

GUIDE FOR BUILDING AND CLASSING

DRILLSHIPS AUGUST 2011

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GUIDE FOR BUILDING AND CLASSING

DRILLSHIPS

HULL STRUCTURAL DESIGN AND ANALYSIS

AUGUST 2011 (Updated January 2018 – see next page)

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Foreword

This *ABS Guide for Building and Classing Drillships* provides criteria that can be applied in the classification of the hull structure of monohull surface-type and ship-shaped drilling units (i.e., drillships).

Requirements for classification of drillships are included in the *ABS Rules for Building and Classing Mobile Offshore Drilling Units (MODU Rules)*. The hull strength criteria contained in this Guide are to be used in conjunction with Part 3, Chapter 2 of the *MODU Rules*.

The requirements for conditions of classification are contained in the separate, generic *ABS Rules for Conditions of Classification – Offshore Units and Structures (Part 1)* for all units, installations, vessels or systems in offshore service. The purpose of the *Rules for Conditions of Classification “Part 1”* is to emphasize the common applicability of the classification requirements in “Part 1” to ABS-classed offshore units, pipelines, risers, and other offshore structures, and thereby make “Conditions of Classification” more readily a common Rule of the various ABS Rules and Guides, as appropriate.

Section 1 of this Guide specifies only the unique supplemental requirements applicable to drillships. These supplemental requirements are always to be used with the aforementioned *ABS Rules for Conditions of Classification – Offshore Units and Structures (Part 1)*.

The effective date of this Guide is 1 August 2011. The application of this Guide is optional, and unless this Guide is specifically requested by an ABS Request For Class (RFC), ABS design review will follow current practice. However, from 1 January 2012, the *ABS MODU Rules* will require compliance with this Guide.

Reference Note

Reference to a paragraph in the *Steel Vessel Rules* or *MODU Rules* is made in the format ‘P-C-S/ss.p.sp’ where ‘P’ is the Part, ‘C’ is the Chapter, ‘S’ is the Section, ‘ss’ is the Subsection, ‘p’ is the Paragraph and ‘sp’ is the Subparagraph.

Reference to a paragraph in this Guide is made in the format ‘S/ss.p.sp’, where ‘S’ is the Section, ‘ss’ is the Subsection, ‘p’ is the Paragraph and ‘sp’ is the Subparagraph.

Reference to a Figure or Table in this Guide is made, respectively, in the format ‘S, Figure #’, or ‘S, Table #’.



GUIDE FOR BUILDING AND CLASSING DRILLSHIPS

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SECTION 1 Introduction

1 General

The requirements for conditions of classification are contained in the separate, generic *ABS Rules for Conditions of Classification – Offshore Units and Structures (Part 1)*.

The requirements contained in this Guide for hull structural design and analysis of drillships are to be used in conjunction with Part 3, Chapter 2 of the *ABS Rules for Building and Classing Mobile Offshore Drilling Units (MODU Rules)*.

1.1 Classification Notations

As described in 1-1-3 of the *MODU Rules*, the notation **Drillship** is assigned to ship type, displacement hull offshore drilling units equipped with propulsion machinery. The notation denotes that the unit is designed and built under ABS survey in accordance with the *MODU Rules*. A complete description of applicable class notations for drillships is provided in Section 1-1-3 of the *ABS Rules for Building and Classing Mobile Offshore Drilling Units (MODU Rules)*.

1.1.1 Additional Class Notations

In addition to the class notations in Section 1-1-3 of the *MODU Rules*, below are additional class notations specific to drillships.

1.1.1(a) Fatigue Life Notation. Drillships designed and built to the requirements in this Guide and maintained in accordance with the applicable ABS requirements are intended to have a structural design life of not less than 20 years for a new build hull structure. The design fatigue life is to be verified to be in compliance with the fatigue criteria in this Guide for a minimum design fatigue life of 20 years. The “design fatigue life” refers to the target value set by the owner or designer, not the value calculated in the analysis.

It is a mandatory requirement that the required fatigue strength analysis for a minimum design fatigue life of 20 years of critical details and welded joints in drillships is to be in accordance with 5/9.1 and 5/9.3, and Appendix 2.

i) **SFA Notation.** The application of spectral fatigue analysis is optional and when requested, spectral fatigue analysis may be applied to assess fatigue strength for anticipated drilling locations during the life of the drillship. Environmental data with operating duration probabilities of each drilling location including transit condition are to be applied in the spectral fatigue analysis. The transit condition is to be considered in the North Atlantic Ocean. The spectral fatigue calculations are to be in accordance with the ABS methodology applicable to offshore installations*. The fatigue life notation **SFA** will be assigned for a minimum design fatigue life of 20 years and published in the *Record*. The fatigue life notation **SFA (number of years)** is assigned if the design fatigue life is specified to be greater than 20 years. The **(number of years)** refers to the design fatigue life equal to 25 years or more (in 5-year increments), as specified by the owner or designer. When the **SFA** notation is requested for 25 years or more, the fatigue analysis of 5/9.1 and 5/9.3 and Appendix 2 is also to satisfy the increased design fatigue life of the drillship.

* Refer to the *ABS Guide for the Fatigue Assessment of Offshore Structures* or the *ABS Guide for Spectral-Based Fatigue Analysis for Floating Production, Storage and Offloading (FPSO) Installations*.

1.1.2(b) Dynamic Loading Approach. The application of Dynamic Loading Approach is optional and when requested, the ABS Dynamic Loading Approach and notation **DLA** may be applied. The ABS Dynamic Loading Approach and notation **DLA** may be applied to assess the adequacy of the drillship structure. In such cases, the drillship will be classed and distinguished in the *Record* by the notation **DLA**. The **DLA** notation will be placed after the appropriate hull classification notation.

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, derrick structure, 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 drillship. The adequacy of the hull structure for all combinations of the dynamic loadings in transit condition using the wave environment of the North Atlantic with a 20-year service life 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 Guide.

1.1.2(c) Hull Construction Monitoring Program. Drillships designed and reviewed to the *Drillship Guide* are to comply with the requirements of the Offshore Hull Construction Monitoring Program in Appendix 5 of this Guide and have the notation **OHCM**.

1.3 Application

1.3.1 General

This Guide contains hull structure, hull interface structure and topside structure design and analysis requirements for the classification of new build drillships. This Guide is intended for use in conjunction with the *ABS Rules for Building and Classing Steel Vessels (Steel Vessel Rules)*, *ABS Rules for Building and Classing Mobile Offshore Drilling Units (MODU Rules)* or other applicable ABS Rules and Guides. This Guide has many cross-references to the *Steel Vessel Rules* and *MODU Rules*. These cross-references are presented in a simple format throughout this Guide in order to provide quick reference to the users, (i.e., 1-2-3/4.5.6 of the Rules denotes Part 1, Chapter 2, Section 3/Subparagraph 4.5.6 of the Rules).

1.3.2 Ship Size and Proportion

The requirements contained in this Guide are applicable to drillships intended for having lengths of 150 meters (492 feet) or more, and having parameters within the range as specified in 3-2-1/1 of the *Steel Vessel Rules*.

1.3.3 Direct Calculations

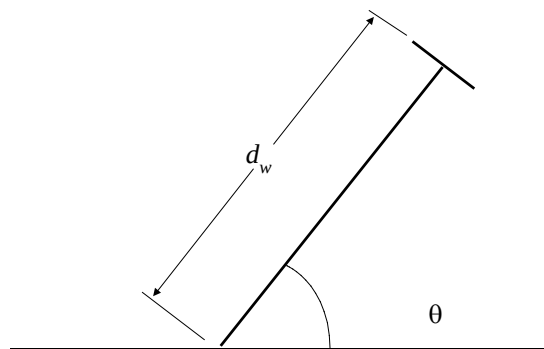
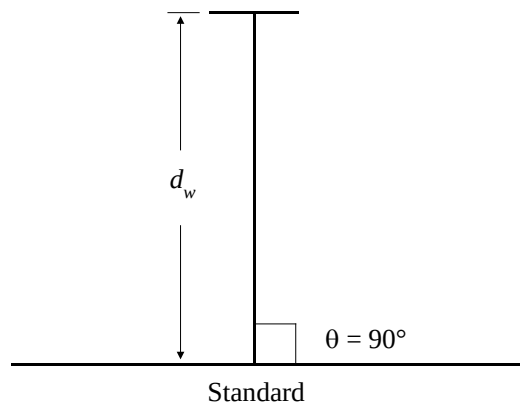
Direct calculations with respect to the determination of design loads and the establishment of alternative strength criteria based on first principles, will be accepted for consideration, provided that all the supporting data, analysis procedures and calculated results are fully documented and submitted for review. In this regard, due consideration is to be given to the environmental conditions, probability of occurrence, uncertainties in load and response predictions, and reliability of the structure in service.

1.5 Internal Members

1.5.1 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 3-1-2/13.3 of the *Steel Vessel Rules* or Section 4, Figure 4, as applicable). For structural members with angle θ (see Section 1, Figure 1) between web and associated plating not less than 75 degrees, the section modulus, web sectional area, and moment of inertia of the “standard” ($\theta = 90$ degrees) section may be used without modification. Where the angle θ is less than 75 degrees, the sectional properties are to be directly calculated about an axis parallel to the associated plating (see Section 1, Figure 1).

FIGURE 1



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

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

where

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

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

Effective section area may be obtained by the following equation:

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

where

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

1.5.2 Detailed Design

The detailed design of internals is to follow the guidance given in 3-1-2/15 of the *Steel Vessel Rules* and in 4/1.5 of this Guide.

See also Appendix 2, "Fatigue Strength Assessment of Drillships".

1.11 Breaks

Special care is to be taken to provide structural reinforcements against local stresses at the ends of the cargo tank spaces, superstructures, etc., and in way of concentrated loads from the drilling derrick, pipe rack, set back, drilling mud storage, etc. The main longitudinal bulkheads are to be suitably tapered at their ends. Where effective longitudinal bulkheads are provided in the poop or deckhouse, they are to be located such as to provide effective continuity between the structure in way of and beyond the main cargo spaces.

1.13 Variations

Drillships of a special type or design, differing from those described in this Guide, will be specially considered on the basis of equivalent strength.

1.15 Loading Guidance (Operating Manual) (1 August 2017)

The drillship is to be provided with a loading manual and a loading instrument as required by 3-2-1/7 and Appendix 3-2-A2 of the *Steel Vessel Rules* for a Category 1 Vessel.

1.17 Alternatives

Any departure from the requirements of this Guide may be considered by ABS on the basis of an additional risk assessment to that required per Subsection 2/3 of this Guide, or at least a separate, clearly identified part of the risk assessment. In the case of such departures, classification is subject to ABS's approval upon a demonstration of equivalence in line with the principles of ABS Guides and Rules, as well as recognized and generally accepted good engineering practice. Risk acceptance criteria are to be developed in line with the principles of the ABS Rules and are subject to ABS's approval. The *ABS Guidance Notes on Risk Assessment Application for the Marine and Offshore Oil and Gas Industries* contain an overview of risk assessment techniques and additional information.

A risk approach justification of alternatives may be applicable either to the drillship as a whole or to individual systems, subsystems or components. As appropriate, account must be given to remote hazards outside of the bounds of the system under consideration. Such account must include incidents relating to remote hazards directly affecting or being influenced by the system under consideration. ABS will consider the application of risk-based techniques in the design of the drillship, verification surveys during construction and surveys for maintenance of class.

Portions of the drillship not included in the risk assessment are to comply with the applicable parts of the ABS Rules and Guides.

The following are the responsibility of the owner/operator and to be considered by ABS:

- i) Risk acceptance criteria
- ii) Hazard identification
- iii) Risk assessment
- iv) Risk management
- v) Compliance of the system under consideration with the applicable requirements of Flag and Coastal State

3 Definitions

The following definitions of symbols and terms are to be understood (in the absence of other specifications) where they appear in the Guide.

3.1 Length

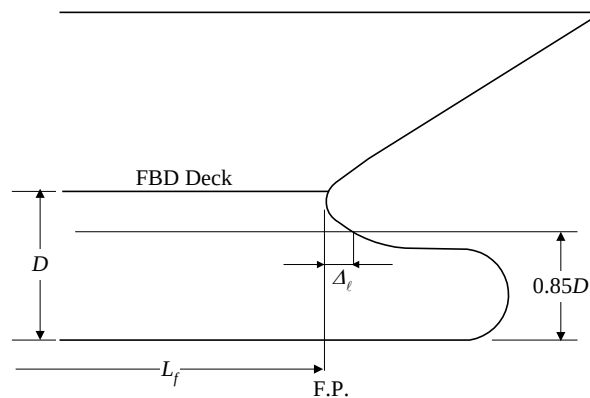
3.1.1 Scantling Length (L)

L is the distance in meters (feet) on the summer load line from the fore side of the stem to the centerline of the rudder stock. For use with the Rules, L is not to be less than 96% and need not be greater than 97% of the length on the summer load line. The forward end of L is to coincide with the fore side of the stem on the waterline on which L is measured.

3.1.2 Freeboard Length (L_f)

L_f is the distance in meters (feet) on a waterline at 85% of the least molded depth measured from the top of the keel from the fore side of the stem to the centerline of the rudder stock or 96% of the length on that waterline, whichever is greater. Where the stem is a fair concave curve above the waterline at 85% of the least molded depth and where the aftermost point of the stem is above the waterline, the forward end of the length, L_f , is to be taken at the aftermost point of the stem above that waterline. See Section 1, Figure 2.

FIGURE 2



3.3 Breadth (B)

B is the greatest molded breadth in meters (feet).

3.5 Depth

3.5.1 Molded Depth (D)

D is the molded depth at side in meters (feet) measured at the middle of L from the molded base line to the top of the freeboard-deck beams. In vessels having rounded gunwales, D is to be measured to the point of intersection of the molded lines of the deck and side shell plating. In cases where watertight bulkheads extend to a deck above the freeboard deck and are to be recorded in the *Record* as effective to that deck, D is to be measured to the bulkhead deck.

3.5.2 Scantling Depth (D_s)

The depth D_s for use with scantling requirements is the distance in meters (feet) from the molded base line to the strength deck as defined in 1/3.13.3 of this Guide.

3.7 Draft (d)

d is the molded draft, and is the distance in meters (feet) from the molded base line to the summer load line.

3.9 Molded Displacement (Δ)

Δ is the molded displacement of the vessel in metric tons (long tons), excluding appendages, taken at the summer load line.

3.11 Block Coefficient (C_b)

C_b is the block coefficient obtained from the following equation:

$$C_b = \Delta / 1.025 L B_{wl} d \quad (\text{SI \& MKS units})$$

$$C_b = 35 \Delta / L B_{wl} d \quad (\text{US units})$$

where

Δ = molded displacement, as defined in 1/3.9.

L = scantling length, as defined in 1/3.1.1

d = draft, as defined in 1/3.7

B_{wl} = the greatest molded breadth at summer load line

3.13 Decks

3.13.1 Freeboard Deck

The freeboard deck normally is the uppermost continuous deck having permanent means for closing all openings. Where a vessel is designed for a special draft, considerably less than that corresponding to the least freeboard obtainable under the International Load Line Regulations, the freeboard deck, for the purpose of the Rules, may be taken as the actual lowest deck from which the draft can be obtained under those regulations.

3.13.2 Bulkhead Deck

The bulkhead deck is the highest deck to which the watertight bulkheads extend and are made effective.

3.13.3 Strength Deck

The strength deck is the deck that forms the top of the effective hull girder at any part of its length. See 3-2-1/11.1 of the *Steel Vessel Rules*.

3.13.4 Superstructure Deck

A superstructure deck is a deck above the freeboard deck to which the side shell plating extends. Except where otherwise specified, the term “superstructure deck” where used in the Rules refers to the first such deck above the freeboard deck.

3.15 Deadweight and Lightship Weight

For the purpose of this Guide, deadweight is the difference in metric tons (long tons) between the displacement of the drillship at its summer load line in water having a specific gravity of 1.025 and the lightship weight. For the purpose of this Guide, lightship weight is the displacement of the drillship with all of its machinery, equipment and outfit, including permanent ballast, required spare parts and liquids in machinery and piping to their working levels but without liquids in storage or reserve supply tanks, items of consumable or variable loads, stores or crews and their effects.

3.17 Mode of Operation

A *Mode of Operation* is a condition or manner in which a drillship may operate or function while on location or in transit and includes the following.

3.17.1 Normal Drilling Condition

A *Normal Drilling Condition* is a condition wherein a unit is on location to perform drilling or other related functions, and combined environmental and operational loading are within the appropriate design limits established for such operations. The drillship may be either afloat or moored to the sea bed.

3.17.2 Severe Storm Condition

A *Severe Storm Condition* is a condition wherein a drillship may be subjected to the most severe environmental loadings for which it was designed. During the severe storm condition, it may be necessary to discontinue drilling or similar operations due to the severity of the environmental loadings. The drillship may be either afloat or moored to the sea bed.

3.17.3 Transit Conditions

Transit Conditions are all drillship movements from one geographical location to another.

3.19 Units

This Guide is written in three systems of units, viz., SI units, MKS units and US customary units. Each system is to be used independently of any other system.

Unless indicated otherwise, the format of presentation in this Guide of the three systems of units is as follows:

SI units (MKS units, US customary units)



SECTION 2 Design Considerations

1 General Requirements

1.1 General

The proposed scantlings are to comply with the requirements specified in this Guide and where referenced in the *Steel Vessel Rules* and *MODU Rules*. The hull structure strength requirements specified in this Guide are based on a “net” scantling approach. The drillship is to be designed for unrestricted service, unless a **Restricted Service** notation is requested. The design criteria for the hull structure of drillships are applied in two phases. In the first phase, initial design scantlings of the structural hull design are selected, considering nominal, maximum expected loadings that a component is likely to experience during its lifetime of operation. This phase is called the Initial Scantling Evaluation (ISE) and is governed by the criteria contained in Section 4. A second phase 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 phase is referred to as the Total Strength Assessment (TSA) and is governed by the criteria specified in Section 5.

The strength requirements of the hull structure specified in the ISE phase and the TSA phase are based on net scantlings. The finite element structural analyses required in the TSA phase may be carried out using either net scantlings or gross scantlings. If the TSA analyses are carried out using gross scantlings, the resulting stresses are to be converted to net scantling stresses according to 5/1.7 to check the strength requirements. The nominal design corrosion values given in Section 2, Table 1 are deducted from gross scantlings to obtain net scantlings. Owner’s extra scantlings (i.e., Owner’s specified additional thickness), as included in the vessel’s design specifications, are not to be used in the evaluation.

The application of the hull design criteria to reflect the mode of operation can be accomplished through the introduction of a series of Environmental Severity Factors (ESFs). Reference is to be made to 3/1.1 and Appendix 1 for the applicable structural design and analysis criteria that have been modified to reflect site-specific service conditions. ESFs for North Atlantic environmental conditions are to be used as a minimum requirement for the transit, normal drilling and severe storm conditions. For normal drilling conditions, environmental conditions provided by the owner or designer may be used in lieu of the North Atlantic environmental conditions for TSA strength evaluation. If the environmental conditions provided by the owner or designer are more severe than the North Atlantic conditions, then the more severe environmental condition are required to be used as the minimum requirement for the normal drilling condition.

The design and analysis requirements for the topside and hull interface structures are contained in Section 7. The strength requirements of these structures are based on gross scantlings and are in accordance with offshore practice.

1.3 Initial Scantling Requirements

For unrestricted service the longitudinal strength of the hull structure is to satisfy the hull girder strength requirements of Subsection 4/3. The total hull girder shear force and bending moment is to be considered as the maximum algebraic sum of the maximum still water shear force and bending moment for on-site conditions (normal drilling or severe storm) or transit condition combined with the corresponding wave-induced shear force and bending moments for on-site or transit. The initial thickness of plating, the section modulus of longitudinals/stiffeners, and the scantlings of the transverse bulkhead structures of the hull structure are to be determined in accordance with the initial scantling criteria of Section 4 for the “net” scantlings. When using “net” scantlings the relevant nominal design corrosion values given in Section 2, Table 1 are then added to obtain the full or “gross” scantling requirements.

1.5 Total Strength Assessment – Failure Modes

In the total strength assessment required in Section 5, either “net” scantling or “gross” scantling values may be used in the finite element model. When “gross” scantlings are used the resulting stresses are to be converted to net scantling stresses according to 5/1.7 to check the strength requirements which are based on net scantlings.

A total strength assessment of the structures, determined on the basis of the initial strength criteria in Section 4 is to be carried out in accordance with Section 5 against the following four failure modes:

1.5.1 Material Yielding

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

1.5.2 Buckling and Ultimate Strength

For each individual member, plate or stiffened panel, the buckling and ultimate strength is to be in compliance with the requirements specified in Subsection 5/5. In addition, the hull girder ultimate strength is to be in accordance with 4/3.5 and Appendix 3.

1.5.3 Fatigue

The fatigue strength of structural details and welded joints in highly stressed regions is to be analyzed in accordance with Subsection 5/9 and Appendix 2.

1.5.4 Hull Girder Ultimate Strength

The hull girder ultimate longitudinal bending capacities for either hogging or sagging conditions are to be evaluated in accordance with Appendix 3. The hull girder ultimate bending capacity for the severe storm or North Atlantic environmental conditions, whichever is more severe, is to satisfy the limit state specified in 4/3.9.

1.7 Topside and Hull Interface Structures

The hull design must consider the interface between deck-mounted (or above-deck) equipment modules and the hull structure. 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, derrick support, flare boom foundation, gantry foundation, mooring, blow-out preventer (BOP) and lower marine riser package (LMRP) support foundations, 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 plating, deck longitudinals and upper parts of longitudinal and transverse bulkhead structures, as well as foundations of the hull-mounted equipment. The analysis of the hull interface structure as defined above is to be performed using direct calculation of local 3-D hull interface finite element models as described in Subsection 7/1.

The structural strength of topside structures such as mud modules, mud process modules, subsea control module, drill floor and substructure, riser storage area, well test area, BOP guide frame, helicopter deck, etc., are to be assessed according to 7/3.5

1.9 Material Selection

Material selection for hull structures, hull interface structures and topside structures are included in Appendix 6.

3 Net Scantlings and Nominal Design Corrosion Values

3.1 General

As indicated in 2/1.1, the strength criteria specified in this Guide are based on a “net” scantling approach. The “net” thickness or scantlings correspond to the minimum strength requirements acceptable for classification. In addition to the coating protection specified in the *Steel Vessel Rules* for all ballast tanks, nominal design corrosion values for plating and structural members as given in Section 2, Table 1 are to be 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 2/3.3. These minimum values are introduced solely for the purpose of scantling requirements and strength criteria as indicated in 2/1.1, 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, it is recommended that additional design margins are 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.

3.3 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 Section 2, Table 1 as follows:

- i) 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.
- ii) 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.
- iii) 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.
- iv) For void or dry 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.

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. For example, the calculated required net thickness is 11.27 mm with a nominal design corrosion margin of 1.25 mm based on a 25 year design life. Then the rounded required net thickness is 11.5 mm. The offered gross thickness is 12.5 mm, therefore the offered net thickness is 11.25 mm (12.5 mm – 1.25 mm). The calculated required gross thickness is 12.52 mm (11.27 mm + 1.25 mm) and the rounded required gross thickness is 12.5 mm. The offered net thickness of 11.25 mm is therefore acceptable, rather than the rounded required net thickness of 11.5 mm.

TABLE 1
Nominal Design Corrosion Values (NDCV) ^(1, 2)

<i>Structural Element/Location</i>		<i>Nominal Design Corrosion Values in mm (in.)</i>		
		<i>Liquid Tank (Oil)</i>	<i>Ballast Tank/ Liquid Tank (Water/Mud)</i>	<i>Void/Dry Space</i>
Deck Plating		1.0 (0.04)	2.0 (0.08)	1.0 (0.04)
Side Shell Plating		N.A.	1.5 (0.06)	1.0 (0.04)
Bottom Plating and Bilge Strakes		N.A.	1.0 (0.04)	1.0 (0.04)
Inner Bottom Plating	Ballast Tank/Liquid Tank (Water/Mud)	1.5 (0.06)	2.0 (0.08)	1.5 (0.06)
	Void/Dry Space	1.0 (0.04)	1.5 (0.06)	1.0 (0.04)
Moonpool Bulkhead and Transom (Exposed to atmosphere or sea)		1.0 (0.04)	1.5 (0.06)	1.0 (0.04)
Tight/Non-Tight Tween Deck Tight/Non-Tight Flat Tight Stringer	Liquid Tank (Oil)	1.0 (0.04)	1.5 (0.06)	1.0 (0.04)
	Ballast Tank/Liquid Tank (Water/Mud)	1.5 (0.06)	2.0 (0.08)	1.5 (0.06)
	Void/Dry Space	1.0 (0.04)	1.5 (0.06)	1.0 (0.04)
Other Longitudinal Bulkhead Plating Transverse Bulkhead Plating	Liquid Tank (Oil)	1.0 (0.04)	1.5 (0.06)	1.0 (0.04)
	Ballast Tank/Liquid Tank (Water/Mud)	1.5 (0.06)	1.5 (0.06)	1.0 (0.04)
	Void/Dry Space	1.0 (0.04)	1.0 (0.04)	1.0 (0.04)
Deck Stiffeners and Deck Supporting Members Stiffeners and supporting members on tank top and supporting members in Splash Zone (1.5 meters down from tank top)		1.5 (0.06)	2.0 (0.08)	1.0 (0.06)
Double Bottom Tanks Internals (Stiffeners, Floors and Girders)		N.A.	2.0 (0.08)	1.0 (0.06)
Double Bottom Tight Girder	Ballast Tank/Liquid Tank (Water/Mud)	N.A.	2.0 (0.08)	1.5 (0.06)
	Void/Dry Space	N.A.	1.5 (0.06)	1.0 (0.04)
Vertical Stiffeners and Supporting Members Elsewhere ⁽³⁾		1.0 (0.04)	1.0 (0.04)	1.0 (0.04)
Non-vertical Longitudinals/Stiffeners and Supporting Members Elsewhere ⁽⁴⁾		1.5 (0.06)	2.0 (0.08)	1.0 (0.04)
Exposed to atmosphere on both sides		1.0 (0.04)		

Notes

- 1 It is recognized that corrosion depends on many factors including coating properties, cargo composition 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 Vertical elements are defined as elements sloped at an angle greater than 25° to the horizontal line.
- 4 Non vertical elements are defined as elements sloped at an angle less than 25° to the horizontal line.



SECTION 3 Loads

1 General

1.1 The Concept and Application of Environmental Severity Factors

The structural design loads for drillships shall consider transit, drilling and severe storm conditions. To adjust the loadings and load effects produced at the on-site conditions (compared to the transit unrestricted ocean condition), a series of “Environmental Severity Factors” (ESFs) can be derived for the normal drilling and severe storm conditions that are specified by the Owner. 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 unrestricted ocean service and the on-site conditions. 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 cargo loading patterns and external drafts. The implied value of all ESFs of both the alpha and beta types for the unrestricted full ocean condition is 1.0.

The determination of the environmental severity factors is to be carried out in accordance with Appendix 1 using the ABS Eagle Drillship program. The values of β to be used in this Guide is to be in accordance with 2/1.1. The values of α to be used in this Guide is not to be more than 1.0.

1.3 Load Components

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

3 Static Loads

The sign convention for bending moments and shear forces is as follows in Section 3, Figure 1.

3.1 Still-water Bending Moment and Shear Force

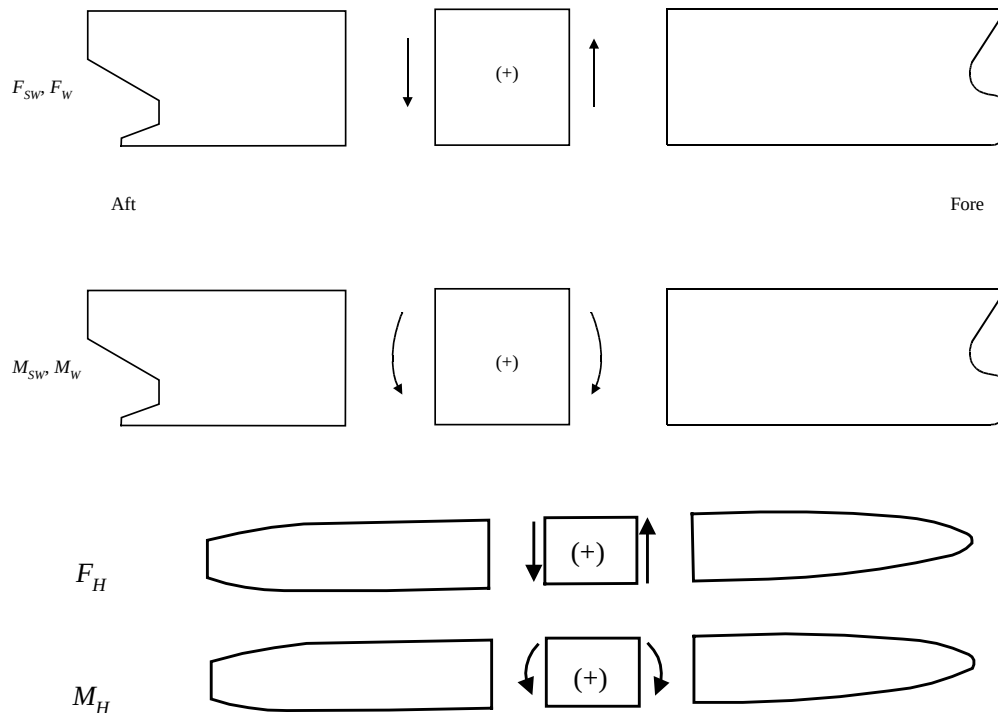
Still-water bending moment and shear force calculations, determining the bending moment and hull girder shear force values along the drillship’s entire length, are to be submitted together with the distribution of lightship weights.

The calculations are to consider the loading conditions for departure, arrival, transit, normal drilling and severe storm conditions including the effect of bunker, fresh water and consumable stores. Where loading conditions are considered more severe, calculations for such conditions are to be submitted in addition to those listed.

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.

Loading patterns based on the operational modes of transit, normal drilling and severe storm conditions shall be considered in determining local static loads.

FIGURE 1
Sign Convention



5 Wave-induced Loads

Where a direct calculation of the wave-induced loads is not available, the approximation equations given below with Environmental Severity Factors (ESFs) may be used to calculate the design loads in the transit, normal drilling and severe storm conditions.

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

5.1 Vertical Wave Induced Longitudinal Bending Moments and Shear Forces

5.1.1 Vertical Wave Bending Moment Amidships

The wave bending moment, expressed in kN-m (tf-m, Ltf-ft), for transit, normal drilling and severe storm conditions may be obtained from the following equations.

$$M_{ws} = -k_1 \beta_{VBM} C_1 L^2 B (C_b + 0.7) \times 10^{-3} \quad \text{Sagging Moment}$$

$$M_{wh} = +k_2 \beta_{VBM} C_1 L^2 B C_b \times 10^{-3} \quad \text{Hogging Moment}$$

where

$$k_1 = 110 \text{ (11.22, 1.026)}$$

$$k_2 = 190 \text{ (19.37, 1.772)}$$

$$\beta_{VBM} = \text{ESF for vertical bending moment as defined in Appendix 1}$$

$$\begin{aligned}
C_1 &= 10.75 - \left(\frac{300 - L}{100} \right)^{1.5} & 90 \leq L \leq 300 \text{ m} \\
&= 10.75 & 300 < L \leq 350 \text{ m} \\
&= 10.75 - \left(\frac{L - 350}{150} \right)^{1.5} & 350 \leq L \leq 500 \text{ m} \\
C_1 &= 10.75 - \left(\frac{984 - L}{328} \right)^{1.5} & 295 \leq L \leq 984 \text{ ft} \\
&= 10.75 & 984 < L < 1148 \text{ ft} \\
&= 10.75 - \left(\frac{L - 1148}{492} \right)^{1.5} & 1148 \leq L \leq 1640 \text{ ft} \\
L &= \text{length of vessel, as defined in 1/3.1.1, in m (ft)} \\
B &= \text{breadth of vessel, as defined in 1/3.3, in m (ft)} \\
C_b &= \text{block coefficient, as defined in 1/3.11, but not to be taken less than 0.6}
\end{aligned}$$

5.1.2 Envelope Curve of Wave Bending Moment

The vertical 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 Section 3, Figure 2.

5.1.3 Wave Shear Force

The envelopes of maximum shearing forces induced by waves, F_w , as shown in Section 3, Figures 3 and 4, may be obtained from the following equations.

$$\begin{aligned}
F_{wp} &= +k \beta_{VSF} F_1 C_1 L B (C_b + 0.7) \times 10^{-2} & \text{for positive shear force} \\
F_{wn} &= -k \beta_{VSF} F_2 C_1 L B (C_b + 0.7) \times 10^{-2} & \text{for negative shear force}
\end{aligned}$$

where

$$\begin{aligned}
F_{wp}, F_{wn} &= \text{maximum shearing force induced by wave, in kN (tf, Ltf)} \\
\beta_{VSF} &= \text{ESF for vertical shear force as defined in Appendix 1} \\
k &= 30 (3.059, 0.2797) \\
F_1 &= \text{distribution factor, as shown in Section 3, Figure 3} \\
F_2 &= \text{distribution factor, as shown in Section 3, Figure 4}
\end{aligned}$$

C_1 , L , B and C_b are as given in 3/5.1.1.

FIGURE 2
Distribution Factor M

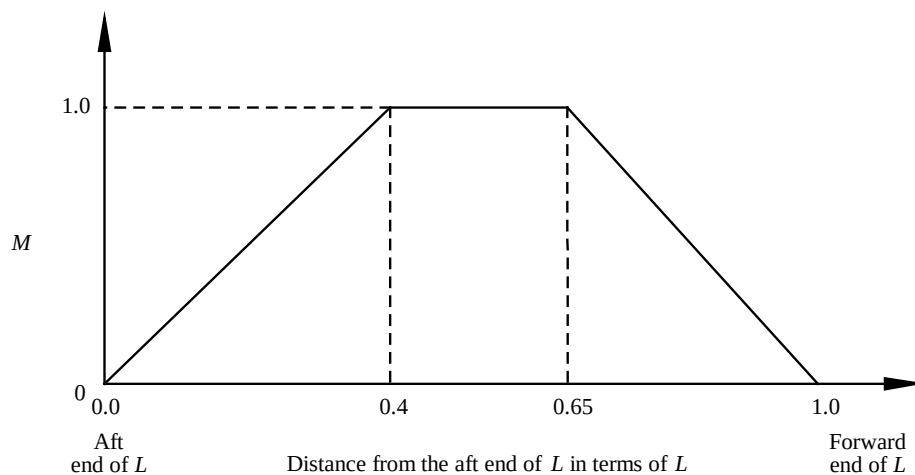


FIGURE 3
Distribution Factor F_1

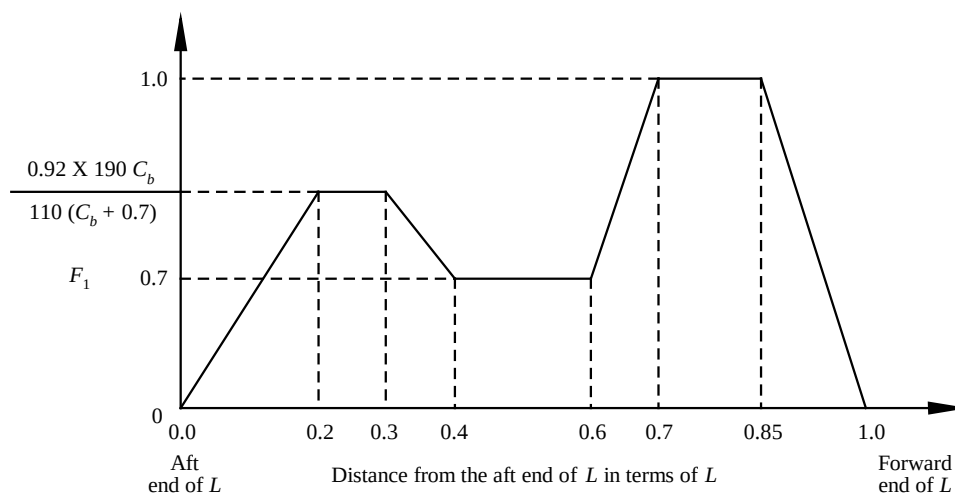
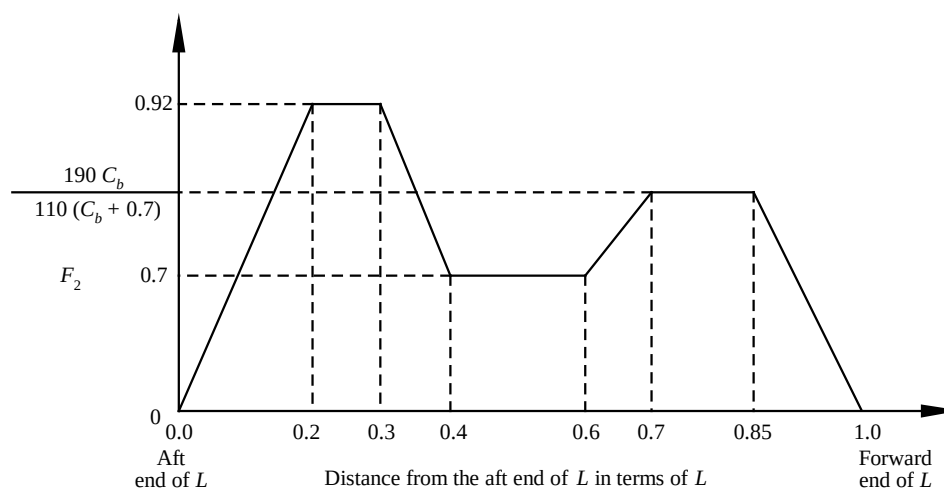


FIGURE 4
Distribution Factor F_2



5.3 Horizontal Wave Induced Bending Moment and Shear Forces

5.3.1 Horizontal Wave Bending Moment

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

$$M_H = \pm m_h K_3 \beta_{HBM} C_1 L^2 D C_b \times 10^{-3}$$

where

m_h = distribution factor, as given by Section 3, Figure 5

K_3 = 180 (18.34, 1.68)

β_{HBM} = ESF for horizontal bending moment as defined in Appendix 1

C_1 , L and C_b are as given in 3/5.1.1.

D = depth of vessel, as defined in 1/3.5, in m (ft)

5.3.2 Horizontal Wave Shear Force

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

$$F_H = \pm f_h k \beta_{HSF} C_1 L D (C_b + 0.7) \times 10^{-2}$$

where

f_h = distribution factor as given in Section 3, Figure 6

k = 36 (3.67, 0.34)

β_{HSF} = ESF for horizontal shear force as defined in Appendix 1

C_1 , L and C_b are as defined in 3/5.1.1 and D is defined in 3/5.3.1.

FIGURE 5
Distribution Factor m_h

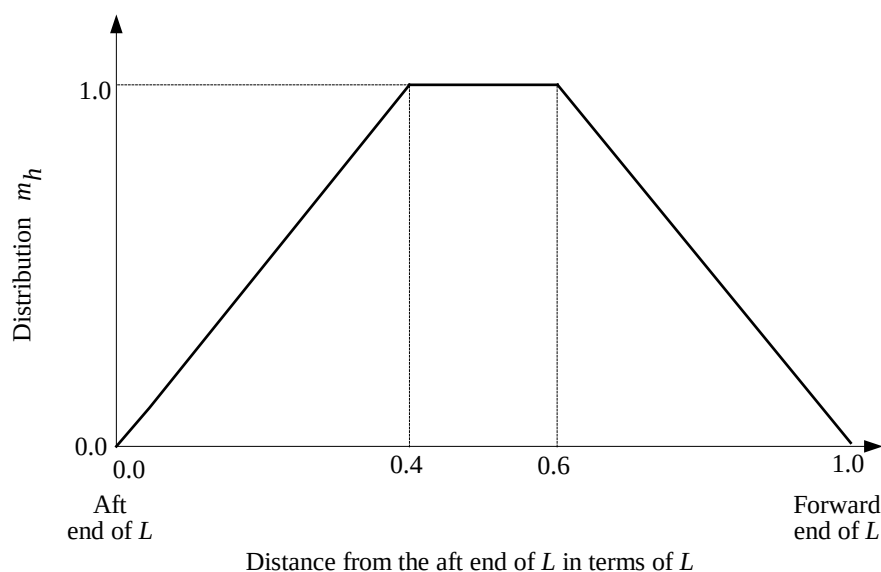
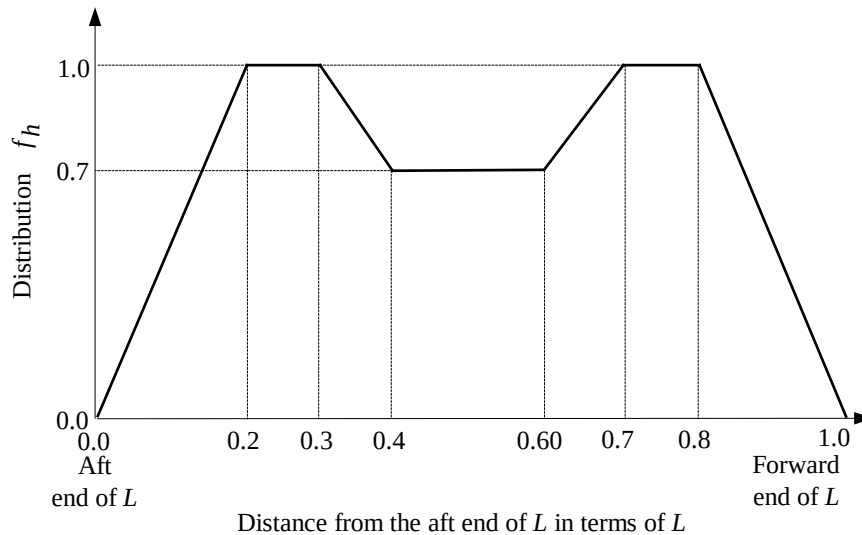


FIGURE 6
Distribution Factor f_h



5.5 External Pressures

5.5.1 Pressure Distribution

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

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

where

- ρg = specific weight of sea water
= 1.005 N/cm²-m (0.1025 kgf/cm²-m, 0.4444 lbf/in²-ft)
- h_s = hydrostatic pressure head in still water, in m (ft)
- $\beta_{EPS/EPP}$ = ESF for external pressure starboard/port, as defined in Subsection A1/3
- k_u = load factor, and may be taken as unity unless otherwise specified.
- h_{de} = hydrodynamic pressure head induced by the wave, in m (ft), may be calculated as follows:
= $k_c h_{di}$

where

- k_c = correlation factor for a specific combined load case, as given in 3/7.3 and Subsection 3/9
- h_{di} = hydrodynamic pressure head, in m (ft), at location i ($i=1, 2, 3, 4$ or 5 ; see Section 3, Figure 7)
= $k_\ell \alpha_i h_{do}$ in m (ft)
- k_ℓ = distribution factor along the length of the drillship
= $1 + (k_{\ell o} - 1) \cos \mu$, $k_{\ell o}$ is as given in Section 3, Figure 8
= 1.0 amidships
- h_{do} = $1.36 k C_1$ in m (ft)

C_1	=	as defined in 3/5.1.1
k	=	1 (1, 3.281)
α_i	=	distribution factor around the drillship's girth at location i .
	=	$1.00 - 0.25 \cos \mu$ for $i = 1$, at WL, starboard
	=	$0.40 - 0.10 \cos \mu$ for $i = 2$, at bilge, starboard
	=	$0.30 - 0.20 \sin \mu$ for $i = 3$, at bottom centerline
	=	$2\alpha_3 - \alpha_2$ for $i = 4$, at bilge, port
	=	$0.75 - 1.25 \sin \mu$ for $i = 5$, at WL, port
		α_i at intermediate locations of i may be obtained by linear interpolation.
μ	=	wave heading angle, to be taken from 0° to 90° (0° for head sea, 90° for beam sea for wave coming from starboard)

The distribution of the total external pressure including static and hydrodynamic pressure is illustrated in Section 3, Figure 9.

5.5.2 Extreme Pressures

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

5.5.3 Simultaneous Pressures

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

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

where

$$\beta_{EPS/EPP} = \text{ESF for external pressure starboard/port, as defined in Subsection A1/3}$$

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

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

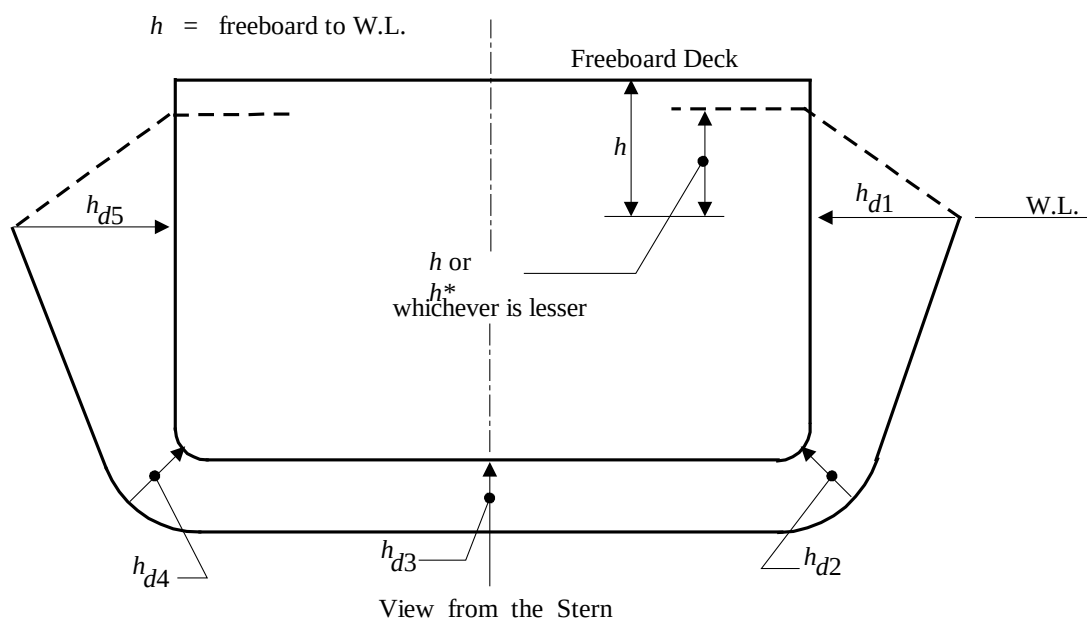
where

x	=	distance from A.P. to the station considered, in m (ft)
x_o	=	distance from A.P. to the reference station*, in m (ft).
L	=	vessel length, as defined in 1/3.1.1, in m (ft)
μ	=	wave heading angle, to be taken from 0° to 90°
k_{fo}	=	± 1.0 , as specified in Section 3, Table 1

* The reference station is the point along the drillship's length where the wave trough or crest is located and may be taken as the target location of hull girder loads of the 3-D structural model.

The simultaneous pressure distribution around the drillship's girth is to be determined based on the wave heading angles specified in Subsections 3/7 and 3/9.

FIGURE 7
Distribution of h_{di}



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

FIGURE 8
Pressure Distribution Function $k_{\ell o}$

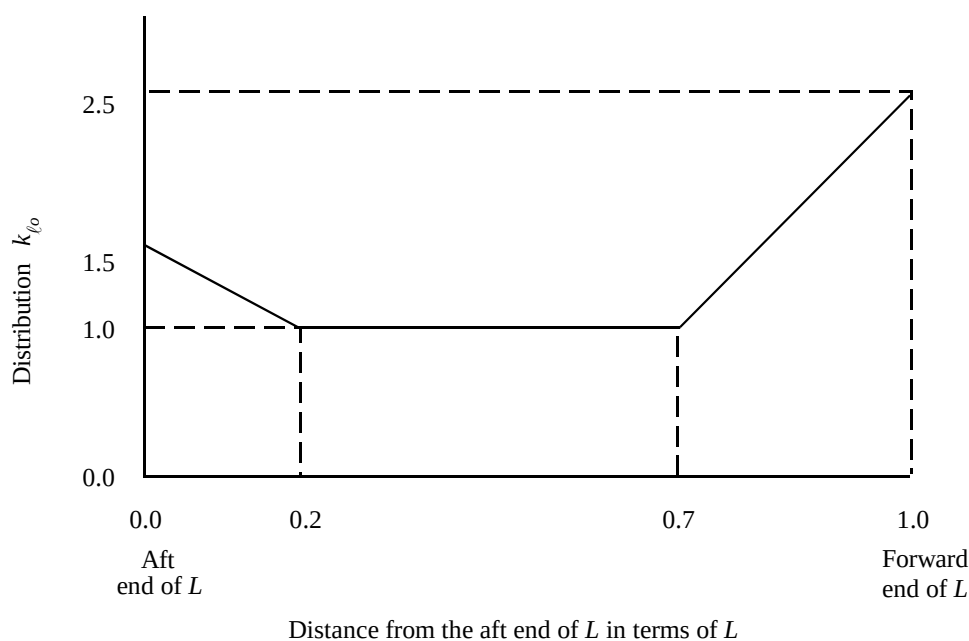
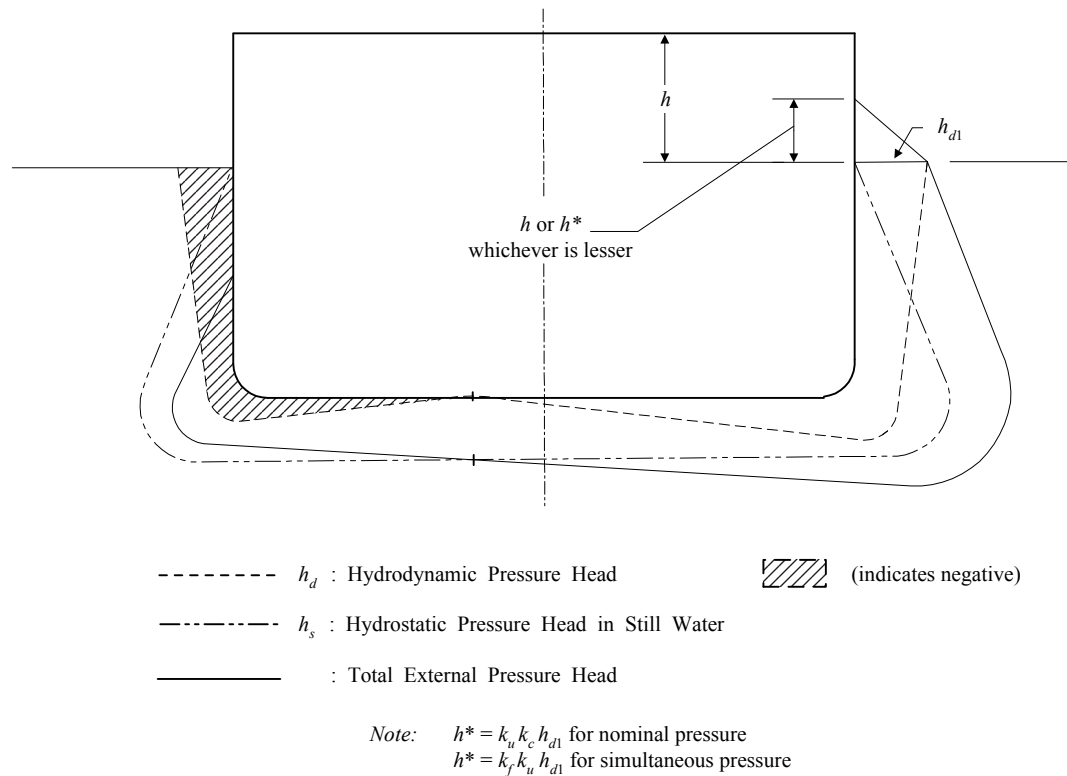


FIGURE 9
Illustration of Determining Total External Pressure



5.7 Internal Pressures – Inertia Forces and Added Pressure Heads

5.7.1 Ship Motions and Accelerations

In determining cargo pressures and liquid pressures, the dominating drillship motions, pitch and roll, and the resultant accelerations induced by the wave are required. When a direct calculation is not available, the equations given below may be used.

5.7.1(a) *Pitch*. The pitch amplitude: (positive bow up)

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

The pitch natural period:

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

where

β_{PMO} = ESF for pitch motion, as defined in Subsection A1/3

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

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

d_i = draft amidships for the relevant loading conditions.

L and C_b are defined in 1/3.1.1 and 1/3.11, respectively.

5.7.1(b) *Roll*. The roll amplitude: (positive starboard down)

$$\begin{aligned}\theta &= C_R \beta_{RMO} (35 - k_\theta C_{di} \Delta / 1000) && \text{if } T_r > 20 \text{ seconds.} \\ \theta &= C_R \beta_{RMO} (35 - k_\theta C_{di} \Delta / 1000) (1.5375 - 0.027 T_r) && \text{if } 12.5 \leq T_r \leq 20 \text{ seconds} \\ \theta &= C_R \beta_{RMO} (35 - k_\theta C_{di} \Delta / 1000) (0.8625 + 0.027 T_r) && \text{if } T_r \leq 12.5 \text{ seconds}\end{aligned}$$

where

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

$$k_\theta = 0.005 \text{ (0.05, 0.051)}$$

$$C_R = 1.05$$

$$\beta_{RMO} = \text{ESF for roll motion, as defined in Subsection A1/3}$$

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

$$d_i = \text{draft amidships for the relevant loading conditions, m (ft)}$$

$$d_f = \text{draft, as defined in 1/3.7, m (ft)}$$

$$\Delta = k_d L B d_f C_b \text{ kN (tf, Ltf)}$$

$$k_d = 10.05 \text{ (1.025, 0.0286)}$$

L and B are as defined in Subsection 1/3.

The roll natural motion period:

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

where

$$k_4 = 2 \text{ (1.104) for } k_r, GM \text{ in m (ft)}$$

$$k_r = \text{roll radius of gyration, in m (ft), and may be taken as}$$

$$= 0.35B \text{ for draft greater than } 2/3 d_f$$

$$= 0.45B \text{ for draft between } 1/2 d_f \text{ and } 2/3 d_f$$

$$= 0.39B \text{ for draft not greater than } 1/2 d_f$$

$$GM = \text{metacentric height, to be taken as:}$$

$$= GM \text{ (full) for full draft}$$

$$= 1.1 GM \text{ (full) for } 9/10 d_f$$

$$= 1.5 GM \text{ (full) for } 2/3 d_f$$

$$= 2.0 GM \text{ (full) for } 1/2 d_f$$

Linear interpolation may be used for intermediate drafts.

$$GM \text{ (full)} = \text{metacentric height for full draft condition}$$

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

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

$$a_v = C_v \beta_{VAC} k_v a_o g \quad \text{m/sec}^2 \text{ (ft/sec}^2\text{)} \quad \text{positive downward}$$

$$a_\ell = C_\ell \beta_{LAC} k_\ell a_o g \quad \text{m/sec}^2 \text{ (ft/sec}^2\text{)} \quad \text{positive forward}$$

$$a_t = C_t \beta_{TAC} k_t a_o g \quad \text{m/sec}^2 \text{ (ft/sec}^2\text{)} \quad \text{positive starboard}$$

where

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

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

$$k_o = 1.34 - 0.47C_b$$

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

$$\mu = \text{wave heading angle in degrees, } 0^\circ \text{ for head sea, and } 90^\circ \text{ for beam sea for wave coming from starboard}$$

$$\beta_{VAC} = \text{ESF for vertical acceleration, as defined in Subsection A1/3}$$

$$\beta_{LAC} = \text{ESF for longitudinal acceleration, as defined in Subsection A1/3}$$

$$\beta_{TAC} = \text{ESF for transverse acceleration, as defined in Subsection A1/3}$$

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

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

$$C_\ell = 0.35 - 0.0005(L - 200) \quad \text{for } L \text{ in m}$$

$$= 0.35 - 0.00015(L - 656) \quad \text{for } L \text{ in ft}$$

$$k_\ell = 0.5 + 8y/L$$

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

$$k_t = 0.35 + y/B$$

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

$$x = \text{longitudinal distance from the A.P. to the station considered, in m (ft)}$$

$$y = \text{vertical distance from the waterline to the point considered, in m (ft), positive upward}$$

$$z = \text{transverse distance from the centerline to the point considered, in m (ft), positive starboard}$$

$$g = \text{acceleration of gravity} = 9.8 \text{ m/sec}^2 \text{ (32.2 ft/sec}^2\text{)}$$

5.7.2 Internal Pressures

5.7.2(a) *Distribution of Internal Pressures.* The internal pressure, p_i (positive toward tank boundaries) for a completely or partially filled tank may be obtained from the following formula:

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

where

$$p_o = (p_{vp} - p_n) \geq 0 \quad \text{in liquid tank with oil or water/mud, N/cm}^2 \text{ (kgf/cm}^2\text{, lbf/in}^2\text{)}$$

$$= 0 \quad \text{in ballast tank}$$

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

- p_n = 2.06 N/cm² (0.21 kgf/cm², 3.00 lbf/in²)
- ρg = specific weight of the liquid, to be not less than 1.005 N/cm²-m (0.1025 kgf/cm²-m, 0.4444 lbf/in²-ft)
- η = local coordinate in vertical direction for tank boundaries measuring from the top of the completely filled tanks, or from the free surface of the liquid for a partially filled tank, as shown in Section 3, Figure 10, in m (ft)
- $\Delta\eta$ = 0 for the liquid of ballast tank whose tank top extends to the upper deck or for a partially-filled tank whose the free surface of the liquid is below the tank top
 = a distance equivalent to $\frac{2}{3}$ of the distance from tank top to the top of the overflow (The exposed height is minimum 760 mm above freeboard deck or 450 mm above superstructure deck.) for the lower tank whose tank top does not extend to the upper deck.
- k_s = load factor
 = 1.0 for all loads from ballast tanks
 = 0.878 for ρg of 1.005 N/cm²-m (0.1025 kgf/cm²-m, 0.4444 lbf/in²-ft) for all loads from liquid tank with oil or water/mud
 = 1.0 for ρg of 1.118 N/cm²-m (0.114 kgf/cm²-m, 0.4942 lbf/in²-ft) and above for all loads from liquid tank with oil or water/mud
 For ρg of oil or water/mud between 1.005 N/cm²-m (0.1025 kgf/cm²-m, 0.4444 lbf/in²-ft) and 1.118 N/cm²-m (0.114 kgf/cm²-m, 0.4942 lbf/in²-ft), the factor k_s may be determined by interpolation
- k_u = load factor and may be taken as unity unless otherwise specified
- h_d = wave-induced internal pressure head, including inertial force and added pressure head.
 = $k_c(\eta a_i/g + \Delta h_i)$ in m (ft)
- k_c = correlation factor and may be taken as unity unless otherwise specified
- a_i = effective resultant acceleration at the point considered, and may be approximated by:

$$0.71C_{dp}[w_v a_v + w_\ell (\ell/h) a_\ell + w_t (b/h) a_t] \text{ m/sec}^2 \text{ (ft/sec}^2\text{)}$$

C_{dp} is specified in 3/5.7.2(d).

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

w_v , w_ℓ and w_t are weighted coefficients, showing directions, as specified in Section 3, Tables 1 and 2.

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

In general, the added pressure head may be calculated based on the distance from the reference point of the tank to the point considered in the direction of gravitational force in the vessel-fixed coordinate system. The reference point is (1) the highest point of the tank boundary after the inclination of the tank due to roll and pitch, or (2) the average height of the points, after roll and pitch, which is $\Delta\eta$ above the top of the tank at the overflow, whichever is greater.

For prismatic tanks on starboard side, whose tank top extends to the upper deck, added pressure head may be calculated as follows:

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

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

$$\zeta_e = b - \zeta$$

$$\eta_e = \eta$$

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

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

$$\zeta_e = \zeta - \delta_b$$

$$\eta_e = \eta - \delta_h$$

ξ, ζ, η are the local coordinates, in m (ft), for the point considered with respect to the origin in Section 3, Figure 10.

C_{ru} is specified in 3/5.7.2(d).

δ_b and δ_h are the local coordinate adjustments, in m (ft), for the point considered with respect to the origin shown in Section 3, Figure 10.

where

$$\theta_e = 0.71 C_\theta \theta$$

$$\phi_e = 0.71 C_\phi \phi$$

$$\ell = \text{length of the tank, in m (ft)}$$

$$h = \text{depth of the tank, in m (ft)}$$

$$b = \text{breadth of the tank considered, in m (ft)}$$

ϕ and θ are pitch and roll amplitudes, as given in 3/5.7.1(a) and 3/5.7.1(b).

C_ϕ and C_θ are weighted coefficients, showing directions as given in Section 3, Tables 1 and 2.

For prismatic lower tanks on starboard side, whose tank top does not extend to the upper deck, the added pressure head may be calculated as follows assuming the reference point based on the average height of the overflow.

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

$$\Delta h_i = (\xi - \ell/2) \sin(-\phi_e) + C_{ru} (\zeta_e \sin \theta_e \cos \phi_e + \eta_e \cos \theta_e \cos \phi_e - \eta_e)$$

$$\zeta_e = b_a - \zeta$$

$$\eta_e = \eta + \Delta\eta$$

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

$$\Delta h_i = (\ell/2 - \xi) \sin \phi_e + C_{ru} \{ \zeta_e \sin(-\theta_e) \cos \phi_e + \eta_e \cos \theta_e \cos \phi_e - \eta_e \}$$

$$\zeta_e = \zeta - b_a$$

$$\eta_e = \eta + \Delta\eta$$

b_a is the transverse distance of over flow from ξ axis. All other parameters are as defined above.

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

5.7.2(c) *Simultaneous Internal Pressures.* In performing a 3D structural analysis, the internal pressures may be calculated in accordance with 3/5.7.2(a) and 3/5.7.2(b) above for tanks in the mid-body. For tanks in the fore or aft body, the pressures are to be determined based on linear distributions of accelerations and motions along the length of the vessel according to 3/5.7.1(c).

5.7.2(d) *Definition of Tank Shape and Associated Coefficients*

i) *Rectangular Tank*

The following tank is considered as a rectangular tank:

$$b/b_1 \leq 3.0 \text{ or } h/h_1 \leq 3.0$$

where

b = extreme breadth of the tank considered

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

h = extreme height of the tank considered

h_1 = least height of double bottom part of the tank considered, as shown in Section 3, Figure 10

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

$$C_{dp} = 1.0$$

$$C_{ru} = 1.0$$

ii) *J-shaped Tank*

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

$$b/b_1 \geq 5.0 \text{ and } h/h_1 \geq 5.0$$

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

$$C_{dp} = 0.7$$

$$C_{ru} = 1.0$$

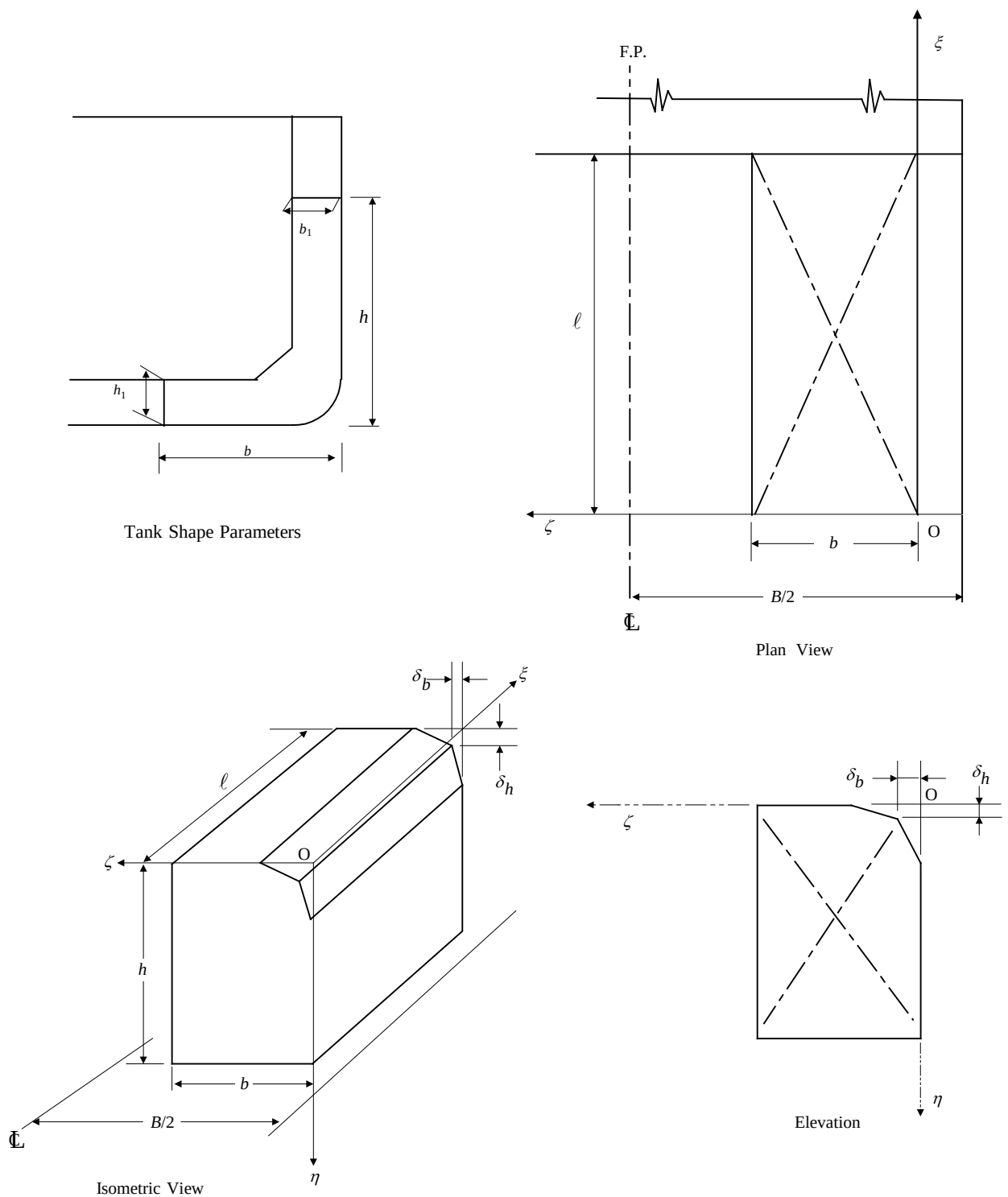
iii) In the case where the minimum tank ratio of b/b_1 or h/h_1 , whichever is lesser, is greater than 3.0 but less than 5.0, the coefficient C_{dp} of the tank is to be determined by the following interpolation:

An intermediate tank between rectangular and J-shaped tank:

$$C_{dp} = 1.0 - 0.15 (\text{the lesser of } b/b_1 \text{ or } h/h_1 - 3.0)$$

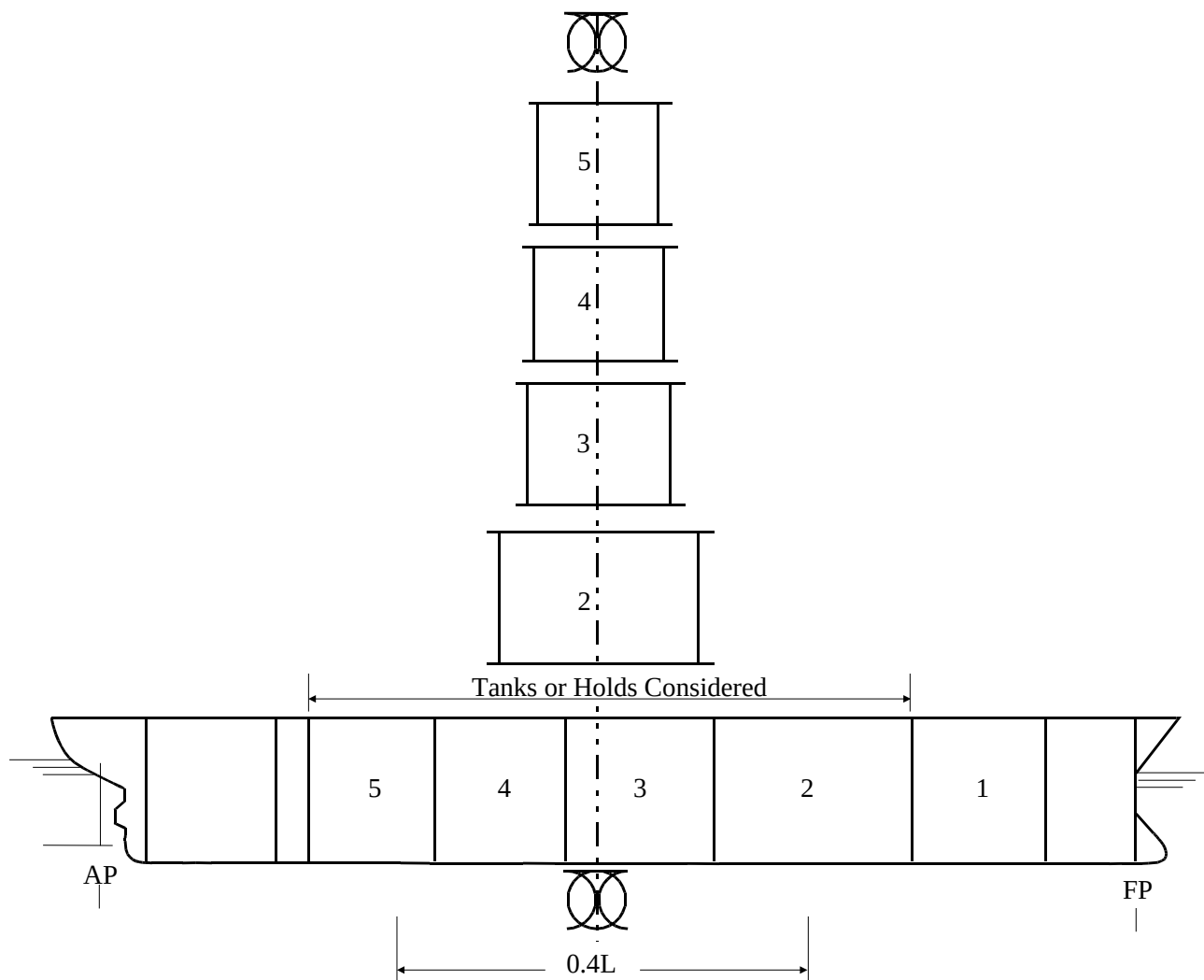
$$C_{ru} = 1.0$$

FIGURE 10
Definition of Tank Geometry



For lower ballast tanks, η is to be measured from a point located at $\frac{2}{3}$ the distance from the top of the tank to the top of the overflow (minimum 760 mm above deck).

FIGURE 11
Location of Tank or Hold for Nominal Pressure Calculation



7 Nominal Design Loads

7.1 General

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

7.3 Hull Girder Loads – Longitudinal Bending Moments and Shear Forces

7.3.1 Total Vertical Bending Moment and Shear Force

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

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

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

where

M_{sw}, M_w = still-water bending moment and wave-induced bending moment, respectively, as specified in 3/3.1 and 3/5.1.1 for either hogging or sagging conditions.

F_{sw}, F_w = still-water and wave-induced shear forces, respectively, as specified in 3/3.1 and 3/5.1.3 of 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 Subsection A1/3.

β_{VSF} = ESF for vertical shear force as defined in Subsection A1/3.

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

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

7.3.2 Horizontal Wave Bending Moment and Shear Force

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

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

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

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

7.5 Local Loads for Design of Transverse Bulkhead Structures

In determining the required scantlings of the stringers, stiffeners and plating of transverse bulkhead structures, the nominal loads induced by the liquid pressures distributed over both sides of the structural panel at the tank boundaries are to be considered for the worst possible load combinations. In general, considerations are to be given to the following two load cases accounting for the worst effects of the dynamic load components.

- i) Maximum internal pressures for a fully filled tank with the adjacent tanks empty and minimum external pressures, where applicable.
- ii) Empty tank with the surrounding tanks full and maximum external pressures, where applicable.

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

$$\begin{aligned}
 \text{i)} \quad p_i &= k_s \rho g (\eta + k_u h_d) && \text{max. and} \\
 p_e &= \rho g (h_s + \beta_{EPS/EPP} k_u h_{de}) && \text{min.} \\
 \text{ii)} \quad p_i &= 0 && \text{and} \\
 p_e &= \rho g (h_s + \beta_{EPS/EPP} k_u h_{de}) && \text{max.}
 \end{aligned}$$

where

$$\begin{aligned}
 k_u &= 1.0 \\
 \beta_{EPS/EPP} &= \text{ESF for external pressure starboard/port, as defined in Subsection A1/3}
 \end{aligned}$$

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

Specific information required for calculating the nominal loads are given in Section 3, Table 2 for various structural members and configurations.

7.7 Local Pressures for Design of Plating and Longitudinals

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

The necessary details for calculating p_i and p_e are given in Section 3, Table 2.

9 Combined Load Cases

9.1 Combined Load Cases for Structural Analysis

For assessing the strength of the hull girder structure and in performing a structural analysis as outlined in Section 5, the combined load cases specified in Section 3, Table 1 are to be considered. Additional combined load cases may be required as warranted.

The modes of operation of the drillship to be considered for each combined load case in Section 3, Table 1 are the transit condition, normal drilling condition and severe storm condition, each condition with loading patterns according to the loading manual. As a minimum for each of the modes of operation, the maximum static hull girder load (maximum still water shear force and bending moment) conditions, with corresponding load patterns in the loading manual, together with the combined load cases in Section 3, Table 1 are to be analyzed. In addition tank testing and drydocking conditions (afloat condition prior to drydocking) in still water conditions are to be analyzed. Tank test loading patterns are to consider each tank with hydrostatic test head and adjacent tanks or holds empty at $1/3$ draft. For double bottom tanks the hydrostatic test head is the greater of the head to the top of overflow, or to the bulkhead deck. For other tanks the hydrostatic test head is the greater of the head to the top of overflow, or to 2.4 m (8 ft) above top of tank, or to the top of the tank plus setting of any pressure relief valve.

The combined load cases as specified in Section 3, Table 1 with loading patterns for transit, normal drilling and severe storm conditions, and corresponding hull girder loads, are to be included in the FE analysis. In addition, tank testing and drydocking conditions in still water conditions are also to be analyzed.

The total external pressure distribution including static and hydrodynamic pressure is illustrated in Section 3, Figure 9.

9.3 Combined Load Cases for Fatigue Analysis

For the transit and normal drilling conditions, corresponding loading patterns and their associated probability of operating duration are to be considered for each combined load case specified in Appendix 2, Tables 2A and 2B.

9.5 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.

9.5.1 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 Section 3, Table 1 are to be considered.

9.5.2 Fatigue Strength

For assessing the fatigue strength of structural joints, the combined load cases given in 3/9.3 are to be used for a first level fatigue strength assessment as outlined in Appendix 2, “Fatigue Assessment of Drillships”.

TABLE 1
Combined Load Cases*

	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 Subsection 3/5)										
Vertical B.M.	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)	Sag (–)	Hog (+)
k_c	1.0	1.0	0.7	0.7	0.3	0.3	0.4	0.4	0.7	0.7
Vertical S.F.	—	—	—	—	—	—	—	—	(+)	(–)
k_c	—	—	—	—	—	—	—	—	1.0	1.0
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
B. External Pressure (See 3/5.5)										
k_c	0.5	0.5	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0
k_{f0}	-1.0	1.0	-1.0	1.0	-1.0	1.0	-1.0	1.0	-1.0	1.0
C. Internal Tank Pressure (See 3/5.7)										
k_c	0.4	0.4	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5
w_v	0.75	-0.75	0.75	-0.75	0.25	-0.25	0.4	-0.4	0.75	-0.75
w_ℓ	Fwd Bhd 0.25	Fwd Bhd -0.25	Fwd Bhd 0.25	Fwd Bhd -0.25	—	—	Fwd Bhd 0.2	Fwd Bhd -0.2	Fwd Bhd 0.25	Fwd Bhd -0.25
	Aft Bhd -0.25	Aft Bhd 0.25	Aft Bhd -0.25	Aft Bhd 0.25	—	—	Aft Bhd -0.2	Aft Bhd 0.2	Aft Bhd -0.25	Aft Bhd 0.25
w_t	—	—	—	—	Port Bhd -0.75	Port Bhd 0.75	Port Bhd -0.4	Port Bhd 0.4	—	—
	—	—	—	—	Stbd Bhd 0.75	Stbd Bhd -0.75	Stbd Bhd 0.4	Stbd Bhd -0.4	—	—
C_ϕ , Pitch	-1.0	1.0	-1.0	1.0	0.0	0.0	-0.7	0.7	-1.0	1.0
C_θ , Roll	0.0	0.0	0.0	0.0	1.0	-1.0	0.7	-0.7	0.0	0.0
D. Reference Wave Heading and Motion of Drillship										
Heading Angle	0	0	0	0	90	90	60	60	0	0
Heave	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up
Pitch	Bow Down	Bow Up	Bow Down	Bow Up	—	—	Bow Down	Bow Up	Bow Down	Bow Up
Roll	—	—	—	—	Stbd Down	Stbd Up	Stbd Down	Stbd Up	—	—

* $k_u = 1.0$ for all load components.

** Load cases 1 through 8 are to be analyzed for the structural model that is fully balanced under the boundary forces to achieve the target hull girder vertical bending moment at the section of the concerned hold. Load cases 9 and 10 are to be analyzed for the structural model that is fully balanced under the boundary forces to achieve the target hull girder vertical shear force at the fwd transverse bulkhead of the concerned hold. Maximum hull girder vertical bending moment within that hold is to be adjusted to be the target hull girder vertical bending moment.

TABLE 2
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

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 ballast tank	A_i	A_e	design draft/0°	Midtank of empty ballast tanks	—	B_e
2. Inner Bottom Plating & Long'l (adjacent to liquid tank)	2/3 design draft/0°	Full ballast tank, adjacent tanks or holds empty	A_i	—	design draft/0°	Fwd end of full liquid tank, ballast tanks empty	A_i	—
Inner Bottom Plating & Long'l (void or dry space)					** Flooded Condition	Flooded hold, adjacent tanks or holds empty		
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 (liquid tank)	design draft/0°	Full liquid tank	D_i	—				
5. Deck Plating & Long'l (Ballast Tank)	2/3 design draft/0°	Full ballast tank	D_i	—				
6. * Long'l Bhd. Plating & Long'l (liquid tank)	design draft/60°	Starboard side of full liquid tank, ballast tank except J-shape or double bottom ballast tank with adjacent tank or hold empty	B_i	—		Starboard side of full J-shape or double bottom ballast tank with adjacent tank or hold empty	B_i	
* Long'l Bhd. Plating & Long'l (void or dry space)					** Flooded Condition	Flooded hold, adjacent tanks or holds empty		
7. * Centerline Bhd. Plating & Long'l (liquid tank)	design draft/60°	Starboard side of full liquid tank, ballast tank with adjacent tank or hold empty	E_i	—				
* Centerline Bhd. Plating & Long'l (void or dry space)					** Flooded Condition	Flooded hold, adjacent tanks or holds empty		
8. * Moonpool Transverse Side Plating & Stiffener	2/3 design draft/0°	Full ballast tank, liquid tank	A_i	A_e	design draft/0°	Adjacent tank or hold empty	—	B_e
* Moonpool Longitudinal Side Plating & Long'l	2/3 design draft/60°	Starboard side of full ballast tank	B_i	A_e	design draft/60°	Adjacent tank or hold empty	—	B_e
9. * Trans. Bhd. Plating & Stiffener (liquid tank not adjacent to side shell)	design draft/0°	Fwd. bhd. of full liquid tank, adjacent tanks or holds empty	A_i	—				
(Void or dry space)					** Flooded Condition	Flooded hold, adjacent tanks or holds empty		

TABLE 2 (continued)
Design Pressure for Local and Supporting Members

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
10. * Trans. Bhd. Plating & Stiffener (liquid tank adjacent to side shell)	2/3 design draft/0°	Fwd. bhd. of full liquid tank, adjacent tanks or holds empty	A_i	—				
(Void or dry space)					** Flooded Condition	Flooded hold, adjacent tanks or holds empty		
11. Watertight Bottom Girder Plating & Long'l	2/3 design draft/ 60°	Starboard side of full ballast tank with adjacent tank or hold empty	B_i	—				
12. Tween deck Plating & Long'l					** Flooded Condition	Flooded hold, adjacent tanks or holds empty		
13. Watertight Flat Plating & Long'l	2/3 design draft/ 60°	Starboard side of full liquid tank, ballast tank with adjacent tank or hold empty			** Flooded Condition	Adjacent hold is flooded with tanks or holds empty		

* See Note 4

** 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

$$A_i: w_v = 0.75, w_\ell(\text{fwd bhd}) = 0.25, w_\ell(\text{aft bhd}) = -0.25, w_t = 0.0, c_\phi = -1.0, c_\theta = 0.0$$

$$B_i: w_v = 0.4, w_\ell(\text{fwd bhd}) = 0.2, w_\ell(\text{aft bhd}) = -0.2, w_t(\text{starboard}) = 0.4, w_t(\text{port}) = -0.4, c_\phi = -0.7, c_\theta = 0.7$$

$$C_i: w_v = -0.75, w_\ell(\text{fwd bhd}) = 0.25, w_t = 0.0, c_\phi = -1.0, c_\theta = 0.0$$

$$D_i: w_v = 0.4, w_\ell(\text{fwd bhd}) = 0.2, w_t(\text{centerline}) = 0.4, c_\phi = -0.7, c_\theta = -0.7$$

b) For p_e

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

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

- 2 For structures within $0.4L$ amidships, the nominal pressure is to be calculated for a hold located amidships. Each hold with liquid oil or water/mud in the region is to be considered as located amidships, as shown in Section 3, Figure 11. The nominal pressure is to be calculated at the location being considered for the structures beyond $0.4L$ amidships.
- 3 In calculation of the nominal pressure, ρg of the fluid cargoes is not to be taken less than $1.005 \text{ N/cm}^2\text{-m}$ ($0.1025 \text{ kgf/cm}^2\text{-m}$, $0.4444 \text{ lbf/in}^2\text{-ft}$).
- 4 For structural members 4, 6, 7, 9 and 10, sloshing pressures are to be considered in accordance with 3/11.3. For calculation of sloshing pressures, refer to 3/11.5 with ρg not less than $1.005 \text{ N/cm}^2\text{-m}$ ($0.1025 \text{ kgf/cm}^2\text{-m}$, $0.4444 \text{ lbf/in}^2\text{-ft}$).

TABLE 2 (continued)
Design Pressure for Local and Supporting Members

- 5 The nominal pressure for the watertight requirement in the flooded condition may be taken as the hold flooded to the deepest equilibrium waterline in the compartments damaged condition. This waterline level is not to be less than the hold flooded to the freeboard deck, as allowed in 1/3.13.1 for the structural members above $0.5 \times \text{Depth}$. 0.75 times the vertical distance from the structural members to the freeboard deck, but not less than $0.35 \times \text{depth}$, is to be applied for members below $0.5 \times \text{depth}$.

11 Sloshing Loads

11.1 General

11.1.1

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 liquid cargo or ballast tanks which will be partially filled between 20% and 90% of tank capacity. The sloshing pressure heads given in this Subsection may be used for determining the strength requirements for the tank structures. Alternatively, sloshing loads may be 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.

11.1.2

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.

11.3 Strength Assessment of Tank Boundary Structures

11.3.1 Tank Length and Pitch Induced Sloshing Loads

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

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

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

11.3.2 Roll Induced Sloshing Loads

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

11.3.3

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

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

11.3.4

For each of the anticipated loading conditions, the “critical” filling levels of the tank should be avoided so that the natural periods of fluid motions in the longitudinal and transverse directions will not synchronize with the natural periods of the drillship’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 drillship’s motion.

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

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

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

where

$$\ell_e = \text{effective length of the tank, as defined in 3/11.5.1, in m (ft)}$$

$$b_e = \text{effective breadth of the tank, as defined in 3/11.5.1 in m (ft)}$$

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

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

β_T , β_L , d_ℓ and d_b are as defined in 3/11.5.1. The natural periods given in 3/5.7 for pitch and roll of the drillship, T_p and T_r , using the actual GM value, if available, may be used for this purpose. Otherwise, $^{2/3}$ of scantling draft can be used in 3/5.7 for calculating the natural pitch and roll periods of the drillship.

11.5 Sloshing Pressures

11.5.1 Nominal Sloshing Pressure

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

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

where

$$k_s = \text{load factor as defined in 3/5.7.2(a)}$$

$$h_e = \begin{cases} k_u [h_c + (h_t - h_c)(y - d_m)/(h - d_m)] & \text{for } y > d_m \\ c_m h_m + k_u h_c & \text{for } 0.15h \leq y \leq d_m \text{ (} c_m h_m \text{ need not exceed } h \text{)} \end{cases}$$

h_e calculated at $y = 0.15h$ for $y < 0.15h$, but h_e is not to be smaller than $c_m h_m$.

$$c_m = \text{coefficient in accordance with Section 3, Figure 13}$$

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

$$d_m = \text{filling level, in m (ft), as shown in Section 3, Figure 12}$$

$$k_u = \text{load factor, and may be taken as unity unless otherwise specified.}$$

$$h_c = \text{maximum average sloshing pressure heads, in m (ft), to be obtained from calculations as specified below for at least two filling levels, } 0.55h \text{ and the one closest to the resonant period of ship's motions, between } 0.2h \text{ and } 0.9h. h_c \text{ may be taken as constant over the tank depth, } h \text{ (See Section 3, Figure 12)}$$

- h_t = sloshing pressure heads for upper bulkhead, in m (ft), to be obtained from calculation below
 h = depth of tank, in m (ft)
 y = vertical distance, in m (ft), measured from the tank bottom to the point considered

ρg is as defined in 3/5.7.2.

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

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

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

where

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

$$h_{\ell} = \phi_{es} \ell_e C_{\ell} \beta_T [0.018 + C_{\ell} (1.0 - d_{\ell}/H_{\ell})/\phi_{es}] d_{\ell}/H_{\ell} \quad \text{m (ft) for } \phi_{es}$$

$$h_b = \theta_{es} b_e C_{b} \beta_L [0.016 + C_b (1.0 - d_b/H_b)/\theta_{es}] d_b/H_b \quad \text{m (ft) for } \theta_{es}$$

$C_{\phi s}$ and $C_{\theta s}$ are the weighted coefficients as given in Section 3, Figure 13,

where

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

$$\phi_{es} = 0.71\phi$$

$$\theta_{es} = 0.71\theta$$

The pitch amplitude ϕ and roll amplitude θ are as defined in 3/5.7.1 with $d_i = 2/3d_r$ and $V = 10$ knots

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

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

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

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

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

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

β_T^* represents β^* for transverse bulkheads.

β_L^* represents β^* for longitudinal bulkheads.

$$\beta = (\beta_o)(\beta_u)(\beta_s)$$

β_T represents β for transverse bulkheads.

β_L represents β for longitudinal bulkheads.

$$\beta_o = 1.0 \quad \text{for tanks without a swash bulkhead}$$

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