 Tension-Tension Fatigue Damage

For each sea state, the tension range of a mooring line component is to be calculated according to mooring analysis procedures given in 3. Three methods for combining fatigue damage due to low frequency and wave frequency tensions can be used.

4.2.1 Simple Summation Method

The simple summation method assumes that the total damage is the sum of low frequency and wave frequency fatigue damages. The simple summation method will generally give an acceptable estimate of

fatigue damage if the ratio of the tension standard deviations between wave frequency and low frequency response satisfies the following condition:

$$\frac{\sigma_{wf}}{\sigma_{\ell f}} \geq 1{,}5 \quad \text{or} \quad \frac{\sigma_{wf}}{\sigma_{\ell f}} \leq 0{,}05$$

Where σ_{wf} and $\sigma_{\ell f}$ are wave frequency and low frequency tension standard deviation, respectively. The simple summation method may underestimate fatigue damage if both low and wave frequency tensions contribute significantly to the total fatigue damage.

Based on a Rayleigh distribution of tension peaks the fatigue damages for sea state *i*, can be calculated by the following equation:

$$D_i = \frac{n_{Wi}}{K}\left(\sqrt{2}R_{W\sigma i}\right)^M \Gamma\left(1+\frac{M}{2}\right) + \frac{n_{Li}}{K}\left(\sqrt{2}R_{L\sigma i}\right)^M \Gamma\left(1+\frac{M}{2}\right)$$

$$n_i = \nu_i T_i = \nu_i \cdot P_i \cdot 3{,}15576 \times 10^7$$

where:

D_i = annual fatigue damage from wave frequency and low frequency tensions in sea state *i*

n_{Wi} = number of wave frequency tension cycles per year for sea state *i*

$R_{W\sigma i}$ = ratio of standard deviation of wave frequency tension range to reference breaking strength (RBS). The standard deviation of the tension range should be taken as twice the standard deviation of tension.

Γ = Gamma function

n_{Li} = number of low frequency tension cycles per year for sea state *i*. The average zero up-crossing frequency may be estimated by $1/T_N$, where T_N is the natural period of the vessel computed at the vessel's mean position.

$R_{L\sigma i}$ = ratio of standard deviation of low frequency tension range to RBS. The standarddeviation of the tension range should be taken as twice the standard deviation of tension.

ν_i = zero up-crossing frequency (hertz) of the tension spectrum in sea state *i*

T_i = time spent in sea state *i* per year

P_i = probability of occurrence of sea state *i*

4.2.2 Combined Spectrum Method

Combined Spectrum method uses the standard deviation of the combined spectrum to calculate the total damage. Based on a Rayleigh distribution of tension peaks, the fatigue damage for sea state *i* can be calculated from the following equation:

$$D_i = \frac{n_i}{K}\left(\sqrt{2}R_{\sigma i}\right)^M \Gamma\left(1+\frac{M}{2}\right)$$

$$n_i = \nu_{ci} T_i = \nu_{ci} \cdot P_i \cdot 3{,}15576 \times 10^7$$

The standard deviation of the combined low and wave frequency tension range, $R_{\sigma i}$, is computed from the standard deviations of the low frequency tension ranges $R_{L\sigma i}$, and wave frequency tension ranges $R_{\sigma i}$ by:

$$R_{\sigma i} = \sqrt{R_{W\sigma i}^2 + R_{L\sigma i}^2}$$

The number of cycles, n_i, in the combined spectrum is calculated with the zero up-crossing frequency (hertz) of the combined spectrum, ν_{ci}, which is given by:

$$\nu_{\sigma i} = \sqrt{\lambda_{Li}\nu_{Li}^2 + \lambda_{Wi}\nu_{Wi}^2}$$

where,

ν_{Wi} = zero up-crossing frequency (hertz) of the wave frequency tension spectrum in environmental state *i*

ν_{Li} = zero up-crossing frequency (hertz) of the low frequency tension spectrum in environmental state *i*

$$\lambda_{Li} = \frac{R_{Li}^2}{R_{Li}^2 + R_{Wi}^2}$$

$$\lambda_{Wi} = \frac{R_{Wi}^2}{R_{Li}^2 + R_{Wi}^2}$$

4.2.3 Time Domain Cycle Counting Method

Time domain cycle counting method calculates the fatigue damage using a cycle counting method, such as the Rainflow method, to calculate the number of tension cycles and the expected value of the tension range from a time history of tensions.

4.2.4 Long-term Fatigue Damage due to VIM

For long-term fatigue analysis, the sum of fatigue damage due to VIM from all current bins is to be added to the fatigue damage from wind and waves to yield total fatigue damage.

When assessing fatigue due to VIM, the oscillation period of the VIM at the offset position corresponding to the specific current bin under consideration is to be used when calculating the number of tension cycles. This period can vary with current direction and magnitude.

4.2.5 Fatigue Damage due to Single Worst Case Event

The fatigue damage due to a single worst case event, such as 100-year hurricane or 100-year loop current event, is to be analyzed and evaluated against the required fatigue design safety factors.

4.3 Bending-Tension Fatigue Damage

The assessment of bending-tension fatigue damage includes the analysis of chain tension, relative rotation angle between the chain lines, bending moment, stress concentration factor, and others. The Joint Industry Project of Chain Out-of-Plane Bending has done a lot of research work and has provided recommendations on the assessment of bending-tension fatigue. Annex 11 provides guidelines for the bending-tension fatigue analysis including mooring analysis, FEM analysis and/or static OPB/IPB test that could be conducted to assess the bending damage.

Section 7 Process and Import/Export Systems

A. Hydrocarbon Production and Process Systems 7–1
B. Import and Export Systems 7–7

A. Hydrocarbon Production and Process Systems

1. General

1.1 Installations Classed as FPSO or FPS

Hydrocarbon production and processing systems are to comply with the requirements of the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII) and 2. through 11.

1.2 Installations Classed as FOI (Production Facilities not Classed)

The entire production facility need not comply with the requirements of this Section. However, the following systems and equipment for the production facilities are to be in accordance with the requirements of the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII).

System/Equipment	Rules for Facilities on Offshore Installation (Pt.5, Vol.XII), Section
Facility Layout	3, C.3
Area Classification	3, F.8
Electrical System Circuit Protection	3, F.3.5
Electrical Installations in Classified Areas	3, F.8
Fire Water Systems	3, H.3.1
Dry Chemical Systems, as applicable	3, H.3.2
Fixed Fire Extinguishing Systems	3, H.3.3
Paint Lockers, Laboratory Spaces, and Flammable Material Store Rooms	3, H.3.4
Emergency Control Station	3, H.3.6
Operation After Facility Total Shutdown	3, H.3.7
Portable and Semi-portable Extinguishers	3, H.3.8
Gas and Fire Detection Systems	3, H.4
Structural Fire Protection	3, H.5
Muster Areas	3, H.6
Means of Escape	3, H.7
Lifesaving Requirements	3, H.8
Personnel Safety Equipment and Safety Measures	3, H.9

For installations with the **FOI** class notation, equipment certification by BKI or Recognized Organization is required for equipment in the above listed systems.

1.3 Installations Classed as FOI (with Production Facilities Indicated in the Register)

The entire production facility need not comply with the requirements of this Section. However, safety features are to be in accordance with the following requirements of the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII) in addition to the requirements in 1.2.

System/Equipment	Rules for Facilities on Offshore Installation (Pt.5, Vol.XII), Section
Facility Layout	3, C.3
Safety System	3, C.7.2
Process Shutdown Systems	3, G.7

1.4 Installations Classed as FSO without Production and process Facilities onboard

1) For installations classed as FSO without production and process systems installed on board, the requirements of the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII).are not applicable. All relevant sections of Rules for Machinery Installations (Pt.1, Vol.III) and Rules for Electrical Installations (Pt.1, Vol.IV) respectively and Rules for Ships Carrying Dangerous Chemicals in Bulk (Pt.1, Vol.X), if chemicals, are to be complied.
2) In addition, for such FSO installations moored through external turret mooring system, the turret is to be provided with fire fighting equipment in accordance with the requirements of Rules for Single Point Mooring (Pt.5, Vol.IX), Sec.4, D.2.
3) For such FSO installations moored through internal turret mooring system, in addition to item 1) above, the turret area is to be provided with the following safety systems and equipment in accordance with the requirements of the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII).

System/Equipment	Rules for Facilities on Offshore Installation (Pt.5, Vol.XII), Section
Fixed Fire Extinguishing Systems, as applicable	3, H.3.3
Portable and Semi-Portable Extinguishers, as applicable	3, H.3.8
Gas and Fire Detection Systems, as applicable	3, H.4

2. Scope

This Section is applicable to the following:

1) Systems that process hydrocarbon liquids, gases or mixtures from completed wells.
2) Production support systems associated with the process system, such as water, steam, hydraulics, pneumatics and power supply to the process.
3) Fire protection systems for the protection of the process equipment and the process area.
4) Systems that are utilized for stimulation of a completed well, such as chemical, gas or water injection downhole through a Christmas tree.
5) Power generation systems for export purposes.
6) Electrical systems and components associated with the process facilities.
7) Systems other than those mentioned above, such as methanol production and/or processing, and desalination, will be the subject of special consideration.

The scope of the hydrocarbon process system is defined in Section 2, A.3. The scope of the hydrocarbon process system may also include the controls for the well head and subsurface safety valve, if these are included in the process safety shutdown system.

3. Installations

Hydrocarbon production systems are typically installed on the following types of installations.

3.1 Ship-Type Installations - Oil Carriers

Where tankers are to retain the propulsion capability for rapid deployment in the event of environmental conditions exceeding the approved design environmental criteria, the flow lines and the export lines are to be fitted with quick disconnect systems. The documentation regarding the disconnecting procedure is to be submitted for review. For detailed requirements for the disconnect system of the process lines and the mooring systems, see A.8.8.

3.2 Column-Stabilized Installations and Tension Leg Platforms

These installations may be used simultaneously for operations other than hydrocarbon processing, such as drilling.

4. Subsea Equipment

Subsea equipment is not a part of the classification boundaries as defined in Section 1, A.1. However, subsea equipment may be classed if desired by the Owner, provided these items are approved by BKI for compliance with the requirements of the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII) and applicable Sections.

BKI is prepared to certify the subsea equipment if the manufacturers/owners wish to obtain BKI certification. The design, construction and testing of the subsea equipment are to be in accordance with of the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, C.11.3.

For a unit that has the riser system classed by BKI, the riser installation winch needs to comply with the following:

1) For a winch that is on board for the installation of the risers only (and removed after installation), the equipment does not need to be reviewed by BKI. However, the supporting structure needs to be designed to provide satisfactory strength for the reaction forces specified by the manufacturer or the maximum anticipated loads during the installation process.
2) If the riser installation winch is to remain on board after the installation, the equipment will need to be in compliance with recognized industry standards. The manufacturer will need to submit details to demonstrate compliance with the industry standards, either in the form of certificates issued by recognized certification bodies or by submitting details and calculations to BKI for review and approval.

5. Other Codes and Standards

Use of national or international standards or codes other than those listed herein in the design and construction of the equipment and components is subject to prior approval and acceptance by BKI. The standards or codes being applied are to be adhered to in their entirety.

6. Non-Standard Equipment

Equipment not designed to a recognized standard may be accepted based on approval of detailed design calculations and testing results that verify the integrity of the equipment which is submitted for review and found satisfactory.

7. Design and Construction

7.1 General

Hydrocarbon process systems and associated equipment are to be designed to minimize the risk of hazards to personnel and property. This criterion is implemented by complying with the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), as well as this Guidelines. The implementation of this criterion is intended to:

1) Prevent an abnormal condition from causing an upset condition.
2) Prevent an upset condition from causing a release of hydrocarbons.
3) Safely disperse or dispose of hydrocarbon gasses and vapors released.
4) Safely collect and contain hydrocarbon liquids released.
5) Prevent formation of explosive mixtures.
6) Prevent ignition of flammable liquids or gasses and vapors released.
7) Limit exposure of personnel to fire hazards.

7.2 Arrangements

General arrangement drawings are to be submitted for review, in accordance with Section 1, C.3. The arrangements depicted are to comply with the Rules for Facilities on Offshore Installation (Pt.5, Vol.XII), Sec. 3, C.3 and H.5 applicable Sections of this Guidelines, and the Part 1. Seagoing Ship or Part 5. Offshore Technology.

7.3 Structural Considerations

Structure that supports production facilities or forms an integral part of the equipment is to be designed to a recognized standard. Plans and calculations are to be submitted for BKI review. Process liquid weights and dynamic loads due to installation motions and other loads, such as wind imposed loads, are to be considered. (See Section 4, A.5.).

8. Process System`

8.1 Submittals

The various data and plans that are to be submitted to the BKI for review are listed in Section 1, C.3.

8.2 Piping System and Manifolds

Piping of the process and process support systems are to comply with the requirements of API 14E and ASME/ANSI B31.3 and B31.1, as applicable. Refer to Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, C and D.

8.3 Pressure Relief and Depressurization Systems

Pressure relief and depressurization systems are to comply with API RP 520 and API RP 521. Refer to Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, C.6.

8.4 Process Equipment and Vessels

Process equipment and vessels are to comply with the applicable requirements in Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, C.9 and 5, A.2.

8.5 Prime Movers

Internal combustion engines and gas or steam turbines are to comply with Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, D.2.5 and 5, A.2.

8.6 Safety Systems

Safety systems are to comply with Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, C.4.2 and C.5. Specific items to be addressed are as follows:

1) The process safety and shutdown system is to comply with API RP 14C.
2) Fire detection and gas detection is to comply with API RP 14C and API RP 14G, respectively. The location of the fire and gas detectors is to be to the satisfaction of the attending Surveyors.
3) The process safety shutdown system is required to shut down the flow of hydrocarbon from all wells and process systems. The discharge of processed hydrocarbons to the export lines is also to be controlled by the process safety shutdown system. Redundancy is to be provided in the power source to the process safety shutdown system such that upon failure of the main power source, the secondary power source is brought online automatically.

8.7 Control System

Control systems, in general, are to comply with Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, G. Additionally, computer based control systems are to comply with the following:

1) The control system is to be totally independent of the alarm and monitoring system.
2) Where computers are utilized for monitoring, alarm and control, the arrangements are to be such that a fault in one of these functions will not impair the capability of other functions.
3) The computer system for monitoring alarms and control is to include redundancy arrangements in order to maintain continued operation of the hydrocarbon process system.

8.8 Quick Disconnect System

Where the Floating Installation is fitted with a quick disconnect system, the control of this system is to be totally independent of the process safety shutdown system required for the hydrocarbon process system. However, the source of power for the process safety shutdown system and controls for the quick disconnect system need not be totally independent, provided that the failure in one system does not render the other system ineffective, e.g., failure through leakage in the hydraulic or pneumatic control lines.

Means are to be provided for the activation of the quick disconnect system from the control station and locally in the vicinity where the disconnect arrangements are located.

The disconnect arrangement is to be designed such that upon its activation, all process flow to the Floating Installation is automatically stopped immediately without leakage of process fluids.

8.9 Electrical Installations

Electrical installations for the hydrocarbon process system are to comply with the requirements of Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, F.

9. Hazardous Area Classification

Hazardous areas are to be delineated and classified, as required by Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, F.8. In general, API RP 500 or 505 is to be applied to process areas, and the Part 1. Seagoing Ship or the Rules For Mobile Offshore Units (Pt.5, Vol.VI) are applied to non-process areas, as modified by Rules for Facilities on Offshore Installations (Pt.5, Vol.XII), Sec.3, F.8.

10. Fire Protection

Fire extinguishing systems and firefighting equipment associated with the hydrocarbon process facilities are to comply with Rules for Facilities on Offshore Installation (Pt.5, Vol.XII) Sec. 3, H.

11. Fabrication and Testing

Inspection and testing of hydrocarbon process and associated equipment at the manufacturer's facility are to be in accordance with Rules for Facilities on Offshore Installation (Pt.5, Vol.XII) Table 5.1. Construction and fabrication is to be performed in accordance with approved plans and procedures. Representative survey interventions are listed as follows.

11.1 Pressure Vessels, Accumulators, Heat Exchangers, Separators and Manifolds

1) The construction, fabrication and material are in accordance with design codes shown on the approved plans.
2) Witness weld procedure and welder performance qualification tests.
3) Visual inspection of weld joints, witness nondestructive testing.
4) Fit up and joining of all pipe connections and pipe supporting arrangement.
5) Dimensional inspection during fit-up and after completion.
6) Internal examination.
7) Witness calibration of hydrostatic testing equipment.
8) Witness hydrostatic tests.

11.2 Pumps, Compressors and Diesel/Gas Engines

1) Witness mechanical running tests.
2) Witness testing of auxiliary equipment and protective devices (controls, filters, coolers, oil pumps, alarms, trips, governors).

11.3 Motors and Generators

1) Functional running test for machines greater than 100 kW.
2) Witness testing of auxiliary equipment and protective devices.

11.4 Switchboards and Control Panels

Inspection and witness testing at the manufacturer's facility is not required for switchboards and control panels. These components will be accepted for use, provided they have been designed and constructed to a recognized national or international code or standard.

Control and alarm panels for fire protection and safety systems are to be function-tested at the manufacturer's facility. These tests are to be conducted in the presence of the Surveyor.

11.5 Process and Process Support Piping

Fabrication, inspection and testing of process and utility piping is to be performed to the satisfaction of the attending Surveyor.

B. Import and Export Systems

1. General

This Subsection applies to import and export systems utilized in Floating Installations when the class notations specified in Section 1, A.5.3 are requested. These systems include rigid and flexible risers, connecting flow lines, submerged jumpers and floating offloading hoses. (Section 2, A.5 for definitions of related items).

1.1. Riser Classification Boundaries

The import/export system is assumed to consist of only rigid, flexible hose/pipe or a combination of both rigid and flexible hose/pipe, and associated riser components, such as the tensioning system, buoyancy modules, line buoys, permanent clamps, anchoring systems and safety control systems.

In a typical Floating Installation import (or export) system, the applicable starting and termination points are the riser's connection point to the PLEM and the riser's connection point to the installation or floating structure. The connection points are typically the discharge (or input) flange of the PLEM and the input (or discharge) flange of the installation or floating structure.

For export vessel transfer systems, the connection points are the discharge flange of the installation or floating structure and the end connection to the input flange onboard the export vessel, see 4.4.

1.1.1 The Import System

The Import System is to include the import risers starting from the Import PLEM, but not including the Import PLEM.

For a typical flexible riser system, the import riser may start at the PLEM/wellhead flanges and terminate at the input flange of the installation or floating structure.

1.1.2 The Export System

The Export System is to include the export risers that may start from the discharge flanges of the installation or floating structure and terminate at the Export PLEM, but not including the Export PLEM.

The criteria given here for Import Risers are applicable to Export Risers where classification is requested. Where Import and/or Export Risers induce mooring restraint to the floating installation, design, construction and classification of the Riser(s) providing restraint and their connection to the seabed will require special consideration.

1.2. Basic Design Considerations

The import/export system is to be designed to maintain its under the most unfavorable combination of external environmental loads, internal loads due to fluid contents, pressure and temperature and accidental loads. This is accomplished by ensuring that riser system design is consistent and compatible with the design philosophy used for the Floating Installation.

The dynamic response of the import/export system is to be investigated to the level of detail necessary to ensure that interference between the floating production installation and the associated mooring system does not affect the integrity of the installation or the import/export system. Where conditions are such that analytical investigation (vortex induced vibration analysis, for example) is not adequate to account for installation interference or interference due to multiple riser configurations, etc., model testing or other means of verification are to be performed and requested documentation provided to the BKI for review.

The riser is to survive the maximum installation offset, as defined in Section 6, A.1.2.2.

2. Submission of Plans and Design Data

Documentation outlining the design, manufacture, installation and operating assumptions applicable to the project is to be submitted for review at the initiation of the project. The following summarizes the typical information that is required to help ensure that the design basis and criteria selection is consistent with the design philosophy. In general, the following are to be submitted for review:

1) Site plan indicating bathymetric features, the location of obstructions to be removed, the location of permanent manmade structures and other important features related to the characteristics of the sea floor.
2) Material specifications for the import/export system, its supports and coatings.
3) Pipe manufacture, testing and quality control procedures.
4) Flow diagrams indicating temperature and pressure profiles.
5) Specifications and plans for instrumentation, control systems and safety devices.
6) Specifications and plans for installation, field testing, inspection, anticipated component replacement and continued maintenance of the riser system.
7) Environmental and geotechnical report.

3. Environmental Considerations

The environmental loadings are to be calculated in accordance with the methods in Section 2, B.

4. System Design and Analysis

4.1. General

The design of the import/export system should consider all modes of operating, testing, survival and accidental events. The import/export system should be analyzed to determine its response to the design events. Each individual component should be examined for its strength and suitability for the service conditions.

4.2. Rigid Risers

4.2.1 Design Analysis

The analysis of a rigid riser is to follow the appropriate sections of API RP 2RD and API RP 2T for all relevant design load cases. The establishment of the critical design condition must be verified by a suitable verified program that properly simulates the dynamic response of the entire system operating under the required design condition.

The following items, as applicable, are to be appropriately accommodated in the analysis:

1) Environmental conditions
2) Boundary conditions
3) Riser configuration
4) Riser joint properties
5) Buoyancy devices
6) Installation motion (RAOs)
7) Applicable site conditions
8) Effects of internal contents

9) Pressure testing and accidental conditions

4.2.2 Design Limits

Rigid risers are to be designed against the following limits based on the design load cases being investigated.

Maximum Stress, Stability and Buckling. Allowable stresses in plain pipe are to be limited, per API RP 2RD. Overall stability of the riser and local pipe buckling should be evaluated.

Maximum Deflection. Acceptable limits of maximum deflection are to be determined considering the inherent limitations of riser components, equipment used in the riser and the need to avoid interference with the Floating Installation.

Fatigue and Fracture. The riser system is to be designed to ensure that an adequate margin of safety is available for critical components to counteract the effects of fatigue caused by cyclic fluctuations (due to both internal and external loads) over the anticipated life of the system.

The cumulative damage calculated by the use of Miner's Rule is to be 0.1 or less for a critical component which cannot be easily inspected or repaired. For non-critical components which can be easily inspected, the cumulative damage should be 0.3 or less.

4.3. Flexible Risers

4.3.1. In-place Analysis

The in-place analysis is to address all design load cases using motions consistent with the mooring analysis. The scope of the in-place analysis, as a minimum, should include the following:

1) On-bottom stability for flexible flow lines
2) Static and dynamic analysis for flexible riser
3) A system dynamic analysis to ensure:
   A) Maximum tension and minimum radius of curvature are within the manufacturer's recommendations.
   B) Suspended portions of the flexible pipe (e.g., sag bends) are not allowed to bounce on the sea floor or experience compression that might cause kinks.
   C) Suspended flexible pipes are not allowed to chafe against each other, the installation body or mooring lines.
4) Flow-induced motion analysis.
5) Flexible pipe layer stress analysis.
6) The stresses in the flexible pipe layers shall comply with the requirements of API SPEC 17J for the applicable design load cases.
7) Mechanical gripping devices should not cause damage to the weaker exterior layer.
8) Service life analysis.
9) Corrosion protection system design.

4.3.2 Design Limits

Design limits established for the riser system are to be determined in accordance with API RP 17B and confirmed by performance/acceptance testing during the manufacture of the flexible riser and the associated components. Where sufficient test data and service history exist to confirm a component's

capability, the BKI may consider the acceptance of this documentation in lieu of performance/ acceptance testing.

4.4. Export Vessel Transfer System

This system may be classed if requested. Export of fluid to an export vessel is usually limited to stabilized crude oil and is usually accomplished by: (1) Side-by-side transfer, (2) Tandem transfer, or (3) Single Point Moored Buoy via, for example, a floating hose or riser. For certification of these systems, BKI requires compliance to OCIMF Standards and MARPOL. The OCIMF Standard is applicable for operating pressures not greater than 15 bar gauge. In complying with these standards, BKI requires the Owner to observe the guidelines as given in The OCIMF Guide to Manufacturing and Purchasing Hoses for Offshore Moorings and The OCIMF Tandem Mooring and Offloading Guidelines for Conventional Tankers at F(P)SO Facilities, as applicable. The operation and safety considerations for transfer of crude are to be contained in the Floating Installation's operations manual and be consistent with the requirements outlined in The OCIMF Ship to Ship Transfer Guide (Petroleum), The OCIMF Tandem Mooring and Offloading Guidelines for Conventional Tankers at F(P)SO Facilities.

4.5 System Components

All system components are to be designed in accordance with the appropriate criteria issued by the API. The specification for the design and manufacture of the components is to be submitted. The specification is to include at a minimum the performance criteria established from the riser design and analysis and give explicit acceptance criteria needed to ensure the compliance to these criteria.

4.6. Installation Analysis

The installation analysis is to address all aspects of the installation procedure discussed in Section 2, D.1.6. Calculations to demonstrate the structural integrity of the riser and its auxiliary components are to be submitted for review.

The riser pipe is to be checked for all installation loads, tension and bending combination (bending from chute, sleeve, roller or drum) and loads caused by the installation of auxiliary components.

Loads from mechanical gripping devices, such as clamps and tensioners, are to be checked and are not to cause damage to the weaker exterior layer of the flexible pipe.

5. Materials

5.1. Material for Rigid Risers

Material and dimensional standards for steel pipe are to be in accordance with ANSI/ASME B31.4 and B31.8, API RP 2RD and/or other suitable standards approved for the intended application by BKI with respect to chemical composition, material manufacture, tolerances, strength and testing requirements.

5.2. Material for Flexible Risers

The guidelines in API RP 17B and API SPEC 17J may be used to assess the adequacy of the material standards for flexible risers.

Section 8 Materials and Welding

The independent booklet, Rules for Materials (Pt.1, Vol. V) and Rules for Welding (Pt.1, Vol. VI), for steels, irons, bronzes, etc., is to be referred to. This booklet consists of the following Volume:

Rules for Testing and Certification of Materials

Pt 1, Vol. V	Rules for Materials
Pt.1, Vol. W	Guidance for Approval and Type Approval of Material and Equipment for Marine Use

Rules for Welding and Fabrication

Pt.1, Vol. VI	Rules for Welding

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Annex 1 Abbreviations and References

A. Abbreviations 1–1
B. References 1–1

A. Abbreviations

API	American Petroleum Institute	B
ASME	American Society of Mechanical Engineers	B
DEC	Design Environmental Condition	Section 2, B.3.1.1
DIC	Design Installation Condition	Section 2, B.3.1.3
DOC	Design Operating Condition	Section 2, B.3.1.2
FOI	Floating Offshore Installation	Section 2, A.1.
FPO	Floating Production (and Offloading) System	Section 2, A.1.
FPSO	Floating Production, Storage, and Offloading System	Section 2, A.1.1
FSO	Floating Storage and Offloading System	Section 2, A.1.1
HSE	Health and Safety Executive	B
IPB	In Plane Bending	Section 6 & Annex 11
JIP	Joint Industry Project	Section 6
MODU	Mobile Offshore Drilling Unit	B
OCIMF	Oil Company International Marine Forum	B
OPB	Out of Plane Bending	Section 6 & Annex 11
PLEM	Pipe Line End Manifold	Section 2, A.3.4
P&ID	Piping and Instrumentation Diagrams	Section 2, A.2.5
S.A.F.E. Chart	Safety Analysis Function Evaluation Charts	Section 2, A.2.6
SPM	Single Point Mooring	B
IW	Underwater Inspection in Lieu of Drydocking Survey	Section 3, C.1.2 and B

B. References

BKI

Facilities Rules	Rules for Building and Classing Facilities on Offshore Installations (Pt.5, Vol.XII)

MOU Rules	Rules for Building and Classing Mobile Offshore Units (Pt.5, Vol.VI)
Offshore Chain Guide	Rules for Offshore Mooring Chain (Pt.5, Vol.VIII)
Single Point Mooring Rules	Rules for Building and Classing Single Point Mooring Systems (Pt.5, Vol.IX)
Seagoing Ship Rules	Rules for Seagoing ship (Pt.1, Vol.I through Vol.V)
Risk Guidance Notes	Reference Notes on Risk Assessment Application for the Marine and Offshore Oil and Gas Industries (Pt.4, Vol.1)
Fatigue Guide	Guide for the Fatigue Assessment of Offshore Structures (Pt.5, Vol.B)
Risk Guide	Guide for Risk Evaluations for the Classification of Marine-Related Facilities (Pt.5, Vol.A)
Buckling Guide	Guide for Buckling and Ultimate Strength Assessment for Offshore Structures (Pt.5, Vol.C)
SFA Guide	Guide for Spectral-Based Fatigue Analysis for Floating Production, Storage and Offloading (FPSO) Installations (Pt.5, Vol.B)
DLA Guide	Guidelines for Dynamic Loading Approach (Pt.7, Vol.2)

American Institute of Steel Construction :

AISC Code	Manual of Steel Construction - ASD, latest edition

American Society of Mechanical Engineers/American National Standards Institute :

B31.3	Chemical Plant and Petroleum Refinery Piping
B31.4	Liquid Transportation Systems for Hydrocarbons, Liquid Petroleum Gas, Anhydrous Ammonia, and Alcohol
B31.8	Gas Transmission and Distribution Piping Systems
Boiler Code	Boiler and Pressure Vessel Code, Section VIII, latest edition

American Petroleum Institute :

API RP 2A	Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms
API RP 2 SK	Recommended Practice for the Design and Analysis of Station keeping Systems for Floating Structures
API RP 2 SM	Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Rope for Offshore Mooring
API RP 2Q	Replaced by API RP 16Q
API RP 2RD	Recommended Practice for Design of Risers for Floating Production Systems (FPSs) and Tension-Leg Platforms (TLPs)
API RP 2T	Recommended Practice for Planning, Designing, and Construction Tension Leg Platforms

API Bull 2U	Bulletin on Stability Design of Cylindrical Shells.
API Bull 2V	Bulletin on Design of Flat Plate Structures.
API Spec 9A	Specification for Wire Rope.
API RP 9B	Recommended Practice on Application, Care, and Use of Wire Rope for Oil Field Service.
API RP 14C	Recommended Practice for Analysis, Design, Installation, and Testing of Basic Surface Safety Systems on Offshore Production Platforms
API RP 14E	Recommended Practice for Design and Installation of Offshore Production Platform Piping Systems
API RP 14J	Recommended Practice for Design and Hazards Analysis for Offshore Production Facilities
API RP 17B/ISO 13628-11	Recommended Practice for Flexible Pipe
API RP 500	Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I Division 1 and Division 2
API RP 505	Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1 and Zone 2.
API RP 520	Recommended Practice for Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries
Part I	Sizing and Selection
Part II	Installation
API Std 521/ISO 23251	Pressure-Relieving And Depressuring Systems
API Spec 17J	Specification for Unbonded Flexible Pipe

Oil Companies International Marine Forum :

	Guide for Prediction of Wind and Current Loads on VLCCs.
	Guide to Purchasing, Manufacturing, and Testing of Loading and Discharge Hoses.
	The OCIMF Ship to Ship Transfer Guide
	Guidelines for Handling, Storage, Inspection, and Testing of Hoses in the Field
	OCIMF Guidelines for the Purchasing and Testing of SPM Hawsers

United Kingdom's Health and Safety Executive :

HSE Guidance Notes	Offshore Installations: Guidance on DESIGN CONSTRUCTION AND CERTIFICATION. Fourth Edition, 1991, as amended

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Annex 2 Guidance for the Class Notation, Storage Service

A. Introduction 2–1
B. Application 2–1
C. Survey After Construction 2–2

A. Introduction

This guidance clarifies the present BKI policy for treatment of classed oil carriers operating in oil storage service. Under no circumstances is this policy to be used for any other vessel without the specific approval of the Chief Surveyor.

B. Application

This guidance applies to vessels, which are to maintain their current **Oil Tanker** classification or for vessels that have reached their MARPOL phase out date, in such cases these vessels will only be eligible for **Oil Storage Service** notation. The primary class differences between classification as an **FPSO**, **FSO** or **FOI** and **Oil Tanker**, **Storage Service** or **Oil Storage Service** classification are as follows:

1. FPSO, FSO or FOI Notations

1.1 Classed floating production installations (i.e., **FPSO**, **FSO** or **FOI**) require analysis and certification of the mooring system as part of the class requirements for the particular site.

1.2 Those that are classed **Disconnectable** are required to maintain propulsion capability for steaming out of harm's way in an established condition in which the installation is able to safely leave the site before the weather event meets or exceeds the design limits of the fixed mooring system.

2. Storage Service Notation

2.1 For **Oil Storage Service** vessels the mooring arrangements are the responsibility of the Owner, including compliance with Flag and Coastal State requirements.

2.2 In order for a vessel to be classed as :

- ✠ **A 100 Oil Tanker, Storage Service**; or
- **A 100 Oil Tanker, Storage Service**; or
- ✠ **A 100 Oil Storage Service**; or
- **A 100 Oil Storage Service**, the following is required:
  - Written requirements for the conversion to Oil Storage Service are to be obtained from the Assistant Chief Surveyor-Offshore.
  - The attending Surveyor is to report upon the completion of the requirements and recommend Classification as above, as applicable.
  - The vessel's propulsion machinery must be retained to **SM** classification requirements.

2.3 Vessels classed as **Oil Tanker** with special notation **Storage Service** or **Oil Storage Service** will be permitted the **Storage Service** Classification only while remaining in storage service.

- Storage Service, for the purpose of this Class notation, means a vessel that is stationed at a single location, does not transit between ports or different sites and does not carry cargo between ports or sites.

- The vessel serves only in a storage and offloading capacity at a single designated location that is in sheltered waters or at a location that enables the unit to quickly move away from a severe weather event.
- When the vessel leaves the designated "storage service" location, other than to take refuge from severe weather, the "storage service" provisions provided herein no longer apply.
- The vessel is not to transport oil to a port or terminal when taking refuge from weather. It is envisioned that voyages, without cargo, may be necessary for repair works or to a lay-up site when the storage service is seasonal.

2.4 For vessels planned for this service where the location is not sheltered or the vessel is not self-propelled, the requirements for **FPSO**, **FSO** or **FOI** will apply.

C. Survey After Construction

1. General

Vessels in storage service will be surveyed in accordance with the applicable sections of the Rules for Classification and Surveys (Pt.1, Vol.I) except as noted below:

2. Drydocking Surveys

2.1 The vessel is to be properly prepared for the extended positioning. The preparation would normally include a complete Class Renewal Survey appropriate to the age of the vessel, in accordance Rules for Classification and Surveys (Pt.1, Vol.I), Sec.4.I.A.5 and preparation of the underwater parts in accordance with the Rules for Classification and Surveys (Pt.1, Vol.I), Sec.3, B.1.7. All requirements for Close-up Survey and thickness measurements are to be applied. Drydocking Surveys will continue to be required at the regular rule required intervals (normally twice in a 5 year Class Renewal Survey period). However, In-water Survey (IW) examination may be carried out to meet the Drydocking requirements.

2.2 For vessels less than 15 years of age the drydocking requirements for Class Renewal Survey and Intermediate survey may be accomplished by IW for up to 10 years of storage service. For vessels that are over 15 years of age the Intermediate survey drydocking will be permitted to be accomplished by IW, the Class Renewal Survey drydocking will be required to be an out of water docking.

2.3 For vessels exceeding 15 years of age, the time allowable where IW Notation is applied may be extended to a maximum of 10 years in special circumstances where agreed to by the Assistant Chief Surveyor-Offshore.

2.4 Upon completion of the storage service the vessel would be required to proceed to drydock for an out of water drydocking survey if the vessel has been in Storage Service for two years or more.

3. Class Renewal Survey of Hull

Vessels in Storage Service will not be given the ESP notation. However, a vessel in Storage Service will be required to carry out the Class Renewal Survey of Hull in accordance with ESP requirements except that the requirement for an out of water drydocking in association with a Class Renewal Survey may be modified to a IW while the vessel is in storage service, at the storage site, provided no conditions were found to exist that would warrant an out of water drydocking. In these cases, gauging of the underwater sections of the vessel can be taken afloat by qualified divers or from inside the vessel.

4. Intermediate Hull Surveys

Intermediate Hull Surveys, in accordance with the requirements for non-ESP tankers will apply, as long as the vessel remains in Storage Service.

5. Lightering Service

Where transfer of cargo is accomplished by side by side mooring of a shuttle tanker and the Storage Service vessel, the Storage Service vessel will be considered in "Lightering Service".

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Annex 3 Buckling Strength of Longitudinal Members Applied to Reassessed Scantling Determination (See. Fig 4.5)

A. Application 3–1
B. Elastic Buckling Stresses 3–1
C. Critical Buckling Stresses 3–4
D. Working Stress 3–5
E. Scantling Criteria 3–6

A. Application

These requirements apply to plate panels and longitudinals subject to hull girder bending and shear stresses.

B. Elastic Buckling Stresses

1. Elastic Buckling of Plates

1.1 Compression

The ideal elastic buckling stress is given by:

$$\sigma_E = 0{,}9 \cdot m \cdot E \left(\frac{t_b}{a}\right)^2 \qquad [N/mm^2]$$

For plating with longitudinal stiffeners (parallel to compressive stress):

$$m = \frac{8{,}4}{\Psi + 1.1} \qquad \text{For } (0 \leq \Psi \leq 1)$$

For plating with transverse stiffeners (perpendicular to compressive stress):

$$m = c\left[1 + \left(\frac{a}{\ell}\right)^2\right]^2 \frac{2{,}1}{\Psi + 1{,}1} \qquad \text{For } (0 \leq \Psi \leq 1)$$

where

E = $2{,}06 \times 10^5$ [N/mm^2]

t_b = substantial thickness of plating [mm]

a = shorter side of plate panel [mm]

ℓ = longer side of plate panel [mm]

c = 1,3 when plating stiffened by floors or deep girders
= 1,21 when stiffeners are angles or T-sections
= 1,10 when stiffeners are bulb flats
= 1,05 when stiffeners are flat bars

Ψ = ratio of smallest to largest compressive stress, σ_a (see D.1), varying linearly across panel.

1.2 Shear

The ideal elastic buckling stress is given by:

$$\tau_E = 0,9 \cdot k_t \cdot E \left(\frac{t_b}{a}\right)^2 \qquad [N/mm^2]$$

where

$$k_t = 5,34 + 4 \left(\frac{a}{\ell}\right)^2$$

E, t_b, **a** and ℓ are as defined in 1.1

2. Elastic Buckling of Longitudinals

2.1 Column Buckling without Rotation of the Cross Section

For the column buckling mode (perpendicular to plane of plating), the ideal elastic buckling stress is given by:

$$\sigma_E = 10^{-3} \cdot \frac{E \cdot I_a}{A \cdot \ell^2} \qquad [N/mm^2]$$

where

I_a = moment of inertia [cm^4], of longitudinal, including plate flange and calculated with substantial thickness, as specified in 1.1

A = cross-sectional area [cm^2], of longitudinal, including plate flange and calculated with substantial thickness, as specified in 1.1

ℓ = unsupported span [m], of longitudinal

E = as defined in 1.1

2.2 Torsional Buckling Mode

The ideal elastic buckling stress for the torsional mode is given by:

$$\sigma_E = 10^{-4} \cdot \frac{\pi^2 \cdot E \cdot I_w}{I_p \cdot \ell^2} \left(m^2 + \frac{K}{m^2}\right) + 0,385 \cdot E \frac{I_t}{I_p} \qquad [N/mm^2]$$

where

$$K = 10^6 \cdot \frac{C \cdot \ell^4}{\pi^4 \cdot E \cdot I_w}$$

m = number of half waves given by Table A.3.1

E = as defined in 1.1

I_t = St. Venant's moment of inertia [cm^4], of profile (without plate flange)

$= 10^{-4} \frac{h_w \cdot t_w^3}{3}$ for flat bars (slabs)

$= 10^{-4} \cdot \frac{1}{3}\left[h_w \cdot t_w^3 + b_f \cdot t_f^3 \left(1 - 0{,}63 \frac{t_f}{b_f}\right)\right]$ for flanged profiles

I_p = polar moment of inertia [cm^4], of profile about connection of stiffener to plate

$= 10^{-4} \frac{h_W^3 \cdot t_w}{3}$ for flat bars (slabs)

$= 10^{-4}\left(\frac{h_w^3 \cdot t_w}{3} + h_w^2 \cdot b_f \cdot t_f\right)$ for flanged profiles

I_w = warping constant [cm^6], of profile about connection of stiffener to plate

$= 10^{-6} \frac{h_w^3 \cdot t_w^3}{36}$ for flat bars (slabs)

$= 10^{-6}\left(\frac{t_f \cdot b_f^3 \cdot h_w^2}{12}\right)$ for "Tee" profiles

$= 10^{-6} \frac{b_f^3 \cdot h_w^2}{12(b_f + h_w)^2}\left[t_f\left(b_f^2 + 2 \cdot b_f \cdot h_w + 4 \cdot h_w^2\right) + 3 \cdot t_w \cdot b_f \cdot h_w\right]$ for angles and bulb profiles

h_w = web height [mm]

t_w = web substantial thickness [mm]

b_f = flange width [mm]

t_f = flange substantial thickness [mm]. For bulb profiles the mean thickness of the bulb may be used.

ℓ = unsupported span of profile [m]

a = spacing of profiles [mm]

C = spring stiffness exerted by supporting plate panel

$= \frac{k_p \cdot E \cdot t_p^3}{3 \cdot \mathbf{a}\left(1 + \frac{1{,}33 \cdot k_p \cdot h_w \cdot t_p^3}{\mathbf{a} \cdot t_w^3}\right)}$ [N]

k_p = $1 - \eta_p$, not to be taken less than zero

t_p = plate substantial thickness [mm]

η_p = $\frac{\sigma_a}{\sigma_{Ep}}$

σ_a = calculated compressive stress. For longitudinals, see D.1

σ_{Ep} = elastic buckling stress of supporting plate, as calculated in 1

For flanged profiles, k_p need not be taken less than 0,1.

2.3 Web and Flange Buckling

For web plate of longitudinals the ideal buckling stress is given by:

$$\sigma_E = 3{,}8 \cdot C \cdot E \left(\frac{t_w}{h_w}\right)^2 \quad [N/mm^2]$$

where

C = 1,0 for angle or tee stiffeners
= 0,33 for bulb plates
= 0,11 for flat bars

For flanges on angles and T-sections of longitudinals, the following requirements will apply:

$$\frac{b_f}{t_f} \leq 15$$

where

b_f = flange width [mm], for angles, half the flange width for T-sections.

t_f = flange substantial thickness [mm]

Table A3.1 Number of Half Waves

	$0 < K \leq 4$	$4 < K \leq 36$	$36 < K \leq 144$	$144 < K \leq 400$	$(m-1)^2 m^2 < K \leq m^2 (m+1)^2$
m	1	2	3	4	m

C. Critical Buckling Stresses

1. Compression

The critical buckling stress in compression, σ_c, is determined as follows:

$$\sigma_c = \sigma_E \quad \text{when } \sigma_E \leq \frac{\sigma_F}{2}$$

$$= \sigma_F \left(1 - \frac{\sigma_F}{4 \cdot \sigma_E}\right) \quad \text{when } \sigma_E > \frac{\sigma_F}{2}$$

where

σ_F = yield stress of material [N/mm^2], σ_F may be taken as 235 N/mm^2 for mild steel.

σ_E = ideal elastic buckling stress calculated according to B.

2. Shear

The critical buckling stress in shear, τ_c, is determined as follows:

$$\tau_c = \tau_E \quad \text{when } \tau_E \le \frac{\tau_F}{2}$$

$$= \tau_F \left(1 - \frac{\tau_F}{4 \cdot \tau_E}\right) \quad \text{when } \tau_E > \frac{\tau_F}{2}$$

where

τ_F = $\frac{\sigma_F}{\sqrt{3}}$

σ_F = as given in C.1

τ_E = ideal elastic buckling stress in shear calculated according to B.1.2

D. Working Stress

1. Longitudinal Compressive Stress

The compressive stresses are given in the following formula:

$$\sigma_a = 10^5 \frac{\beta_{VBM} \cdot M_{wv} + M_{sw}}{I_n} y \quad [N/mm^2]$$

$$= \text{minimum } 30/k \quad [N/mm^2]$$

where

M_{sw} = maximum still water bending moment at installation site [kN-m]

M_{wv} = wave bending moment [kN-m], as given in Rules for Hull (Pt.1, Vol.II), Sec.5, B.

I_n = moment of inertia of the hull girder based on the reassessed gross scantlings [cm^4]

y = vertical distance [m], from the neutral axis to the considered point

k = as defined in Rules for Hull (Pt.1, Vol.II), Sec.2, B (1,0 for normal strength steel)

β_{VBM} = ESF for vertical bending moment, as defined in Annex 4, C

M_{wv} and M_{sw} are to be taken as sagging or hogging bending moments, respectively, for members above or below the neutral axis.

2. Shear Stresses

2.1. Installations without Effective Longitudinal Bulkheads

The working shear stress, τ_a, in the side shell of installations without effective longitudinal bulkheads is given by the following formula:

$$\sigma_a = 5 \frac{(Q_{SW} + \beta_{VSF} \cdot Q_{WV}) S_y}{t_s \cdot I} \quad [N/mm^2]$$

where

I = moment of inertia of the hull girder section based on the reassessed gross scantlings [cm^4], at the section under consideration.

S_y = first moment [cm^3], about the neutral axis of the area of the effective longitudinal material between the horizontal level at which the shear stress is being determined and the vertical extremity of effective longitudinal material, taken at the position under consideration.

t_s = gross thickness of the side shell plating [cm], at the position under consideration.

Q_{sw} = hull girder shearing force in still water [kN]

Q_{wv} = hull girder shearing force in vertical wave [kN], as specified by Rules for Hull (Pt.1, Vol.II), Sec.5, B , depending upon loading.

β_{VSF} = ESF for vertical shear force, as defined in Annex 4, C

2.2 Installations with Two or More Effective Longitudinal Bulkheads

The working shear stress, τ_a, in the side shell or longitudinal bulkhead plating is to be calculated by an acceptable method and in accordance with Rules for Hull (Pt.1, Vol.II), Sec.5, D.3.

E. Scantling Criteria

1. Buckling Stress

The design buckling stress, σ_c, of plate panels and longitudinals (as calculated in C.1) is to be such that:

$$\sigma_c \geq \beta \cdot \sigma_a$$

where

β = 1 for plating and for web plating of stiffeners (local buckling)

= 1,1 for stiffeners

The critical buckling stress, τ_c, of plate panels (as calculated in C.2) is to be such that:

$$\tau_c \geq \tau_a$$

where

τ_a = working shear stress in the plate panel under consideration [N/mm^2], as determined by D.2

Annex 4 Determination of Environmental Severity Factors

A. General 4–1
B. ESFs of the Beta (β) Type 4–1
C. ESFs of the Alpha (α) Type 4–3

A. General

This Annex provides information for the determination of ESFs for ship-type installation design criteria to account for site-specific conditions compared to unrestricted service conditions.

The formulations from Section 4, A and Section 4, C.2 are modified to reflect the incorporation of various ESF β-types. In the modified formulations, the ESF (β) factors are applied to the dynamic load parameters in the load components.

The general concept of ESF α-types is to compare fatigue damage resulting from different environmental conditions. This type of ESF has two applications. First, it can be used to adjust the fatigue damage induced by the wave-induced dynamic loads at the installation site. Second, it can be used to assess the fatigue damage accumulated during previous services as either a trading vessel or an existing ship-type installation. The α-type ESFs are obtained at different locations for longitudinal stiffeners of the hull structure.

ESF (α) factors are applied to longitudinal stiffener members in the ISCal fatigue analysis. ESF (β) factors are applied to the dynamic load components of the load formulations in the ISCal strength analysis and the GSA strength and fatigue analysis.

B. ESFs of the Beta (β) Type

This type of ESF is used to introduce a comparison of the severity between the intended environment and a base environment, which is the North Atlantic unrestricted service environment.

A presentation of formulations that are modified to reflect the incorporation of the various β ESFs is given in Section 4, C.2 . In the modified formulations, the β factors apply only to the dynamic portions of the load components, and the load components that are considered "static" are not affected by the introduction of the β factors.

The definition of the severity measure β is as follows:

$$\beta = \frac{L_s}{L_u}$$

where

L_s = most probable extreme value based on the intended site (100 years return period), transit (10 years return period), and repair/inspection (1 year return period) and fatigue (20 years return period) environments for the dynamic load parameters specified in Table A4.1

L_u = most probable extreme value base on the North Atlantic environment for the dynamic load parameters specified in Table A4.1

A β of 1,0 corresponds to the unrestricted service condition of a seagoing vessel. A value of β less than 1,0 indicates a less severe environment than the unrestricted case.

Extreme value analysis is to be performed for each dynamic load component to determine maximum value during the design life. Preference is given to an Extreme Value method that follows the so-called long-term approach commonly used for ship structure. However, the use of a validated short-term extreme value approach, which is appropriate to the installation type and installation site's environmental data, will also be considered. The supplementary use of such a short-term approach to confirm or validate the sensitivity of the long-term based design values is encouraged. The result of the short-term approach cannot be used to reduce the long-term extreme value. If the short-term result is significantly larger, the long-term extreme value is to be further studied and validated. The environments specified for use in the short-term approach are "response based", i.e., a 100-year design storm event is one that leads to the maximum responses expected to occur in 100-years. The return period is typically required to 10 years for transit condition, and 1 year for repair and inspection conditions.

There are 13 dynamic load components in the BKI Rules for which the β adjustment factors have been derived. These are for the following dynamic loads or load effects:

Table A4.1 - The 13 Dynamic Load Parameters or ESFs (β_{NN})

No	NN	Name
1	VBM	Vertical Bending Moment
2	HBM	Horizontal Bending Moment
3	EPP	External Pressure Port
4	EPS	External Pressure Starboard
5	VAC	Vertical Acceleration
6	TAC	Transverse Acceleration
7	LAC	Longitudinal Acceleration
8	PMO	Pitch Motion
9	RMO	Roll Motion
10	RVM	Relative Vertical Motion at Forepeak
11	WHT	Wave Height
12	VSF	Vertical Shear Force
13	HSF	Horizontal Shear Force

As mentioned, the β values are a direct function of the long-term environmentally-induced loads at the installation site compared to the unrestricted service environment that is the basis of the Rules. The β values also need to address other differences and factors between the design basis of a sea going and a moored installation/transit/repair/inspection. These include:

1) Different design basis return periods for environmental loads (20 for unrestricted seagoing vs. 100 years for intended site, 10 years for transit and 1 year for repair/inspection condition).
2) Effects of mooring system on predicted installation load effects (including weathervaning type behavior of a turret moored system).
3) Different assumed wave energy spreading characterization between the open ocean and a site- specific situation.
4) Different basis of extreme design storm characterization (i.e., long-term winter storm vs. hurricane dominated characterization).
5) Relative nearness of natural periods of global system response to significant environmentally- induced loadings at such periods (i.e., possible dynamic amplification effects).

If a direct analysis of a floating offshore installation were to be performed, the influences of the mentioned factors would need to be assessed and used in the installation's design. It is not the intention of the alternative approach offered here to discourage direct analysis, but it is expected that the approach based on the use of the ESFs will still be used as an important basis of structural design/assessment of a ship-type floating offshore installation.

Notwithstanding the listed β factors and their intended usage, it is still necessary to introduce a limit to prevent design parameters from being unrealistically low. This limit is that the result of an application of a β factor (e.g., in the calculation of a required scantling) is not to be less than 85 percent of the unrestricted service (Rule) value. The reasons for introducing this limit are to reflect successful service experience, a desire not to inadvertently create a reordering of the dominant structural failure modes, and to avoid the introduction of new controlling limit states (unacceptable deflections, vibrations, etc.).

It has also been necessary to introduce additional load cases or situations that reflect the relatively greater importance these cases may have for floating offshore installations with possibly reduced scantlings due to the calmer site conditions. Examples of these additional conditions are the more rigorous check of the tank test loading condition, inspection and repair conditions, and the hull strength assessment for the transit to site condition.

C. ESFs of the Alpha (α) Type

This type of ESF compares the fatigue damage between the specified environment and a base environment, which is the North Atlantic environment.

First, this type of ESF is used to adjust the expected fatigue damage induced from the dynamic components due to environmental loadings at the installation's site. Second it can be used to assess the fatigue damage accumulated during the historical service either as a trading vessel or as an FPI, including both the historical site(s) and historical transit routes.

The definition of the severity measure α is as follows:

$$\alpha = \left(\frac{D_u}{D_s} \right)^C$$

where

D_u = annual fatigue damage based on the North Atlantic environment (unrestricted service) at the details of the hull structure

D_s = annual fatigue damage based on a specified environment, for historical routes, historical sites, transit and intended site, at the details of the hull structure

C = 0,65

For fatigue damage calculation, a closed form spectral-based fatigue analysis procedure can be used. The fundamental task of a spectral fatigue analysis is the determination of the stress transfer function, which express the relationship between the stress at a particular structural location per unit wave amplitude and wave frequency and heading. The stress transfer function needs to be determined from the load transfer function and its corresponding stress factor, which is a conversion factor to obtain the stress transfer function from the load transfer function. The load transfer function, which depends on hull form geometry, is to be calculated for regular waves of unit amplitude for ranges of wave frequencies and wave heading. The stress factor can be obtained through structural analysis techniques, which can be either a simple beam theory or finite element analysis procedures. The sophistication of the structural analysis needed depends on the physical system to be analyzed, the type of structural detail and the type of structural loading considered. For the longitudinal stiffener, the stress factors may be calculated by the simple beam theory.

The response spectra of the stress transfer functions can be determined by given wave spectra. In the 'short-term closed form' approach, the stress range is normally expressed in terms of probability density functions for different short-term sea states. These short-term probability density functions are derived by a spectral approach based on the Rayleigh distribution method whereby it is assumed that the variation of stress is a narrow banded random Gaussian process. When a narrow banded assumption is not valid for the stress process, a damage correction factor, e.g. Wirsching's "rainflow correction" factor, is applied in the calculation of the short-term fatigue damage. Having calculated the short-term damage, the total fatigue damage is calculated through their weighted linear summation (using Miner's rule). More detailed mathematical representations of the steps of the fatigue damage calculation can be found in the Guidance for Fatigue Assessment of Offshore Structure (Pt.5, Vol.B).

The α type ESFs are obtained for details of the hull structure, where these details follow those defined for ship-type installation hull structure in Section 4, C.

An α of 1,0 corresponds to the unrestricted condition of a seagoing vessel. A value of α greater than 1,0 indicates a less fatigue-inducing environment than the unrestricted case.

Annex 5 Fatigue Strength Assessment of Ship-Type Installations

A. General 5–1
B. Connections to be Considered for the Fatigue Strength Assessment 5–2
C. Fatigue Strength Assessment 5–6
D. Fatigue Inducing Loads and Determination of Total Stress Ranges 5–11
E. Resulting Stress Ranges 5–22
F. Determination of Stress Concentration Factors (SCFs) 5–23
G. Stress Concentration Factors Determined From Finite Element Analysis 5–29
H. Fatigue Assessment of Structures Considering Low Cycle Fatigue 5–33
I. Low Cycle Fatigue Damage 5–35
J. Combined Fatigue Damage 5–39
K. Fatigue Strength Assessment for Service as a Trading Vessel 5–39

A. General

1. Note

This Annex provides a designer-oriented approach to fatigue strength assessment which may be used for certain structural details in lieu of more elaborate methods such as spectral fatigue analysis. The term "assessment" is used here to distinguish this approach from the more elaborate analysis.

The criteria in this Annex are developed from various sources, including the Palmgren-Miner linear damage model, S-N curve methodologies, a long-term environment data of the North-Atlantic Ocean (Walden's Data), etc., and assume workmanship of commercial marine quality acceptable to the Surveyor. The capacity of structures to resist the fatigue is given in terms of fatigue damage to allow designers the maximum flexibility possible.

2. Applicability

The criteria in this Annex are specifically written for ship-type installations to which Section 4, C is applicable.

3. Loadings

The criteria have been written for ordinary wave-induced motions and loads. Other cyclic loadings, which may result in significant levels of stress ranges over the expected lifetime of the installation, are also to be considered by the designer.

4. Effects of Corrosion

To account for the mean wastage throughout the service life, the total stress range calculated using the net scantlings (i.e., deducting nominal design corrosion values, see Table 4.8 is modified by a factor C_f (see E.1.1).

5. Format of the Criteria

The criteria are presented as a comparison of fatigue strength of the structure (capacity) and fatigue inducing loads (demands), in the form of a fatigue damage parameter, DM. The calculated fatigue damage, DM, is to be less than or equal to 1 for the design life of the installation, which corresponds to a fatigue life of 20 years.

B. Connections to be Considered for the Fatigue Strength Assessment

1. General

These criteria have been developed to allow consideration of a broad variation of structural details and arrangements, so that most of the important structural details in the installation can be subjected to an explicit (numerical) fatigue assessment using these criteria. However, where justified by comparison with details proven satisfactory under equal or more severe conditions, an explicit assessment can be exempted.

2. Guidance on Locations

As a general guidance for assessing fatigue strength for a ship-type installation, the following connections and locations should be considered:

2.1 Connections of Longitudinal Stiffeners to Transverse Web/Floor and to Transverse Bulkhead

1) Two (2) to three (3) selected side longitudinals in the region from the 1,1 draft to about 1/3 draft in the midship region and also in the region between 0,15**L** and 0,25**L** from **F.P.**, respectively
2) One (1) to two (2) selected longitudinals from each of the following groups:
   - Deck longitudinals, bottom longitudinals, inner bottom longitudinals and longitudinals on side longitudinal bulkheads
   - One longitudinal on each of the longitudinal bulkheads within 0,1**H** from the deck is to be included

For these structural details, the fatigue assessment is to be first focused on the flange of the longitudinal at the rounded toe welds of attached flat bar stiffeners and brackets, as illustrated for Class F item 2) and Class F2 item 1) in Table A5.1.

Then, the critical spots on the web plate cut-out, on the lower end of the stiffener as well as the weld throat are also to be checked for the selected structural detail. For illustration, see F.2.1 and F.2.2.1), F.2.2.2) and F.2.2.3).

Where the longitudinal stiffener end bracket arrangements are different on opposing sides of a transverse web, both configurations are to be checked.

2.2 Shell, Bottom, Inner Bottom or Bulkhead Plating at Connections to Webs or Floors (for Fatigue Strength of Plating)

1) One (1) to two (2) selected locations of side shell plating near the summer LWL amidships and between 0,15**L** and 0,25**L** from **F.P.** respectively
2) One (1) to two (2) selected locations in way of bottom and inner bottom amidships
3) One (1) to two (2) selected locations of lower strakes of side longitudinal bulkhead amidships

2.3. Connections of the Slope Plate to Inner Bottom and Side Longitudinal Bulkhead Plating at the Lower Cargo Tank Corners

One selected location amidships at transverse web and between webs, respectively. For this structural detail, the value of σ_R, the total stress range as specified in E.1, is to be determined from fine mesh F.E.M. analyses for the combined load cases, as specified for Zone B in D.3.2.

2.4. End Bracket Connections for Transverses and Girders

One (1) to two (2) selected locations in the midship region for each type of bracket configuration

2.5. Other Regions and Locations

Other regions and locations, highly stressed by fluctuating loads, as identified from structural analysis.

Table A5.1 Fatigue Classification for Structural Detail

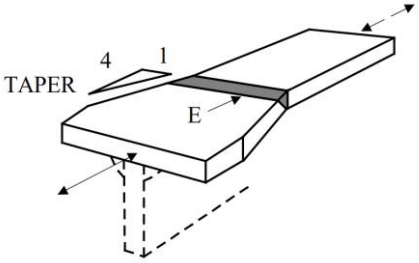
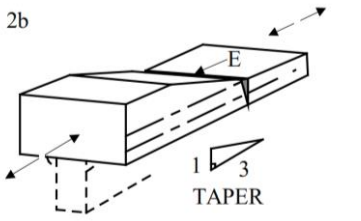
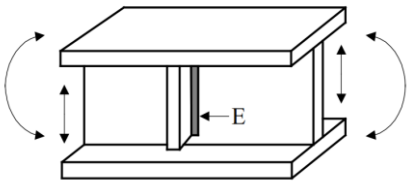
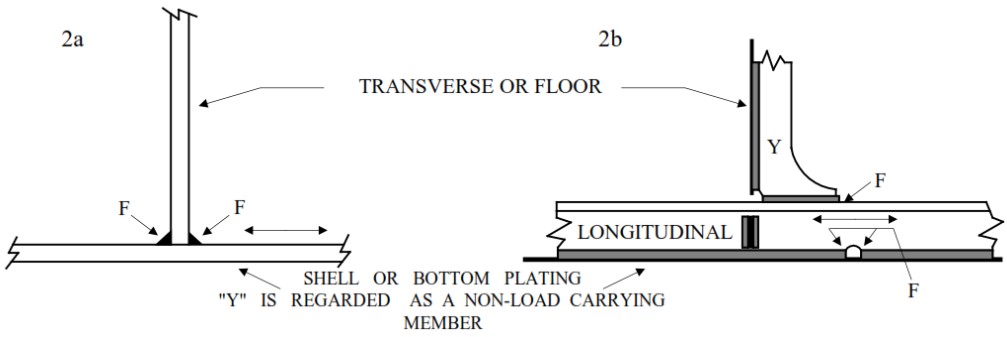
Class Designation	Description
B	Parent materials, plates or shapes as-rolled or drawn, with no flame-cut edges
C	1) Parent material with automatic flame-cut edges 2) Full penetration seam welds or longitudinal fillet welds made by an automatic submerged or open arc process, and with no stop-start positions within the length
D	1) Full penetration butt welds between plates of equal width and thickness made either manually or by an automatic process other than submerged arc, from both sides, in downhand position 2) Welds in C-2) with stop-start positions within the length
E	1) Full penetration butt welds made by other processes than those specified under D-1) 2) Full penetration butt welds made from both sides between plates of unequal widths machined to a smooth transition with a slope not more than 1 in 4. Plates of different thickness are to be likewise machined with a slope not more than 1 in 3, unless a transition within the weld bead is approved. 2a  2b  3) Welds of brackets and stiffeners to web plate of girders 
F	1) Full penetration butt welds made on a permanent backing strip between plates of equal width/thickness or between plates of unequal width/thickness, as specified in E-2 2) Rounded fillet welds as shown below 

Table A5.1 Fatigue Classification for Structural Detail (*continued*)

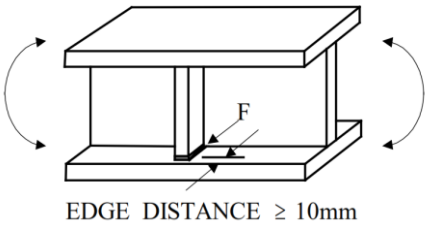
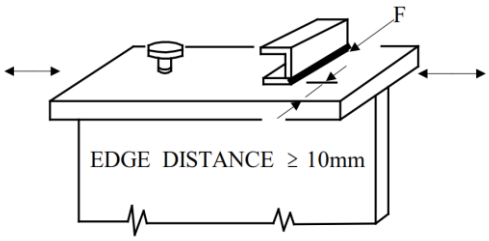
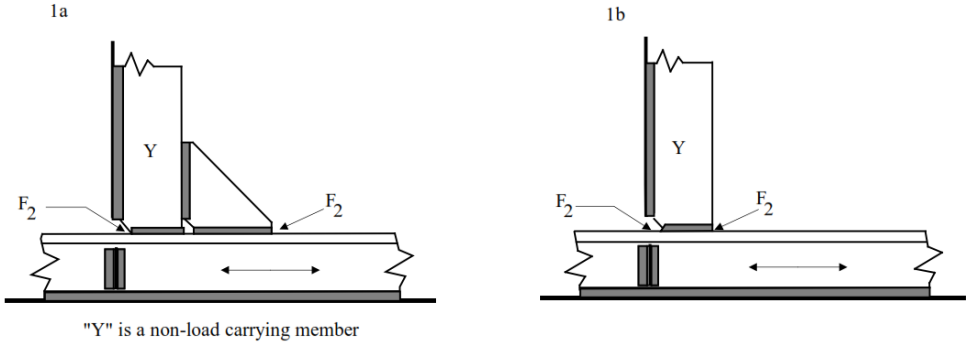
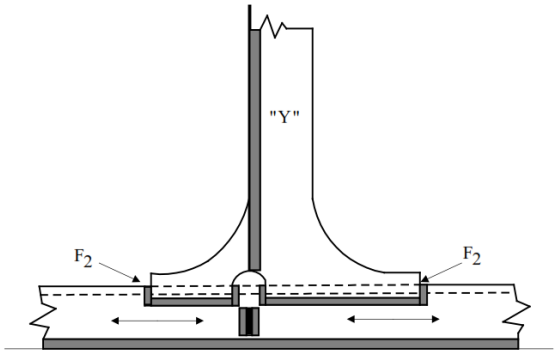
Class Designation	Description
F	3) Welds of brackets and stiffeners to flanges  4) Attachments on plate or face plate  (Class G for edge distance < 10 mm)
F_2	1) Fillet welds as shown below with rounded welds and no undercutting  "Y" is a non-load carrying member 2) Overlapped joints with soft-toe brackets as shown below 

Table A5.1 Fatigue Classification for Structural Detail (*continued*)

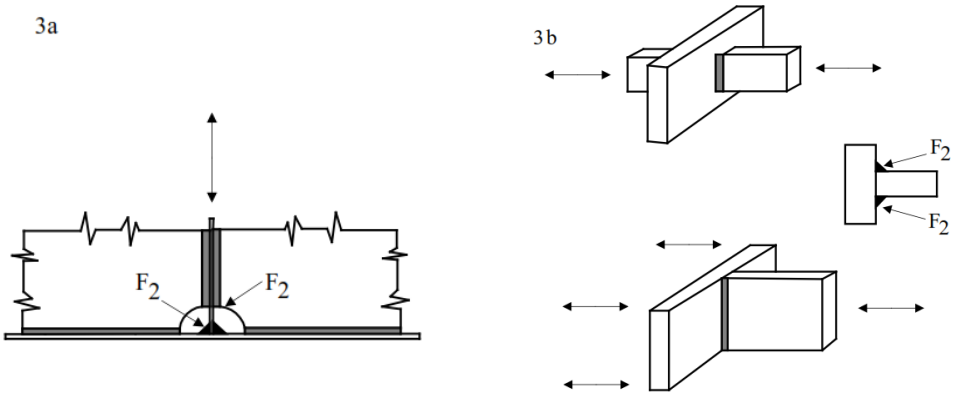
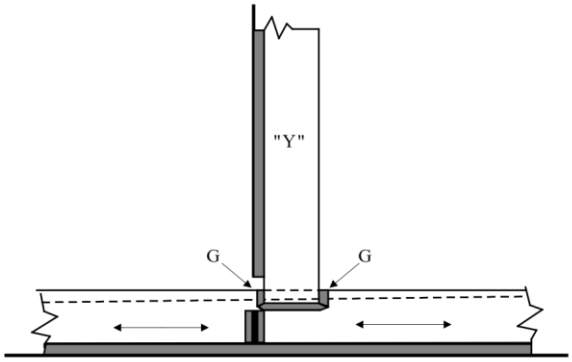
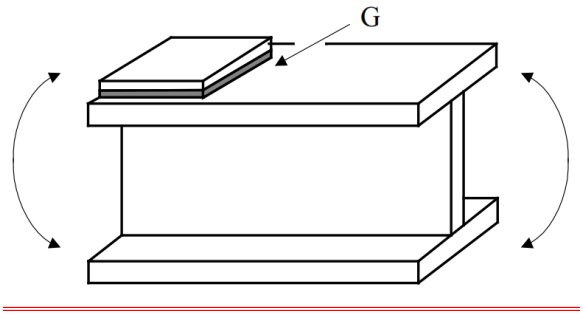
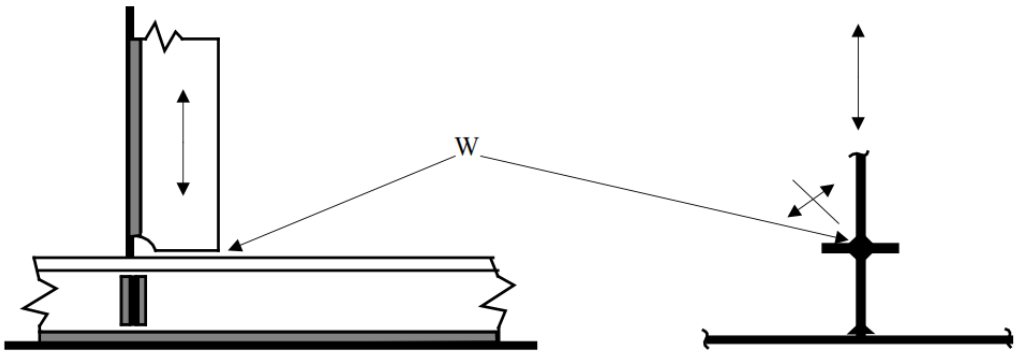
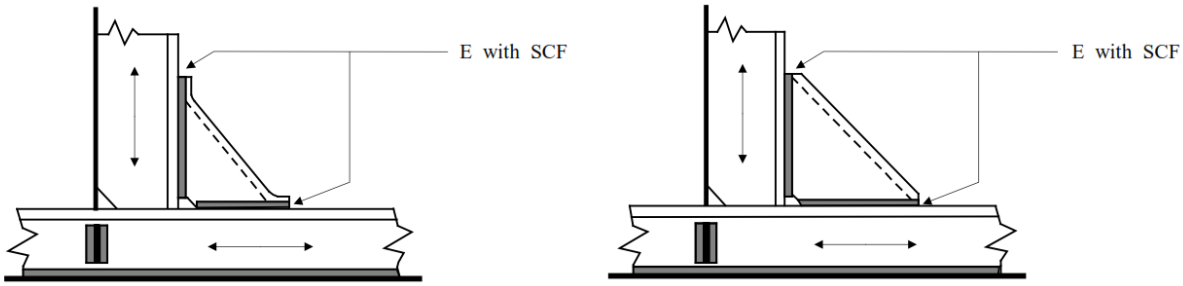
Class Designation	Description
F_2	3) Fillet welds with any undercutting at the corners dressed out by local grinding 
G	1) Fillet welds in F_2 – 1) without rounded toe welds or with limited minor undercutting at corners or bracket toes 2) Overlapped joints as shown below  3) Fillet welds in F_2 – 3) with minor undercutting 4) Doubler on face plate or flange 

Table A5.1 Fatigue Classification for Structural Detail (*continued*)

Class Designation	Description
W	Fillet welds-weld throat 

Note:

1 *For brackets connecting two or more load carrying members, an appropriate stress concentration factor (SCF) determined from fine mesh 3D or 2D finite element analysis is to be used. In this connection, the fatigue class at bracket toes may be upgraded to class E as shown below.*



2 *Additional information on stress concentration factors and the selection of compatible S-N data is given in F.*

C. Fatigue Strength Assessment

1. Assumptions

The fatigue strength of a structural detail under the loads specified here, in terms of fatigue damage, is to be evaluated using the criteria contained in this Subsection. The key assumptions employed are listed below for guidance.

- A linear cumulative damage model (i.e., Palmgren-Miner's Rule) has been used in connection with the S-N data in Fig. A5.1. (extracted from "Offshore Installations: Guidance on Design, Construction and Certification", Department of Energy, U.K., Fourth Edition—1990, London: HMSO)
- Cyclic stresses due to the loads in D. have been used and the effects of mean stress have been ignored.
- The target life of the installation is taken at 20 years.
- The long-term stress ranges on a detail can be characterized using a modified long term stress distribution parameter (γ).
- Structural details are classified and described in Table A5.1, "Fatigue Classification of Structural Details".
- Simple nominal stress (e.g., determined by P/A and M/W) is the basis of fatigue assessment, rather than more localized peak stress in way of weld.

The structural detail classification in Table A.5.1 is based on the joint geometry and the direction of the dominant load. Where the loading or geometry is too complex for a simple classification, a finite element analysis of the details is to be carried out to determine stress concentration factors. Sub-Section G. contains guidance on finite element analysis modelling to determine stress concentration factors for weld toe locations that are typically found at longitudinal stiffener end connections.

2. Criteria

The criteria are presented as a comparison of fatigue strength of the structure (capacity), and fatigue inducing loads (demands), in the form of a fatigue damage parameter, DM. The calculated fatigue damage, DM, is to be less than or equal to 1 for the design life of the installation, which corresponds to a fatigue life of 20 years.

3. Long Term Stress Distribution Parameter, γ

In Table A5.1, the permissible stress range is given as a function of the long-term distribution parameter, γ, as defined below.

$$\gamma = 1{,}40 - 0{,}2 \cdot \alpha \cdot L^{0,2} \quad \text{for} \quad 150 < L < 305 \text{ m}$$

$$\gamma = 1{,}54 - 0{,}245 \cdot \alpha^{0,8} \cdot L^{0,2} \quad \text{for} \quad L > 305 \text{ m}$$

where

α = 1,0 for deck structures, including side shell and longitudinal bulkhead structures within 0,1**H** from the deck

= 0,93 for bottom structures, including inner bottom and side shell, and longitudinal bulkhead structures within 0,1**H** from the bottom

= 0,86 for side shell and longitudinal bulkhead structures within the region of 0,25**H** upward and 0,3**H** downward from the mid-depth

= 0,80 for transverse bulkhead structures

α may be linearly interpolated for side shell and longitudinal bulkhead structures between 0,1**H** and 0,25**H** (0,2**H**) from the deck (bottom).

L and **H** are the installation's length and depth, as defined in Rules for Hull (Pt.1, Vol.II), Sec.1, H.2.1 and H.2.7.

4. Cumulative Fatigue Damage

The content of this section is applicable to ship-type installations. For fatigue strength assessment for service as a trading vessel, refer to L.1.

Unless otherwise specified, the resultant cumulative damage is to be taken as:

$$DM = 0{,}15 \cdot DM_1 + 0{,}35 \cdot DM_2 + 0{,}35 \cdot DM_3 + 0{,}15 \cdot DM_4$$

where

DM_i = cumulative fatigue damage ratio for the applicable loading condition i, where i =1 to 4, as specified in Fig A5.2A, including 8 loading cases, as shown in Tables A5.2A through A5.2D

= $\sigma_{i,1-2} \cdot DM_{i,1-2} + \sigma_{i,3-4} \cdot DM_{i,3-4} + \sigma_{i,5-6} \cdot DM_{i,5-6} + \sigma_{i,7-8} \cdot DM_{i,7-8}$

$\sigma_{i,j-k}$ = heading probability for loading condition i, to be based on submitted actual information.

In case the actual heading information is not available prior to application of these requirements, the following table of $\sigma_{i,j-k}$ factor can be used.

σi,j-k Factors(1,[2,3])

Loading Pair, j-k	1-2	3-4	5-6	7-8
Direction	0	90	60	30
A	0,40	0,10	0,20	0,30
B	0,60	0,00	0,10	0,30
C	1,00	0,00	0,00	0,00

Notes :

1 *When an installation's mooring system type and arrangement, and heading orientation have not been determined prior to application of these requirements, cases A, B and C are to be investigated and greater results are to be used.*

2 *If an installation's mooring system type and arrangement have been determined, but the actual heading information is not available, case A and B are to be used for installations with spread mooring, or, installations with turrets located more than 25% of the installation length aft of the bow, or for locations with non-colinear wind, wave and current conditions regardless of the mooring system. The greater results of these two cases are to be used.*

3 *If an installation's mooring system type and arrangement has been determined, but the actual heading information is not available, Case B and C are to be applied for installations with turrets located less than 25% of the installation length aft of the bow. The greater results of these two cases are to be used.*

Assuming the long term stress ranges fit a two-parameter long term stress distribution, the cumulative fatigue damage DM_i for each relevant condition is to be taken as:

$$DM_{i,j-k} = \frac{N_L}{K_2} \cdot \frac{(0{,}01 \cdot \sigma_{Ri})^m}{K_2 (\ln N_R)^{m/\gamma}} \mu_1 \cdot \Gamma\left(1 + \frac{m}{\gamma}\right)$$

where

N_L = number of cycles for the expected design life. Unless stated otherwise, N_L to be taken as:

= $\frac{U}{4 \log_{10} L}$

= The value is generally between 0,6 x 10^8 and 0,8 x 10^8 cycles for a design life of 20 years.

U = design life [seconds]

= 6,31 x 10^8 for a design life of 20 years

L = rule length [m]

m = S-N curve parameter as defined in Fig. A5.1, Note a)

K_2 = S-N curve parameter as defined in Fig. A5.1, Note a)

σ_{Ri} = stress range at the representative probability level of 10^{-4} [N/cm^2]

N_R = 1 x 10^4, number of cycles corresponding to the probability level of 10^{-4}

γ = long term stress distribution parameter, as defined in 3.

Γ = Gamma function

μ_i = stress coefficient taking into account the change in slope of the S-N curve

$$= 1 - \frac{\left\{\Gamma_0\left(1+\frac{m}{\gamma},\nu_i\right) - \nu_i^{-\frac{\Delta m}{\gamma}}\Gamma_0\left(1+\frac{m+\Delta m}{\gamma},\nu_i\right)\right\}}{\Gamma\left(1+\frac{m}{\gamma}\right)}$$

$$\nu_i = \left(\frac{\sigma_q}{0{,}01\cdot\sigma_{Ri}}\right)^{\gamma} \ln N_R$$

σ_q = stress range at the intersection of the two segments of the S-N curve, see Table in Fig. A5.1, Note a), [N/mm^2]

Δm = slope change of the upper-lower segment of the S-N curve

= 2

$\Gamma_{0(a,x)}$ = incomplete Gamma function, Legendre form

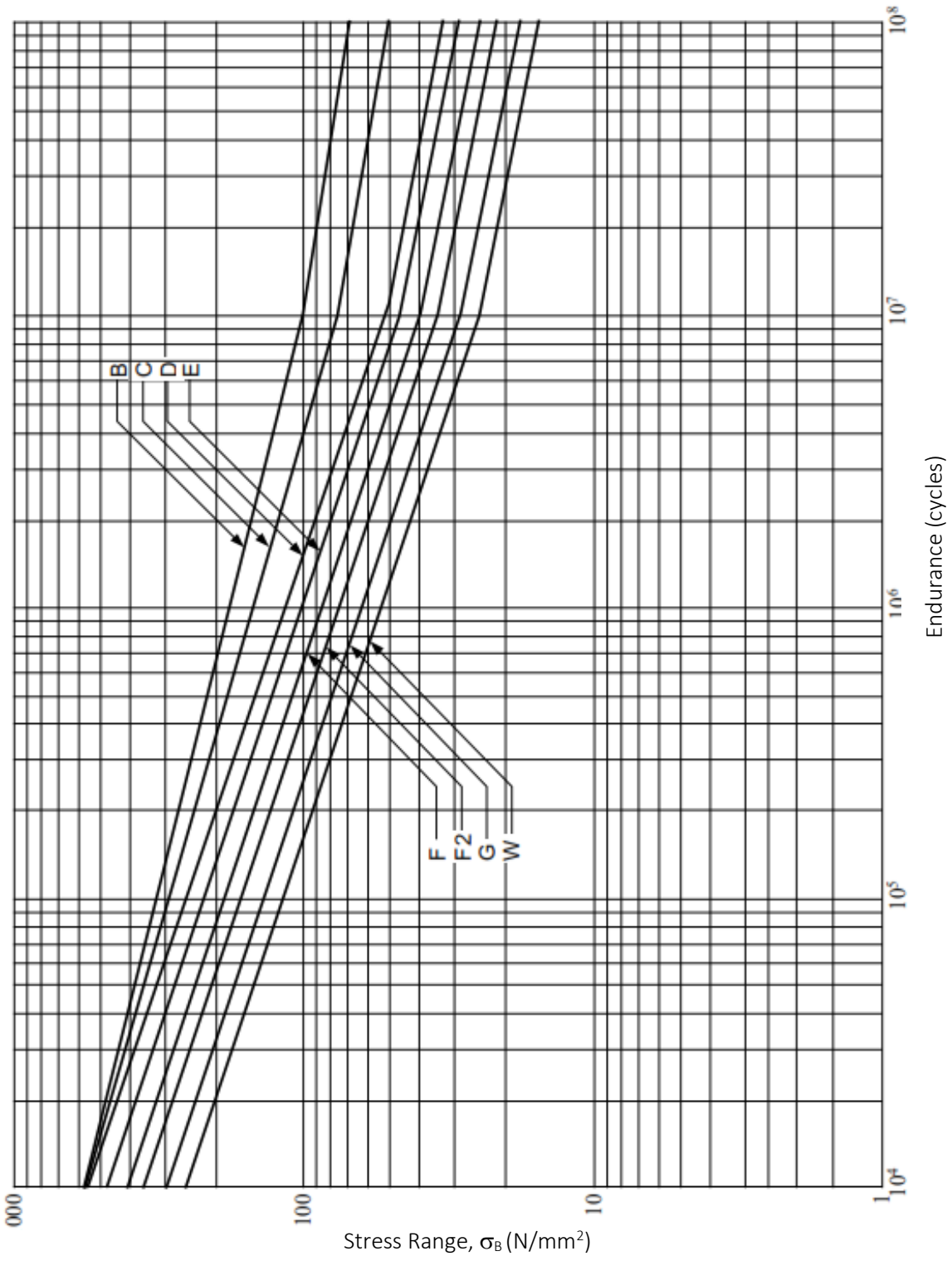


Fig. A5.1 Basic Design S-N Curves

Note:

a) Basic design S-N curves

The basic design curves consist of linear relationships between log(σ_B) and log(N). They are based upon a statistical analysis of appropriate experimental data and may be taken to represent two standard deviations below the mean line.

Thus the basic S-N curves are of the form:

$$log(N) = log(K_2) - m\ log(\sigma_B)$$

where

$$log(K_2) = log(K_1) - 2\sigma$$

N is the predicted number of cycles to failure under stress range S_B

K_1 is a constant relating to the mean S-N curve;

σ is the standard deviation of log N;

m is the inverse slope of the S-N curve.

The relevant values of these terms are shown in the table below.

The S-N curves have a change of inverse slope from m to m + 2 at $N = 10^7$ cycles

Details of basic S-N curves

Class	K_1	K_1		m	Standard deviation		K_2	σ_q N/mm^2
		log_{10}	log_e		log_{10}	log_e		
B	$2{,}343 \times 10^{15}$	15,3697	35,3900	4,0	0,1821	0,4194	$1{,}01 \times 10^{15}$	100,321
C	$1{,}0825 \times 10^{14}$	14,0342	32,3153	3,5	0,2041	0,4700	$4{,}23 \times 10^{13}$	78,2
D	$3{,}988 \times 10^{12}$	12,6007	29,0144	3,0	0,2095	0,4824	$1{,}52 \times 10^{12}$	53,4
E	$3{,}289 \times 10^{12}$	12,5169	28,8216	3,0	0,2509	0,5777	$1{,}04 \times 10^{12}$	47,0
F	$1{,}726 \times 10^{12}$	12,2370	28,1770	3,0	0,2183	0,5027	$0{,}63 \times 10^{12}$	39,8
F_2	$1{,}231 \times 10^{12}$	12,0900	27,8387	3,0	0,2279	0,5248	$0{,}43 \times 10^{12}$	35,0
G	$0{,}566 \times 10^{12}$	11,7525	27,0614	3,0	0,1793	0,4129	$0{,}25 \times 10^{12}$	29,2
W	$0{,}368 \times 10^{12}$	11,5662	26,6324	3,0	0,1846	0,4251	$0{,}16 \times 10^{12}$	25,2

Fig. A5.1 Basic Design S-N Curves (*continued*)

D. Fatigue Inducing Loads and Determination of Total Stress Ranges

1. General

This Subsection provides:

- The criteria to define the individual load components considered to cause fatigue damage (see 2.);
- The load combination cases to be considered for different regions of the hull containing the structural detail being evaluated (see 3.); and
- Procedures to idealize the structural components to obtain the total stress range acting on the structure.

2. Wave-induced Loads - Load Components

The fatigue-inducing load components to be considered are those induced by the seaway. They are divided into the following three groups:

- Hull girder wave-induced bending moments (both vertical and horizontal), see Rules for Hull (Pt.1, Vol.II), Sec.5, B.2 and B.3 and Section 4, C.2.3.1.
- External hydrodynamic pressures, and
- Internal tank loads (inertial liquid loads and added static head due to ship's motion).

3. Fatigue Assessment - Loading Conditions

The content in this Subsection is applicable to ship-type installations. For fatigue strength assessment for service as a trading vessel, refer to L.2.

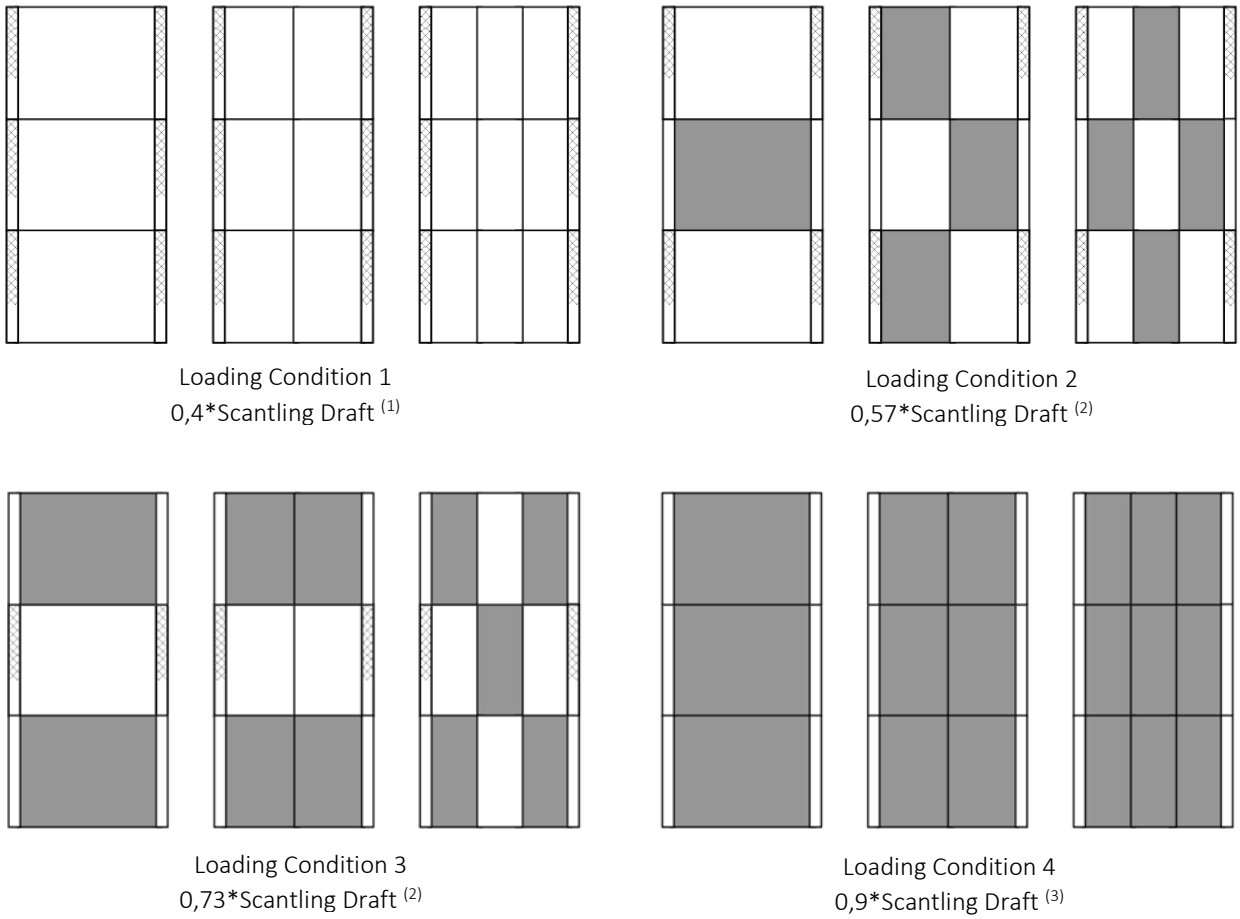
Four (4) loading conditions are considered in the calculation of stress range, as shown in Fig. A5.2. For each loading condition, eight (8) load cases, as shown in Tables A5.2A through 2D, are defined to form four (4) pairs. The combinations of load cases are to be used to find the characteristic stress range corresponding to a probability of exceedance of 10^{-4}, as indicated below.

3.1 Standard Load Combination Cases

1) Calculate dynamic component of stresses for load cases FLC1 through FLC8, respectively, for each of the four loading conditions shown in Fig. A5.2.
2) Calculate four sets of stress ranges, one each for the following four pairs of combined loading cases: FLC1 and FLC2, FLC3 and FLC4, FLC5 and FLC6, and FLC7 and FLC8, for each of the four loading conditions shown in Fig. A5.2.

3.2 Installations with Either Special Loading Patterns or Special Structural Configuration

For installations with either special loading patterns or special structural configurations/features, additional load cases via appropriate probability may be required for determining the stress range.



Note:

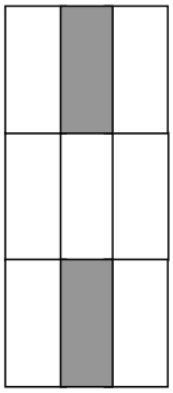
1 *Ballast condition draft* - *if actual minimum on-site operating ballast draft is greater than 0,4 × scantling draft, actual draft can be used (but not to exceed 0,6 × scantling draft)*

This condition is also used for transit condition with actual transit draft between 0,1 × scantling draft and 0,6 × scantling draft

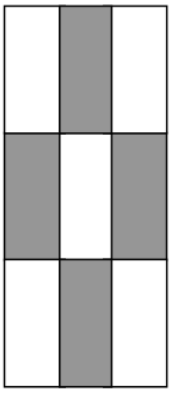
2 *Intermediate drafts* - *draft equally divided between Loading Conditions 1 and 4 drafts*

3 *Full load condition draft* - *if actual maximum on-site operating full load draft is greater than 0,9 × scantling draft, actual draft can be used*

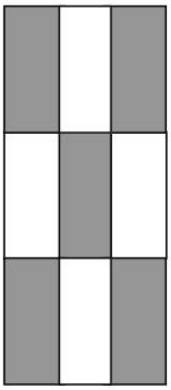
Fig. A5.2A Loading Conditions for Fatigue Strength Assessment - Double Hull and Double Side Single Bottom FPSO/FSO



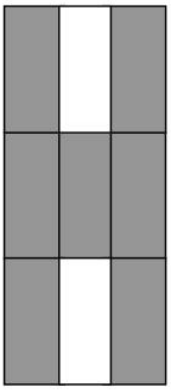
Loading Condition 1
0,4*Scantling Draft (1)



Loading Condition 2
0,57*Scantling Draft (2)



Loading Condition 3
0,73*Scantling Draft (2)



Loading Condition 4
0,9*Scantling Draft (3)

Note:

1 *Light draft condition* - *if actual minimum on-site operating light draft condition is greater than 0,4 × scantling draft, actual draft can be used (but not to exceed 0,6 × scantling draft*

2 *Intermediate drafts* - *draft equally divided between Loading Conditions 1 and 4 drafts*

3 *Full load condition draft* - *if actual maximum on-site operating full load draft is greater than 0,9 × scantling draft, actual draft can be used*

Fig. A5.2B Loading Conditions for Fatigue Strength Assessment - Single Hull FPSO/FSO

Table A5.2A Design Fatigue Load Cases for Fatigue Strength Assessment
(Load Combination Factors for Dynamic Load Components for Loading Condition 1)

	FLC1	FLC2	FLC3	FLC4	FLC5	FLC6	FLC7	FLC8
A. Hull Girder Loads								
Vertical B.M	Sag (-)	Hog (+)	Sag (-)	Hog (+)	Sag (-)	Hog (+)	Sag (-)	Hog (+)
k_c	1,00	1,00	0,30	0,30	0,75	0,75	0,70	0,70
Vertical S.F	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)
k_c	0,60	0,60	0,30	0,30	0,55	0,55	0,10	0,10
Horizontal B.M					(-)	(+)	(-)	(+)
k_c	0,00	0,00	0,10	0,10	1,00	1,00	1,00	1,00
Horizontal S.F					(+)	(-)	(+)	(-)
k_c	0,00	0,00	0,10	0,10	0,85	0,85	0,85	0,85
B. External Pressure								
k_c	0,80	0,80	1,00	1,00	0,70	0,70	0,45	0,45
k_{f0}	-1,00	1,00	-1,00	1,00	-1,00	1,00	-1,00	1,00
C. Internal Tank Pressure								
k_c	0,40	0,40	1,00	1,00	0,75	0,75	0,40	0,40
w_v	0,40	-0,40	0,75	-0,75	0,10	-0,10	0,25	-0,25
w_ℓ	Fwd Bhd 0,20	Fwd Bhd -0,20	-	-	Fwd Bhd 0,50	Fwd Bhd -0,50	Fwd Bhd 0,80	Fwd Bhd -0,80
	Aft Bhd -0,20	Aft Bhd 0,20	-	-	Aft Bhd -0,50	Aft Bhd 0,50	Aft Bhd -0,80	Aft Bhd 0,80
w_t	-	-	Port Bhd -0,85	Port Bhd 0,85	Port Bhd -0,05	Port Bhd 0,05	Port Bhd -0,05	Port Bhd 0,05
	-	-	Stbd Bhd 0,85	Stbd Bhd -0,85	Stbd Bhd 0,05	Stbd Bhd -0,05	Stbd Bhd 0,05	Stbd Bhd -0,05
c_ϕ, Pitch	-0,15	0,15	-0,10	0,10	-0,30	0,30	-0,45	0,45
c_θ, Roll	0,00	0,00	1,00	-1,00	0,05	-0,05	0,05	-0,05
D. Reference Wave Heading and Motion of Installation								
Heading Angle	0	0	90	90	60	60	30	30
Heave	Down	Up	Down	Up	Down	Up	Down	Up
Pitch	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up
Roll	-	-	Stbd Down	Stbd Up	Stbd Down	Stbd Up	Stbd Down	Stbd Up

Note :

1. Rule vertical bending moment range = $|M_{ws} - M_{wh}|$ (see Section 4, C.2.3.2 for M_{ws} and M_{wh})
2. Rules horizontal bending moment range = $2 \times M_h$ (see Section 4, C.2.3.3 for M_h)
3. For each load condition pair, the stress range due to local pressure is the difference between the stress values for Local Pressure Load Conditions. For example, for Load Condition Pair FLC1 & FLC2, the stress range due to local pressure is the difference between the stress values for FLC1 and FLC2.
4. For each load condition pair, the stress range is the sum of the absolute stress range values due to Vertical BM, Horizontal BM and Local Pressure Load Conditions.

Table A5.2B Design Fatigue Load Cases for Fatigue Strength Assessment

(Load Combination Factors for Dynamic Load Components for Loading Condition 2)

	FLC1	FLC2	FLC3	FLC4	FLC5	FLC6	FLC7	FLC8
A. Hull Girder Loads								
Vertical B.M	Sag (-)	Hog (+)	Sag (-)	Hog (+)	Sag (-)	Hog (+)	Sag (-)	Hog (+)
k_c	1,00	1,00	0,25	0,25	0,95	0,95	0,75	0,75
Vertical S.F	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)
k_c	0,55	0,55	0,15	0,15	0,70	0,70	0,25	0,25
Horizontal B.M					(-)	(+)	(-)	(+)
k_c	0,00	0,00	0,10	0,10	1,00	1,00	1,00	1,00
Horizontal S.F					(+)	(-)	(+)	(-)
k_c	0,00	0,00	0,15	0,15	0,80	0,80	0,80	0,80
B. External Pressure								
k_c	0,85	0,85	0,90	0,90	0,90	0,90	0,55	0,55
k_{f0}	-1,00	1,00	-1,00	1,00	-1,00	1,00	-1,00	1,00
C. Internal Tank Pressure								
k_c	0,55	0,55	0,70	0,70	0,20	0,20	0,40	0,40
w_v	0,60	-0,60	0,55	-0,55	0,15	-0,15	0,25	-0,25
w_ℓ	Fwd Bhd 0,20	Fwd Bhd -0,20	-	-	Fwd Bhd 0,45	Fwd Bhd -0,45	Fwd Bhd 0,75	Fwd Bhd -0,75
	Aft Bhd -0,20	Aft Bhd 0,20	-	-	Aft Bhd -0,45	Aft Bhd 0,45	Aft Bhd -0,75	Aft Bhd 0,75
w_t	-	-	Port Bhd -0,95	Port Bhd 0,95	Port Bhd -0,05	Port Bhd 0,05	Port Bhd -0,10	Port Bhd 0,10
	-	-	Stbd Bhd 0,95	Stbd Bhd -0,95	Stbd Bhd 0,05	Stbd Bhd -0,05	Stbd Bhd 0,10	Stbd Bhd -0,10
c_ϕ, Pitch	-0,20	0,20	-0,05	0,05	-0,10	0,10	-0,35	0,35
c_θ, Roll	0,00	0,00	1,00	-1,00	0,05	-0,05	0,05	-0,05
D. Reference Wave Heading and Motion of Installation								
Heading Angle	0	0	90	90	60	60	30	30
Heave	Down	Up	Down	Up	Down	Up	Down	Up
Pitch	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up
Roll	-	-	Stbd Down	Stbd Up	Stbd Down	Stbd Up	Stbd Down	Stbd Up

Note :

1. Rule vertical bending moment range = $|M_{ws} - M_{wh}|$ (see Section 4, C.2.3.2 for M_{ws} and M_{wh})
2. Rules horizontal bending moment range = $2 \times M_h$ (see Section 4, C.2.3.3 for M_h)
3. For each load condition pair, the stress range due to local pressure is the difference between the stress values for Local Pressure Load Conditions. For example, for Load Condition Pair FLC1 & FLC2, the stress range due to local pressure is the difference between the stress values for FLC1 and FLC2.
4. For each load condition pair, the stress range is the sum of the absolute stress range values due to Vertical BM, Horizontal BM and Local Pressure Load Conditions.

Table A5.2C - Design Fatigue Load Cases for Fatigue Strength Assessment

(Load Combination Factors for Dynamic Load Components for Loading Condition 3)

	FLC1	FLC2	FLC3	FLC4	FLC5	FLC6	FLC7	FLC8
A. Hull Girder Loads								
Vertical B.M	Sag (-)	Hog (+)	Sag (-)	Hog (+)	Sag (-)	Hog (+)	Sag (-)	Hog (+)
k_c	1,00	1,00	0,25	0,25	0,90	0,90	0,70	0,70
Vertical S.F	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)
k_c	0,55	0,55	0,10	0,10	0,65	0,65	0,30	0,30
Horizontal B.M					(-)	(+)	(-)	(+)
k_c	0,00	0,00	0,10	0,10	1,00	1,00	1,00	1,00
Horizontal S.F					(+)	(-)	(+)	(-)
k_c	0,00	0,00	0,30	0,30	0,85	0,85	0,80	0,80
B. External Pressure								
k_c	0,85	0,85	0,85	0,85	0,85	0,85	0,75	0,75
k_{f0}	-1,00	1,00	-1,00	1,00	-1,00	1,00	-1,00	1,00
C. Internal Tank Pressure								
k_c	0,55	0,55	0,75	0,75	0,10	0,10	0,40	0,40
w_v	0,55	-0,55	0,55	-0,55	0,15	-0,15	0,30	-0,30
w_ℓ	Fwd Bhd 0,20	Fwd Bhd -0,20	-	-	Fwd Bhd 0,40	Fwd Bhd -0,40	Fwd Bhd 0,80	Fwd Bhd -0,80
	Aft Bhd -0,20	Aft Bhd 0,20	-	-	Aft Bhd -0,40	Aft Bhd 0,40	Aft Bhd -0,80	Aft Bhd 0,80
w_t	-	-	Port Bhd -1,00	Port Bhd 1,00	Port Bhd -0,05	Port Bhd 0,05	Port Bhd -0,15	Port Bhd 0,15
	-	-	Stbd Bhd 1,00	Stbd Bhd -1,00	Stbd Bhd 0,05	Stbd Bhd -0,05	Stbd Bhd 0,15	Stbd Bhd -0,15
c_ϕ, Pitch	-0,15	0,15	-0,15	0,15	-0,20	0,20	-0,45	0,45
c_θ, Roll	0,00	0,00	1,00	-1,00	0,05	-0,05	0,10	-0,10
D. Reference Wave Heading and Motion of Installation								
Heading Angle	0	0	90	90	60	60	30	30
Heave	Down	Up	Down	Up	Down	Up	Down	Up
Pitch	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up
Roll	-	-	Stbd Down	Stbd Up	Stbd Down	Stbd Up	Stbd Down	Stbd Up

Note :

1. Rule vertical bending moment range = $|M_{ws} - M_{wh}|$ (see Section 4, C.2.3.2 for M_{ws} and M_{wh})
2. Rules horizontal bending moment range = $2 \times M_h$ (see Section 4, C.2.3.3 for M_h)
3. For each load condition pair, the stress range due to local pressure is the difference between the stress values for Local Pressure Load Conditions. For example, for Load Condition Pair FLC1 & FLC2, the stress range due to local pressure is the difference between the stress values for FLC1 and FLC2.
4. For each load condition pair, the stress range is the sum of the absolute stress range values due to Vertical BM, Horizontal BM and Local Pressure Load Conditions.

Table A5.2D - Design Fatigue Load Cases for Fatigue Strength Assessment
(Load Combination Factors for Dynamic Load Components for Loading Condition 4)

	FLC1	FLC2	FLC3	FLC4	FLC5	FLC6	FLC7	FLC8
A. Hull Girder Loads								
Vertical B.M	Sag (-)	Hog (+)	Sag (-)	Hog (+)	Sag (-)	Hog (+)	Sag (-)	Hog (+)
k_c	1,00	1,00	0,15	0,15	0,80	0,80	0,70	0,70
Vertical S.F	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)
k_c	0,55	0,55	0,20	0,20	0,50	0,50	0,40	0,40
Horizontal B.M					(-)	(+)	(-)	(+)
k_c	0,00	0,00	0,25	0,25	1,00	1,00	1,00	1,00
Horizontal S.F					(+)	(-)	(+)	(-)
k_c	0,00	0,00	0,25	0,25	0,85	0,85	0,80	0,80
B. External Pressure								
k_c	0,85	0,85	0,90	0,90	0,80	0,80	0,95	0,95
k_{f0}	-1,00	1,00	-1,00	1,00	-1,00	1,00	-1,00	1,00
C. Internal Tank Pressure								
k_c	0,75	0,75	0,80	0,80	0,10	0,10	0,50	0,50
w_v	0,85	-0,85	0,60	-0,60	0,10	-0,10	0,30	-0,30
w_ℓ	Fwd Bhd 0,20	Fwd Bhd -0,20	-	-	Fwd Bhd 0,30	Fwd Bhd -0,30	Fwd Bhd 1,00	Fwd Bhd -1,00
	Aft Bhd -0,20	Aft Bhd 0,20	-	-	Aft Bhd -0,30	Aft Bhd 0,30	Aft Bhd -1,00	Aft Bhd 1,00
w_t	-	-	Port Bhd -1,00	Port Bhd 1,00	Port Bhd -0,05	Port Bhd 0,05	Port Bhd -0,10	Port Bhd 0,10
	-	-	Stbd Bhd 1,00	Stbd Bhd -1,00	Stbd Bhd 0,05	Stbd Bhd -0,05	Stbd Bhd 0,10	Stbd Bhd -0,10
c_ϕ, Pitch	-0,30	0,30	-0,15	0,15	-0,10	0,10	-0,80	0,80
c_θ, Roll	0,00	0,00	1,00	-1,00	0,05	-0,05	0,15	-0,15
D. Reference Wave Heading and Motion of Installation								
Heading Angle	0	0	90	90	60	60	30	30
Heave	Down	Up	Down	Up	Down	Up	Down	Up
Pitch	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up	Bow Down	Bow Up
Roll	-	-	Stbd Down	Stbd Up	Stbd Down	Stbd Up	Stbd Down	Stbd Up

Note :

1. Rule vertical bending moment range = $|M_{ws} - M_{wh}|$ (see Section 4, C.2.3.2 for M_{ws} and M_{wh})
2. Rules horizontal bending moment range = $2 \times M_h$ (see Section 4, C.2.3.3 for M_h)
3. For each load condition pair, the stress range due to local pressure is the difference between the stress values for Local Pressure Load Conditions. For example, for Load Condition Pair FLC1 & FLC2, the stress range due to local pressure is the difference between the stress values for FLC1 and FLC2.
4. For each load condition pair, the stress range is the sum of the absolute stress range values due to Vertical BM, Horizontal BM and Local Pressure Load Conditions.

4. Primary Stress σ_{d1}

σ_{d1v} and σ_{d1h} may be calculated by a simple beam approach. For assessing fatigue strength of side shell and longitudinal bulkhead plating at welded connections, the value of wave-induced primary stress is to be taken as that of maximum principal stress at the location considered to account for the combined load effects of the direct stresses and shear stresses. For calculating the value of σ_{d1v} for longitudinal deck members, normal camber may be disregarded.

5. Secondary Stress σ_{d2}

σ_{d2} may be obtained from orthotropic plating or grillage methods with appropriate boundary conditions.

For those connections specified in B.2.1, the wave-induced secondary bending stress σ_{d2} may be ignored.

6. Additional Secondary Stresses σ^*_{d2} and Tertiary Stresses σ_{d3}

6.1 Calculation of σ^*_{d2}

Where required, the additional secondary stresses acting at the flange of a longitudinal stiffener, σ^*_{d2}, may be approximated by:

$$\sigma^*_{d2} = C_t \cdot C_y \cdot \frac{M}{W} \quad [N/cm^2]$$

where

$$M = C_d \cdot p \cdot a \cdot \frac{\ell^2}{12} \quad [N\text{-}cm]$$

Where flat bar stiffeners or brackets are fitted, the bending moment, M, given above, may be adjusted to the location of the bracket's toe, i.e., M_x in Fig.4.35.

Where a longitudinal has remarkably different support stiffness at its two ends (e.g., a longitudinal connected to a transverse bulkhead on one end), considerations should be given to the increase of bending moment at the joint.

C_d = 1,15 for longitudinal stiffener connections at the transverse bulkhead connection including swash bulkheads

= 1,0 elsewhere

p = wave-induced local net pressure [N/cm^2], for the specified location and load cases at the mid-span of the longitudinal considered

a = spacing of longitudinal stiffener [cm]

ℓ = unsupported span of longitudinal/stiffener [cm], as shown in Fig.4.34.

W = net section modulus of longitudinal with the associated effective plating [cm^3], at flange or point considered. The effective breadth, be, [cm], may be determined as shown in Fig. 4.35.

$C_y = 0{,}656 \cdot \left(\frac{T}{z}\right)^4$ for side shell longitudinals only where $\frac{z}{T} \geq 0{,}9$, but $C_y \geq 0{,}30$

= 1,0 elsewhere

z = distance above keel of side shell longitudinal under consideration

T = scantling draft [m]

C_t = correction factor for the combined bending and torsional stress induced by lateral loads at the welded connection of the flat bar stiffener or bracket to the flange of longitudinal, as shown in Fig. 4.34.

= $1{,}0 + \alpha_r$ for unsymmetrical sections, fabricated or rolled

= 1,0 for tee and flat bars

$\alpha_r = C_n \cdot C_p \cdot \frac{W}{K}$

$C_p = 31{,}2 \cdot d_w \cdot \left(\frac{e}{\ell}\right)^2$

e = horizontal distance between web centerline and shear center of the cross section, including longitudinal and the effective plating

$\approx d_w \cdot b_f^2 \cdot t_f \cdot \frac{u}{2 \cdot W}$ [cm]

K = St. Venant torsion constant for the longitudinal's cross section, excluding the associated plating.

$= \frac{b_f \cdot t_f^3 + d_w \cdot t_w^3}{3}$ [cm^4]

C_n = coefficient given in Fig. A5.3, as a function of ψ, for point (1) shown in Fig. 4.42

$u = 1 - 2 \cdot \frac{b_1}{b_f}$

$\psi = 0{,}31 \cdot \ell \sqrt{\frac{K}{\Gamma}}$

Γ = warping constant

$= \frac{m \cdot I_{yf} \cdot d_w^2 + d_w^3 \cdot t_w^3}{36}$ [cm^6]

$I_{yf} = \frac{t_f \cdot b_f^3}{12}\left(1{,}0 + 3{,}0 \cdot u^2 \cdot \frac{A_w}{A_s}\right)$ [cm^4]

$A_w = d_w \cdot t_w$ [cm^2]

A_s = net sectional area of the longitudinals, excluding the associated plating [cm^2]

$m = 1{,}0 - u\left(0{,}7 - 0{,}1 \cdot \frac{d_w}{b_f}\right)$

d_w, t_w, b_1, b_f, t_f, all [cm], are as defined in Fig. 4.42.

For general applications, a_r need not be taken greater than 0,65 for a fabricated angle bar and 0,50 for a rolled section.

For connection as specified in B.2.2, the wave-induced additional secondary stress σ_{d2}^* may be ignored.

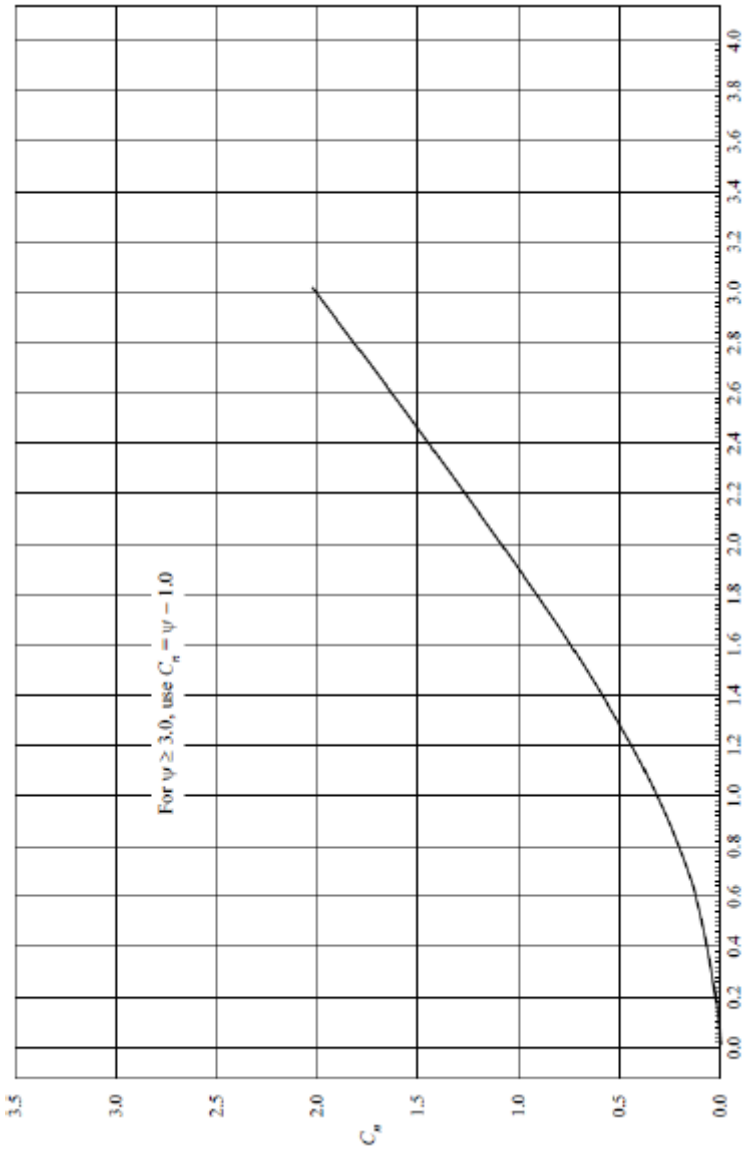


Fig. A5.3 $C_n = C_n(\psi)$

6.2 Calculation of σ_{d3}

For welded joints of a stiffened plate panel, σ_{d3} may be determined based on the wave-induced local loads as specified in 6.1 above, using the approximate equations given below. For direct calculation, non-linear effect and membrane stresses in the plate may be considered.

For plating subjected to lateral load, σ_{d3} in the longitudinal direction is determined as:

$$\sigma_{d3} = 0{,}182 \cdot p\left(\frac{a}{t_n}\right)^2 \qquad [N/cm^2]$$

where

p = wave-induced local net pressure [N/cm^2]

a = spacing of longitudinal stiffeners [cm]

t_n = net thickness of plate [mm]

E. Resulting Stress Ranges

1. Definitions

The content in this section is applicable to ship-type installations. For fatigue strength assessment for service as a trading vessel, refer to L.3.

1.1 The total stress range, σ_R, is computed as the sum of the two stress ranges, as follows:

$$\sigma_R = k_p \cdot c_f (\sigma_{RG} + \sigma_{RL}) \quad [N/cm^2]$$

where

σ_{RG} = global dynamic stress range [N/cm^2]

= $\left|\left(\sigma_{d1vi} - \sigma_{d1vj}\right) + \left(\sigma_{d1hi} - \sigma_{d1hj}\right)\right|$

σ_{RL} = local dynamic stress range [N/cm^2]

= $\left|\left(\sigma_{d2i} + \sigma^*_{d2i} + \sigma_{d3i}\right) - \left(\sigma_{d2j} + \sigma^*_{d2j} + \sigma_{3j}\right)\right|$

k_p = load factor for adjusting the probability of exceedance

= 0,5

c_f = adjustment factor to reflect a mean wasted condition

= 0,95

σ_{d1vi}, σ_{d1vj} = wave-induced component of the primary stresses produced by hull girder vertical bending, [N/cm^2], for load case i and j of the selected pairs of combined load cases, respectively

σ_{d1hi}, σ_{d1hj} = wave-induced component of the primary stresses produced by hull girder horizontal bending, [N/cm^2], for load case i and j of the selected pairs of combined load cases, respectively

σ_{d2i}, σ_{d2j} = wave-induced component of the secondary bending stresses produced by the bending of cross-stiffened panels between transverse bulkheads, [N/cm^2], for load case i and j of the selected pairs of combined load cases, respectively

σ^*_{d2i},σ^*_{d2j} = wave-induced component of the additional secondary stresses produced by the local bending of the longitudinal stiffener between supporting structures (e.g., transverse bulkheads and web frames), [N/cm^2], for load case i and j of the selected pairs of combined load cases, respectively

σ_{d3i},σ_{d3j} = wave-induced component of the tertiary stresses produced by the local bending of plate elements between the longitudinal stiffeners, [N/cm^2], for load case i and j of the selected pairs of combined load cases, respectively

For calculating the wave-induced stresses, sign convention is to be observed for the respective directions of wave-induced loads, as specified in Tables A5.2A through A5.2D. The wave induced local loads are to be calculated with the sign convention for the external and internal loads. However, the total of the external and internal pressures, including both static and dynamic components, need not be taken less than zero.

These wave-induced stresses are to be determined based on the net ship scantlings (see A.2) and in accordance with D.3 through D.6. The results of direct calculation, where carried out, may also be considered.

F. Determination of Stress Concentration Factors (SCFs)

1. General

This Subsection contains information on stress concentration factors (SCFs) to be considered in the fatigue assessment.

Where, for a particular example shown, no specific value of SCF is given when one is called for, it indicates that a finite element analysis is needed. When the fine mesh finite element approach is used, additional information on calculations of stress concentration factors and the selection of compatible S-N data is given in G.

2. Sample Stress Concentration Factors (SCFs)

2.1 Cut-outs (Slots) for Longitudinals

SCFs, fatigue classifications and peak stress ranges may be determined in accordance with Table A5.3 and Fig. A5.4.

Table A5.3 K_s (SCF) Values

Configuration	K_s (SCF)					
	Unsymmetrical Flange			Symmetrical Flange		
Location	[1]	[2]	[3]	[1]	[2]	[3]
Single-side Support	2,0	2,1	-	1,8	1,9	-
Single-side Support with F.B. Stiffener	1,9	2,0	-	1,7	1,8	-
Double-sided Support	3,0	2,6	2,4	2,7	2,4	2,2
Double-sided Support with F.B Stiffener	2,8	2,5	2,3	2,5	2,3	2,1

Note :

a *The value of K_s is given, based on nominal shear stresses near the locations under consideration.*

b *Fatigue classification*

Locations [1] and [2]: Class C or B as indicated in Table A5.1

Location [3]: Class F

c *The peak stress range is to be obtained from the following equations:*

1. ***For location [1] and [2]***

$$\sigma_{Ri} = c_f \left[K_{si} \cdot \tau_{si} + \sigma_{ni} \right]$$

where

c_f = *0,95*

τ_{si} = $\tau_{sc} + \alpha_i \cdot \tau_{swi}$, $\tau_{si} \geq \tau_{sc}$

α_i = *1,8 for single-side support*

= *1,0 for double-sided support*

σ_{ni} = *normal stress range in the web plate*

τ_{swi} = *shear stress range in the web plate*

$$= \frac{Q_i}{A_w}$$

Q_i is the calculated web shear force range at the location considered. A_w is the area of web.

τ_{sc} = *shear stress range in the support (lug or collar plate)*

$$= \frac{C_y \cdot P}{A_c + A_s}$$

C_y is as defined in D.6.1

P = $a \cdot \ell \cdot p_0$

p_0 = *fluctuating lateral pressure*

A_c = *sectional area of the support or of both supports for double-sided support*

A_s = *sectional area of the flat bar stiffener, if any*

K_{si} = *SCFs given above*

a = *spacing of longitudinal/stiffener*

ℓ = *spacing of transverses*

2. ***For Location [3]***

$$\sigma_{R3} = c_f \sqrt{\sigma_{n3}^2 + \left(K_s \cdot \tau_{s2} \right)^2}$$

where

c_f = *0,95*

σ_{n3} = *normal stress range at location [3]*

τ_{s2} = *shear stress range, as defined in 1. above, near location [3]*

K_s = *SCFs given above*

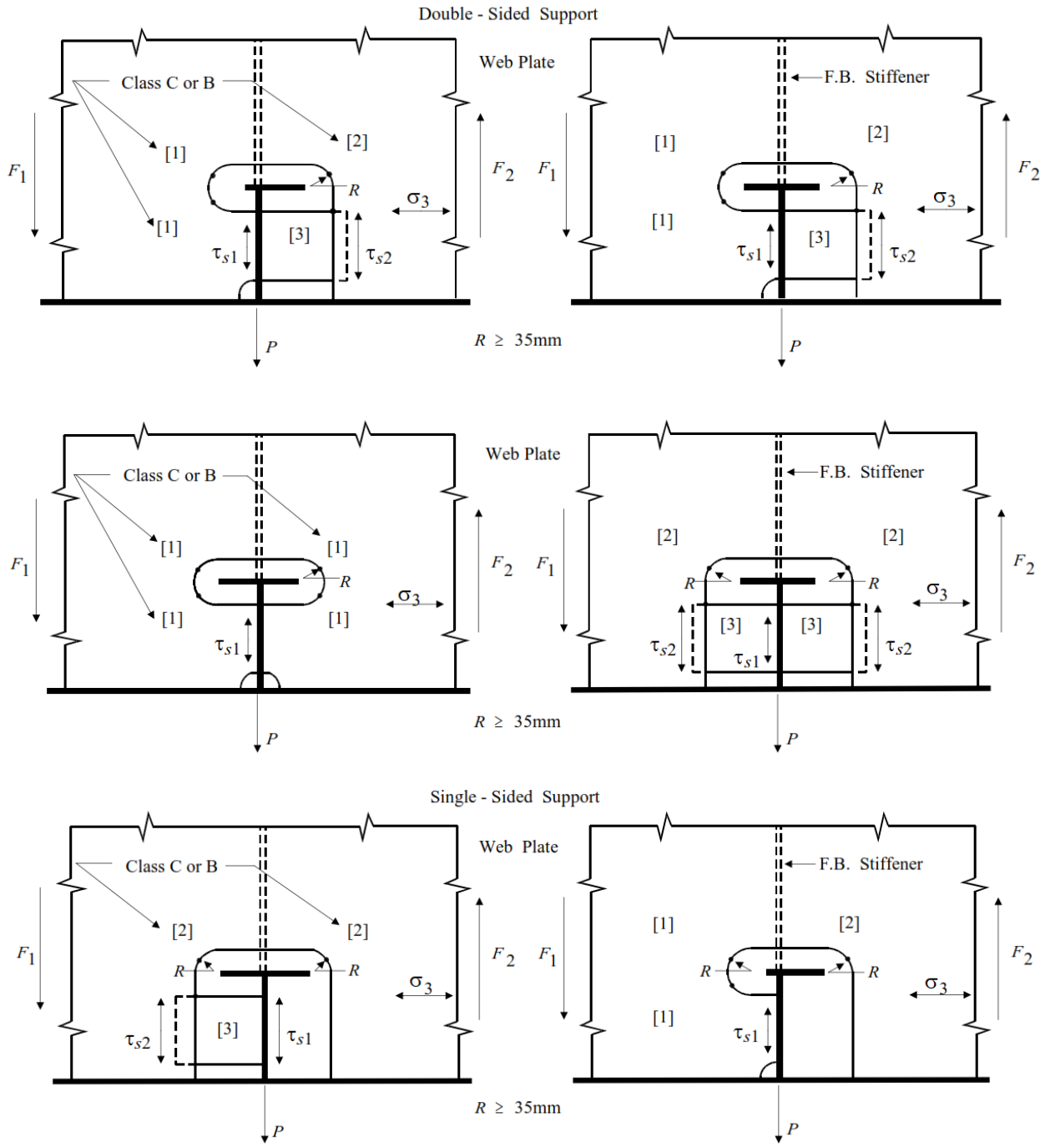


Fig. A5.4 Cut-outs (Slots) For Longitudinal

2.2 Flat Bar Stiffener for Longitudinals

1) For assessing fatigue life of a flat bar stiffener at location [1] or [2] as shown in Fig A5.5, the peak stress range is to be obtained from the following equation :

$$\sigma_{Ri} = \sqrt{(\alpha_i \cdot \sigma_s)^2 + \sigma_{Li}^2} \quad \text{(i = 1 or 2)}$$

where

σ_s = nominal stress range in the flat bar stiffener.

$$= \frac{k_p \cdot c_f \cdot C_y \cdot P}{A_s + A_c}$$

P, A_s, A_c, c_f are as defined in F.2.1 and C_y in D.6.1. For a flat bar stiffener with soft-toed brackets, the brackets may be included in the calculation of A_s.

k_p = load factor for adjusting the probability of exceedance

= 0,5

σ_{Li} = stress range in the longitudinal at Location i (i = 1 or 2), as specified in E

α_i = stress concentration factor at Location i (i = 1 or 2) accounting for misalignment and local distortion

At location [1]

For flat bar stiffener without brackets

α_1 = 1,50 for double-sided support connection

= 2,00 for single-sided support connection

For flat bar stiffener with brackets

α_1 = 1,00 for double-sided support connection

= 1,25 for single-sided support connection

At location [2]

For flat bar stiffener without brackets

α_2 = 1,25 for single or double-sided support connection

For flat bar stiffener with brackets

α_2 = 1,00 for single or double-sided support connection

2) For assessing the fatigue life of the weld throat as shown in Table A5.1, Class W, the peak stress range σ_R at the weld may be obtained from the following equation:

$$\sigma_R = 1{,}25 \cdot \sigma_s \cdot \frac{A_s}{A_{sw}}$$

where

A_{sw} = sectional area of the weld throat. Brackets may be included in the calculation of A_{sw}.

σ_s and A_s are as defined in 2.2 1) above.

3) For assessing fatigue life of the longitudinal, the fatigue classification given in Table A5.1 for a longitudinal as the only load-carrying member is to be considered. Alternatively, the fatigue classification shown in Fig. A5.5, in conjunction with the combined stress effects, σ_R, may be used. In calculation of σ_R, the α_i may be taken as 1,25 for both locations [1] and [2].

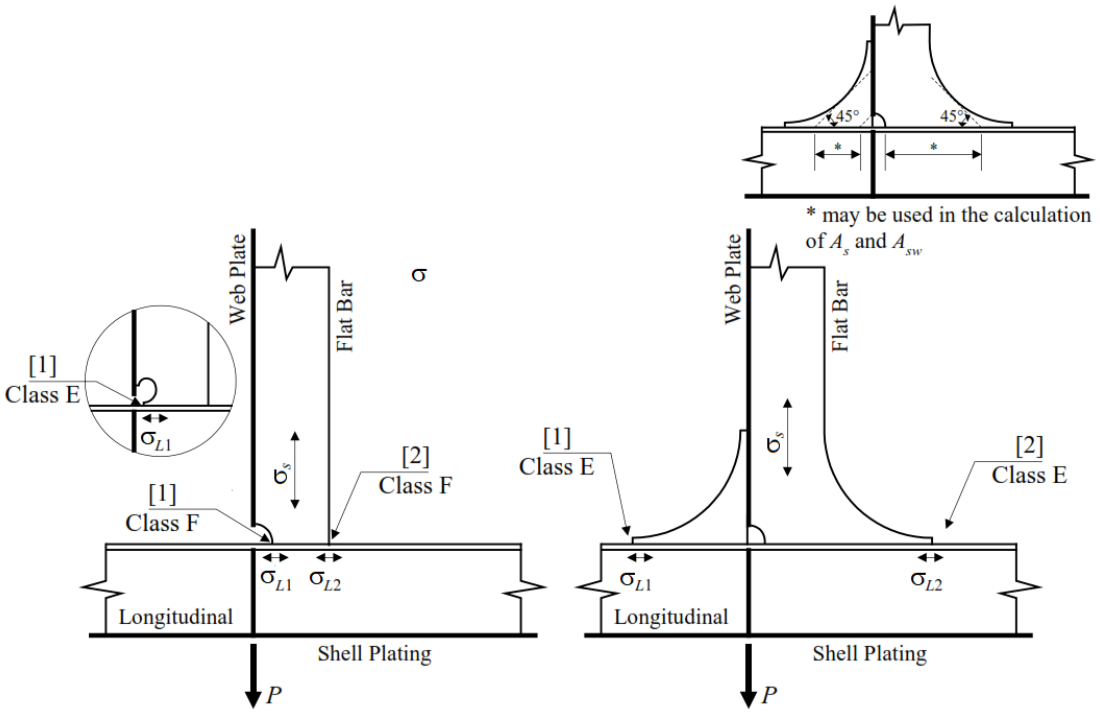


Fig. A5.5 Fatigue Classification for Longitudinals in way of Flat Bar Stiffener

2.3 Connection between Transverse Bulkhead Vertical Web and Double Bottom Girder

Fatigue class designation and SCFs may be determined as shown in Fig. A5.6.

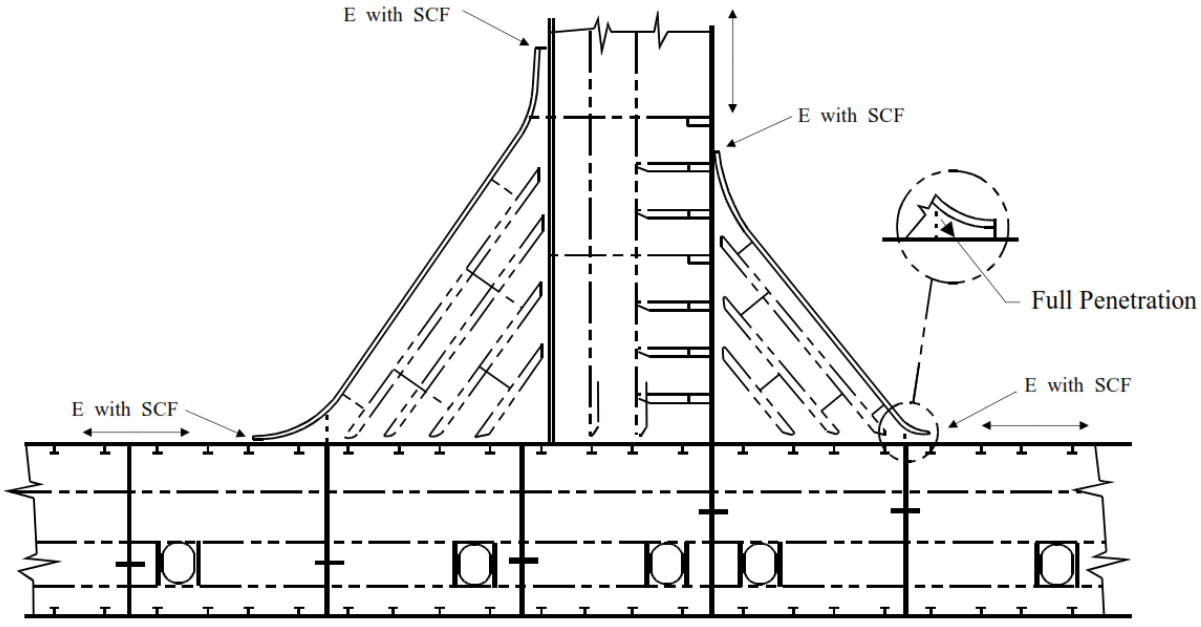


Fig. A5.6

2.4 Connection between Transverse Bulkhead Vertical Web and Deck Girder

Fatigue class designation and SCFs may be determined as shown in Fig. A5.7.

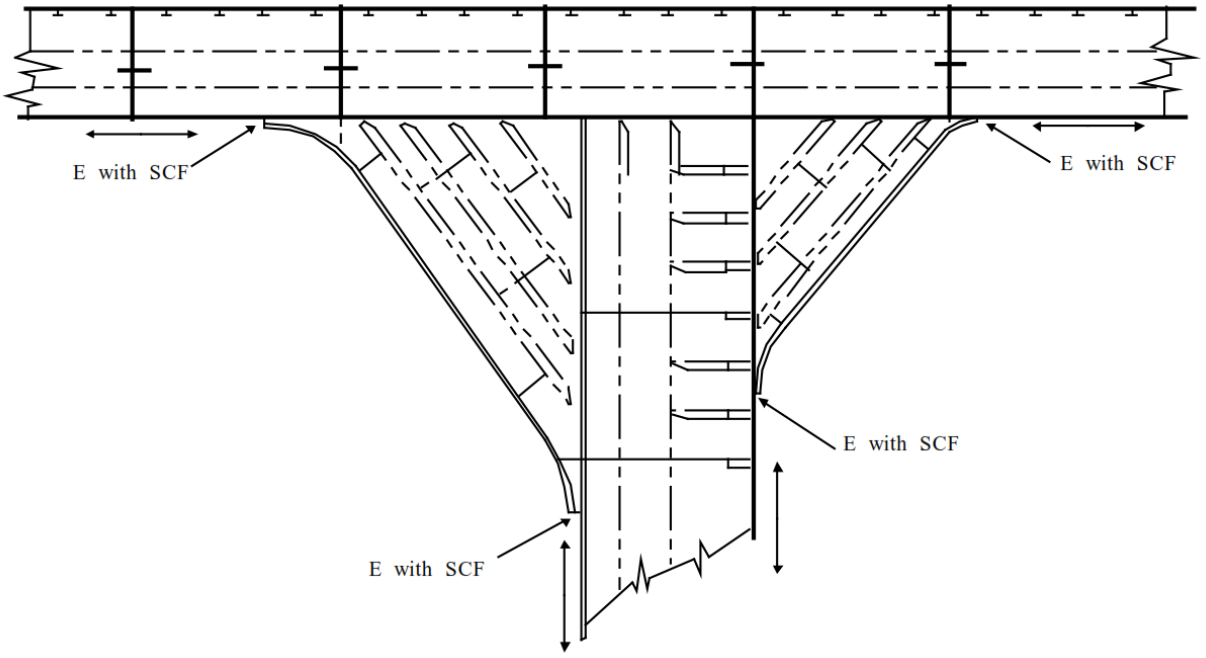


Fig. A5.7

2.5 End Connections of Transverse Bulkhead Horizontal Girder to Longitudinal of Side Shell or Longitudinal Bulkhead

Fatigue class designation and SCFs may be determined as shown in Fig. A5.8.

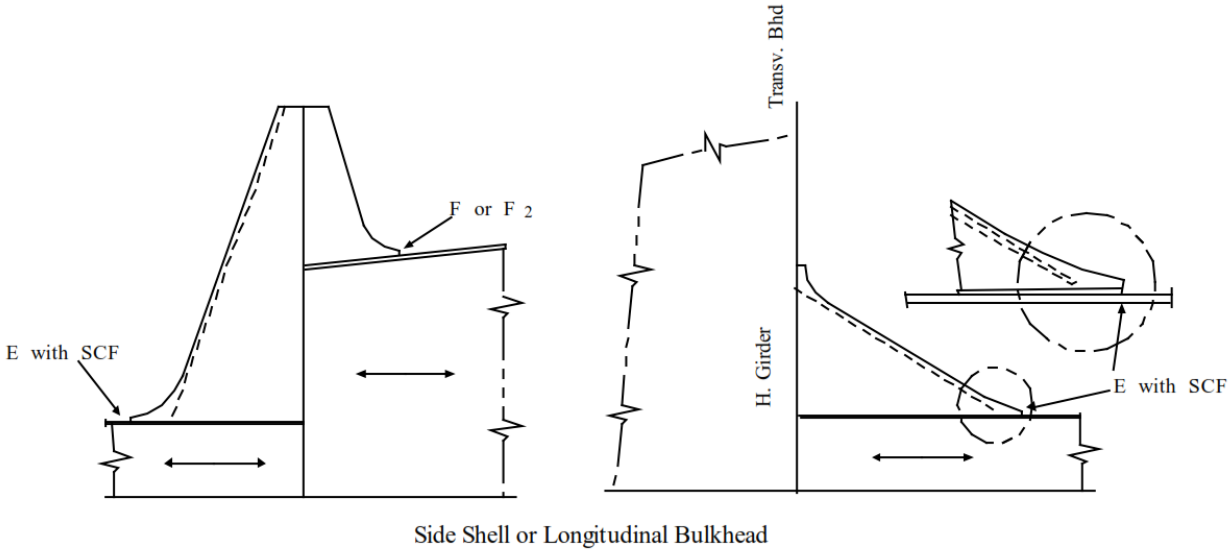


Fig. A5.8

2.6 Connection of Transverse Bulkhead to Longitudinal Bulkhead

Fatigue class designation and SCFs may be determined as shown in Fig. A5.9.

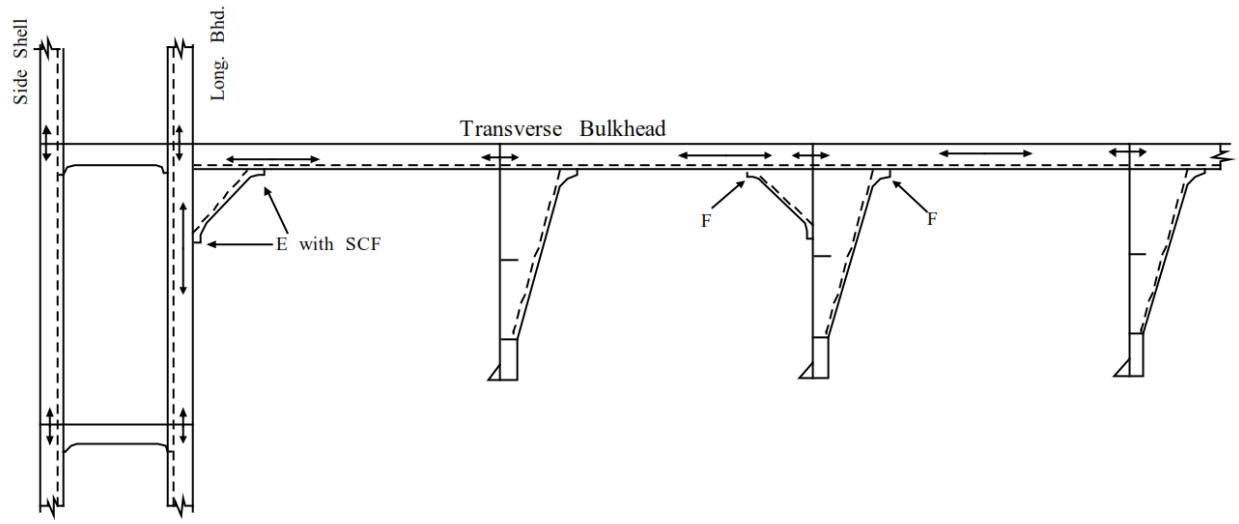


Fig. A5.9

2.7 Doublers and Non-load Carrying Members on Deck or Shell Plating

Fatigue class designation may be determined as shown in Fig. A5.10.

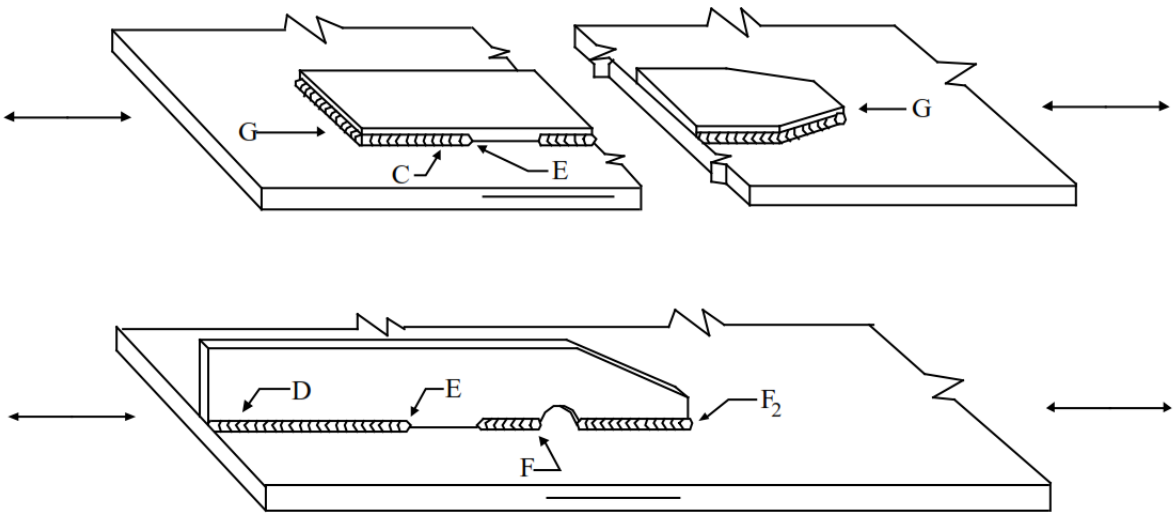


Fig A5.10 Doublers and Non-load Carrying Members on Deck or Shell Plating

G. Stress Concentration Factors Determined From Finite Element Analysis

1. Introduction

S-N data and stress concentration factors (SCFs) are related to each other and therefore should be considered together so that there is a consistent basis for the fatigue assessment.

The following guidance is intended to help make correct decisions.

2. S-N Data

S-N data are presented as a series of straight-lines plotted on log-log scale. The data reflect the results of numerous tests, which often display considerable scatter. The recommended design curves for different types of structural details and welded connections recognize the scatter in test results in that the design curves have been based on the selection of the lower bound, 95% confidence limit. In other words, about 2,5% of the test failure results fall below this curve. Treating the design curve in this manner introduces a high, yet reasonable degree of conservatism in the design and fatigue evaluation processes.

Individual S-N curves are presented to reflect certain generic structural geometry or arrangements. Table A5.1 and F.2 contain sketches of weld connections and other details typically found in ship structures, giving a list of the S-N classification. This information is needed to assess the fatigue strength of a detail. Also needed is a consistent way to establish the demands or load effects placed on the detail, so that a compatible assessment can be made of the available strength versus the demand. Here is where interpretation and judgment enter the fatigue assessment.

S-N curves are obtained from laboratory sample testing. The applied reference stress on the sample which is used to establish the S-N data is referred to as the nominal stress. The nominal stress is established in a simple manner, such as force divided by area and bending moment divided by section modulus (P/A & M/W). The structural properties used to establish the nominal stress are taken from locations away from any discontinuities to exclude local stress concentration effects arising from the presence of a weld or other local discontinuity. In an actual structure, it is rare that a match will be found with the tested sample geometry and loading. One is then faced with the problem of making the appropriate interpretation.

3. S-N Data and SCFs

Selection of appropriate S-N data appears to be rather straightforward with respect to "standard details" offered in Table A5.1 or other similar reference. However, in the case of welded connections in complex structures, it is required that SCFs be used to modify the nominal stress range. An often quoted example of the need to modify nominal stress for fatigue assessment purposes is one shown in Fig. A5.11 below, relating to a hole drilled in the middle of a flat plate traversed by a butt weld.

In this example, the nominal stress σ_N is P/Area, but the stress to be used to assess the fatigue strength at point A is σ_A or $\sigma_N \cdot$ SCF. This example is deceptively simple because it does not tell the entire story. The most obvious deficiency of the example is that one needs to have a definitive and consistent basis to obtain the SCF. There are reference books which indicate that based on the theory of elasticity, the SCF to be applied in this case is 3,0. However, when the SCF is computed using the finite element analysis techniques, the SCF obtained can be quite variable depending on the mesh size. The example does not indicate which S-N curve should be applied, nor does the example say how it may be necessary to alter the selection of the design S-N data in consideration of the aforementioned finite element analysis issues. Therefore, if such interpretation questions exist for a simple example, the higher difficulty of appropriately treating more complex structures should be evident.

Referring to the S-N curves to be applied to welded connections (for example, S-N curves D-W in Fig. A5.1), the SCFs resulting from the presence of the weld itself are already accounted for in these curves. If one were to have the correct stress distribution in the region - from the weld to a location sufficiently away from the weld toe (where the stress is suitably established by the nominal stress obtained from P/A and M/W) - the stress distribution may be generically separated into three distinct segments, as shown in Fig. A5.12 below.

- Region III is a segment where the stress gradient is controlled by the nominal stress gradient.
- Region II is a segment where the nominal stress gradient is being modified due to the presence of other structure, such as the bracket end shown in the figure. This must be accounted for to obtain an appropriate stress to be used in the fatigue analysis at the weld toe.

– Region I is a segment where the stress gradient is being modified due to the presence of the weld metal itself. The stress concentration due to the weld is already accounted for in the S-N design curve and will not be discussed further. Since the typical way to determine the stress distribution is via planar/linear elements which ignore the weld, this is consistent with the method of analysis.

This general description of the stress distribution is again inconclusive because one does not know in advance and with certainty the distances from the weld toe to where the indicated changes of slope for the stress gradient occur. For this reason, definite rules need to be established to determine the slopes, and with this knowledge, criteria established to be used to find the stress at the weld toe which should be used in the fatigue assessment.

In this regard, two approaches can be used to find the stress at the weld toe, which reflect two methods of structural idealization. One of these arises from the use of a conventional beam element idealization of the structure including the end bracket connection, and the other arises from the use of a fine mesh finite element idealization.

Using a beam element idealization, the nominal stress at any location (i.e., P/A and M/W) can be obtained (see Fig. A5.6 for a sample beam element model).

In the beam element idealization, there will be questions as to whether or not the geometric stress concentration due to the presence of other structure is adequately accounted for. This is the "Segment II" stress gradient previously described. In the beam modelling approach shown in the figure, the influence on stresses arising from the "carry over" of forces and bending moments from adjacent structural elements has been accounted for (albeit approximately). At the same time, the strengthening effect of the brackets has been conservatively ignored. Hence for engineering purposes, this approach is considered to be sufficient in conjunction with the nominal stress obtained at the location of interest and the nominal S-N curve, i.e., the F or F2 Class S-N data, as appropriate.

In the fine mesh finite element analysis approach, one needs to define the element size to be used. This is an area of uncertainty because the calculated stress distribution can be unduly affected by both the employed mesh size and the uniformity of the mesh adjacent to the weld toe. Therefore, it is necessary to establish "rules", as given below, to be followed in the producing of the fine mesh model adjacent to the weld toe. Furthermore, since the area adjacent to the weld toe (or other discontinuity of interest) may be experiencing a large and rapid change of stress (i.e., a high stress gradient), it is also necessary to provide a rule which can be used to establish the stress at the location where the fatigue assessment is to be made.

Fig. A5.13 shows an acceptable method which can be used to extract and interpret the "near weld toe" element stresses and to obtain a (linearly) extrapolated stress at the weld toe. When plate or shell elements are used in the modeling, it is recommended that each element size is to be equal to the plate thickness. When stresses are obtained in this manner, the use of the E Class S-N data is considered to be acceptable.

Weld hot spot stress can be determined from linear extrapolation of surface component stresses at t/2 and 3t/2 from weld toe. The principal stresses at hot spot are then calculated based on the extrapolated stresses and used for fatigue evaluation. Description of the numerical procedure is given in 4. below.

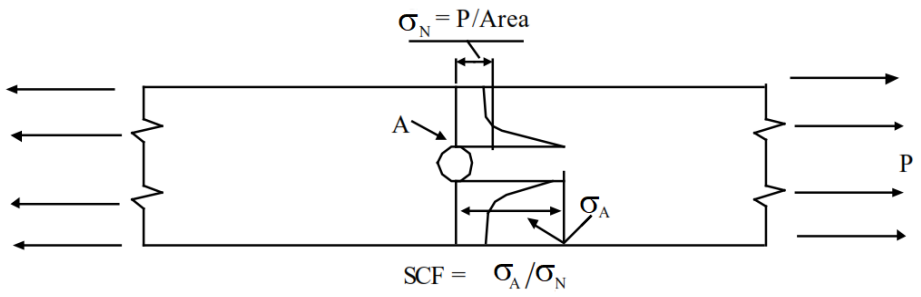


Fig. A5.11

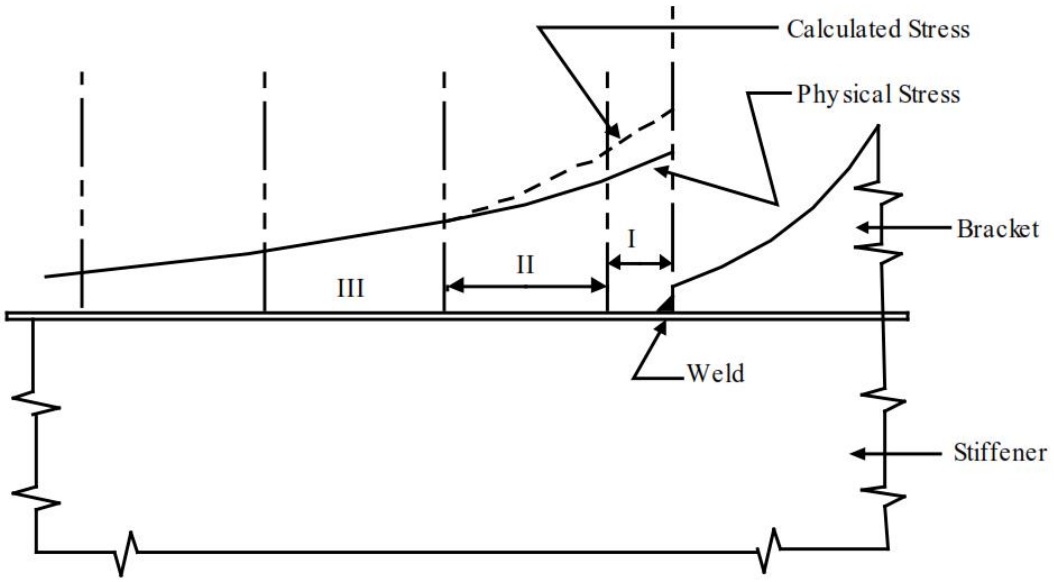


Fig. A5.12

4. Calculation of Hot Spot Stress for Fatigue Analysis

The following method is applied to obtain the hot spot stress at the toe of a weld.

A very fine mesh is to be used in the region of the hotspot stress with a mesh size equal to plate thickness. The hot spot stress is to be determined by using a linear extrapolation as described in Fig. A5.13. Assuming that the applicable surface component stresses of the two points, P_1 and P_2, measured by the distances 0,5t and 1,5t from the weld toe, respectively, have been determined from FEM analysis by the linear interpolation of stresses at centroids of the adjacent two elements, the corresponding hot spot stress can be extrapolated at the hot spot location from the stresses at P_1 and P_2. The weld toe distance, x_{wt}, is not to be taken larger than $0,5 \cdot t_{gross}$.

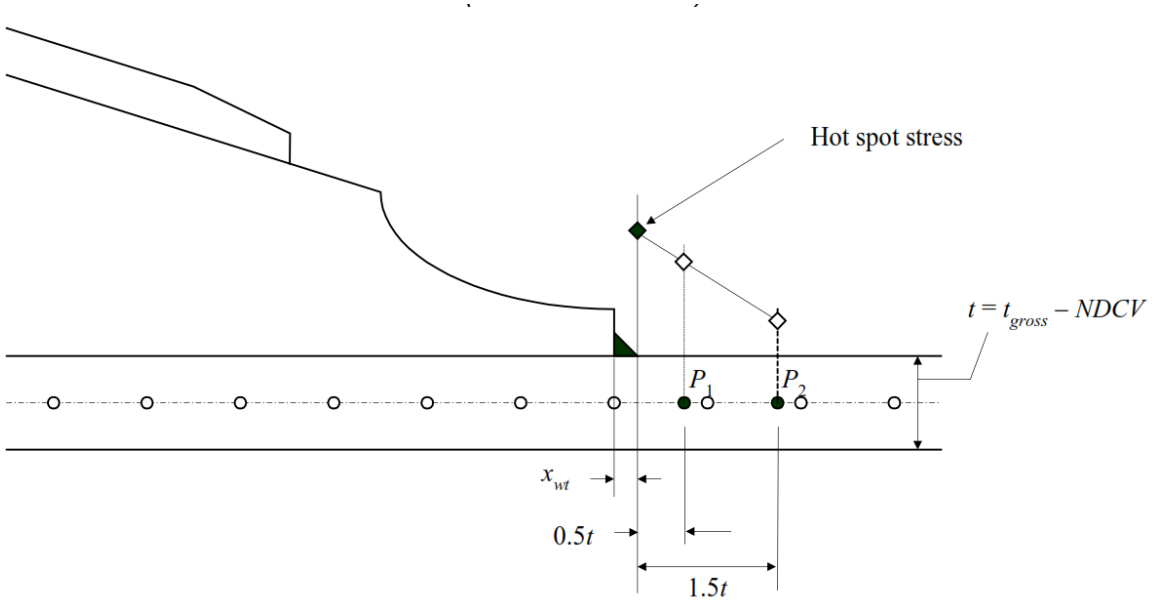


Fig. A5.13

H. Fatigue Assessment of Structures Considering Low Cycle Fatigue

1. Introduction

Certain duty cycles associated with operations of a ship-type installation may produce oscillatory stresses whose magnitudes exceed the yield strength of the material. For welded joints in certain members of ship-type installations during the loading/offloading process, the total number of cycles during the service life is expected to be less than 10^4. Fatigue associated with cyclic plasticity ("low cycle fatigue") is addressed in the following sections. The appropriate low cycle fatigue design S-N curve is defined, the process for computing oscillatory pseudo stress is provided, and the acceptance criterion for total damage, low cycle plus high cycle fatigue, is specified.

2. Applicability

Subsections H. and J. define the procedure for a simplified fatigue assessment which is to be used to evaluate the fatigue strength of critical structural details subjected to low cycle fatigue. The fatigue assessment uses a hot spot stress approach based on FE analysis.

3. Loads

Traditionally, the fatigue strength analysis considers the following dynamic loads (high cycle load) for calculation of the long term distribution of stresses:

- Hull girder loads (i.e., vertical and horizontal wave bending moments)
- Dynamic wave pressure
- Dynamic tank pressure loads resulting from installation motion

However, from low cycle fatigue point of view, fatigue due to the following static loads need to be considered:

- Static cyclic loads due to cargo loading and offloading

4. Selection of Loading Conditions for Low Cycle Fatigue

Fatigue analyses are to be carried out for representative loading conditions according to the intended installation's operation. The following two loading conditions are to be examined:

1) For locations at longitudinal end connections:
   - Full load condition with design still water bending moment, see loading condition 4 in Fig. A5.2A and A5.2B
   - Ballast or light draft condition at with design still water bending moment, see loading condition 1 in Fig. A5.2A and A5.2B
2) For locations other than longitudinal end connections:

   The maximum low cycle fatigue damage calculated from the following two pairs:

   Pair 1
   - Full load condition with design still water bending moment, see loading condition 4 in Fig. A5.2A and A5.2B
   - Ballast or light draft condition with design still water bending moment, see loading condition 1 in Fig. A5.2A and A5.2B

   Pair 2
   - Intermediate condition with design still water bending moment, see loading condition 3 in Fig. A5.2A and A5.2B

– Intermediate condition with design still water bending moment, see loading condition 2 in Fig. A5.2A and A5.2B

5. Acceptance Criteria

The criteria stated in H. and J. are presented as a comparison of fatigue strength of the structural detail (capacity), and fatigue inducing loads (demands), in the form of a fatigue damage parameter, DM. The combined fatigue damage including damages from both low cycle fatigue and high cycle fatigue, DM_{comb}, is to be less than or equal to 1,0 for the design life of the installation, which is not to be taken as less than 20 years.

6. Fatigue Assessment Methods

The hot spot stress approach is to be used for fatigue evaluation of the following details:

6.1 Connections of Longitudinal Stiffeners to Transverse Web/Floor and to Transverse Bulkhead

1) Two (2) to three (3) selected side longitudinals in the region from the 1,1 draft to about 1/3 draft in the midship region and also in the region between 0,15**L** and 0,25**L** from **F.P.**, respectively
2) One (1) to two (2) selected longitudinals from each of the following groups :
   – Deck longitudinals, bottom longitudinals, inner bottom longitudinals and longitudinals on side longitudinal bulkheads
   – One longitudinal on each of the longitudinal bulkheads within 0,1**H** from the deck is to be included

For these structural details, the fatigue assessment is to be first focused on the flange of the longitudinal at the rounded toe welds of attached flat bar stiffeners and brackets, as illustrated for Class F item 2) and Class F2 item 1) in Table A5.1.

Then, the critical spots on the web plate cut-out, on the lower end of the stiffener as well as the weld throat are also to be checked for the selected structural detail. For illustration, see F.2.1 and F.2.2(a), F.2.2(b) and F.2.2(c).

Where the longitudinal stiffener end bracket arrangements are different on opposing sides of a transverse web, both configurations are to be checked.

6.2 Shell, Bottom, Inner Bottom or Bulkhead Plating at Connections to Webs or Floors (for Fatigue Strength of Plating)

1) One (1) to two (2) selected locations of side shell plating near the summer LWL amidships and between 0,15**L** and 0,25**L** from **F.P.** respectively
2) One (1) to two (2) selected locations in way of bottom and inner bottom amidships
3) One (1) to two (2) selected locations of lower strakes of side longitudinal bulkhead amidships

6.3 Connections of the Slope Plate to Inner Bottom and Side Longitudinal Bulkhead Plating at the Lower Cargo Tank Corners

One selected location amidships at transverse web and between webs, respectively

For this structural detail, the value of σ_R, the total stress range as specified in E.1, is to be determined from fine mesh F.E.M. analyses for the combined load cases, as specified for Zone B in D.3.2.

6.4 End Bracket Connections for Transverses and Girders

One (1) to two (2) selected locations in the midship region for each type of bracket configuration.

6.5 Other Regions and Locations

Other regions and locations, highly stressed by fluctuating loads, as identified from structural analysis.

I. Low Cycle Fatigue Damage

1. Low Cycle Fatigue Load

When fatigue is of concern, structural responses are assumed to result from two external sources, the wave loading on the installation and the process of loading and offloading the installation resulting in uneven buoyancy. This loading/offloading process produces very low frequency static loads including oscillatory still water bending moment (SWBM) and still water pressure. Some structural components experience cyclic plasticity when the combination of the two load sources produces cyclic stresses that exceed the yield strength of the material. Typically this occurs at the toe of a weld. Described in this section is the process of defining damage due to low cycle fatigue.

2. Loading Conditions

Static cyclic loads including still-water bending moments and static pressure due to cargo loading and offloading are considered.

3. Stress Range Calculation

3.1 Elastic Hot Spot Stress Range Calculation

In the following, all reference to stress is to be interpreted as the elastic hot spot stress at the toe of a weld in question. Also, at the outset, it will be assumed that the S-N curve defining fatigue strength is given in pseudo hot spot stress. In the elastic high cycle range a pseudo hot spot stress will be the same as an elastic hot spot stress. They will differ in the low cycle range.

As shown in Fig. A5.14, the stress process in certain structural components of an installation can be considered as a superposition of wave induced stresses, $\sigma_W(t)$, and stresses associated with static load, $\sigma_B(t)$. The cycles of σ_B result from the loading/offloading process.

The total or net stress process will be:

$$\sigma(t) = \sigma_B(t) + \sigma_W(t)$$

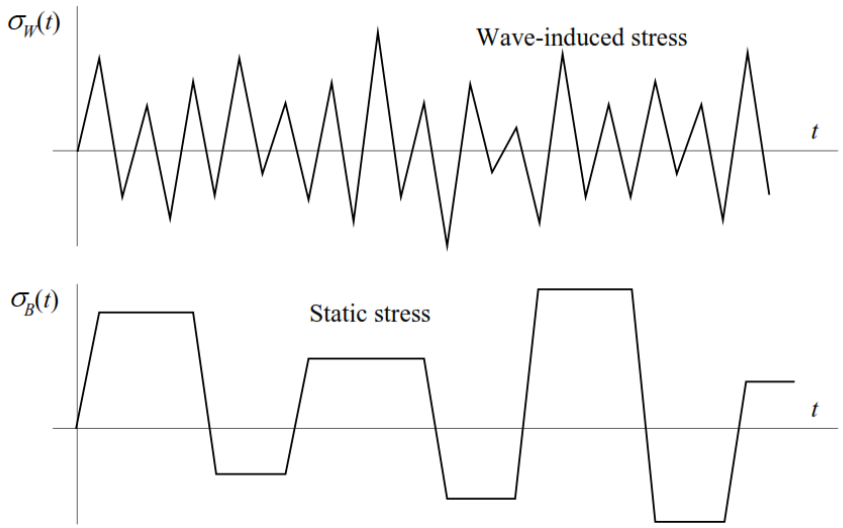


Fig. A.5.14 Sample Functions of σ_W and σ_B

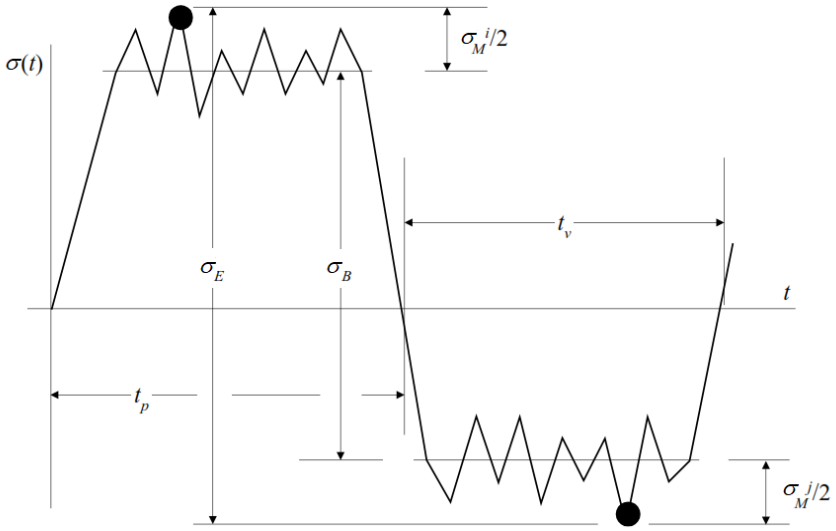


Fig. A5.15 A Single Loading/Offloading Cycle

In one cycle of the static process, as shown in Fig A5.15, the total stress range associated with this cycle is σ_E,

$$\sigma_E = \sigma_B + 0{,}5\left(\sigma_M^i + \sigma_M^j\right)$$

where

σ_B = static stress range for this cycle

σ_M^i = median of the largest stress range of wave induced load for i-th load condition

σ_M^j = median of the largest stress range of wave induced load for j-th load condition

From extreme value theory, the median largest stress range σ_M^i in n cycles is given as :

$$\frac{\sigma_M^i}{\delta} = \sqrt[\gamma]{-\ln\left(1-\sqrt[n]{0{,}5}\right)}$$

where γ and α are the long term stress shape and scale factors, respectively. δ can be determined statistically from long term records of stress ranges or can be calculated by the formula :

$$\delta = \frac{\sigma_R}{\sqrt[\gamma]{\ln(N_s)}}$$

where σ_R is the stress range associated with a probability of exceedance of $\frac{1}{N_s}$, as defined in E.1, and N_s is equal to 10^4.

n may be computed by taking the estimated time for a half cycle divided by the estimated wave period.

The number of cycles for installation's loading and unloading, n_{LCF}, is assumed to be no less than 1200 for 20 years. The actual cycles of loading/offloading may be used for historical sites in FPSO phase

Assume there are 10^8 wave cycles within 20 years, n is then equal to : $\frac{10^8}{n_{LCF} \times 2}$

In general, it is expected that the time in tension will not equal the time in compression. For a conservative analysis, the larger of the two might be selected.

3.2 Pseudo Hot Spot Stress Range Calculation

To transform elastic hot spot stress range to pseudo hot spot stress range, a plasticity correction factor, k_e, is defined as :

$$k_e = \frac{\sigma_L}{\sigma_E}$$

where σ_L is the pseudo hot spot stress range. A plot of k_e as a function of σ_E is given in Fig. A5.16.

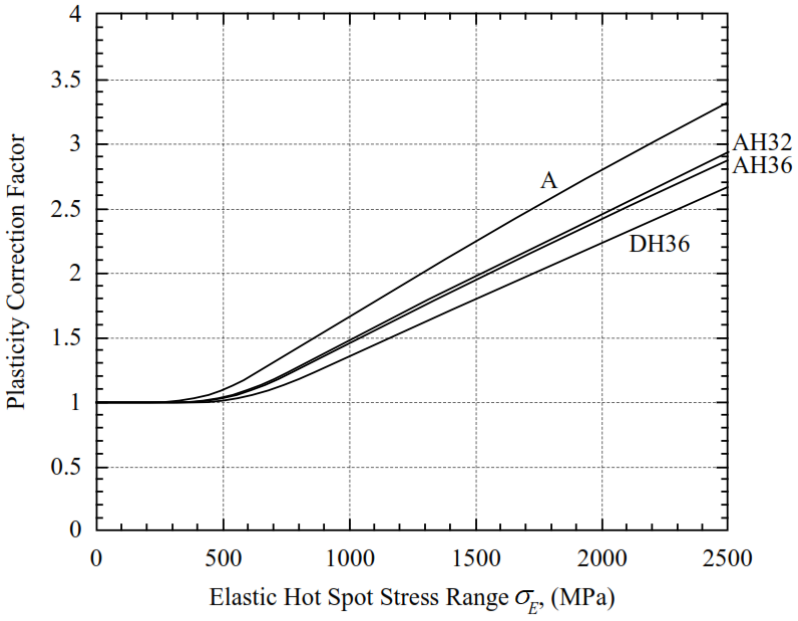


Fig. A5.16 k_e as a Function of σ_E

An approximate analytical formula derived from Fig. A5.16 can be used :

$$k_e = 0,5 + k_m \cdot \sigma_E \quad \text{but should not be less than 1,0}$$

Values of k_m

Material	Mild	KI-32	KI-36	KI=40
k_m	$11,20 \times 10^{-4}$	$9,60 \times 10^{-4}$	$9,40 \times 10^{-4}$	$8,56 \times 10^{-4}$

3.3 Low Cycle S-N Curve and Damage Calculation

The design S-N curve in the low cycle region is defined in Fig. A5.17. It may be considered to be a modified D-Curve.

The low cycle fatigue (LCF) design S-N curve is given as :

$$N \cdot \sigma^q = B \quad \text{for } 100 < N < 10^4$$

where

$q = 2,4$

$B = 3,51 \times 10^{10}$ [MPa]

It is assumed that the LCF design S-N curve is applicable to static induced stresses. Basic application of Miner's rule produces the expression of static stress damage DM_{LCF} is:

$$DM_{LCF} = \frac{N_{LCF} \cdot \sigma_L^q}{B}$$

n_{LCF} is the total cycles of loading/offloading, which is not to be less than 1200 for a ship-type installation to be operated for 20 years. The actual cycles of loading/offloading may be used for historical site in FPSO phase.

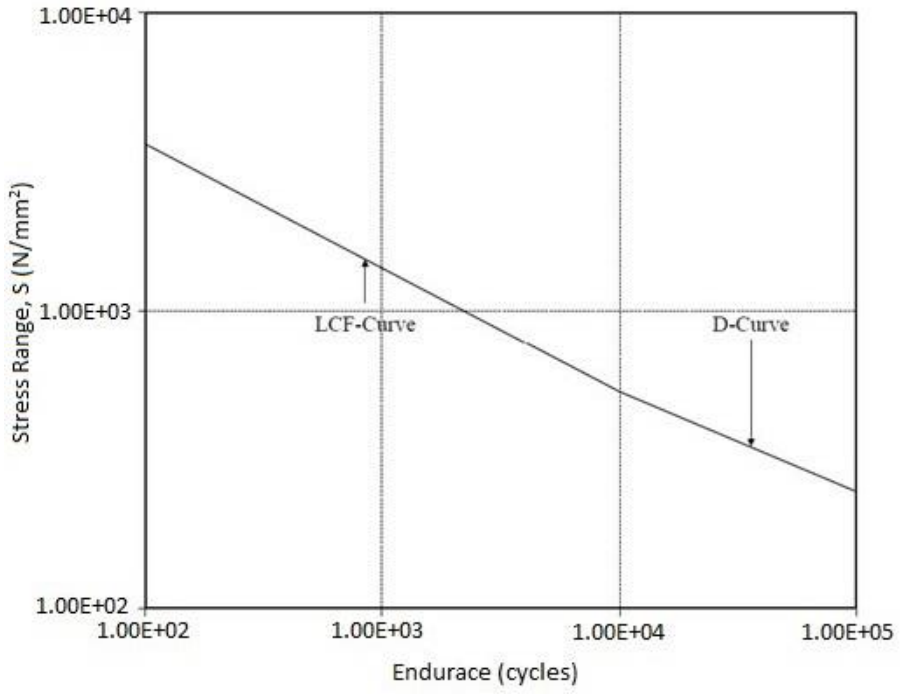


Fig. A5.17 Low Cycle Fatigue Design Curve

J. Combined Fatigue Damage

The total fatigue damage due to both low cycle and high cycle stress can be calculated by

$$DM_{comb} = \frac{\left(DM_{LCF}^2 + 2 \cdot \delta \cdot DM_{LCF} \cdot DM_{HCF} + DM_{HCF}^2\right)}{\sqrt{DM_{LCF}^2 + DM_{HCF}^2}}$$

where

δ = 0,02

DM_{LCF} = low cycle fatigue damage

DM_{HCF} = high cycle fatigue damage

For Longitudinal Stiffener Connections, the total fatigue damage due to both low cycle and high cycle stress can be calculated by

$$DM_{comb} = \frac{\left(DM_{LCF}^2 + 2 \cdot \delta \cdot \frac{DM_{LCF} \cdot DM_{HCF}}{\alpha_{Site}} + \left(\frac{DM_{HCF}}{\alpha_{Site}}\right)^2\right)}{\sqrt{DM_{LCF}^2 + \left(\frac{DM_{HCF}}{\alpha_{site}}\right)^2}}$$

where

α_{Site} = environmental severity factor for the intended site, see Annex 4, C.

K. Fatigue Strength Assessment for Service as a Trading Vessel

1. Cumulative Fatigue Damage for Trading Vessels

The cumulative fatigue damage ratio, DM, as a trading vessel, is equal to 1,0 which corresponds to a fatigue life of 20 years. The design life is not to be less than 20 years. Unless otherwise specified, the cumulative damage is to be taken as :

$$DM = \frac{N_L \cdot (0{,}01 \cdot \sigma_R)^m}{K_2 (\ln N_R)^{\frac{m}{\gamma}}} \mu \cdot \Gamma\left(1 + \frac{m}{\gamma}\right)$$

where

N_L = number of cycles for the expected design life. Unless stated otherwise, N_L to be taken as:

= $\frac{f_0 \cdot U}{4 \cdot \log_{10} L}$

= The value is generally between $0{,}5 \times 10^8$ and $0{,}7 \times 10^8$ cycles for a design life of 20 years

f_0 = 0,85, factor taking into account non-sailing time for operations such as loading and unloading, repairs, etc.

U = design life [seconds]

= $6{,}31 \times 10^8$ for a design life of 20 years

L = rule length [m]

m, K_2 = S-N curve parameter as defined in Fig. A5.1, Note a)

σ_R = stress range at the representative probability level of 10^{-4} [N/cm^2]

N_R = 1 x 10^4, number of cycles corresponding to the probability level of 10^{-4}

γ = long term stress distribution parameter, as defined in Fig. A5.1.

Γ = Gamma function

μ = stress coefficient taking into account the change in slope of the S-N curve

$$= 1 - \frac{\left\{\Gamma_0\left(1+\frac{m}{\gamma},\nu\right) - \nu^{-\frac{\Delta m}{\gamma}}\Gamma_0\left(1+\frac{m+\Delta m}{\gamma},\nu\right)\right\}}{\Gamma\left(1+\frac{m}{\gamma}\right)}$$

$$\nu = \left(\frac{\sigma_q}{0{,}01\cdot\sigma_R}\right)^{\gamma} \ln N_R$$

σ_q = stress range at the intersection of the two segments of the S-N curve [N/mm^2], see Table in Fig. A5.1, Note a).

Δm = slope change of the upper-lower segment of the S-N curve

= 2

$\Gamma_0(a,x)$ = incomplete Gamma function, Legendre form

2. Fatigue Assessment Zones and Controlling Load Combination for Vessels

Eight loading patterns are considered in the calculation of stress range, as shown in Fig. 4.8A or Fig. 4.8B depending on whether the existing vessel to be converted is a single hull or double hull vessel.

Depending on the location of the structural details undergoing the fatigue assessment, different combinations of load cases are to be used to find the appropriate stress range, as indicated below for indicated respective zones.

2.1 Zone A

Zone A consists of deck and bottom structures, and side shell and longitudinal bulkhead structures within 0,1**H** (**H** is installation's molded depth) from deck and bottom, respectively. For Zone A, stresses are to be calculated based on the wave-induced loads specified in Fig. 4.8A, as follows.

1) Calculate dynamic component of stresses for load cases LC1 through LC4, respectively.
2) Calculate two sets of stress ranges, one each for the following two pairs of combined loading cases.
   LC1 and LC2, and
   LC3 and LC4
3) Use the greater of the stress ranges obtained by 2).

2.2 Zone B

Zone B consists of side shell and longitudinal bulkhead structures within the region between 0,25 upward and 0,30 downward from the mid-depth and all transverse bulkhead structures. The total stress ranges for Zone B may be calculated based on the wave-induced loads specified in Table 4.9A, as follows:

1) Calculate dynamic component of stresses for load cases LC5 through LC8, respectively.
2) Calculate two sets of stress ranges, one each for the following two pairs of combined loading cases.
   C5 and LC6, and
   LC7 and LC8
3) Use the greater of the stress ranges obtained by 2).

2.3 Transitional Zone

Transitional zone between A and B consists of side shell and longitudinal bulkhead structures between 0,1**H** and 0,25**H** (0,2**H**) from deck (bottom).

$$\sigma_R = \sigma_{R(B)} - \frac{\left(\sigma_{R(B)} - \sigma_{R(A)}\right) y_u}{0{,}15 \cdot H} \quad \text{for upper transitional zone}$$

$$\sigma_R = \sigma_{R(B)} - \frac{\left(\sigma_{R(B)} - \sigma_{R(A)}\right) y_\ell}{0{,}1 \cdot H} \quad \text{for lower transitional zone}$$

where

$\sigma_{R(A)}$, $\sigma_{R(B)}$ = the total stress range based on the combined load cases defined for Zone A or Zone B, respectively

y_u, y_ℓ = vertical distances from 0,25 **H** (0,3 **H**) upward (downward) from the mid-depth to the location considered

2.4 Installations with Either Special Loading Patterns or Special Structural Configuration

For installations with either special loading patterns or special structural configurations/features, additional load cases may be required for determining the stress range.

3. Definitions for Resulting Stress Ranges for Trading Vessels

The total stress range, σ_R, is computed as the sum of the two stress ranges, as follows:

$$\sigma_R = k_p \cdot c_f \left(\sigma_{RG} + \sigma_{RL}\right) \qquad [N/cm^2]$$

where

σ_{RG} = global dynamic stress range = $\left|\left(\sigma_{d1vi} - \sigma_{d1vj}\right) + \left(\sigma_{d1hi} - \sigma_{d1hj}\right)\right|$ [N/cm^2]

σ_{RL} = local dynamic stress range = $c_w \left|\left(\sigma_{d2i} + \sigma^*_{d2i} + \sigma_{d3i}\right) - \left(\sigma_{d2j} + \sigma^*_{d2j} + \sigma_{d3j}\right)\right|$ [N/cm^2]

c_f = adjustment factor to reflect a mean wasted condition
= 0,95

c_w = coefficient for the weighted effects of the two paired loading patterns
= 0,75

k_p = load factor for adjusting the probability of exceedance
= 0,5

σ_{d1vi}, σ_{d1vj} = wave-induced component of the primary stresses produced by hull girder vertical bending [N/cm^2], for load case i and j of the selected pairs of combined load cases, respectively

σ_{d1hi}, σ_{d1hj} = wave-induced component of the primary stresses produced by hull girder horizontal bending [N/cm^2], for load case i and j of the selected pairs of combined load cases, respectively

σ_{d2i}, σ_{d2j} = wave-induced component of the secondary bending stresses produced by the bending of cross-stiffened panels between transverse bulkheads, [N/cm^2], for load case i and j of the selected pairs of combined load cases, respectively

σ^*_{d2i},σ^*_{d2j} = wave-induced component of the additional secondary stresses produced by the local bending of the longitudinal stiffener between supporting structures (e.g., transverse bulkheads and web frames), [N/cm^2], for load case i and j of the selected pairs of combined load cases, respectively

σ_{d3i}, σ_{d3j} = wave-induced component of the tertiary stresses produced by the local bending of plate elements between the longitudinal stiffeners, [N/cm^2], for load case i and j of the selected pairs of combined load cases, respectively

For calculating the wave-induced stresses, sign convention is to be observed for the respective directions of wave-induced loads, as specified in Table 4.9A. The wave-induced local loads are to be calculated with the sign convention for the external and internal loads. However, the total of the external and internal pressures, including both static and dynamic components, need not be taken less than zero.

These wave-induced stresses are to be determined based on the net ship scantlings (see A.2) and in accordance with D.3 through D.6. The results of direct calculation, where carried out, may also be considered.

Annex 6 Hull Girder Ultimate Strength

A. General 6–1
B. Plate Element 6–2
C. Stiffener Element 6–5
D. Corner Element 6–8

A. General

The hull girder ultimate strength calculation is based on the "gross" ship approach, wherein the nominal design corrosion values are not considered. The hull girder ultimate bending capacity M_u for the design environmental condition (DEC) is to satisfy the limit state specified in Section 4, C.3.2.3.

The method for calculating the ultimate hull girder ultimate bending capacity M_u is to identify the critical failure modes of the main longitudinal structural elements. Structural elements compressed beyond their buckling limit have reduced strength according to their buckling and ultimate strength characteristics. All relevant failure modes for individual structural elements, such as plate buckling, beam-column buckling, torsional stiffener buckling, local buckling of stiffeners, and their interactions, are to be considered in order to identify the weakest inter-frame failure mode.

In applying the incremental-iterative approach, the following assumptions and limitations are generally to be observed:

- The ultimate strength, M_u, is calculated for the hull transverse sections between two adjacent transverse frames;
- The transverse main supporting members, including frames, girders and floors, and their associated effective plating are to have a moment of inertia not less than I_G obtained from the following equation:

$$\frac{I_G}{i_0} \geq 0{,}2 \left(\frac{B_s}{\ell}\right)^3 \left(\frac{B_s}{\mathbf{a}}\right)$$

  where I_G, i_o, B_s, ℓ and **a** are defined in Section 4, C.4.4.5.3.
- The hull transverse section remains plane during each curvature increment application;
- The hull material has an elasto-plastic behavior;
- The element stress, σ_i, corresponding to the element strain, ε_i, is selected as the minimum stress among the values obtained from each of the relevant load-end shortening curves, $\sigma_i - \varepsilon_i$, in this Annex;
- The hull transverse section is divided into a set of individual elements; the elements while considered to be acting independently are combined to provide the ultimate strength resistance of the hull's transverse cross section. These elements are:
  - Plate element, for unstiffened plates;
  - Stiffener element, consisting of a stiffener with an associated effective width of plating;
  - Corner element, consisting of a plate intersection with a web plate.

The procedure for calculating the hull girder ultimate capacity, M_u, based on the incremental-iterative approach is described below.

Each step of the incremental procedure is represented by the calculation of the bending moment M^j, which acts on the hull transverse section as the effect of an imposed curvature χ^j.

For each step, the value χ^j is obtained by adding an increment of curvature, $\Delta\chi$, to the curvature χ^{j-1} value from the previous step. The increment of curvature corresponds to an increment of rotation of the hull's transverse section around its instantaneous horizontal neutral axis.

The rotation angle increment induces axial strain, ε, in each structural element of the hull section, whose value depends on the distance between the element's location and the instantaneous horizontal neutral axis. In the sagging condition, the structural elements above the instantaneous horizontal neutral axis are shortened, whereas the elements below the instantaneous horizontal neutral axis are lengthened. This is reversed in the hogging condition.

The structural element stress, σ_i, induced by strain, ε_i, is to be obtained from the load-end shortening curve $\sigma_i - \varepsilon_i$ of the element, as described in this Annex, which takes into account the nonlinear elasto-plastic behavior of the element. The stress in each element is converted to a force. The equilibrium of the element forces is then used in an iterative process to determine the instantaneous horizontal neutral axis position of the hull's transverse cross-section.

Once the position of the instantaneous horizontal neutral axis is determined with the relevant element force distribution, the bending moment capacity of the section, M^j, about the instantaneous horizontal neutral axis, is obtained by combining the contribution from each element.

Fig. A6.1 is a flow chart showing the main steps of the incremental-iterative approach.

The nonlinear material behavior for in-plane tension or compression is different for different element types. When a structural element is in tension, full plasticity beyond yield (up to a rupture limit) is normally anticipated. However, when a structural element is under compression, elasto-plastic material and nonlinear geometric behavior occur. The tensile and compressive behavior for the different structural elements used in calculating hull girder ultimate strength can be described by the so-called, 'load-end shortening' curves, as described in detail in the following.

B. Plate Element

Unstiffened plates comprising the hull transverse sections may collapse in one of two failure modes:

- Yielding in tension
- Buckling in compression

The load-end shortening curve, $\sigma_i - \varepsilon_i$, for unstiffened plate buckling, is shown in Fig. A6.2 and is defined by the following equations:

1. Yielding in Tension

When an unstiffened plate is stretched in tension, the load-end shortening curve, $\sigma_i - \varepsilon_i$, is idealized as the elastic-perfectly plastic relationship:

$$\frac{\sigma_i}{R_{eH}} = \begin{cases} \bar{\varepsilon}_i & \text{for } 0 \le \bar{\varepsilon}_i \le 1 \\ 1 & \text{for } \bar{\varepsilon}_i > 1 \end{cases} \quad \text{..... (A3.1)}$$

2. Buckling in Compression

The stress acting on an unstiffened plate, σ_i, should be limited to its ultimate strength, σ_u, and not less than critical buckling stress, σ_c, as specified in the following. The load-end shortening curve, $\sigma_i - \varepsilon_i$, for unstiffened plate buckling, is defined by the following equation:

– When $\bar{\varepsilon}_i \leq \dfrac{\sigma_u}{R_{eH}}$

$$\sigma_t^E = R_{eH} \cdot \bar{\varepsilon}_i$$

– When $\bar{\varepsilon}_i > \dfrac{\sigma_u}{R_{eH}}$

$$\frac{\sigma_{ip}^E}{R_{eH}} = \begin{cases} C_E & \text{for } \alpha \geq 1 \\ C_E \cdot \dfrac{a}{\ell} + 0{,}1 \cdot \left(1 - \dfrac{a}{\ell}\right) \cdot \left(1 - \dfrac{1}{\beta_E^2}\right)^2 & \text{for } \alpha < 1 \end{cases}$$

$$\sigma_{ci}^E \leq \sigma_{ip}^E \leq \sigma_u$$

where:

C_E = 1,0 for $\beta_E \leq 1{,}0$

= $\dfrac{2}{\beta_E} - \dfrac{1}{\beta_E^2}$ for $\beta_E > 1{,}0$

$\beta_E = \dfrac{a}{t\sqrt{\bar{\varepsilon}_i^n \cdot \dfrac{R_{eH}}{E}}}$

$\sigma_{ci}^E = \dfrac{\sigma_{ei}}{\bar{\varepsilon}_i^n}$ for $\sigma_e \leq p_r \cdot R_{eH} \cdot \bar{\varepsilon}^n$

= $R_{eH}\left[1 - p_r\left(1 - p_r\right)\dfrac{R_{eH} \cdot \bar{\varepsilon}_i^n}{\sigma_{ei}}\right]$ for $\sigma_e > p_r \cdot R_{eH} \cdot \bar{\varepsilon}^n$

$\bar{\varepsilon}_i$ = relative strain ratio, equal to $\dfrac{\varepsilon_i}{\varepsilon_y}$

ε_i = element axial strain

ε_y = initial yield strain

n = exponent to $\bar{\varepsilon}$ denoting post-buckling behavior, which may be taken as 2,0 for steel

σ_u = plate ultimate strength $\geq \sigma_c$

σ_c and σ_u are set equal to σ_{ci} and σ_{ip} when n = 0.

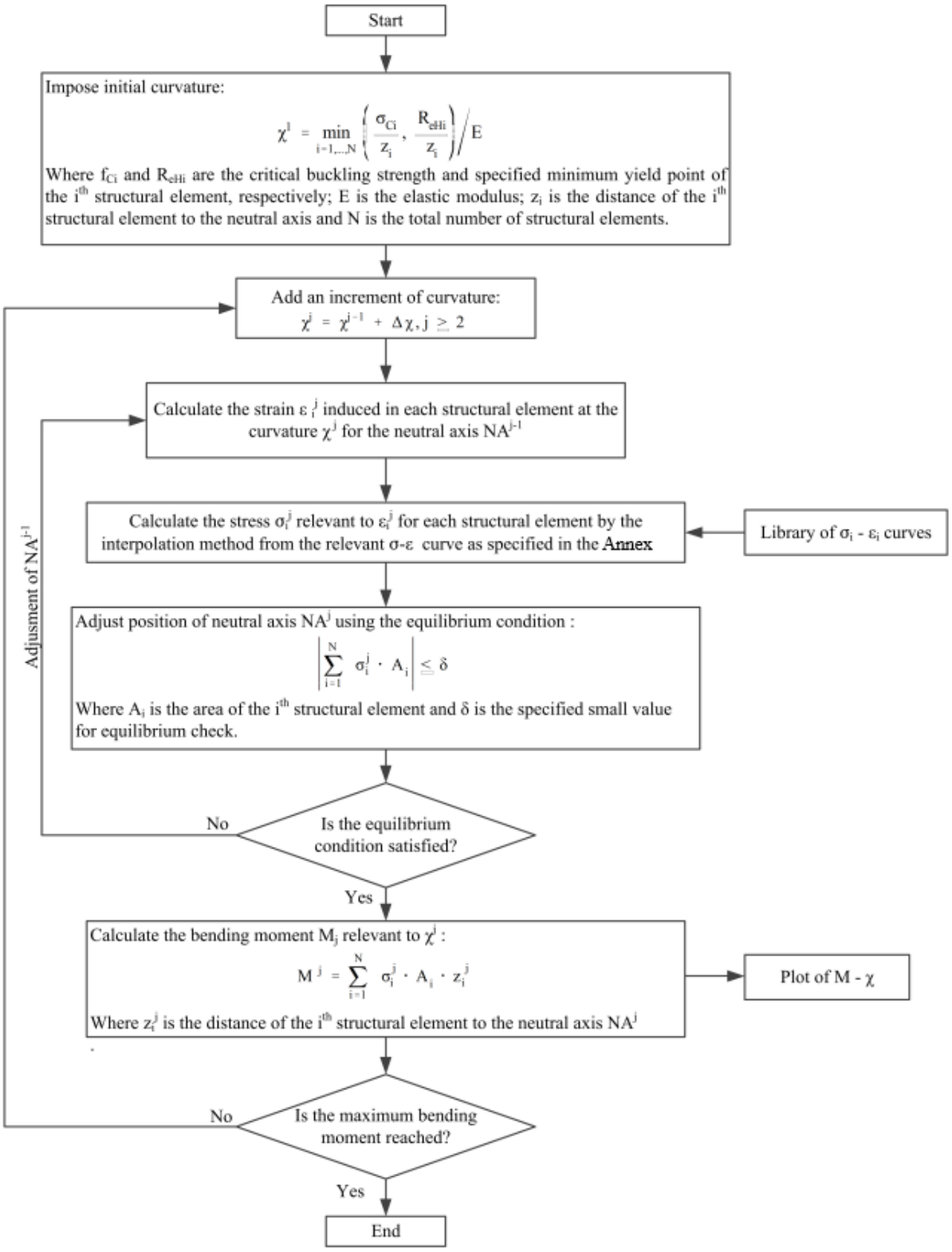


Fig. A6.1 Flow Chart for the Evaluation of the Bending Moment-Curvature Curve, M-χ

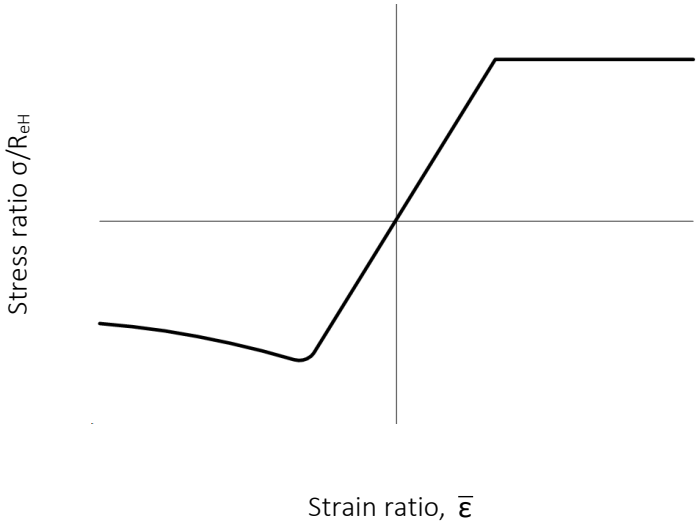


Fig. A6.2 Load-End Shortening Curve for Plate Element

C. Stiffener Element

A longitudinal plate stiffener (i.e., axis is normal to the hull's transverse section) may fail in one of four modes:

- Yielding in tension
- Beam-column buckling
- Torsional-flexural buckling
- Local buckling of stiffeners

The load-end shortening curves, σ_i - ε_i, for each failure mode are described below.

1. Yielding in Tension

The load-end shortening curve for yielding in tension is the same as in A.

2. Beam-Column Buckling

The load-end shortening curve, $\sigma_i - \varepsilon_i$, as shown in Fig. A6.3 for beam-column buckling is defined by the following equation:

- When $\bar{\varepsilon}_i \leq \frac{\sigma_{ca}}{R_{eH}}$

$$\sigma_{ci} = R_{eH} \cdot \bar{\varepsilon}_i$$

- When $\bar{\varepsilon}_i > \frac{\sigma_{ca}}{R_{eH}}$

$$\sigma_{ci} = \sigma^E_{ca} \frac{A_s + s^E_e \cdot t}{A_s + \mathbf{a} \cdot t} \leq \sigma_{ca} \frac{A_s + s_e \cdot t}{A_s + \mathbf{a} \cdot t}$$

where

$$\sigma_{ca}^{E} = \frac{\sigma_{E(C)}}{\bar{\varepsilon}_i^{n}} \qquad \text{for } \sigma_{E(C)} \le p_r \cdot R_{eH} \cdot \bar{\varepsilon}^{n}$$

$$= R_{eH}\left[1 - p_r\left(1 - p_r\right)\frac{R_{eH} \cdot \varepsilon_i^{n}}{\sigma_{E(C)}}\right] \qquad \text{for } \sigma_{E(C)} > p_r \cdot R_{eH} \cdot \bar{\varepsilon}^{n}$$

$$s_e^{E} = C_E \cdot \mathbf{a}$$

$$C_E = 1{,}0 \qquad \text{for } \beta_E \le 1{,}0$$

$$= \frac{2}{\beta_E} - \frac{1}{\beta_E^2} \qquad \text{for } \beta_E > 1{,}0$$

σ_{ca} is set equal to σ_{ca}^{E} when n = 0

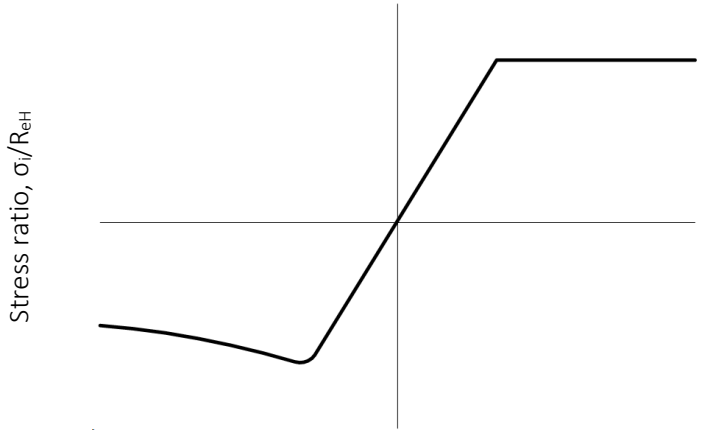


Fig. A6.3 Load-End Shortening Curve for Beam-Column Buckling

3. Torsional-Flexural Buckling

The load-end shortening curves, $\sigma_i - \varepsilon_i$, as shown in Fig. A6.4 for torsional-flexural buckling is defined by the following equation:

– When $\bar{\varepsilon}_i \le \frac{\sigma_{ct}}{R_{eH}}$

$$\sigma_{ci} = R_{eH} \cdot \bar{\varepsilon}_i$$

– When $\bar{\varepsilon}_i > \frac{\sigma_{ct}}{R_{eH}}$

$$\sigma_i = \frac{\sigma_{ct}^{E} \cdot A_s + \sigma_{ip}^{E} \cdot \mathbf{a} \cdot t}{A_s + \mathbf{a} \cdot t}$$

where

$$\sigma_{ct}^{E} = \frac{\sigma_{ET}}{\bar{\varepsilon}_i^{n}} \quad \text{for } \sigma_{ET} \le p_r \cdot R_{eH} \cdot \bar{\varepsilon}^{n}$$

$$= R_{eH}\left[1 - p_r\left(1 - p_r\right)\frac{R_{eH} \cdot \bar{\varepsilon}_i^{n}}{\sigma_{ET}}\right] \quad \text{for } \sigma_{ET} > p_r \cdot R_{eH} \cdot \bar{\varepsilon}^{n}$$

σ_{ct}^{E} should be less than σ_{ct}.

σ_{ct} and σ_{ET} are the critical and elastic torsional/flexural buckling stresses and are calculated in Section 4, C.4.4.3.2, where gross scantlings are used.

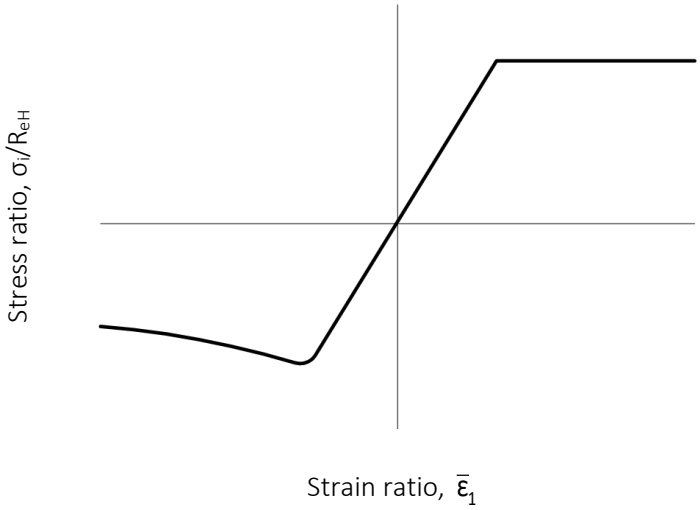


Fig. A6.4 Load-End Shortening Curve for Torsional-Flexural Buckling

4. Local Buckling of Stiffeners

This failure mode should be assessed if the proportions of stiffeners specified in Section 4, C.4.4.5 are not satisfied. The load-end shortening curve, $\sigma_i - \varepsilon_i$, as shown in Fig. A6.5 for local buckling of stiffeners is defined by the following equation:

– when $\bar{\varepsilon}_1 \le \dfrac{\sigma_{c\ell}}{R_{eH}}$

$$\sigma_i = R_{eH} \cdot \bar{\varepsilon}_i$$

– When $\bar{\varepsilon}_1 > \dfrac{\sigma_{c\ell}}{R_{eH}}$

$$\sigma_i = \frac{\sigma_{c\ell}^{E} \cdot A_s + \sigma_{ip}^{E} \cdot \mathbf{a} \cdot t}{A_s + \mathbf{a} \cdot t}$$

where

$$\sigma_{c\ell}^{E} = \frac{\sigma_{c\ell}}{\bar{\varepsilon}_i^{n}} \quad \text{for } \sigma_{c\ell} \le p_r \cdot R_{eH} \cdot \bar{\varepsilon}^{n}$$

$$= R_{eH}\left[1 - p_r\left(1 - p_r\right)\frac{R_{eH} \cdot \bar{\varepsilon}_i^{n}}{\sigma_{c\ell}}\right] \quad \text{for } \sigma_{c\ell} > p_r \cdot R_{eH} \cdot \bar{\varepsilon}^{n}$$

$\sigma_{c\ell}^{E}$ should be less than $\sigma_{c\ell}$.

$\sigma_{c\ell}$ and $\sigma_{e\ell}$ are local critical and elastic buckling stress and are calculated in Section 4, C.4.4.2, where gross scantlings are used.

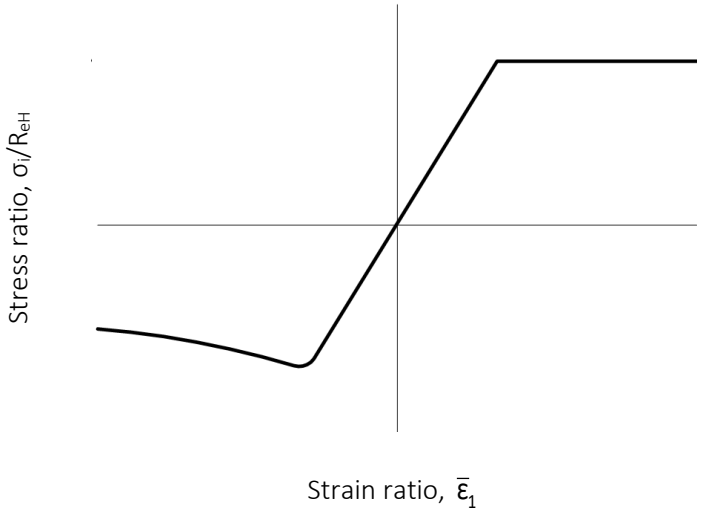


Fig. A6.5 Load-End Shortening Curve for Local Buckling

D. Corner Element

Corner elements are considered stocky elements, which collapse due to 'fully plastic' development. The relevant load-end shortening curve, $\sigma_i - \varepsilon_i$, as shown in Fig. A6.6, is idealized by the elastic-perfectly plastic relationship given in the following:

$$\frac{\sigma_i}{R_{eH}} = \begin{cases} -1 & \text{for} \quad \bar{\varepsilon}_i < 1 \\ \bar{\varepsilon}_i & \text{for} \quad -1 \le \bar{\varepsilon}_i \le 1 \\ 1 & \text{for} \quad \bar{\varepsilon}_i > 1 \end{cases}$$

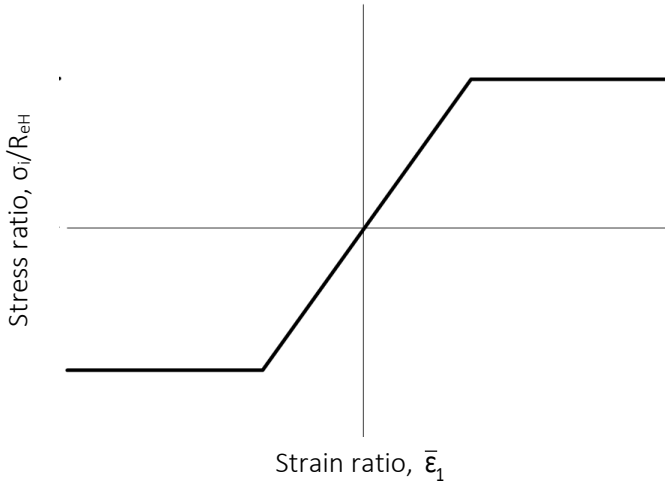


Fig. A6.6 Load-End Shortening Curve for a Corner Element

Annex 7 Finite Element Analysis for Ship-Type Installations

A. Objective 7–1
B. Scope of Application 7–1
C. Extent of the 3-D Global Finite Element Model 7–2
D. Coordinate System of the Model 7–2
E. Element Types 7–2
F. General Guidance for 3-D Global FE Modeling 7–6
G. Loading Conditions 7–6
H. Procedure to Adjust Hull Girder Shear Force and Bending Moment 7–8
I. Boundary Conditions 7–16
J. Validation of 3-D Global Response 7–18
K. Detailed Stress Assessment - Local FEA 7–19
L. Fatigue Assessment - Fatigue FEA 7–20

A. Objective

This Annex provides guidance for the calculation of structural responses by performing finite element analysis of the ship structures, as required by the Global Strength Assessment (GSA) in Section 4, C.4.

In general, this guidance is based on the requirements for a three cargo tank length model as outlined in Section 4, C.4.6. However the guidance provided on selection of element types and mesh size, and fine mesh analysis is also applicable to a cargo block or full ship length model.

With this Annex, it is intended that the structural idealization, load application, and analysis procedure used for the finite element structural analysis are performed in a consistent manner and based on sound engineering judgment.

B. Scope of Application

The strength requirements specified in Section 4, C.4 are based on a "net" ship approach. For new construction, the nominal design corrosion margins, given in Table 4.8 and Fig. 4.6 for the double hull ship-type installations and Section 4, C.6.1.1 for the single hull ship-type installations, are to be deducted from the scantlings for the finite element analysis and strength assessment of the hull structures. For an installation being converted from a vessel to FPI service, the reassessed net scantlings are used for the finite element analysis and strength assessment. The reassessed net scantlings are obtained by deducting the nominal design corrosion margins from the reassessed scantlings.

The analysis includes a three-dimensional global model of the three-hold hull girder and local fine-mesh models as follows:

– Transverse web frames, longitudinal girders, horizontal girders, side stringers, and centerline ring frames, etc.

These local fine-mesh models are used to determine the additional requirement for critical areas of the main supporting members of the hull girder.

The guidelines described herein regarding structural idealization, finite element modeling techniques, and analysis procedures are also applicable to general hull structural analyses.

C. Extent of the 3-D Global Finite Element Model

The purpose of the 3-D global FE analysis is to determine the overall structural response of the hull girder structure, including primary and secondary bending, and also to obtain appropriate boundary conditions for use in the local fine-mesh FE analysis of local structures. The extent of the hull structure to be modeled is to cover three cargo tank lengths located at about amidships, as shown in Fig. A7.1. It is to extend two frames fore and aft of the two end bulkheads. All primary load-carrying members are to be modeled. Secondary structural members which may affect the overall load distribution should also be appropriately accounted for.

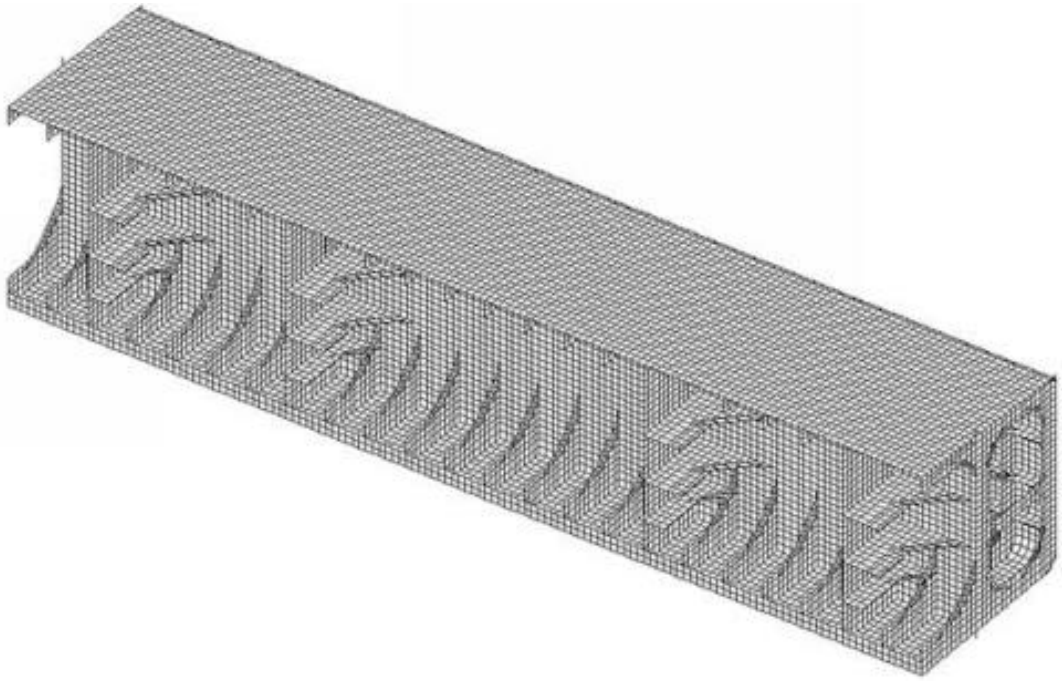


Fig. A7.1 Extent of 3-D Global Finite Element Model

D. Coordinate System of the Model

The global coordinate (right-hand) system of this reference finite element model is defined as follows:

X axis: Longitudinal direction, positive forward,

Y axis: Vertical direction, positive upwards from baseline,

Z axis: Transverse direction, positive toward starboard from centerline

Origin: At the intersection of baseline and centerline at first watertight bulkhead of the aft end of the model

The six degrees of freedom for the nodes are defined with respect to the Cartesian global X, Y and Z axes of the 3-D finite element model, (See Fig. A7.1), as u_x, u_y, and u_z for the three translational degrees of freedom, and θ_x, θ_y, and θ_z for the three rotational degrees of freedom.

E. Element Types

The structural elements, whose geometry, configuration and stiffness approximate the actual ship's hull structure, are of three types commonly used.

1) Rod (or truss) elements, with axial stiffness only and constant cross-sectional area along the length of the element.
2) Bar (or Beam) elements without offset, with axial, torsional and bi-directional shear and bending stiffness and with constant properties along the length of the element.
3) Shell (or bending plate) elements, with in-plane stiffness and out-of-plane bending stiffness with constant thickness.

Higher order element types exist, however the above three simple types of element are sufficient for a good representation of the hull girder. The appropriate usage of the aforementioned element types in the modeling procedure is discussed in the following sections.

1. Plate Elements

For finite element modeling of a hull structure, the plating is typically represented by bending plate elements.

In general, the plate element mesh is to follow the stiffener system as far as practicable, hence representing the actual plate panels between stiffeners. The mesh size is to satisfy the following requirements:

1) One element between every longitudinal stiffeners, see Fig. A7.2. Longitudinally, the element length is not to be greater than 2 longitudinal spaces.
2) One element between every vertical stiffener on transverse bulkheads, see Fig. A7.3.
3) One element between every web stiffener on transverse and vertical web frames, cross ties and stringers, see Fig. A7.2 and Fig. A7.4.
4) At least three elements over the depth of double bottom girders and floors, transverse web frames, vertical web frames and horizontal stringers on transverse bulkheads.
5) For cross tie, deck transverse and horizontal stringers on transverse wash bulkheads and longitudinal bulkheads with a smaller web depth, 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 the adjacent structure is to be adjusted to suit.
6) The mesh on the hopper tank web frame shall be fine enough to represent the shape of the web ring opening, see Fig. A7.2.
7) The curvature of the free edge on large brackets of primary supporting members is to be modeled accurately to avoid unrealistic high stress due to geometry discontinuities. In general, a mesh size equal to the stiffener spacing is acceptable.
8) The bracket toe may be terminated at the nearest nodal point provided that the modeled length of bracket arm does not exceed the actual bracket arm length.
9) The bracket flange of a transverse is not to be connected to the longitudinal plating, see Fig. A7.5. An acceptable mesh is shown in Fig. A7.5.
10) The aspect ratio of the plate elements is in general not to exceed three. The use of triangular plate elements is to be kept to a minimum. Where possible, the aspect ratio of plate elements in areas where there are likely to be high stresses or a high stress gradient is to be kept close to one and the use of triangular elements is to be avoided.
11) Typical mesh arrangements of the cargo tank structures are shown in Fig. A7.1.

Manholes on transverse and longitudinal structures, such as double bottom floors and longitudinal girders, are generally ignored in the global model. Leaving out plate elements or reducing plate thicknesses to account for such manholes in the 3-D model are not advisable, because this would sometimes result in unrealistic shearing stresses for the thinned plates or the adjacent elements. The actual behavior of a round or elliptical manhole with or without a flange is quite different from the modeled thin plate or element opening which is usually rectangular.

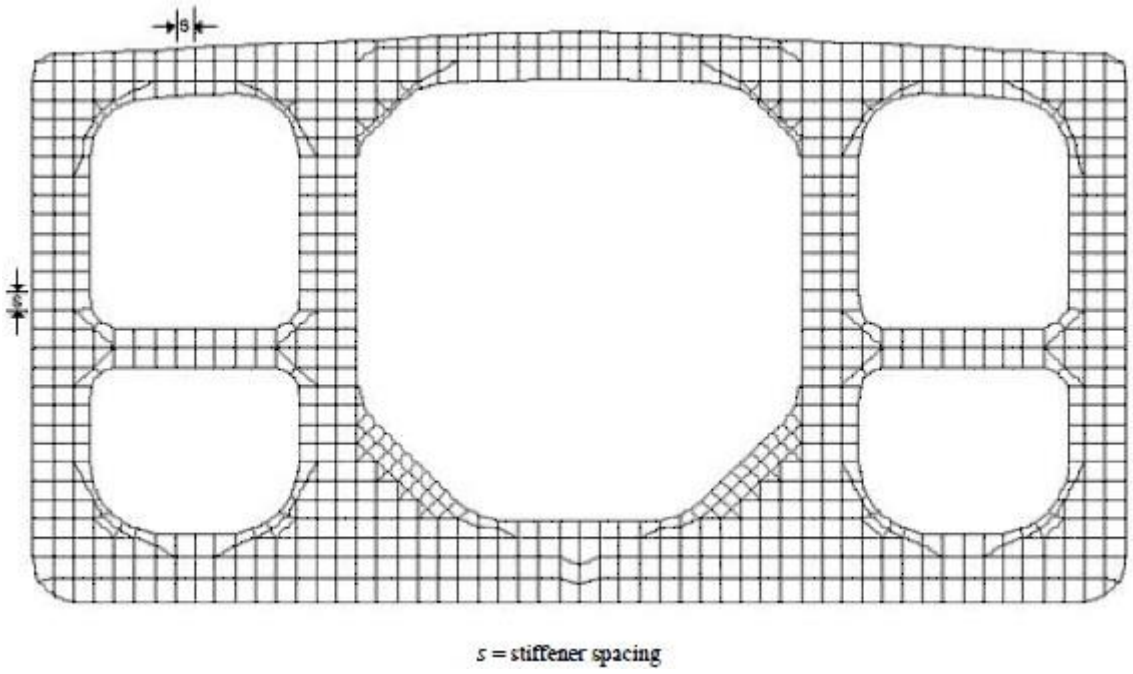


Fig. A7.2 Typical Finite Element Mesh on Web Frame

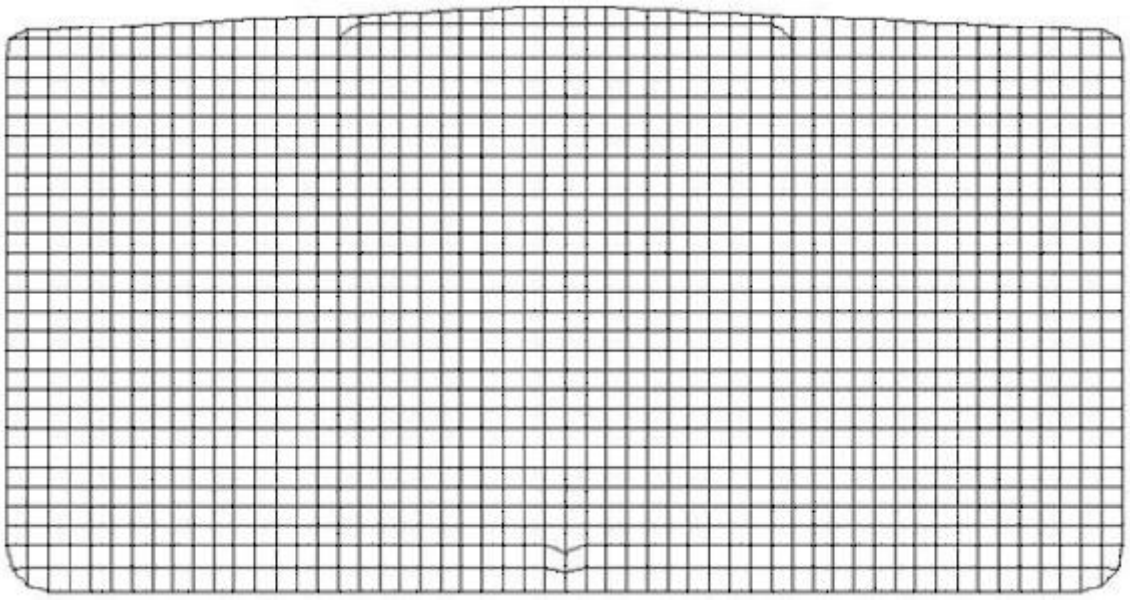


Fig. A7.3 Typical Finite Element Mesh on Transverse Bulkhead

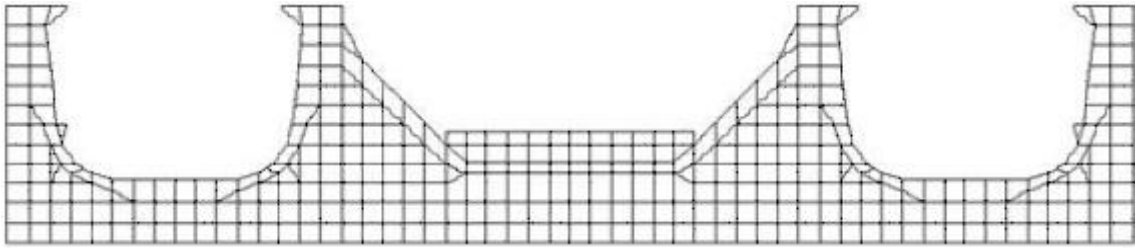


Fig. A7.4 Typical Finite Element Mesh on Horizontal Transverse Stringer on Transverse Bulkhead

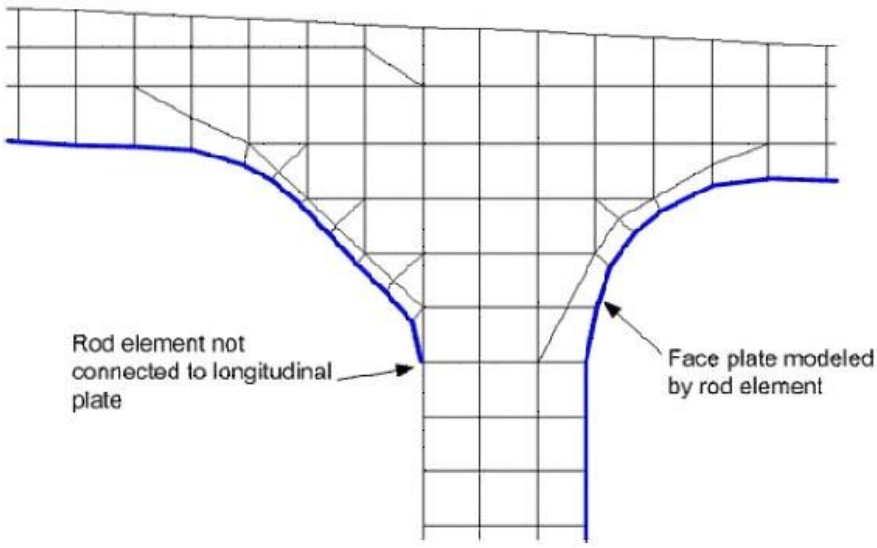


Fig. A7.5 Typical Finite Element Mesh on Transverse Web Frame Main Bracket

2. Bar (or Beam) Elements for Stiffeners

All local stiffeners are to be modeled. The stiffeners may be modeled using line elements positioned in the plane of the plating. Bar elements are to be used in areas under action of lateral loads whilst rod elements in E.3 may be used to represent local stiffeners on internal structural members under no lateral loads.

The bar elements are to have the following properties:

1) Stiffeners are typically modeled by bar elements without offset.
2) The bar element cross sectional area is based on the net stiffener area excluding the area of the attached plating.
3) Out of plane bending properties are to represent the inertia of the combined plating and stiffener.
4) The width of the attached plate is to be taken as half + half stiffener spacing on each side of the stiffener.
5) The eccentricity of the neutral axis is not required to be modeled.

3. Rod (or Truss) Elements for Stiffeners

Web stiffeners on primary support members are to be modeled. 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 utilization factors obtained need not be corrected for the adjustment. Buckling stiffeners on large brackets, deck transverse and stringers parallel to the flange are to be modeled. These stiffeners may be modeled using rod elements.

4. Rod Elements for Face Plates of Primary Supporting Members

All face plates are to be accounted for and may be modeled by rod elements.

For a typical hull structure, there are numerous secondary flat bars, stiffeners, tripping brackets and panel “breakers”. These structural members are mainly to provide local stiffness to plate panels against buckling or vibration. These secondary stiffening members generally need not be included in the global model as their influence on the overall response of the hull structure is negligible.

F. General Guidance for 3-D Global FE Modeling

The approach of finite element modeling adopted here is to use a 3-D global finite element model to obtain the overall response of the hull girder under the imposed sea loading. The stress results of the global model are used not only to assess the hull girder plating of the deck, side shell, bottom, inner bottom, longitudinal bulkheads, transverse bulkheads and stools or deck box girders but also to assess the main supporting members. The boundary conditions for the local FE models are the appropriate nodal displacements obtained from the 3-D global model analysis. Therefore, in developing the 3-D global finite element model, special attention should be paid to the following general guidance:

1) The finite element model should include all primary load-carrying members. Secondary structural members which may affect the overall load distribution are also be appropriately accounted for.
2) Structural idealization should be based on the stiffness and anticipated response of the structure, not wholly on the geometry of the structure itself.
3) A common mistake is to simply match the finite element mesh with the configuration of the structure. Very often a finite element model, created in this way, which "looks good" and represents the structural geometry well, but in reality it represents the structural properties and performance poorly.
4) It is desirable to have consistent modeling throughout the entire length of the three cargo tanks considered. However, the middle tank is to always have the desired mesh, where more accurate results are expected (due to boundary effects) and are therefore used in the strength assessment. If approximations have to be made, do so only in the two end-tanks.
5) It is important to consider the relative stiffness between associated structural members and their anticipated response under the specified loading.
6) Bottom transverses in single-hull vessels and double bottom floors in double-hull vessels usually have high restraint at the ends, and therefore require an adequate mesh to achieve reasonable accuracy.

G. Loading Conditions

1. Combined Load Cases and Loading Pattern

The standard combined load cases as specified in Table 4.9A through 4.9C with the corresponding loading pattern specified in Fig. 4.8A are to be used in the FE analysis.

2. Sloshing Load Cases

In assessing the strength of tank boundary supporting structures, the two combined load cases as specified in Table 4.10 with the corresponding loading pattern specified in Fig. 4.25 are to be considered in the FE analysis.

3. Target Hull Girder Vertical Bending Moment and Vertical Shear Force

3.1 Hull Girder Vertical Bending Moment

The hull girder vertical bending moment is to reach the following required value, $M_{v\text{-}targ}$, which is a combination of the rule-required still water bending moment and the wave-induced vertical bending moment, at a section within the length of the middle tank of the three tanks FE model:

$$M_{v-targ} = M_{SW} + k_u \cdot k_c \cdot \beta_{VBM} \cdot M_{WV}$$

where

M_{sw} = still water bending moment to be applied to the FE load case, as specified in Rules for Hull (Pt.1, Vol.II), Sec.5, B.2

M_{wv} = vertical wave bending moment for the dynamic load case under consideration, calculated in accordance with Rules for Hull (Pt.1, Vol.II), Sec.5, B.3.1

β_{VBM} = ESF for vertical bending moments as defined in Annex 4, B

k_u = load factor, is taken as 1.0 as specified in Table 4.9A through 4.9C and Table 4.11

k_c = correlation factor, is taken value as specified in Table 4.9A through 4.9C and Table 4.11

3.2 Hull Girder Vertical Shear Force

The hull girder vertical shear force is to reach the following required F_{targ} value at the forward transverse bulkhead position of the middle tank. The target hull girder vertical shear force is a combination of the rule-required still water shear force and the wave-induced vertical shear force:

$$Q_{targ} = Q_{SW} + k_u \cdot k_c \cdot \beta_{VSF} \cdot Q_{WV}$$

where

Q_{sw} = vertical still water shear force to be applied to the FE load case, as specified in Rules for Hull (Pt.1, Vol.II), Sec.5, B.2

Q_{wv} = vertical wave shear force for the dynamic load case under consideration, calculated in accordance with Rules for Hull (Pt.1, Vol.II), Sec.5, B.3.2

β_{VBM} = ESF for vertical shear force as defined in Annex 4, B

k_u = load factor, is taken as 1,0 as specified in Table 4.9A through 4.9C and Table 4.11

k_c = correlation factor, is taken value as specified in Table 4.9A through 4.9C and Table 4.11

3.3 Balance of Hull Girder Bending Moment and Shear Force

The required target values of hull girder vertical bending moment and shear force are to be achieved in the same load case where required by Table 4.9A through 4.9C and Table 4.11. The procedure to apply the required shear force and bending moment distributions is described in H.1.

4. Target Hull Girder Horizontal Wave Bending Moment

The hull girder horizontal wave bending moment at a section within the length of the middle tank of the three tanks FE model is to reach the value required by the dynamic load case where required by Table 4.9A through 4.9C and Table 4.11, calculated in accordance with Section 4, C.2.4.2.2.

The procedure to adjust the required hull girder horizontal bending moment is described in H.1.

H. Procedure to Adjust Hull Girder Shear Force and Bending Moment

1. General

The procedure described in this Subsection is to be applied to adjust the hull girder horizontal bending moment, vertical shear force and vertical bending moment distributions on the three cargo tanks FE model to achieve the required target values.

Vertical distributed loads are applied to each frame position, together with a vertical bending moment applied to the model ends to produce the required target value of vertical shear force at the forward bulkhead of the middle tank of the FE model, and the required target value of vertical bending moment at a section within the length of the middle tank of the FE model. The required target values are specified in G.3.

A horizontal bending moment is applied to the ends of the model to produce the required target value of horizontal bending moment at a section within the length of the middle tank of the FE model. The required values are specified in G.4.

2. Shear Force and Bending Moment due to Local Loads

2.1 Vertical Shear Forces

The vertical shear forces generated by the local loads are to be calculated at the transverse bulkhead positions of the middle tank of the FE model. The vertical bending moment distribution generated by the local loads is to be calculated along the length of the middle tank of the three cargo tank FE model. The FE model can be used to calculate the shear forces and bending moments. Alternatively, a simple beam model representing the length of the 3-tank FE model with simply supported ends may be used to determine the shear force and bending moment values.

2.2 Horizontal Bending Moment Distribution

For beam and oblique sea conditions, the horizontal bending moment distribution due to dynamic sea pressure and dynamic tank pressure is to be calculated along the length of the middle tank of the FE model.

2.3 Local Loads

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

1) Ship structural weight distribution over the length of the 3-tank model (static loads). Where a simple beam model is used, the weight of the structure of each tank can be distributed evenly over the length of the cargo tank. The structural weight is to be calculated based on a thickness of the net scantlings to be considered as used in the construction of the cargo tank FE model, see B.
2) Weight of cargo and ballast (static loads)
3) Static sea pressure and dynamic wave pressure
4) Dynamic tank pressure

3. Procedure to Adjust Vertical Shear Force Distribution to Target Values

3.1 Adjustment in Shear Forces at Transverse Bulkhead Positions

The required adjustment in shear forces at the transverse bulkhead positions (ΔQ_{aft} and ΔQ_{fwd} as shown in Fig. A7.6) are to be generated by applying vertical load at the frame positions as shown in Fig. A7.7. It is to be noted that vertical correction loads are not to be applied to any transverse tight bulkheads, any frames

forward of the forward tank and any frames aft of the aft tank of the FE model. The sum of the total vertical correction loads applied is equal to zero.

3.2 Adjustment in Shear Forces at Aft and Forward Transverse Bulkheads of Middle Tank of FE Model

The required adjustments in shear forces at the aft and forward transverse bulkheads of the middle tank of the FE model in order to generate the required target shear forces at the bulkheads are given by:

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

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

where

ΔQ_{aft} = required adjustment in shear force at aft bulkhead of middle tank

ΔQ_{fwd} = required adjustment in shear force at forward bulkhead of the middle tank

Q_{targ} = required shear force value to be achieved at forward bulkhead of middle tank, see G.3.2

Q_{aft} = shear force due to local loads at aft bulkhead of middle tank

Q_{fwd} = shear force due to local loads at forward bulkhead of the middle tank

3.3 Vertical Loads to be Applied to Each Frame

The value of the vertical loads to be applied to each frame to generate the increase in shear force at the bulkheads may be calculated using a simple beam model. For the case where an uniform frame spacing is used within each tank, the amount of vertical force to be distributed at each frame may be calculated in accordance with the equations below. The length and frame spacing of individual cargo tanks may be different.

$$\delta_{w1} = \frac{\Delta Q_{aft} \cdot (2 \cdot \ell - \ell_2 - \ell_3) + \Delta Q_{fwd} \cdot (\ell_2 + \ell_3)}{(n_1 - 1) \cdot (2 \cdot \ell - \ell_1 - 2 \cdot \ell_2 - \ell_3)}$$

$$\delta_{w2} = \frac{W_1 + W_3}{(n_2 - 1)} = \frac{(\Delta Q_{aft} - \Delta Q_{fwd})}{(n_2 - 1)}$$

$$\delta_{w3} = \frac{-\Delta Q_{fwd} \cdot (2 \cdot \ell - \ell_1 - \ell_2) - \Delta Q_{aft} \cdot (\ell_1 + \ell_2)}{(n_3 - 1) \cdot (2 \cdot \ell - \ell_1 - 2 \cdot \ell_2 - \ell_3)}$$

$$F = 0{,}5 \cdot \left(\frac{W_1 \cdot (\ell_2 + \ell_1) - W_3 \cdot (\ell_2 + \ell_3)}{\ell} \right)$$

where

ℓ_1 = length of aft cargo tank of model

ℓ_2 = length of middle cargo tank of model

ℓ_3 = length of forward cargo tank of model

ΔQ_{aft} = required adjustment in shear force at aft bulkhead of middle tank, see Fig. A7.6

ΔQ_{fwd} = required adjustment in shear force at fore bulkhead of middle tank, see Fig. A7.6

F = end reactions due to application of vertical loads to frames.

W_1 = total evenly distributed vertical load applied to aft tank of FE model

= $(n_1 - 1)\,\delta w_1$

W_2 = total evenly distributed vertical load applied to middle tank of FE model

= $(n_2 - 1)\,\delta w_2$

W_3 = total evenly distributed vertical load applied to forward tank of FE model

= $(n_3 - 1)\,\delta w_3$

n_1 = number of frame spaces in aft cargo tank of FE model

n_2 = number of frame spaces in middle cargo tank of FE model

n_3 = number of frame spaces in forward cargo tank of FE model

δ_{w1} = distributed load at frame in aft cargo tank of FE model

δ_{w2} = distributed load at frame in middle cargo tank of FE model

δ_{w3} = distributed load at frame in forward cargo tank of FE model

$\Delta\ell_{end}$ = distance between end bulkhead of aft cargo tank to aft end of FE model

$\Delta\ell_{fore}$ = distance between fore bulkhead of forward cargo tank to forward end of FE model

ℓ = total length of FE model (beam) including portions beyond end bulkheads:

= $\ell_1 + \ell_2 + \ell_3 + \Delta\ell_{end} + \Delta\ell_{fore}$

Note:

1. *Positive direction of loads, shear forces and adjusting vertical forces in the formulae is in accordance with Fig. A7.6 and Fig. A7.7.*
2. *$W_1 + W_3 = W_2$*

3.4 Adjusting Load to be Applied to Structural Parts of Transverse Frames

The amount of adjusting load to be applied to the structural parts of each transverse frame section to generate the vertical load, δw_i, is to be in accordance with Fig. A7.8. This load is to be distributed at the finite element grid points of the structural parts. Where 4-node or 3-node finite plate elements are used, the load to be applied at each grid point of a plate element is given by:

$$F_{i-grid} = \frac{\sum_{1}^{n} 0{,}5 \cdot A_{i-elem}}{A_s} \cdot F_s$$

where

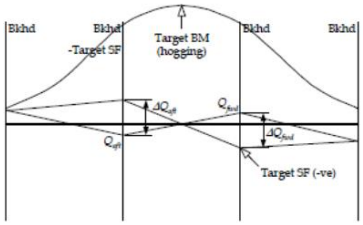
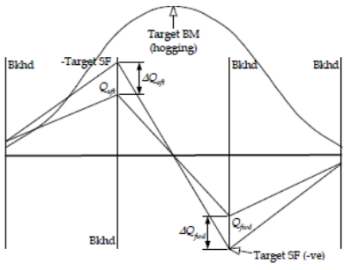
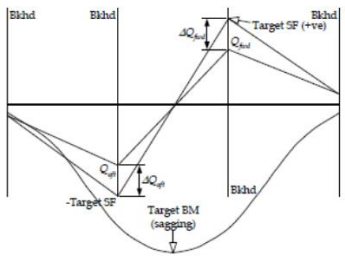
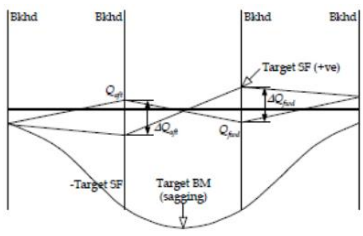
$F_{i\text{-}grid}$ = load to be applied to the i-th FE grid point on the individual structural member under consideration (i.e., side shell, longitudinal bulkheads and bottom girders, inner hull longitudinal bulkheads, hopper plates, upper slope plates of inner hull and outboard girders as defined in Fig. A7.8)

$A_{i\text{-}elem}$ = sectional area of each plate element in the individual structural member under consideration (see Fig. A7.8), which is connected to the i-th grid point

N = number of plate elements connected to the i-th grid point

F_s = total load applied to an individual structural member under consideration, as specified in Fig. A7.8

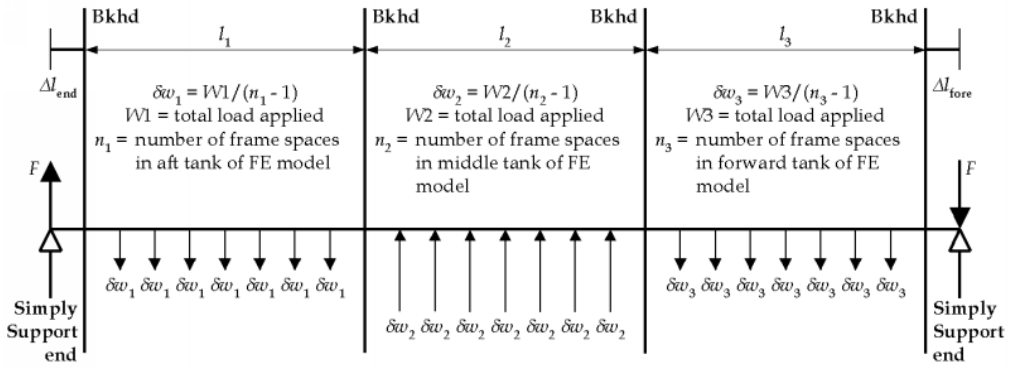
A_s = plate sectional area of the individual structural member under consideration (i.e., side shell, longitudinal bulkheads, bottom girders, inner hull longitudinal bulkheads, hopper plates, upper slope plates of inner hull and outboard girders as defined in Fig. A7.8)

Condition	Target			Aft Bhd		Fore Bhd	
	BM	SF	Bhd pos	SF	ΔQ_{aft}	SF	ΔQ_{fwd}
	Hog	-ve	Fore	$-Q_{targ}$	$-Q_{targ}-Q_{aft}$	$Q_{targ}(-ve)$	$Q_{targ}-Q_{fwd}$
	Hog	-ve	Fore	$-Q_{targ}$	$-Q_{targ}-Q_{aft}$	$Q_{targ}(-ve)$	$Q_{targ}-Q_{fwd}$
	Sag	+ve	Fore	$-Q_{targ}$	$-Q_{targ}-Q_{aft}$	$Q_{targ}(+ve)$	$Q_{targ}-Q_{fwd}$
	Sag	+ve	Fore	$-Q_{targ}$	$-Q_{targ}-Q_{aft}$	$Q_{targ}(+ve)$	$Q_{targ}-Q_{fwd}$

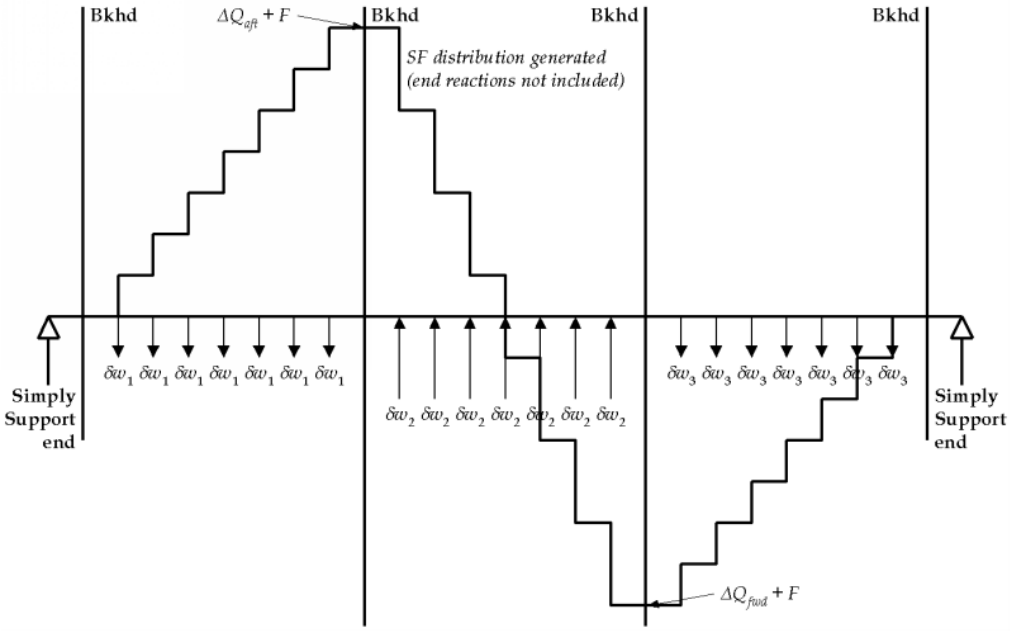
Note

For definition of symbols, see H.3.2

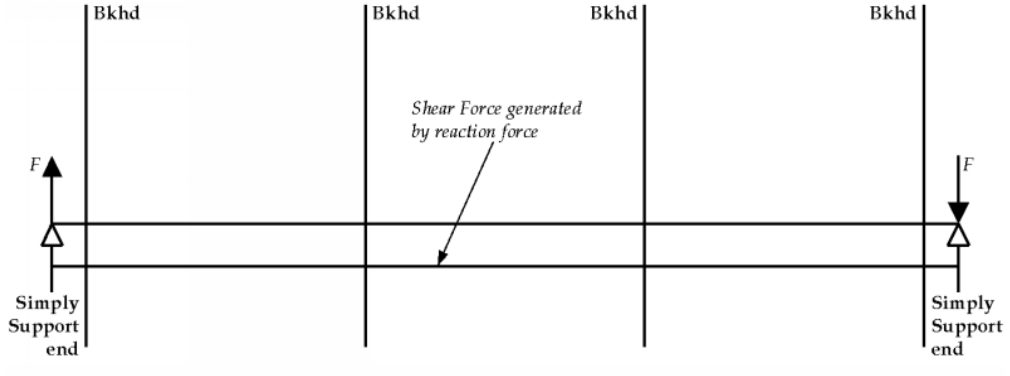
Fig. A7.6 Position of Target Shear Force and Required Shear Force Adjustment at Transverse Bulkhead Positions



Note: Transverse bulkhead frames not loaded
Frames beyond aft transverse bulkhead of aft most tank and forward bulkhead of forward most tank not loaded
F = Reaction load generated by supported ends



Shear Force distribution due to adjusting vertical force at frames

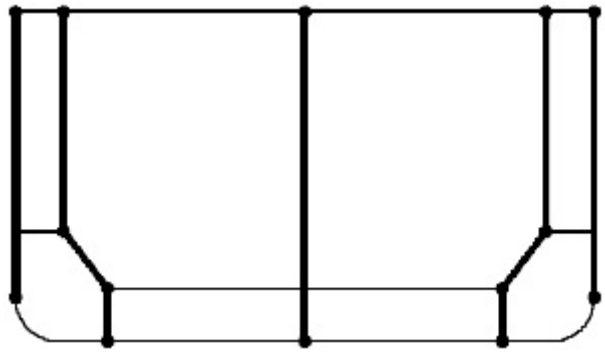


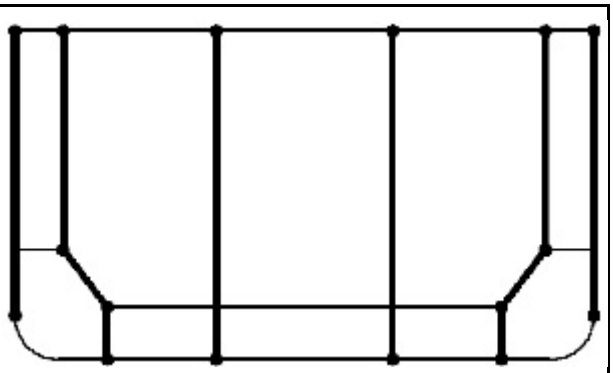
Note: F = 0 if $l_1 = l_3$ and $\Delta l_{fore} = \Delta l_{end}$, and loads are symmetrical about mid-length of model

Note:

For definition of symbols, see H.3.3

Fig. A7.7 Distribution of Adjusting Vertical Force at Frames and Resulting Shear Force Distributions





Structural Member	Applied Load Fs
Side Shell	$Q \cdot \delta_{wi}$
Longitudinal bulkhead including bottom girder beneath	$Q \cdot \delta_{wi}$
Inner hull longitudinal bulkhead (vertical part)	$Q \cdot \delta_{wi} \cdot \frac{A_{lh}}{A_2}$
Hopper plate	$Q \cdot \delta_{wi} \cdot \frac{A_{Hp}}{A_2}$
Upper slope plating of inner hull	$Q \cdot \delta_{wi} \cdot \frac{A_{Usp}}{A_2}$
Outboard girder	$Q \cdot \delta_{wi} \cdot \frac{A_{Og}}{A_2}$

where

δ_{wi} = vertical load to be applied to each transverse frame section, see H.3.3

Q = shear force distribution factor of structural part calculated at the mid-tank position in accordance with Table A7.1

A_{lh} = plate sectional area of individual inner hull longitudinal bulkhead

A_{Hp} = plate sectional area of individual hopper plate

A_{Usp} = plate sectional area of individual upper slope plate of inner hull

A_{Og} = plate sectional area of individual outboard girder

A_2 = plate sectional area calculated in accordance with Table A7.1

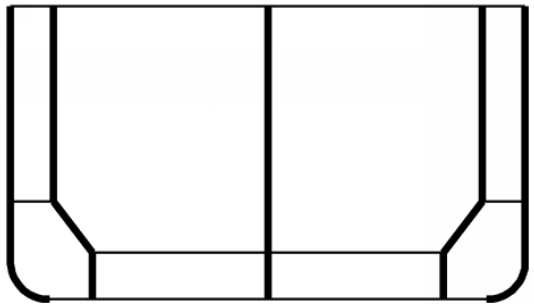
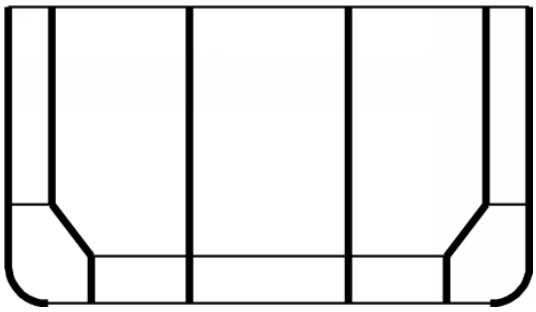
Notes :

1 Adjusting load is to be applied in plane to the hopper slope plate and upper slope plate of inner hull.

2 Adjusting load given is to be applied to individual structural member.

Fig. A7.8 Distribution of Adjusting Load on a Transverse Section

Table A7.1 Shear Force Distribution Factors

	Side Shell	$Q = 0{,}055 + 0{,}097 \cdot \frac{A_1}{A_2} + 0{,}020 \cdot \frac{A_2}{A_3}$
	Inner Hull	$Q = 0{,}193 - 0{,}059 \cdot \frac{A_1}{A_2} + 0{,}058 \cdot \frac{A_2}{A_3}$
	CL longitudinal bulkhead	$Q = 0{,}504 - 0{,}076 \cdot \frac{A_1}{A_2} - 0{,}156 \cdot \frac{A_2}{A_3}$
	Side Shell	$Q = 0{,}028 + 0{,}087 \cdot \frac{A_1}{A_2} + 0{,}023 \cdot \frac{A_2}{A_3}$
	Inner Hull	$Q = 0{,}119 - 0{,}038 \cdot \frac{A_1}{A_2} + 0{,}072 \cdot \frac{A_2}{A_3}$
	Longitudinal bulkhead	$Q = 0{,}353 - 0{,}049 \cdot \frac{A_1}{A_2} - 0{,}095 \cdot \frac{A_2}{A_3}$

where :

A_1 = plate sectional area of individual side shell (i.e., on one side), including bilge

A_2 = plate sectional area of individual inner hull longitudinal bulkhead (i.e., on one side), including hopper slope plate, double bottom side girder in way and, where fitted, upper slope plating of inner hull.

A_3 = plate sectional area of individual longitudinal bulkhead, including double bottom girder in way

Notes:

1 Where part of the structural member is not vertical, the area is to be calculated using the projected area in the vertical direction.

2 All plate areas are to be calculated based on the modeled thickness of the cargo tank FE model.

4. Procedure to Adjust Vertical and Horizontal Bending Moments to Target Values

4.1 End Vertical Bending Moment

An additional vertical bending moment is to be applied at both ends of the cargo tank finite element model to generate the required vertical bending moment in the middle tank of the model. This end vertical bending moment can be calculated as follows:

$$M_{v\text{-end}} = M_{v\text{-targ}} - M_{v\text{-peak}}$$

where

$M_{v\text{-end}}$ = additional vertical bending moment to be applied at both ends of finite element model

$M_{v\text{-targ}}$ = required target hogging (positive) or sagging (negative) vertical bending moment, as specified in G.3.1

$M_{v\text{-peak}}$ = maximum or minimum bending moment within the length of the middle tank due to the local loads described in H.2.3 and the additional vertical loads applied to generate the required shear force, see H.3 $M_{v\text{-peak}}$ 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). $M_{v\text{-peak}}$ can be obtained from FE analysis.

Alternatively, $M_{v\text{-}peak}$ may be calculated as follows based on a simply supported beam model:

$= \max \{M_o + x \cdot F + M_{lineload}\}$

M_o = vertical bending moment at position x, due to the local loads described in H.2.3

$M_{lineload}$ = vertical bending moment at position x, due to application of vertical line loads at frames to generate required shear force, see H.3

F = reaction force at ends due to application of vertical loads to frames, see H.3

x = longitudinal position of frame in way of the middle tank of FE model from end, see H.3

4.2 End Horizontal Bending Moment

For beam and oblique sea load cases, an additional horizontal bending moment is to be applied at the ends of the cargo tank FE model to generate the required horizontal bending moment at a section within the length of the middle tank of the model. The additional horizontal bending moment can be calculated as follows:

$$M_{h\text{-}end} = M_{h\text{-}targ} - M_{h\text{-}peak}$$

where

$M_{h\text{-}end}$ = additional horizontal bending moment to be applied to ends of FE model

$M_{h\text{-}targ}$ = required positive or negative horizontal bending moment, see G.4

$M_{h\text{-}peak}$ = maximum or minimum horizontal bending moment within the length of the middle tank due to the local loads described in H.2.3. $M_{h\text{-}peak}$ 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).

4.3 Application of End Bending Moments to Achieve Target Values

The vertical and horizontal bending moments are to be calculated over the length of the middle tank of the FE model to identify the position and value of each maximum/minimum bending moment as specified in H.4.1 and H.4.2.

The additional vertical bending moment, $M_{v\text{-}end}$, and horizontal bending moment, $M_{h\text{-}end}$, are to be applied to both ends of the cargo tank model.

The vertical and horizontal bending moments may be applied at the model ends by distributing axial nodal forces to all longitudinal elements according to the simple beam theory as follows:

$$(F_x)i = \frac{M_{v-end}}{I_z} \cdot \frac{A_i}{n_i} \cdot y_i \qquad \text{for vertical bending moment}$$

$$(F_x)i = \frac{M_{h-end}}{I_y} \cdot \frac{A_i}{n_i} \cdot z_i \qquad \text{for horizontal bending moment}$$

where

$M_{v\text{-}end}$ = vertical bending moment to be applied to the ends of the model

$M_{h\text{-}end}$ = horizontal bending moment to be applied to the ends of the model

$(F_x)_I$ = axis force applied to a node of the i-th element

I_z = hull girder vertical moment of inertial of the end section about its horizontal neutral axis

I_y = hull girder horizontal moment of inertial of the end section about its vertical neutral axis (normally centerline)

y_i = vertical distance from the neutral axis to the centre of the cross sectional area of the i-th element

z_i = horizontal distance from the neutral axis to the centre of the cross sectional area of the i-th element

A_i = cross sectional area of the i-th element

n_i = number of nodal points of i-th element on the cross section, ni = 2 for 4-node plate element

I. Boundary Conditions

1. General

All boundary conditions described in this Subsection are in accordance with the global co-ordinate system defined in D. The boundary conditions to be applied at the ends of the cargo tank FE model are given in Table A7.2. The analysis may be carried out by applying all loads to the model as a complete load case or by combining the stress responses resulting from several separate sub-cases.

Ground spring elements, i.e., spring elements with one end constrained in all 6 degrees of freedom, with stiffness in global y degree of freedom are to be applied to the grid points along deck, inner bottom and bottom shell as shown in Fig. A7.9.

Ground spring elements with stiffness in global z degree of freedom are to be applied to the grid points along the vertical part of the side shells, inner hull longitudinal bulkheads and oil-tight longitudinal bulkheads as shown in Fig. A7.9.

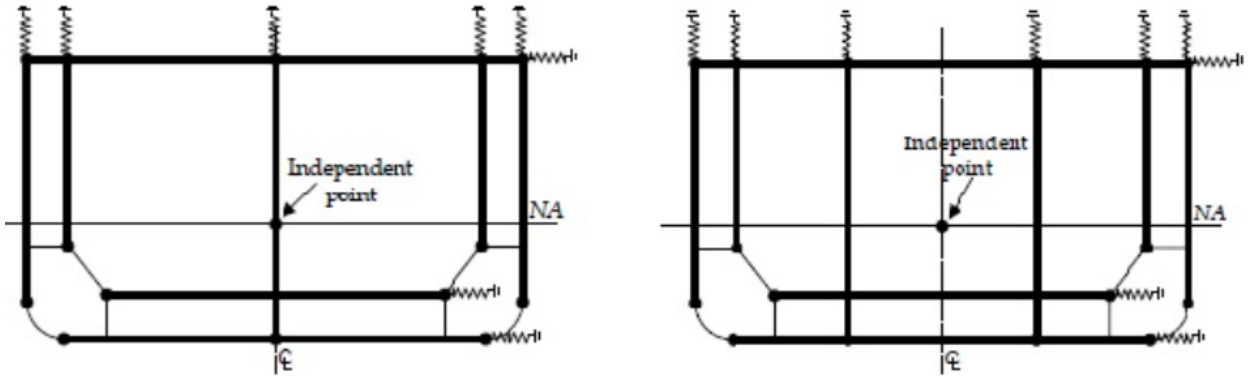


Fig. A7.9 Spring Constriants at Model Ends

Table A7.2 Boundary Constraints at Model Ends

Location	Translation			Rotation		
	δ_x	δ_y	δ_z	θ_x	θ_y	θ_z
Aft End						
Aft end (all longitudinal elements)	RL	-	-	-	RL	RL
Independent point aft end, see Fig. A7.9	Fix	-	-	-	$M_{v\text{-}end}$	$M_{h\text{-}end}$
Deck, inner bottom and outer shell	-	-	Springs	-	-	-
Side, inner skin and longitudinal Bulkheads	-	Springs	-	-	-	-
Fore End						
Fore end (all longitudinal elements)	RL	-	-	-	RL	RL
Independent point fore end, see Fig. A7.9	-	-	-	-	$M_{v\text{-}end}$	$M_{h\text{-}end}$
Deck, inner bottom and outer shell	-	-	Springs	-	-	-
Side, inner skin and longitudinal Bulkheads	-	Springs	-	-	-	-

Where:

- No constraint applied (free)

RL Nodal points of all longitudinal elements rigidly linked to independent point at neutral axis on centerline

Notes :

1 *All translation and rotation displacements are in accordance with the global coordinate system defined in D.*

2 *Where $M_{h\text{-}end}$ is not applied, the independent points at the fore and aft ends are to be free in θ_z*

3 *Where $M_{v\text{-}end}$ is not applied, the independent points at the fore and aft ends are to be free in θ_y.*

4 *Where no bending moment is applied, the independent points at the fore and aft ends are to be free in θ_y and θ_z.*

5 *Where bending moment is applied as nodal forces, the independent points at the fore and aft ends are to be free in the corresponding degree of freedom of rotations (i.e. θ_y and/or θ_z).*

2. Calculation of Spring Stiffness

The springs are typically represented by rod elements, having only axial stiffness. The stiffness is equivalent to the support given to the considered end bulkhead by the cutout longitudinal structural members. The resulting cross-sectional can be determined by the following formula:

$$A = \left(\frac{1}{1+\nu}\right) \cdot \frac{A_s \cdot \ell}{\ell_{tk} \cdot n} = 0{,}77 \cdot \frac{A_s \cdot \ell}{\ell_{tk} \cdot n}$$

where

A = cross-sectional area of the bar [cm^2]

A_s = shearing area of the individual structural member under consideration (i.e., plating of deck, inner bottom, bottom shell, side shell, inner hull longitudinal bulkheads or oil- tight longitudinal bulkhead). A_s is to be calculated based on the thickness of the cargo tank finite element model for areas indicated in Table A7.3 for the appropriate structural member under consideration [cm^2]

ν = Poisson's ratio of the material, taken as 0,3

ℓ_{tk} = length of cargo tank, between bulkheads of the middle tank of the FE model [cm]

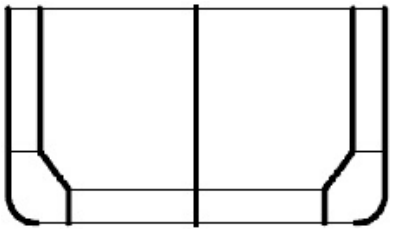
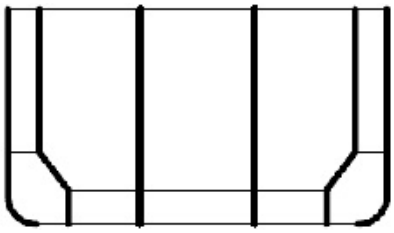
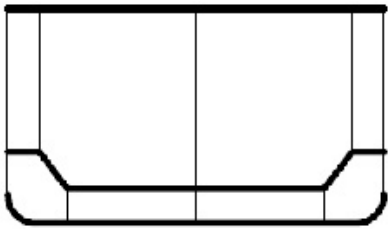
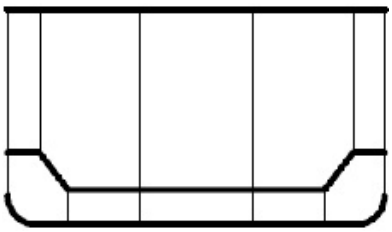
n = number of nodal points to which the spring elements are applied to the structural member under consideration

ℓ = length of the bar [cm]

The bar area A is determined by a given bar length ℓ, which can be any value. In practice, however, all values of l in the finite element model are conveniently chosen to be the same round figure, for example, equal to 100 cm.

One end of the rod is to be constrained in all six degrees of freedom.

Table A7.3 Shear Areas to be Considered for the Calculation of Spring Stiffness

Vertical springs		
	Side	Area of side shell plating, including bilge
	Inner hull longitudinal bulkheads	Area of inner skin plating, including hopper slope plate and double bottom side girder in way
	Longitudinal bulkheads	Area of longitudinal bulkhead plating, including double bottom girder in way
	Note: *Where part of the structural member is not vertical, the area is to be calculated using the projected area in the vertical direction.*	
Horizontal springs		
	Deck	Area of deck plating
	Inner bottom	Area of inner bottom plating, including hopper slope plate and horizontal stringer in way
	Bottom shell	Area of bottom shell plating, including bilge
	Note: *Where part of the structural member is not horizontal the area is to be calculated using the projected area in the horizontal direction*	

J. Validation of 3-D Global Response

1. Correlation with Beam Theory

It has been shown that the primary hull girder bending stress and deflection obtained by the finite element analysis are in good agreement with classical beam theory results, even with the open deck configuration of the hull girder. In order to verify that proper modeling of the hull structure has been made, and that appropriate loading and boundary conditions have been imposed on the model, it is useful to compare the results with that obtained by beam theory. The check is usually carried out for the vertical bending moment since it is the most predominate bending moment and for which a high proportion of the hull girder section modulus is used.

The comparison should be made in areas where local loads have minimal effects and also at the minimum section modulus, i.e., mid-hold. The best correlation is obtained at the deck at side where the section modulus is calculated for and also has the minimum effect of local loading.

Because of secondary bending, shear lag, or stresses due to alternate hold or upper wing ballast loading, some variation in hull girder bending stresses can be expected between the resultant FEA stresses as compared to classical beam theory stresses.

2. Additional Remarks

When comparison of hull girder stresses shows good correlation with beam theory, it can be concluded that the overall response of the finite element model to applied loads is correct.

However, it is still possible that at some local areas of the model, stress levels and deflections are not consistent with the applied loading. A large-scale local deflection display of the questionable area will usually provide some clues as to the cause for such unreasonable results. If it is a problem of element connectivity, the display will clearly show a separation of adjoining members. Certainly, errors in element properties are always a possibility, and can be easily checked in the appropriate display of the model.

In general, the experienced or knowledgeable user should be able to predict the structural behavior and stress level distributions under the specified loading. There will be logical conclusions for any variance in the predicted stress and deformation patterns of the finite element model.

If possible, it is recommended that before starting the structural analysis, the engineer should take the time to review previously-performed structural analyses on similar installations, in order to better visualize the analysis procedures and resultant structural response.

K. Detailed Stress Assessment - Local FEA

1. General

1.1 Application

This Subsection describes the procedure for the detailed stress assessment with refined meshes to evaluate highly stressed areas of primary supporting members.

2. Analysis Model

2.1 Areas to be Refined

Where the global cargo hold analysis is carried out using a model complying with the modeling criteria of this Annex, the areas listed in Table A7.4 are to be refined at the locations whose calculated stresses exceed 95% of the allowable stress as specified in Section 4, C.4.2.2.

Table A7.4 Typical Details to be Refined

▪ Critical Areas in Transverse Web Frame ▪ Critical Areas in Horizontal Girders on Transverse Bulkhead ▪ Critical Areas of Buttress Structure

2.2 Refining Method

Two methods can be used for refining the high stressed areas:

– Detailed stresses in refined areas can be analyzed by separate sub-models.

– Refined areas can be directly included in FE model used for the global cargo hold analysis.

2.3 Modeling

a) **Element Type**. Each structural member is to be modeled by using proper element type for the structure in accordance with the principle in this guidance.

b) **Mesh**. The element size in refined areas is to be approximately one fourth of the representative spacing of ordinary stiffeners in the corresponding area (i.e., 200 × 200 mm mesh size for structures whose ordinary stiffener spacing is 800 mm). In addition, the web height of primary supporting members is to be divided at least into 3 elements.

The aspect ratio of element is not to exceed 3. Quad elements are to have 90° angles as much as practicable, or to have angles between 45° and 135°.

c) **Extent of Sub-model**. The minimum extent of sub-model is to be such that the boundaries of the sub-model correspond to the locations of adjacent supporting members.

2.4 Loading Conditions

Loading conditions, which are applied to the 3-D FE model for the global cargo hold analysis, are to be considered in the detailed stress assessment.

2.5 Boundary Conditions

Nodal forces or nodal displacements obtained from the global cargo hold analysis are to be applied to the sub-models. Where nodal forces are given, the supporting members located at the boundaries of a sub-model are to be included in the sub-model. Where nodal displacements are given and additional nodes are provided in sub-models, nodal displacements at the additional nodes are to be determined by proper interpolations.

3. Analysis Criteria

3.1 Allowable Stress

Von Mises equivalent stresses in plate elements and axial stresses in line elements within refined areas are not to exceed the allowable stresses defined in Section 4, C.7.2.

L. Fatigue Assessment - Fatigue FEA

1. General

1.1 Application

The Hot Spot Stresses are to be calculated based on the method specified in Annex 5 for the critical detail addressed in Section 4, C.4.7 for fatigue evaluation.

Detailed description of fatigue assessment (e.g., loading conditions, acceptance criteria, S-N curve, etc.) is also specified in Annex 5.

Annex 8 Hull Girder Shear Strength for Ship-Type Installation

A. Introduction 8–1
B. Allowable Still-water Shearing Force 8–1
C. Distribution Factors 8–3

A. Introduction

This Annex is a supplement to Rules for Hull (Pt.1, Vol.II), Sec.5, B, and is intended to provide a simplified method for determining the allowable still-water shearing forces, in accordance with the Rule requirements, for ship-type installations having two or three longitudinal oil-tight bulkheads, where the wing bulkheads are located no closer than 20% of the breadth from the side shell.

The computational method presented in this Annex is deduced from shear flow and three-dimensional finite element calculation results and is applicable to ship-type installations having single bottom construction with deep bottom transverses and swash transverse bulkheads. For ship-type installations having either double bottom, double skin or deep bottom girders, the allowable still-water shearing force will be subject to special consideration.

With the present Rule side shell thickness, local load effects are not considered for the side shell, as the longitudinal bulkhead generally governs the permissible shear force at any particular location.

B. Allowable Still-water Shearing Force

The allowable still-water shearing force, in kN, at any transverse section of the installation is the lesser of the Q_{sw} obtained from 1. and 2. with any applicable modification as specified in 3.

1. Considering the Side Shell Plating

$$Q_{sw} = \frac{0{,}935 \cdot \tau_T \cdot t_s \cdot H_s}{N_s} - Q_{wv}$$

2. Considering Various Longitudinal Bulkhead Plating

$$Q_{sw} = \frac{1{,}05 \cdot \tau_T \cdot t_b \cdot D_b}{K_1 \cdot N_b} - Q_{wv}$$

In general, in the absence of a local load, two locations need be checked for each bulkhead: the lower edge of the thinnest strake and at the neutral axis of the section. When a local load is present, the Q_{sw} should be computed at the base of each longitudinal bulkhead strake for use with .3. For installations having three longitudinal bulkheads, the Q_{sw} should be calculated considering both the centreline and wing bulkheads.

Q_{wv} = wave induced shear force [kN], as specified by Rules for Hull (Pt.1, Vol.II), Sec.5, B

τ_T = permissible total shear stress [kN/cm^2], as specified in Rules for Hull (Pt.1, Vol.II), Sec.5, C.6,

t_s = thickness of the side shell plating at the neutral axis of the section [cm]

t_b = thickness of the centreline or wing longitudinal bulkhead plating at the location under consideration [cm]

H_s = depth of the hull girder at the section under consideration [cm]

D_b = depth of the longitudinal bulkhead at the section under consideration [cm]

N_s, N_b = shear distribution factors for side shell and longitudinal bulkheads, respectively, and may be determined by C.

K_1 = $1+\frac{y}{8\cdot \bar{y}}$

y = distance measured from the deck or bottom (depending on whether the strake considered is above or below the neutral axis of the section) to the lower edge of the bulkhead strake under consideration [cm]

$\bar{y}$ = distance measured from the deck (bottom) to the neutral axis of the section, when the strake under consideration is above (below) the neutral axis [cm]

3. Reduction for Local Loads

When the loading head in the center tank is different from that in an adjacent wing tank, then the allowable Q_{SW} computed at the various bulkhead locations in 2. may have to be reduced, as follows.

3.1 For the case of a two longitudinal bulkhead installation, when the center tank head is less than that in any adjacent wing tank, no reduction need be made.

3.2 For two and three bulkhead installations, when the center tank head exceeds that in a wing tank, within the center tank region, a hull girder shear force reduction, R, is to be computed at the corresponding locations on the bulkheads used in 2. These reductions is to be determined for both wing and centerline bulkheads, and may be calculated as follows.

$$R = W_c\left(\frac{2{,}1\cdot K_2\cdot N_w}{3\cdot K_1\cdot N_b}-1\right)\ [kN]$$

If $(2{,}1\cdot K_2\cdot N_w)$ is less than or equal to $(3\cdot K_1\cdot N_b)$, R should be taken as zero.

K_1, N_b = as previously defined

N_w = distribution factor for local loads, as specified in C.

K_2 = $1+\frac{A}{A_b}$

A = total area of the longitudinal bulkhead plating above the lower edge of the strake under consideration [cm^2]

A_b = total area of the longitudinal bulkhead plating under consideration [cm^2]

W_c = effective local load which may be denoted by W_{c1} and W_{c2}, at the fore and aft ends of the center tank, respectively

$$W_{c1} = \frac{\rho\cdot b_c}{\ell_c}\left[h_{c1}\cdot\ell_1\left(\ell_2+\frac{\ell_1}{2}\right)+h_{c2}\frac{\ell_2^2}{2}\right]$$

$$W_{c2} = \frac{\rho\cdot b_c}{\ell_c}\left[h_{c1}\cdot\frac{\ell_1^2}{2}+h_{c2}\cdot\ell_2\left(\ell_1+\frac{\ell_2}{2}\right)\right]$$

ρ = density of the cargo (ballast) [kgf/m^3]

ℓ_c, b_c = length and breadth [m], respectively, of the center tank

h_{C1}, h_{C2} = excess fluid heads in the center tank. Where the head in a wing tank exceed that in the center tank, see 3.3 below.

ℓ_1, ℓ_2 = longitudinal distances from the respective center tank ends to the succeeding wing tank transverse bulkheads

3.3 When the head in wing tanks exceeds that in the center tank, within the center tank region, h_c is to be taken as zero for two longitudinal bulkhead installations. However, a reduction should be applied only to the Q_{sw} computed while considering the centerline bulkhead in 2. This reduction may be computed by the equations in 3.2, except that b_c is to be taken as the combined breadth of both wing tanks ($b_c = 2 \cdot b_w$), and h_c is the excess head in the wing tank above that in the center tank.

3.4 Where adjacent tanks are loaded with cargoes of different densities, the heads in 3.3 are to be corrected to account for the difference in density.

C. Distribution Factors

The distribution factors N_s, N_b and N_w may be determined by the following equations.

1. For Installations Having Two Longitudinal Bulkheads

$$N_b = 0{,}32 - 0{,}06\,\frac{A_s}{A_b}$$

$$N_s = 0{,}5 - N_b$$

$$N_w = 0{,}31\,\frac{n-1}{n}$$

where

A_s = total projected area of the side shell plating [cm]

A_b = as previously defined

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

For Installations Having Three Longitudinal Bulkheads

$$N_b\,(\text{center}) = 0{,}26 - 0{,}044\,\frac{A_s}{A_b} + C_1$$

$$N_b\,(\text{wing}) = 0{,}25 - 0{,}044\,\frac{A_s}{A_b} - C_2$$

$$N_s = 0{,}5 - 0{,}5 \cdot N_b\,(\text{center}) - N_b\,(\text{wing})$$

$$N_w\,(\text{center}) = \left(0{,}7 \cdot N_b + 0{,}15\right)\frac{n-1}{n}$$

$$N_w\,(\text{wing}) = \left(1{,}5 \cdot N_b - 0{,}1\right)\frac{n-1}{n}$$

A_s, A_b, n are as previously defined, however, A_b should be either the center or wing bulkhead area, depending on which is being considered

C_1 = 0 for K > 0,9

C_1 = 0,1 (1 – K) – 0,005 for K ≤ 0,9

$K = \frac{A_b(\text{wing})}{A_b(\text{center})}$

C_2 = 0 for K > 0,9

C_2 = 0,04 (1 – K) for K ≤ 0,9

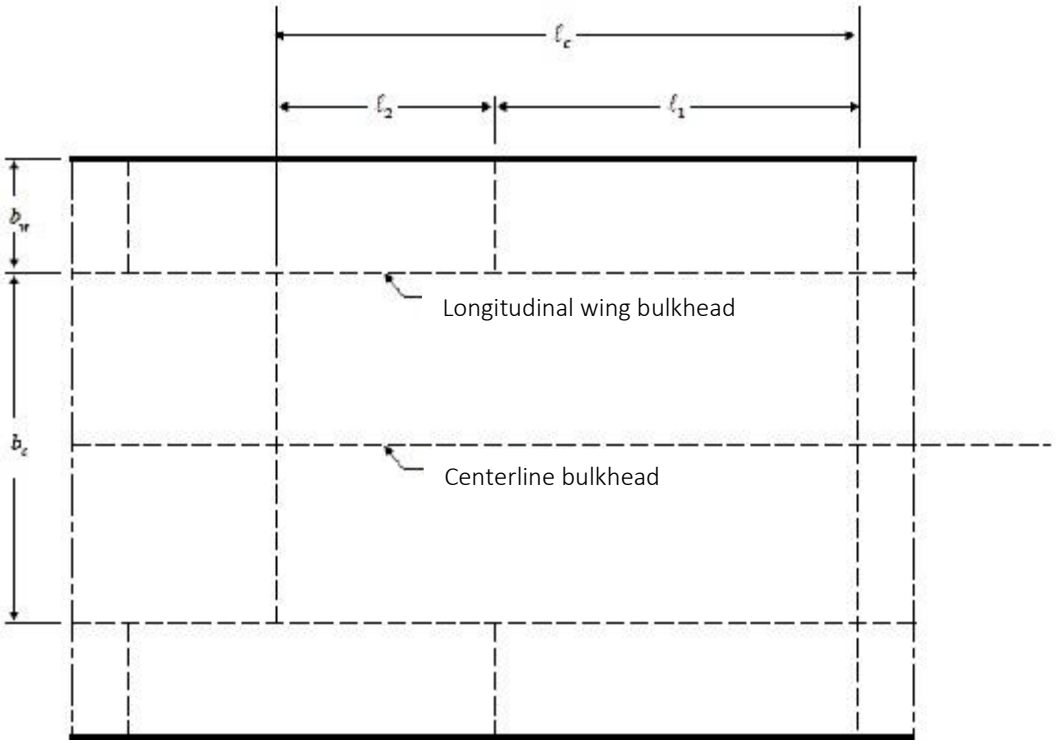


Fig. A8.1 -Center Tank Region

Annex 9 Wave Impact Criteria

A. Application and Scope 9–1
B. Impact Load 9–1
C. Areas of Wave Impact 9–2
D. Structural Strength 9–3
E. Compactness and Detailing 9–6

A. Application and Scope

Wave impact is referred to in several locations in this Guidelines; see Section 5, A.1.3.1 for a Column Stabilized Vessel, Section 5, B.1.3.1 for a TLP and Section 5, C.1.3.1 for a Spar vessel. The criteria given herein are mandatory for the Classification of a non-ship type FPI. For a ship-type FPI, wave impacts in the form of bow and bottom slamming are considered in Section 4, C.2.7.

These criteria consider wave breaking loads on the hull and topside deck of an FPI, such as a Column Stabilized Vessel and a TLP, for in-service and pre-service conditions. Wave impact is considered a solitary and unusual load that is resisted by local structural components, possibly into the post yield range of their strength. Therefore criteria are included so that the needed post yield strength is available (i.e., member 'compactness' and detailing criteria are provided).

B. Impact Load

1. Column, Pontoon and Hard Tank

Where the column or pontoon of a column stabilized vessel or a TLP is subjected to wave impact, the scantlings of the plating, stiffeners and girders of the framed shell are to be determined using the following wave impact pressure, p_s:

$$p_s = 37{,}84 \cdot f_s \cdot H_s \qquad [kN/m^2]$$

where

f_s = 1,0 for plate panels between stiffeners, and the stiffeners themselves

= 0,626 for girders in a stiffened shell having a rectangular cross-section

= 0,492 for girders in a stiffened shell having a circular cross-section

H_s = significant wave height [m], of the design sea state having a 100 year return period. Where the structure is subjected to wave impact during its transit to the installation site, H_s, for the critical sea state during transit is also to be considered.

2. Other Members

The main bracing members of a Column Stabilized Vessel or a TLP between the columns or between columns and the topside deck, and the members of an open-truss in a topside deck of a Column Stabilized Vessel, TLP or Spar are small diameter tubular members. The p_s determined above for plating (i.e., f_s = 1,0) can be divided by 1,9 and multiplied by the member's width to obtain the impact force per unit length along the member.

C. Areas of Wave Impact

1. General

The wave impact zone is the region in which structural elements will be subject to wave impact loads. The wave impact zone is the vertical distance from the SWL to the crest elevation of the maximum wave associated with the design sea state.

The horizontal extent of the wave impact zone is all of the outward facing portions of the hull. For example, a circular corner leg column of a TLP will have a 270 degree arc of its surface exposed to wave impact. The shielding from impact provided by adjacent structural members may be considered where justification is provided.

2. Column, Pontoon and Hard Tank

Wave impact areas are used to determine the design loads on individual members. The areas that will be subjected to wave impact are as follows:

- For individual plate panels between stiffeners, the wave impact pressure is considered to act uniformly over the entire panel.
- For an individual plate stiffener with its associated shell plating, the pressure is considered to act uniformly along the length of the stiffener. The area on which the pressure acts for the stiffener has a width equal to the spacing between stiffeners and a height that is the length of the stiffener. Even if only a portion of a stiffener is in the wave impact zone, the entire stiffener length is to be considered loaded by the specified pressure.
- For girders in the wave impact zone, the area over which the pressure is applied is as follows:
  - For horizontal members (e.g., girders, decks and flats) the loaded area is:

    Vertically: The lesser of the sum of one-half the plate stiffener spans above and below the horizontal member, or $0,62 \cdot H_s$

    Horizontally: The length of the horizontal member between points of effective flexural support.
  - For vertical girders and similar structural members (e.g., vertical webs and bulkheads) the loaded area is:

    Vertically: The lesser of the distance between points of effective flexural support, or $0,62 \cdot H_s$

    Horizontally: The sum of one-half the distance on either side of the web to the next vertical girder or bulkhead.

    (Where the actual framing is other than the conventional orthotropic plate framing system envisioned, modification of the specified areas will be considered in consultation with BKI).

3. Other Members

- Portions of a main brace exposed to wave impact will need sufficient flexural and shear strength to resist the impact load. The impact load per unit of length along the brace extends from the SWL to the crest elevation of the maximum wave associated with the design sea state.
- Additionally all portions of the brace in the impact zone are to be able to resist the local pressure given in B.1 divided by 1,9.

D. Structural Strength

1. General

Individual structural elements in the wave impact zone are to satisfy the criteria given below. As mentioned previously wave impact is considered a solitary local load. Typically, it is envisioned that structural elements will be initially designed considering the scantling requirements and the global strength requirements for the specified in-service and pre-service conditions in this Guidelines. The parts of the FPI structure in the wave impact zone, will then be assessed for their resistance to wave impact. As needed, the design of an element is to be suitably increased using the criteria given below to account for wave impact. Since some of the affected structural elements will need to mobilize post yield behavior to resist the wave impact load it is important that both the strength criteria given below and the 'Compactness and Detailing' criteria given in the next subsection are satisfied.

2. Shell Plating

The thickness of shell plating, t, in the wave impact zone is not to be less than the following.

$$t = \frac{\mathbf{a} \cdot c_k}{70{,}7}\sqrt{\frac{p_s}{R_{eH}}} + 1{,}5 \quad [\text{mm}]$$

where

t = thickness [mm]

p_s = pressure from B.1 [kN/m^2]

$\mathbf{a}$ = spacing of stiffeners [mm]

c_k = $\dfrac{3{,}075 \cdot \sqrt{\alpha} - 2{,}077}{\alpha + 0{,}272}$ for $1 \le \alpha \le 2$

= 1,0 for $\alpha > 2$

α = aspect ratio of the panel (longer edge/shorter edge)

R_{eH} = specified minimum yield point or strength [N/mm^2]

3. Stiffener

The plastic section modulus, W_P, of plate stiffeners with their associated shell plating is not to be less than the following

$$W_p = 125 \cdot c \cdot p_s \cdot \mathbf{a}\frac{\ell^2}{R_{eH}} \quad [\text{cm}^3]$$

where

$\mathbf{a}$ = stiffener spacing [m]

p_s = pressure from B.1 [kN/m^2]

ℓ = length of stiffener [m], between supports; where brackets are fitted in accordance with Table 5.1 and have a slope of approximately 45 degrees, the length ℓ may be measured to a point on the bracket located at a distance from the toe equal to 25% of the length of the bracket.

R_{eH} = specified minimum yield point [N/mm^2]

c = 0,5 when both ends of the stiffener have effective end brackets

= 0,67 when one end has effective end bracket and other end is continuous into the next stiffened panel

= 0,8 when both ends of a stiffener are continuous into the next stiffened panel

= 1,0 for a single span stiffener without effective flexural restraint at ends.

The plastic section modulus, W_P, may be obtained from the following equations, where b_f, t_f, d_w, t_w, b_p, and t_p [cm] are as indicated in Fig. 9A.1:

$$W_p = b_f \cdot t_f \left(d_w + \alpha + \frac{t_f}{2} \right) + d_w \cdot t_w \left(\frac{d_w}{2} + \alpha \right) + b_p \left(\alpha^2 - \alpha \cdot t_p + \frac{t_p^2}{2} \right)$$

when $b_p \cdot t_p > b_f \cdot t_f + d_w \cdot t_w$

$$W_p = b_f \cdot t_f \left(d_w - \beta + \frac{t_f}{2} \right) + t_w \left(\beta^2 - \beta \cdot d_w + \frac{d_w^2}{2} \right) + b_p \cdot t_p \left(\beta + \frac{t_p}{2} \right)$$

when $b_p \cdot t_p \leq b_f \cdot t_f + d_w \cdot t_w$

where

$$\alpha = 0{,}5 \cdot \frac{b_p \cdot t_p - d_w \cdot t_w - b_f \cdot t_f}{b_p}$$

$$\beta = 0{,}5 \cdot \frac{d_w \cdot t_w + d_f \cdot t_f - b_p \cdot t_p}{t_w}$$

The shear area of the stiffener, A_W, is not to be less than :

$$A_w = \frac{p_s \cdot \mathbf{a} \cdot \ell}{0{,}12 \cdot R_{eH}} \quad [cm^2]$$

where p_s, **a**, ℓ, and R_{eH} are as defined above.

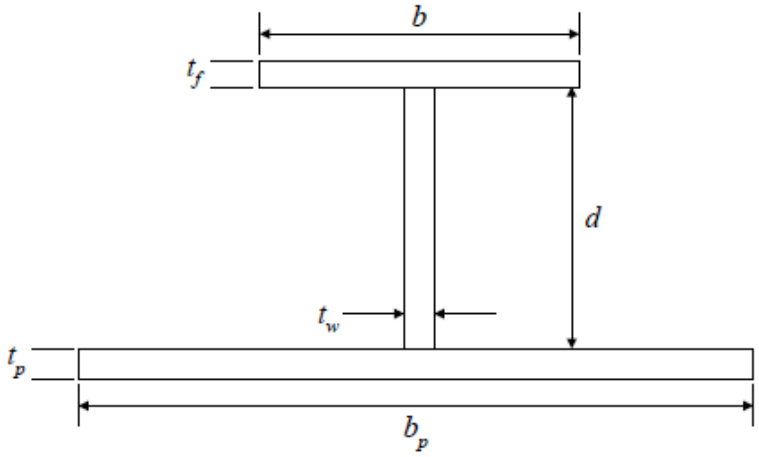


Fig. 9A.1 - Stiffener Section

4. Girder

The elastic section modulus, W, of a girder supporting stiffeners on flat plating, including the associated shell plating is not to be less than:

$$W = \frac{91{,}0 \cdot p_s \cdot \mathbf{a} \cdot b \cdot \ell}{R_{eH}} \quad [cm^3]$$

where

p_s = pressure from B.1 [kN/m^2]

ℓ = length of girder [m], between supports. The ends of girders should have flexural restraint either from being continuous with adjacent structure or the provision of brackets in accordance with Table 5.1. In the latter case, the length l may be measured to a point on the bracket located at a distance from the toe equal to 25% of the length of the bracket.

b = dimension of the loaded area perpendicular to the length [m]

R_{eH} = specified minimum yield point [N/mm^2]

The shear area of the girder, A_w, is not to be less than:

$$A_w = \frac{p_s \cdot b \cdot \ell}{0{,}108 \cdot R_{eH}} \quad [cm^2]$$

where p_s, b, ℓ, and R_{eH} are as defined above.

Where the stiffened shell is curved, the girder scantlings are to be determined based on an established shell analysis method. The scantlings of the curved girder are to be based on linear elastic behavior where the maximum bending stress due to wave impact is limited to the yield stress.

For a vertical girder whose length is not completely in the wave impact zone, adjustment to the above calculated section modulus and web area can be made using an appropriate method based on linear elastic behavior.

5. Other Members

For a smaller diameter member (e.g. a brace that can be appropriately analyzed as a single or system of 'beam-column' elements) a structural calculation is to be performed to demonstrate the adequacy of the member to resist the impact load (acting alone) along its length as determined from C.3. The calculation should appropriately account for the support at the ends of the member. Permissible stresses are those given in Rules for Mobile Offshore Unit (Pt.5, Vol.VI), Sec.4, C.2 for combined loadings, or alternatively the pertinent member strength and allowable stress criteria of the API-RP2A can be used, where the basic allowable stress is increased by one-third.

The adequacy of the member's local strength subjected to direct wave impact is to be demonstrated. A brace segment composed of a stiffened plate is to satisfy the criteria given above in 2. and 3., as applicable. Brace segments which are circular shell structures are to satisfy the applicable criteria given in the Guidance for Buckling and Ultimate Strength Assessment for Offshore Structures (Pt.5, Vol.C), Sec. 4, where gross member properties may be used; alternatively API-RP2A, may be used. The local impact pressure on the cylindrical shell can be considered as a uniform hoop stress; increased allowable stresses are permitted.

6. Deck, Flat, and Bulkhead

When the main support to a plate stiffener is not a flexural element (such as a girder), it may be a deck, flat or bulkhead. In such a case the in-plane strength and buckling resistance of the deck, flat or bulkhead should be sufficient to assure that the stiffener's supports and boundary conditions will perform as intended in design. The Guidance for Buckling and Ultimate Strength Assessment for Offshore Structures (Pt.5, Vol.C) is to be used in the assessment of stiffened panels comprising affected decks, flats and bulkheads.

E. Compactness and Detailing

The following criteria are to be satisfied for structural elements subjected to wave impact.

- The web of a plate stiffener or girder is to be continuously welded to the shell plate and the flange.
- An attached flange should preferably be symmetric with respect to webs (e.g., T-section).
- For an unsupported element (e.g., projection of flange from a web) the ratio of outstand (b) to thickness (t) is not to exceed $0{,}4 \cdot \sqrt{E/R_{eH}}$, where E and R_{eH} are, respectively, the modulus of elasticity and yield strength of the material in the same units of measure.
- For a supported element (e.g. web of a flanged stiffener) the ratio of web depth (d) to its thickness (t) is not to exceed $1{,}5 \cdot \sqrt{E/R_{eH}}$
- It is to be shown, using an appropriate method, that the unsupported length of the stiffener's flange is less than that for which the stiffener will be subject to torsional instability. For example refer to Guidance for Buckling and Ultimate Strength Assessment for Offshore Structures (Pt.5, Vol.C), Sec.3, C.2, where gross member properties can be used.
- Tripping brackets, arranged to support the flanges of the girders, are generally to be fitted at intervals of about 3 m, close to any changes of section, and in line with the flanges of struts.
- The web depth of a girder is to be at least 2,5 times the depth of the largest stiffener cut-out opening.
- The load paths between all elements, including welds, are to be reviewed to verify that all supporting members and their connections will have sufficient strength and buckling resistance so that element support and boundary conditions will behave as intended.

Annex 10 Offshore Hull Construction Monitoring Program

A. Introduction 10–1
B. Application 10–1
C. Critical Area 10–1
D. Determination of Critical Areas 10–2
E. Construction Monitoring Plan 10–2
F. Surveys After Construction 10–3
G. Notation 10–3

A. Introduction

The structural strength criteria specified in the BKI Rules are used by designers to establish acceptable scantlings in order for installations constructed to such standards and properly maintained to have adequate durability and capability to resist the failure modes of yielding, buckling and fatigue.

The application of the FPI Guidelines and other review techniques to assess a design for compliance with Rule criteria also gives the designer and BKI the ability to identify areas that are considered critical to satisfactory in-service performance.

Knowing that the actual structural performance is also a function of construction methods and standards, it is prudent to identify 'critical' areas, particularly those approaching design limits, and use appropriate specified construction quality standards and associated construction monitoring and reporting methods to limit the risk of unsatisfactory in-service performance.

Accordingly, this Appendix defines what is meant by critical areas, describes how they are to be identified and recorded, delineates what information the shipyard is to include in the construction monitoring plan and lays out the certification regime to be followed.

B. Application

Floating installations designed and reviewed to the FPI Guidelines are to comply with the requirements of this Annex and have the notation **OHCM**.

C. Critical Area

The term critical area, as used in these Guidelines, is defined as an area within the structure that may have a higher probability of failure during the life of the vessel compared to the surrounding areas, even though they may have been modified in the interest of reducing such probability. The higher probability of failure can be a result of stress concentrations, high stress levels and high stress ranges due to loading patterns, structural discontinuities, corrosion prone environment, or a combination of these factors.

In order to provide an even greater probability of satisfactory in-service performance, the areas that are approaching the acceptance criteria can be identified so that additional attention may be paid during fabrication.

The objective of heightened scrutiny of building tolerance and monitoring in way of the critical areas is to minimize the effect of stress increases incurred as a result of the construction process. Improper alignment and fabrication tolerances may be potentially influential in creating construction-related stress.

D. Determination of Critical Areas

Critical areas can be determined by the following procedure:

1. Rule- and Experience-based Critical Areas

The critical areas can be identified based on the Rules and previous service experiences:

1) Typical critical areas can be found in the Section 4, C.4.7 for ship-type FPIs and Section 3, B.3.2.3 for non-ship-type FPIs, and industry standards from API Recommendation Practices and Specifications and IACS, Tanker Structure Cooperative Forum, etc. which are to be further confirmed through detailed structural analysis based on D.2.
2) Input from BKI personnel, owners, designers, and/or shipyards based on previous in-service experience from similar units, such as locations sensitive to cracking, buckling, or corrosion that could impair the structural integrity of the unit.
3) Details where fabrication is difficult, such as blind alignment, complexity of structural details and shape, limited access, etc.

2. Design-specific Critical Areas

While a Rule or experience-based critical areas may be identified to a generic location, the design-specific critical area should then be identified to a very specific location based on the engineering analysis. This information will be used to provide an enhanced degree of granularity with respect to the survey and inspection of the specific design and also to help guide the Surveyor and the clients' inspector towards the areas where additional attention is warranted.

A critical area is determined through the structural analysis based on the criteria noted as follows:

- The calculated von-Mises stress, componential stress or, buckling stress (only for the individual members and cylindrical shells of non-ship type units, such as cylindrical legs in self-elevating units or bracing members in semi-submersibles) greater than 0.9 of the allowable stress (i.e., UC ≥ 0.9) in terms of the buckling strength or local yielding criteria as specified in the Section 4, A.3.2.5, Section 4, A.4.4, Section 5, A.2.3.1.6, Section 5, B.3.3.1.6 or Section 5, C.3.3.1.6.
- The calculated fatigue life (FL) less than 1.25 times the target fatigue life (TFL) (i.e., FL ≤ 1.25 x TFL) based on the local fine mesh fatigue analysis.

Special attention needs to be paid to the location where weld improvements with means of toe grinding and weld profiling, etc., are to be made to meet the fine-mesh fatigue design criteria. This special location needs to be identified with a special mark on the structural critical area plan.

E. Construction Monitoring Plan

The Construction Monitoring Plan for critical areas is to be prepared by the shipyard and submitted for BKI approval prior to the start of fabrication. The plan is to include:

1) Structural drawings indicating the location of critical areas as identified by the BKI review see D.
2) Construction standards and control procedures to be applied
3) Verification and recording procedures at each stage of construction, including any proposed non-destructive testing
4) Procedures for defect correction

An approved copy of the Construction Monitoring Plan is to be placed onboard the floating installation.

F. Surveys After Construction

To monitor critical areas during service, an approved copy of the Construction Monitoring Plan is to be available on board for all subsequent surveys.

G. Notation

Floating installations having been found in compliance with the requirements of these Guidelines may be distinguished in the Record with the notation OHCM.

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Annex 11 Mooring Chain Fatigue Due to Bending

A. General 11–1
B. Interlink Stiffness and Sliding Threshold 11–1
C. Tension-Bending Fatigue Analysis Approach 11–2
D. Tension-Bending Fatigue Damage Calculation 11–3
E. Stress Concentration Factors (SCFs) 11–4
F. S-N Curve 11–4
G. Mitigation Method 11–5

A. General

Out of Plane Bending (OPB) can occur in links at the connection between mooring lines and the moored floater where adjacent chain links have relative angular movement, see Fig. A11.1. Those links are subject to bending induced stress in addition to tension-tension stress, which should be included in the fatigue assessment.

This Annex provides informative guidance on the assessment of OPB fatigue calculations.

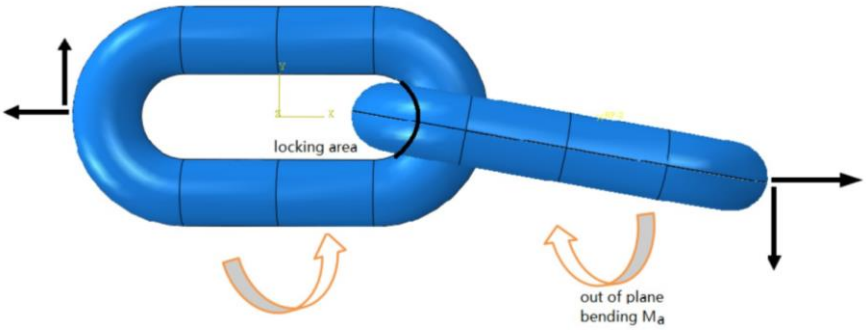

Fig. A11.1 Interlink Out of Plane Bending (OPB)

B. Interlink Stiffness and Sliding Threshold

1. Interlink Bending Moment and Contact Stiffness

The bending stress of a chain link is a function of the mooring chain tension and the interlink rotation angle. The higher the tension and rotation angle, the higher the bending moment on the chain link.

The interlink OPB bending moment and the OPB stress can be expressed as follows

$$M_{OPB} = k \cdot \left(\frac{T}{0{,}14 d^2} \right)^a \cdot \left(\frac{d}{100} \right)^{2a+b} \cdot \frac{\pi d^2}{16} \quad [\text{N.m}]$$

$$\sigma_{OPB} = M_{OPB} / \frac{\pi d^2}{16} \quad [\text{N/m}^2]$$

where

d = chain nominal diameter [m]

T = line tension [N]

k = $354 \cdot \left(1 - \frac{0{,}93}{0{,}93 + \theta + \left(0{,}307 \cdot \theta^3\right) + \left(0{,}048 \cdot \theta^5\right)}\right)$

a = 0,439 + 0,532 · tanh (1,02 · θ)

b = –0,433 – 1,64 · tanh (1,32 · θ)

θ = interlink angle [°]

The formulation on interlink stiffness is based on the study using chain diameters from 84 mm to 146 mm and grades of R3, R3S and R4. Out of these diameter and grade range, the formulation is to be considered with special care.

2. Interlink Sliding Threshold

The OPB moment increases with the line tension, interlink rotation and chain diameter. However an upper bound of OPB bending moment can be reached when sliding occurs at the interlink, as shown in Fig. A11.2.

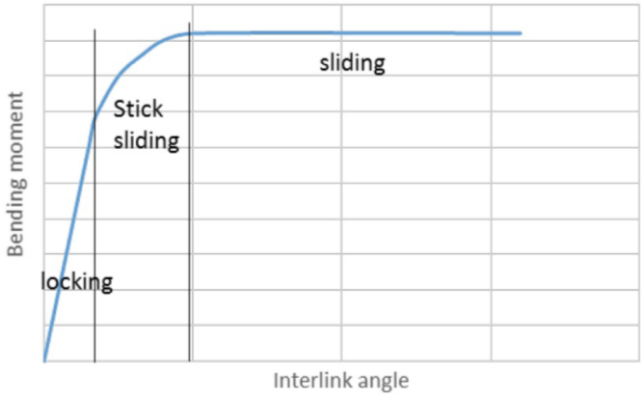

Fig. A11.2 Chain Bending Moment vs Interlink Angle

The moment threshold is related to link geometry shape and can be expressed as following:

$$\Delta M_{OPB_Sliding} = 0{,}5 \cdot \mu \cdot T \cdot d$$

where

μ = interlink friction coefficient

The interlink friction coefficient should be obtained based on laboratory test. At early design stage, the interlink friction coefficient of 0,5 in air and 0,3 in seawater can be used.

C. Tension-Bending Fatigue Analysis Approach

The chain link tension-bending fatigue damage calculation includes the following 5 steps. A flow chart is given in Fig. A11.3.

1) Global response analysis in time domain for each sea states according to mooring analysis procedures given in Section. 6, D.
2) Full-scale testing or FEA analysis for selected chain links to obtain the interlink angles, line tension, OPB and In-Plane Bending (IPB) bending moments.

3) FEA analysis for stress concentration factors (SCFs) at hotspots.
4) Calculation of total stress at selected hotspots.
5) Calculation of chain link fatigue damage using rainflow cycle counting from the stress time history and appropriate S-N curve.

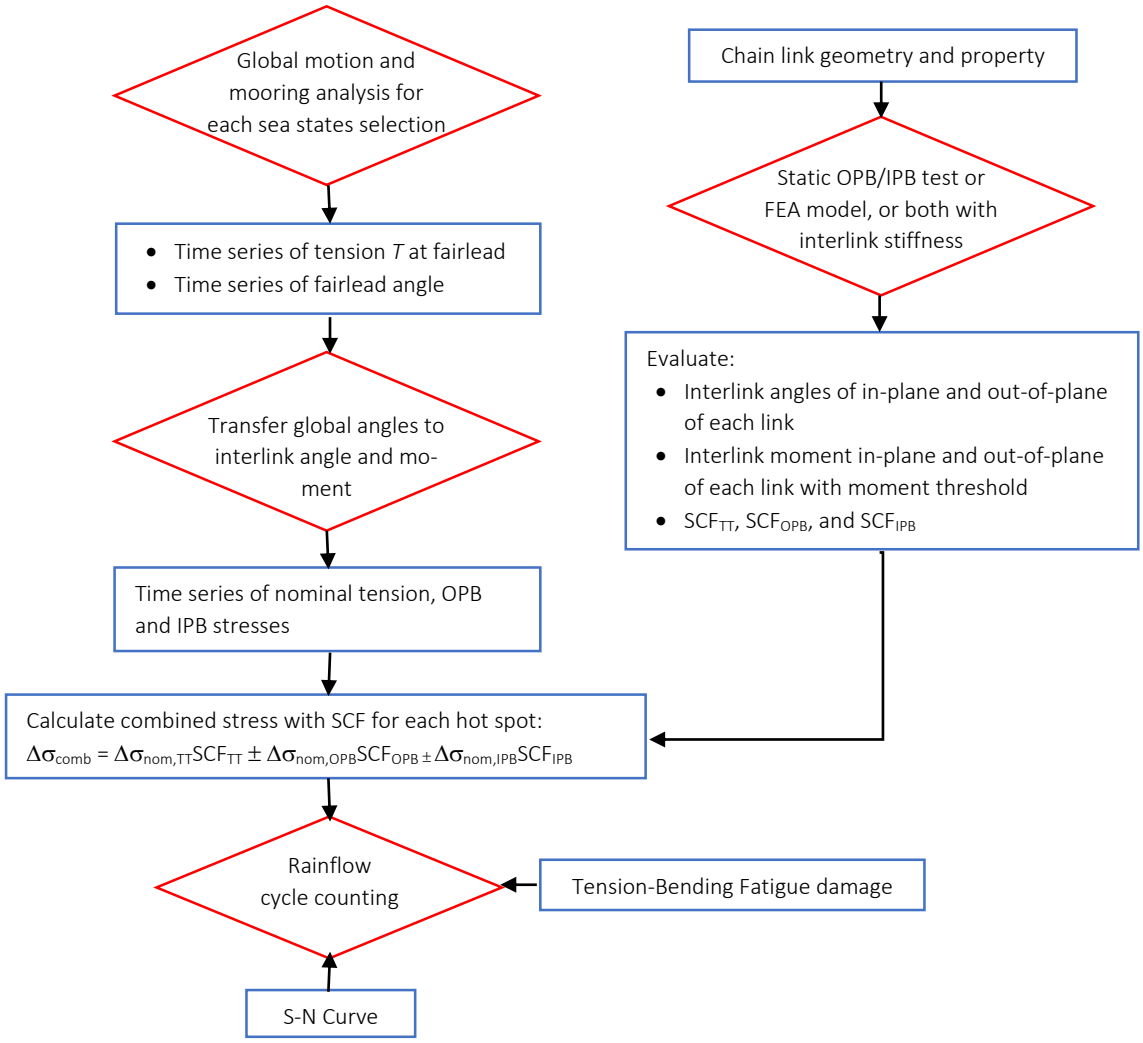

Fig. A11.3 Flow Chart to Calculate OPB Fatigue Damage

D. Tension-Bending Fatigue Damage Calculation

1. Combined Stress Range

In the case of tension-tension loading, the hot spot locations are at the transition from the straight legs to inner bend and at the outer crown. In the case of OPB loading, the hotspots are located in the inner bend region, close to the contact area between the two links. There are four OPB hotspots on each side of the chain link that have similar OPB and IPB amplitudes but with different directions. For a given loading combination of tension, in-plane and out-of-plane angle variation, each simultaneous stress range contribution can be added using the following formula:

$$\Delta\sigma_{combined} = \Delta\sigma_{nom,TT}SCF_{TT} \pm \Delta\sigma_{nom,OPB}SCF_{OPB} \pm \Delta\sigma_{nomJPB}SCF_{IPB}$$

1.1 TT stress

The tensile stress range can be calculated as follows:

$$\Delta\sigma_{nom,TT} = \frac{2 \cdot \Delta \cdot T}{\pi \cdot d^2}$$

where

ΔT = tension range [N]

1.2 OPB stress

The relationship between the OPB stress range and the interlink OPB bending moment range is as follows:

$$\Delta\sigma_{nom,OPB} = \frac{16 \cdot \Delta \cdot M_{OPB}}{\pi \cdot d^3}$$

1.3 IPB stresss

The relationship between the IPB stress range and the interlink IPB bending moment range is as follows:

$$\Delta\sigma_{nom,IPB} = \frac{2{,}33 \cdot \Delta \cdot M_{IPB}}{\pi \cdot d^3} \qquad \text{for studless chain}$$

$$\Delta\sigma_{nom,IPB} = \frac{2{,}06 \cdot \Delta \cdot M_{IPB}}{\pi \cdot d^3} \qquad \text{for studlink chain}$$

E. Stress Concentration Factors (SCFs)

Cyclic stresses and corresponding stress concentration factors for the different loadings are defined as follows:

$$SCF_{TT} = \frac{\Delta \cdot O_{TT}}{\Delta \cdot O_{nom,TT}}$$

$$SCF_{OPB} = \frac{\Delta \cdot O_{OPB}}{\Delta \cdot O_{nom,OPB}}$$

$$SCF_{IPB} = \frac{\Delta \cdot O_{IPB}}{\Delta \cdot O_{nom,IPB}}$$

Finite element analysis (FEA) is recommended for T-T, IPB and OPB loading and SCF calculations at OPB hotspots using nominal link shape.

F. S-N Curve

An S-N curve should be established based on sufficient full scale OPB fatigue test data and linear regression analysis. Two standard deviations may need to be considered to determine the S-N curve for the fatigue damage assessment. The Joint Industry Project of Chain Out-of-Plane Bending recommends a single slope design S-N curve of:

$$NT^M = K$$

where

$\log K = 12{,}575$

$M = 3$

The curve is based on the testing data in sea water under free corrosion condition.

G. Mitigation Method

Chain links with high tension loads and constrained relative rotation are prone to bending-tension fatigue damage. The following methods can be considered for the mitigation of the OPB induced fatigue damage:

- Doubly articulated chain stopper to reduce the effect of motions of the floating structure on the mooring line
- Use of very low friction bushings in chain stoppers
- Reduce pretension to reduce OPB stress
- Increase the lever arm or hawse pipe length between bushings and first chain link
- Off-set the chain stopper
- Careful orientation of the link at the end of the hawse pipe
- Straight chain hawse may be superior to curved chain hawse for minimizing the OPB, as the straight hawse tends to evenly spread the chain rotation among several interlinks while the curved one may result in concentration of the chain rotation to a single interlink
- A periodically shift of the chain links at the fairlead so additional fatigue damage due to bending can be more evenly distributed

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Annex 12 Vortex Induce Motion (VIM)

A. General 12–1
B. VIM Design Parameters 12–1
C. Strength Design 12–3
D. Fatigue Analysis 12–4
E. Model Testing 12–6
F. Methods to Improve Mooring Design for VIM 12–7

A. General

Many floating units possessing cylindrical structures such as spars, TLPs, and semi-submersibles can be susceptible to vortex induced motion (VIM) when they are exposed to currents.

The parameters that affect the VIM include:

1) Reduced velocity (see the definition in B.2)
2) Flow characteristics (flow profile, steady/oscillatory flow, turbulence intensity)
3) Column geometry
4) Mass ratio of the column to the displaced fluid
5) External damping due to mooring and riser
6) Reynold's number
7) Surface roughness
8) VIM suppression devices, such as strakes configurations (width & length coverage, etc.)
9) Line pretension
10) Orientation of floating unit (Semi-submersible)

This Annex provides guidelines on VIM design parameters, experience in model testing, full scale measurement, strength and fatigue analysis procedures, and methods to minimize VIM.

B. VIM Design Parameters

1. Susceptibility of VIM

The vortex shedding frequency in steady flow is given by:

$$f_s = S_t \frac{V_c}{D} \quad [\text{Hz}]$$

where

f_s = vortex shedding frequency [Hz]

S_t = Strouhal number

V_c = current velocity [m/s]

D = member diameter [m]

VIM is expected to occur if the natural frequency of a floating installation coincides with the vortexshedding frequency. The natural frequency of a moored floating installation is related to the characteristics of the floater and the mooring lines and can be obtained from a mooring analysis program.

2. Reduced Velocity V_r

The reduced velocity, V_r, depends on the natural frequency of the moored floater in horizontal plane, the dimension of submerged columns and the current speed as follows.

$$V_r = \frac{V_c \cdot T_n}{D} \quad [m/s]$$

where

V_c = fluid velocity normal to the member axis [m/s]

T_n = natural period of the moored floater perpendicular to the current direction [sec]

D = member diameter [m]

T_n is a function of mooring stiffness and the floating units' mass including added mass, which is typically determined by analytical tools or model testing. Where available, field measurement data should be used to calibrate the added mass values. The mooring stiffness is typically evaluated at the mean offset resulted from current, associated wind and waves. Since the mean offset is a function of drag force, which is dependent on the VIM amplitude, the process of selecting the appropriate offset for VIM calculation is iterative. Calibration of calculated values with available model test or field measurement data may be desirable when such data are available.

VIM can occur under relatively mild currents (for example 1 to 2 knots) if the natural period of the floating unit is long, which may be the case with deep-water mooring systems.

3. Transverse (Cross Flow) VIM

Transverse VIM occurs when the vortex shedding frequency is close to the transverse natural frequency of a moored floater. The floater typically oscillates in the direction perpendicular to the current in a periodic pattern. The transverse motion is normally expressed as the ratio of single amplitude transverse VIM to the diameter of the column (A/D).

The transverse (lift) force may be given as follows:

$$q_{VIM}(t) = \frac{1}{2} \cdot \rho \cdot V_c \cdot D \cdot C_L \cdot \sin(2 \cdot \pi \cdot f_s \cdot t)$$

where

V_c = characteristic current velocity, typically the highest velocity in the current profile [m/s]

ρ = density of the fluid [kg/m^3]

C_L = lift force coefficient

f_s = vortex shedding frequency [Hz]

4. Inline VIM

Inline VIM is the motion in the direction of the current. The magnitude of inline A/D is typically much less than the transverse A/D. Field measurement data for a classic spar with an equally spaced spread mooring system indicate inline A/D is of 10% to 15% of the transverse A/D. However, the magnitude can be higher if the natural period for the inline motion is about half of the natural period for the transverse motion. Also, unsymmetrical mooring system stiffness could result in a VIM trajectory for which the major axis of the VIM is not transverse to the current direction.

Model tests are typically used to determine drag coefficient, C_d, to be used in design. A "base drag" C_{d0} is assumed for the case where A/D = 0,0 (no VIM) and amplification factors are applied to account for VIM effects. The drag augmentation is a function of A/D and V_r, which can be expressed as:

$$C_d = C_{d0}\left[1 + k\frac{A}{D}, Vr\right]$$

The mean drag force on the cylinder is given by:

$$F_d = C_d \cdot \frac{1}{2} \cdot \rho \cdot V_c^2 \cdot A_p \quad [N]$$

where

C_d = mean drag coefficient (absolute current velocity) in the presence of VIM

A_p = projected area [m^2]

C. Strength Design

1. VIM Design Amplitude

An example of V_r versus A/D design amplitude is provided in Fig. A12.1 showing the lock-in transition, locked-in region, and the locked-out region. This type of curve is typically used to define the VIM response amplitude to be used in mooring analysis. It is important to note that, for most moored offshore floating units experiencing VIM, the shape of this curve will likely vary with current direction(i.e., the amplitude of response varies with current direction for the same reduced velocity). Care is to be taken when defining the VIM response versus current heading in the mooring analysis.

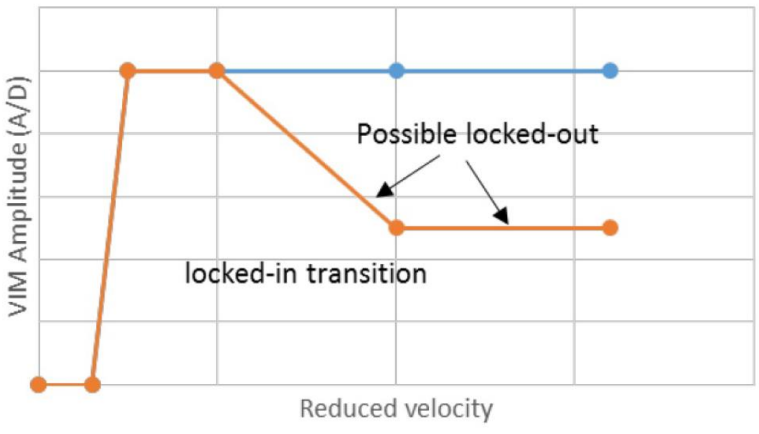

Fig. A12.1 Example VIM Amplitude versus Reduced Velocity

2. Strength Analysis Procedure

Mooring analysis for VIM conditions require special computer software that is capable of modeling VIM in the time domain. A simplified analysis procedure can be used if the waves associated with the VIM current are mild. Once the VIM design amplitudes are established, the following simplified analysis procedure can be used:

1) Select a current direction. The environment heading at 15 degree increment is recommended so that the most critical headings are identified.
2) Determine the mean offset of the floater under the design current with associated wind and waves.
3) Calculate C_d based on the design VIM amplitude established. If this C_d value is significantly different from the estimated C_d used in Step 2, iteration may be required as follows:
   A) Peak A/D is selected to determine the drag coefficient C_d used in the calculation of the mean load acting on a floater
   B) Mean load, mean offset and the natural period of the floater are calculated.
   C) With this system natural period, the reduced velocity V_r is calculated, and the corresponding new A/D is found.
   D) The whole process is iterated until the convergent is achieved.
4) Determine the envelope of possible maximum offsets of the floater including the effects of current associated wind and wave (Step 2), in-line and transverse VIM (Step3).
5) Determine line tensions and anchor loads corresponding to the envelope of possible maximum offsets calculated in Step 4 by quasi-static mooring analysis.
6) Evaluate additional line tensions due to transverse and in-line VIM, which is superimposed on the quasi-static values obtained in Step 5.
7) Repeat Steps 1–6 to obtain line tensions and anchor loads for other current directions.
8) Identify the worst direction for design check.

D. Fatigue Analysis

1. Long Term Fatigue Damage

The recommended procedure for long term fatigue damage evaluation is provided below:

1) Current events can be represented by a number of discrete current bins. Each current bin consists of a reference direction and a reference current velocity with associated wave and wind conditions. The probability of occurrence of each current bin must be specified. The number of reference directions depends on the directionality of the current at the site, and the specified directions are to include those for which significant VIM is predicted. The required number of reference current velocities normally falls in a range of 10 to 50. Fatigue damage prediction can be fairly sensitive to this number for certain mooring systems, and therefore it is best determined by a sensitivity study.
2) Select a current bin and calculate the duration t_i for the current bin in a year based on the probability of occurrence for the current velocity and direction.
3) Determine the natural period T_n of the moored unit under the current bin without VIM based on an estimated C_d.
4) Specify extreme in-line and transverse A/D values for the current bin based on available model test or field measurement data. The mean A/D for fatigue analysis can be evaluated by multiplying the

extreme A/D with a coefficient g, which should be determined by available model test or field measurement data.

5) Determine in-line and trnsverse VIM amplitude coefficient C_v, which is a function of reduced velocity, and is equal to 1,0 at peak VIM under lock-in condition.

6) Calculate the reduced velocity for the current bin and further modify the mean in-line and transverse A/D (Step 4) by C_v.

7) Determine drag coefficient C_d for the current bin based on the modified mean transverse A/D Step 6). If this C_d value is significantly different from the estimated C_d in Step 3, iteration may be required.

8) Perform mooring analysis based on the modified mean in-line and transverse A/D (Step 6), and C_d (Step 7), using the procedure for strength design. Determine average tension ranges R_i, and corresponding average response period T_i from the time trace of line tensions for a few VIM cycles. Note the average response period T_i may vary due to the relative orientation of the mooring line and current.

9) Determine number of cycles to failure N_i corresponding to R_i for the mooring component of interest using an appropriate T-N curve.

10) Calculation of annual fatigue damage for the *i*-th current bin is represented as:

$$D_i = \frac{n_i}{K} E\left[R_i^M\right]$$

where

D_i = annual fatigue damage to the component due to VIM in current bin *i*

N_i = number of tension cycles encountered in current bin *i* per year [sec]

$E\left[R_i^M\right]$ = expected value of the normalized tension range R_i raised to the power M, in current bin *i*

The number of tension cycles per year in each state can be determined as:

$$n_i = \nu_i \cdot T_i = \nu_i \cdot P_i \cdot 3{,}15576 \times 10^7$$

where

ν_i = zero up-crossing frequency (hertz) of the tension spectrum in current bin *i*

T_i = time spent in current bin *i* per year

p_i = probability of occurrence of current bin *i*

11) Repeat steps 2 to 10 for other current bins.

12) Determine cumulative fatigue damage for all current bins, and then combined with the fatigue damage from wind and waves to obtain total fatigue damage D. The predicted fatigue life is 1/D (years), which is to be greater than the service life times a factor of safety.

2. Single Extreme VIM Event

It is possible that considerable fatigue damage can be caused by a single extreme VIM event. Therefore in addition to the long-term fatigue damage evaluation, a fatigue analysis for the 100-year VIM fatigue event is also recommended. Since VIM response is largely dependent on reduced velocity, the current for worst case VIM may not coincide with the 100-year return period loop or hurricane current. The highest VIM amplitudes for fatigue consideration could occur under a lower return period current. The current

direction is to be the worst direction identified in the strength analysis. Instead of using a constant extreme design current for the whole event, current variation based on field measurements for strong loop currents can be considered. The duration of this event may be different from that obtained from the long term current distribution.

E. Model Testing

1. Model Test Parameters

1.1 Flow Similitude

The basis for hydrodynamic model testing is that geometric and dynamic similitude between prototype and model fluid flow is preserved. Reynolds number scaling and Froude number scaling are the two relevant scaling parameters for hydrodynamic model testing of offshore structures.

The Reynolds number is defined as:

$$R_e = (V_c D)/\nu$$

where

R_e = Reynolds number

V_c = characteristic velocity (e.g., flow velocity) [m/s]

D = characteristic length (e.g., hull diameter) [m]

ν = kinematic viscosity of the fluid [m^2/sec]

The Froude Number, F_n, is defined as:

$$F_n = \frac{V_c}{\sqrt{gD}}$$

where

g = gravity acceleration [m/s^2]

Satisfying the Reynolds and Froude scaling simultaneously for the model and prototype flows, however, is practically impossible. For a model dimension D that is substantially smaller than prototype, either the gravity, g, needs to be significantly increased, or viscosity, ν, of the testing fluid needs to be significantly decreased. Neither of these changes is practical in a model basin.

For separated flow dynamics that cause VIM, Reynolds number scaling is the governing scaling law. Reynolds scaling is particularly difficult to achieve for an offshore floating structure. There are currently two basic testing approaches for supercritical and subcritical Reynolds numbers:

- *Supercritical Reynolds Number Model Testing*. It is important to test at supercritical Reynolds numbers in order to attain a flow regime which is similar to the flow experienced in full scale. However, supercritical Reynolds number model testing places significant demand on the capacity of the model basin and to date supercritical model tests have only modeled 1-DOF and with a uniform current profile.
- *Subcritical Reynolds Number Model Testing*. For a helically straked cylinder, in the near field flow separation is controlled by the sharp edges of the strakes and not by boundary layer effects. In addition, it is possible to include the effects of 6-DOF motions and current profile in the model test.

As stated above, model tests conducted to date can accurately model certain parameters but only approximate others. Both approaches have advantages and disadvantages, and both show acceptable agreement with full scale data.

1.2 Dynamic Similitude

In addition to hydrodynamic scaling, dynamic similitude requires that the rigid body dynamics for the full scale and model scale systems are similar. Dynamic scaling is associated with the floating unit's rigid body modes, mass ratio, and reduced velocity.

Modeling all of the rigid-body modes (e.g., surge, sway, heave, roll, pitch, and yaw) may not be critical as long as modes that are candidates for lock-in are included. The two degrees of freedom might actually couple (lock-in simultaneously). In this case it is important that the sway and roll modes and periods be properly scaled. On the other hand, if the transverse sway is the dominant VIM response, then tests with a single-degree of freedom rigid body mode have shown reasonable agreement between model test and full scale data.

VIM 'lock-in' for a typical spar usually occurs for values of $4 \leq Vr \leq 10$. The reduced velocity for model flow must correspond to the reduced velocity for the prototype flow in order to achieve proper fluid-structure VIM similarity. That is, in addition to selections of proper scaling for V_c and D, scaling for period T_n should also be appropriate. Mass ratio has a large effect on the range of lock-in, and possibly the amplitude.

Mass ratio for a free floating body is by definition equal to 1,0 (displacement = weight). This mass ratio is to be maintained for model tests as well.

1.3 Geometric Similitude

Geometric similitude is achieved when the geometry of the model and prototype bodies is similar. The geometry of the hull and strakes, if appropriate, is to be accurately scaled. This includes any construction openings in the strakes, brackets, chains, anodes, external pipes and other appurtenances that may affect the flows around the body. Some members may result in viscous damping effects that are Reynolds number dependent. Care is to be exercised to size these members to result in a representative amount of damping in model tests.

1.4 Damping

The VIM response could be affected by damping. The damping (hydrodynamic and mechanical) generated in the model basin is to be consistent with the damping expected in the field. Since mechanical damping may be generated by the testing equipment and is absent in the field, care is to be taken to understand the effect of damping on the VIM response and to mitigate such effects. Hydrodynamic damping, due to mooring lines, risers and wave effects should be considered in the model test if possible and should be included when estimating the amplitude the VIM.

F. Methods to Improve Mooring Design for VIM

1. Polyester Rope for Middle Section

The use of polyester ropes in the middle section of mooring lines may sometimes minimize VIM due to the relative flexibility of the rope along the water depth when subject to current load. Also, the use of polyester rope may reduce V_r, which in turn may prevent lock-in.

2. Improved Chain Fairlead

The chain section in contact with the fairlead is more susceptible to fatigue failure because of the presence of bending loads in addition to tension. Chain fairleads with seven pockets are commonly used for spar moorings. The use of chain fairleads with nine pockets can reduce chain bending, thus reducing chain fatigue damage in this section. Also chain fairlead design resulting in a tight fit between the chain and the fairlead pocket can yield a much lower stress concentration factor and longer fatigue life. Alternatively, bending shoes that yield low stress concentration in chain can be used.

3. Strake Design

VIM can be reduced by improved strake design. Options include improving strake shape, increasing strake height, and eliminating discontinuities and holes in strakes. To evaluate the effectiveness of these options, a rigorous model test program is required.

4. Hull Appurtenances

Hull appurtenances such as anodes, chain, fairleads, and pipes may affect spar VIM response. Measures to eliminate or reduce the adverse impact of these appurtenances may reduce VIM. A rigorous model test program is required to evaluate the effectiveness of these measures.

5. Tightened Mooring

VIM is not observed in the model basin when Vr is below a threshold value. This condition can be achieved in some cases by tightening the mooring system. For example using higher initial tensions, or tightening the mooring system in advance of high current events, thus reducing the natural period of the moored floating unit, and eliminating VIM for current speeds below the maximum design value. The adoption of this measure is to be based on rigorous model testing and analysis, and on addressing sensitivity to higher current and lower threshold V_r. An operational procedure for a tight mooring during high current events is also to be developed.