IRS

RULES FOR BUILDING AND CLASSING STEEL VESSELS

PART 8: SPECIAL SERVICE VESSELS

A : OIL TANKERS

JANUARY 2015

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CHANGES

General

The present edition of the rules includes amendments and additions approved by the Technical Committee as of December 2014 and supersedes the December 2013 edition of the same chapter.

The rule changes come into force as described below.

Text affected by the main rule changes in this edition is highlighted in red colour. However, where the changes involve a whole chapter, section or sub-section, only the title may be in red colour.

This chapter is valid until superseded by a revised chapter.

Main changes coming into force 1 January 2015

• Chapter 1, Sec.2 Rule Principles

— Change in 3.1.3 Design life.

• Chapter 1, Sec.5 Structural Arrangements

— 5. Access arrangements: Added 5.1.1.6

• Chapter 3, Sec.2 Ship in operation renewal criteria

— 2. In service survey plan: Added 2.1

Corrections and Clarifications

In addition to the above stated rule requirements, a number of corrections and clarifications have been made to the existing rule text.

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CHAPTER 1 GENERAL

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SECTION 1 INTRODUCTION

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1. Introduction to Special requirements for Oil Tankers

1.1. General

1.1.1. Applicability

Applications of these rules are for double hull oil tankers classed with IRS. Oil Tankers for Inland navigation are exempted from complying with this rule.

1.2. Application of IRS Rules

1.2.1. Rules which do not cover the regions of the ship:

1.2.1.1. The relevant requirements of IRS are to be applied to those regions which are not covered by these rules.

Table 1.1.1 Lay out of the Rules

Zones	Topics	Location
Aft zone	Machinery general structure Machinery bottom structure Machinery side structure Machinery deck structure Machinery Internal structure	Chapter 2 Section 2, [4.1]. Chapter 2 Section 2, [4.2]. Chapter 2 Section 2, [4.3]. Chapter 2 Section 2, [4.4]. Chapter 2 Section 2, [4.5-4.8].
	Aft end general structure Aft end bottom structure Aft end shell structure Aft end deck structure Aft end internal structure	Chapter 2 Section 2, [5.1] Chapter 2 Section 2, [5.2] Chapter 2 Section 2, [5.3] Chapter 2 Section 2, [5.4] Chapter 2 Section 2, [5.5-5.7]
Cargo zone	Hull girder strength Hull envelope plating Hull envelope framing Inner bottom Bulkheads Primary support members Sloshing Hull girder ultimate strength Strength assessment Fatigue strength	Chapter 2 Section 2, [1] Chapter 2 Section 2, [2.2] Chapter 2 Section 2, [2.3] Chapter 2 Section 2, [2.4] Chapter 2 Section 2, [2.5] Chapter 2 Section 2, [2.6] Chapter 2 Section 2, [6.2] Chapter 2 Section 3, [1] Chapter2 Section 3, [2] Chapter 2 Section 3, [3]
Fore zone	General structure Bottom structure Side structure Deck structure Internal structure Bottom slamming Bow impact	Chapter 2 Section 2,[3.1] Chapter 2 Section 2,[3.2] Chapter 2 Section 2,[3.3] Chapter 2 Section 2,[3.4] Chapter 2 Section 2,[3.5-3.9] Chapter 2 Section 2,[6.3] Chapter 2 Section 2,[6.4]

Topic	Location
Hull openings and closing arrangements	Chapter 3 Section 1,[1]
Crew protection	Chapter 3 Section 1,[2]
Support structure and structural appendages	Chapter 3 Section 1,[3]
Equipment	Chapter 3 Section 1,[4]
testing procedure	Chapter 3 Section 1,[5]
Ships in operation renewal criteria	Chapter 3 Section 2

SECTION 2 RULE PRINCIPLES

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January 2015

1. Introduction

1.1. Rule Principles

1.1.1. Rule objectives

1.1.1.1. In order to improve the safety of life, environment and property and to provide adequate durability of the hull structure for the design life, the objective of the Rules are required to establish requirements so as to reduce the risks of structural failure.

1.1.2. General

1.1.2.1. The sub-sections contains:

a) The General Assumptions; pertaining to the design, construction and operation of the ship and gives information on the responsibilities of Classification Societies, builders and owners.
b) The Design Basis; which specifies the premises that the design principles of the Rules are based on, in terms of design parameters and assumptions about the ship operation.
c) The Design Principles; which define the fundamental principles used for the structural requirements in the Rules with respect to loads, structural capacity and assessment criteria.
d) The Application of the Design Principles; which describes how the design principles and methods are applied and what criteria are used to demonstrate that the structure meets the objective.

2. General Assumptions

2.1. General

2.1.1. International and national regulations

2.1.1.1. As prescribed internationally by the International Maritime Organization and implemented by National Administrations, ships are required to be designed, constructed and operated in compliance with the regulatory framework mentioned before.

2.1.1.2. On the basis of the assumptions that all applicable statutory requirements are complied with, the Rules are required to be made.

3. Design Basis

3.1. General

3.1.1. The design basis

3.1.1.1. Specification of the design parameters and the assumptions about the ship operation that are used as the basis of the design principles of the Rules are illustrated here.

3.1.1.2. The Rules are applicable for ships in compliance with the specified design basis. Special consideration will be given for deviations from this design basis.

3.1.1.3. Documentation and submission of the design basis used for the design of each ship to IRS is to be done as part of the design review and approval. The IRS shall be advised formally about all deviations from the design basis.

3.1.2. Arrangement and layout

3.1.2.1. Typical double hull tankers of greater than 100 in length and with arrangements are covered by the Rules as follows:

a) Engine room and deck house located aft of the cargo tank region, and
b) In addition to the inner skin, two longitudinal oil-tight bulkheads with no centre line longitudinal bulkhead,
Or
c) In addition to the inner skin one centre line longitudinal oil-tight bulkhead.

3.1.2.2. The ship's structure is assumed to be:

a) Constructed of welded steel structures.
b) Composed of stiffened plate panels.
c) Longitudinally framed with full transverse bulkheads and intermediate web frames.

3.1.2.3. The typical arrangements covered by the Rules are shown in Figure 1.2.1 and assume that the structural arrangements include:

a) Narrow double side structure and double bottom structure with breadth/depth in accordance with statutory requirements.
b) Single deck ships
c) Side longitudinal, centre line longitudinal or transverse bulkheads of plane, corrugated or double skin construction
d) The number and location of bulkheads are arranged in order to conform to the statutory requirements.

The cross sections shown in Figure 1.2.1 are typical examples only and other variations of cross tie and web frame arrangements are also covered.

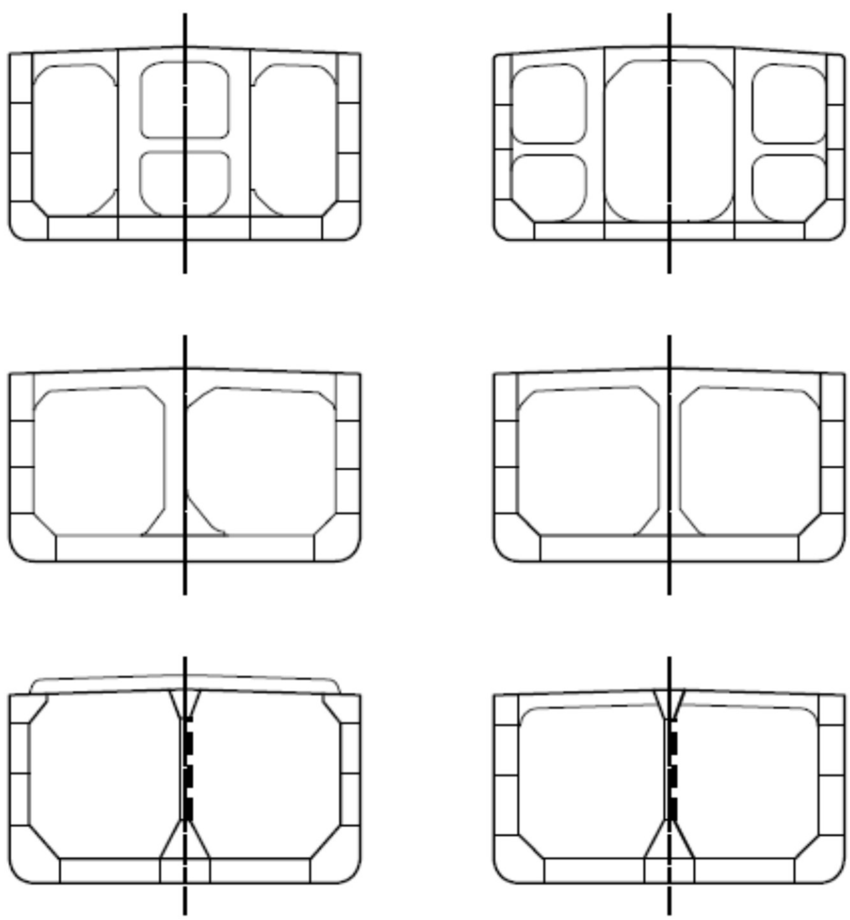


Figure 1.2.1: Typical Arrangements of Double Hull Tankers

3.1.2.4. The following Rules assume the hull form with respect to environmental loading:

a) Full form ship with block coefficient (C_b) greater than 0.7
b) The ship length breadth ratio (L/B) greater than 5
c) Ship breadth depth ratio (B/D) less than 2.5
d) The metacentric height (GM) not greater than 0.12B for homogeneously full load conditions, and 0.33B for ballast conditions.

3.1.3. Design life

3.1.3.1. A design life of 25 years is considered while selecting the appropriate ship design parameters. The specified design life is the nominal period that the ship is assumed to be exposed to operating conditions.

3.1.4. Design speed

3.1.4.1. The designer is to specify the maximum design service speed. As per the Rules, assumptions shows the ability of the ship to operate at this service speed on a continuous basis, but this does not relieves the responsibilities of the owner and personnel to handle the ship properly and reduce speed or change heading in severe weather.

3.1.5. Operating conditions.

3.1.5.1. In order to fulfill the design role, the ship is required to be capable of carrying the intended cargo with the necessary flexibility in operation. The designer is responsible for specifying the cargo loading conditions as required by the Rules and any additional cargo loading conditions that are required by the owner.

3.1.5.2. The Rules assume the following:

a) Examination of a minimum set of specified loading conditions as defined in the Rules are to be done. These are to include both seagoing and harbour loading conditions.
b) In addition to the minimum set of specified loading conditions, submission of all relevant additional loading conditions covering the intended ship's service which results in increased still water shear force, bending moments or increased local static loadings are to be conducted for review.
c) The Trim and Stability Booklet, loading Manual and loading computer systems specify the operational limitations of the ship and these conform to the appropriate statutory and classification requirements.
d) As specified in 3.1.8, all cargo tanks are from a local strength point of view which includes sloshing designed for unrestricted filling for a cargo density. As specified in the Rules and the Loading Manual, application of the limitations to loading patterns resulting in full or empty adjacent tanks are done for primary support members and hull girder shear force and bending moments.

3.1.6. Operating draughts

3.1.6.1. Specification of the design operating draughts is to be considered by the designer which is to be used to derive the appropriate structural scantlings. All operational loading conditions in the Loading Manual are to conform to the specified design operating draughts. The following design operating draughts which are minimum are required to beconsidered:

a) The maximum and minimum mean operational draughts.

b) Maximum scantling draught for the assessment of structure.
c) Minimum draughts forward for the assessment of bottom slamming, with and without ballast tanks in way filled
d) Maximum mean draught for a condition with all cargo tanks abreast empty
e) Maximum mean draught for a condition with empty centre or wing cargo tank.

3.1.7. External environment

3.1.7.1. In order to cover worldwide trading operations and to deal with the uncertainty in the future trading pattern of the ship and the corresponding wave conditions that are be encountered, a severe wave environment is used for the design assessment. The basis of the rule requirements are on a ship trading in the North Atlantic wave environment for its entire design life.

3.1.7.2. The effects of wind and current on the structure are not included since they are considered to be negligible.

3.1.7.3. The effects of ice are not included in the Rules.

3.1.7.4. The Rules assume that the validity of structural assessment of hull strength members is ensured for the following design temperatures:

a) lowest daily mean temperature in air is -10°C
b) lowest daily mean temperature in sea water is 0°C

As specified by IRS, ships operating for long periods in areas with lower daily mean air temperature may be subjected to additional requirements.

3.1.8. Internal environment (cargo and water ballast tanks)

3.1.8.1. If the designer specifies, a specific gravity (SG) of 1.025 or a higher value is required to be used for oil cargoes for the strength assessment of cargo tank structures.

3.1.8.2. A representative mean cargo density throughout the ship's life is required to be utilized, for the fatigue assessment of cargo tank structures. The representative mean density shall be taken as 0.9tonnes/m^3 or the cargo density from the homogeneous full load condition at the full load design draught T_{full}, if this is higher.

3.1.8.3. A SG of 1.025 is to be utilized for water ballast.

3.1.8.4. The Rules are based on the following design temperatures for the cargo:

a) Maximum cargo temperature is 80°C
b) Minimum cargo temperature is 0°C.

3.1.8.5. The design features and assumption upon which corrosion additions in the Rules are indicated are as follows:

a) The basis of corrosion additions are upon a combination of experience and a statistical evaluation of historical corrosion measurements and also on the carriage of a mixture of crude and other oil products with various degrees of corrosive properties.
b) The basis of corrosion additions are on the design life, see 3.1.3.1
c) Generally the ballast tanks are coated. Requirements for coating application and maintenance are not included in the Rules.

3.1.8.6. The values for corrosion additions and wastage allowance are indicated in Chapter 1 Section 6/3 and Chapter 3 Section 2 respectively.

3.1.9. Structural construction and inspection

3.1.9.1. As per the Rules, the structural requirements are developed with the assumption that construction and repair will follow acceptable shipbuilding and repair standards and tolerances. The Rules may require that additional attention is given during construction and repair of critical areas of the structure.

3.1.9.2. As a part of the verification scheme, Tank strength and tightness testing are to be carried out.

3.1.9.3. The Rules define the renewal criteria for the individual structural items. In accordance with IRS Rules and Regulations, the structural requirements included are developed on the assumption that the structure will be subject to periodical survey. All structural elements are to be arranged to allow access for inspection, see Section 5.5. Assumptions are made that a close-up inspection of the critical areas will be carried out on a regular basis.

3.1.10. Owner’s extras

3.1.10.1. If the owner’s specification of requirements goes above the general classification or statutory requirements, the structural design may be affected. Owner’s extras may include requirements for:

a) Vibration analysis
b) Maximum percentage of high strength steel
c) Additional scantling dimensions above that required by the Rules
d) Additional design margin on the loads specified by the Rules, etc.
e) Improved fatigue resistance, in the form of a specified increase of design fatigue life or equivalent.
f) Combinations of cargo loading patterns and draughts exceeding the specified conditions of the Rule.
g) Higher cargo density for fatigue evaluation of ships envisioned to carry high density cargo in part load conditions on a regular basis.

These Rules does not cover Owner’s extras. Owner’s extras that may affect the structural design are to be clearly specified in the design documentation.

4. Design Principles

4.1. Overall Principles

4.1.1. Introduction

4.1.1.1. The underlying design principles of the Rules in terms of loads, structural capacity models and assessment criteria and also construction and in-service aspects are defined in this Sub-Section.

4.1.2. General

4.1.2.1. The Rules are established on the following principles:

a) When the vessel is subjected to operational loads and environmental loads/conditions, then the safety of the structure can be demonstrated by addressing the potential structural failure mode(s),
b) The design complies with the design basis, as stated in Sub-Section 3.
c) The structural requirements are based on a consistent set of loads that represents typical worst possible loading scenarios.

d) In order to clearly identify each component of the requirement, the structural requirements regarding loads, capacity models and assessment criteria are presented in a modular format.

4.1.2.2. The ship's structure shall be designed in a way such that:

a) It consists of inherent redundancy. The structure of the ship works in a hierarchical manner so that if failure of structural elements is lower down in the hierarchy occurs they shall not result in immediate consequential failure of elements higher up in the hierarchy.
b) Minimising permanent deformations. Acceptance of Permanent deformations of local panel or individual stiffened plate members may be given if it does not affect the structural integrity, containment integrity or the performance of structural or other systems.
c) Minimising the incidence of in-service cracking, particularly in locations which; affect the structural integrity or containment integrity, or the performance of structural or other systems which are difficult to inspect and repair.
d) It must have adequate structural redundancy to survive in the event when the structure is accidentally damaged; for example, minor impact leading to flooding of any compartment.

4.2. Loads

4.2.1. Load scenarios

4.2.1.1. The loads which are utilized for assessment of the structure, covers the load scenarios encountered by the ship while operating at sea and in harbour.

4.2.2. Design load combinations

4.2.2.1. In order to represent identified loadscenarios, design load combinations combine both local and global load components. The design load combinations should be sufficiently varied so as to encompass allscenarios that can reasonably occur during normal operation of the vessel.

4.2.2.2. In order to maintain a consistent safety level for all combinations, the design load combinations for the hull and structural members is considered as the most unfavorable combination of load effects.

4.2.2.3. Depending upon the type of load and the load scenario being considered, the design load combinations are based on one of the following combinations of static and dynamic loads:

a) Static design load combinations (S)
It covers application of all relevant static loads and typically covers load scenarios in harbour, tank testing or similar operations.
b) Static plus Dynamic design load combination (S+D)
It also covers application of all relevant static loads and in addition, a realistic combination of simultaneously occurring dynamic load components and typically covers load scenarios for seagoing operations.
c) Impact design load combination
It covers application of impact loads such as bottom slamming and bow impact encountered during seagoing operation. It is usually adequate to ignore other static and dynamic load components in association with an impact load event.
d) Sloshing design load combination
It covers application of sloshing loads encountered during seagoing operations.

e) Fatigue design load
It covers application of all relevant dynamic loads.

f) Accidental design load combination (A)
It covers application of accidental loads which are not considered as occurring during normal operations.

4.2.3. Load categorisation

4.2.3.1. The design load combinations are composed of many different types of loads, which are categorised as shown in Table 1.2.1.

Table 1.2.1: Load Categorisations

Operational Loads	Lightship weight	Steel weight and outfit Machinery and permanent equipment
	Buoyancy loads	Buoyancy of the ship
	Variable loads	Cargo Ballast water Stores and consumables Personnel Temporary equipment
	Other loads	Tug and berthing loads Towing loads Anchor and mooring loads Lifting appliance loads
Environmental loads	Cyclic loading due to wave action including inertia loads	Dynamic wave pressures
		Dynamic loads and dynamic tank pressures due to ship accelerations
	Impact loads or resonantloads	Wave impacts Bottom slamming Liquid sloshing in tanks Green sea loads
Accidental loads		Flooding of compartments
Deformation loads		Thermal loads Deformations due to construction

4.2.3.2. Normally, the operational loads are static loads. They are grouped into lightship weight, buoyancy loads, variable loads and other loads. The operational loads take place as a consequence of the operation and handling of the ship.

4.2.3.3. The environmental loads are dynamic loads due to external influences. As per the Rules the environmental loads are loads due to wave action.

4.2.3.4. The accidental loads include loads which occur as a consequence of an accident or operational mishandling of the ship. As per the Rules the accidental loads are increased tank pressures due to flooding of compartments.

4.2.3.5. The deformation loads are caused by thermal loads and residual stresses. Deformation loads effects are not covered by the Rules.

4.2.4. Characteristic load values

4.2.4.1. The characteristic values of the load components whose application are done in the Rules are dependent on the design load combination being considered. The characteristic loads are typical values and are as follows:

a). The characteristic loads are the expected or specified values, for operational loads
b). The characteristic load is typically a load value which has a low probability of occurrence, i.e. an ‘extreme’ value, for environmental loads.

4.2.5. Operational loads

4.2.5.1. The characteristic values of the static sea pressure on the hull due to the buoyancy are on the basis of draught at the loading condition under consideration.

4.2.5.2. On the basis of the filling height and the specific gravity of the cargo/ballast,the characteristic values of the static tank pressure depends, and also allowances are included for possible overpressure due to the height of air pipes, pressure relief valve settings and capacity of pumps.

4.2.5.3. Due to personnel, stores and consumables, temporary equipment and permanent equipment, the characteristic values of the loads are based on specified values.

4.2.5.4. For tug, berthing, towing and mooring loads, the characteristic values are based on specified values.

4.2.6. Environmental loads

4.2.6.1. In accordance with 4.2.6.2 and calibrated with feedback from service experience and model tests,the Rule formulations for wave loads, as stated in Chapter 2 Section 1.3, depends on the envelope values that are calculated.

4.2.6.2. The general principles for the derivation of the wave load values areas follows:

a) For all similar load scenarios, the application of load values is consistent.
b) The characteristic load value is selected to suit the purpose of the application of the load and the selected structural assessment method, e.g. application of the expected lifetime maximum load is considered for strength assessment while for fatigue assessment application of an average value representing the expected load history is considered.
c) For load calculations, 3-D linear hydrodynamic computational tools are used. The effects of speed are considered.
d) On the basis of long term statistical approach, the derivation of characteristic wave loads, which includes representation of the wave environment (North Atlantic scatter diagram), probability of ship/wave heading and probability of load value exceedance.
e) Non-linear effects are considered for the expected lifetime maximum loads.

4.2.6.3. The combination of dynamic loads considers all simultaneously occurring dynamic load components. One particular load component is maximised or minimised while deriving the simultaneously occurring loads, and the relative magnitude of all simultaneously occurring dynamic load components is specified by the application of dynamic load combination factors (DLCF) based on the envelope load value. These dynamic load combination factors are based on the application of the equivalent design wave approach and are represented as tabulated values.

4.2.6.4. The formulations of the load values for bottom slamming, bow impact loads and green sea loads depends upon the following factors:

a) Vessel draught

b) Hull form
c) Heading
d) Forward speed
e) Location of deck houses/superstructure
f) Geometry of structural elements

4.2.6.5. A transient dynamic response in the structure occurs due to a slamming impact. The formulation of the impact loads considers the impact load as equivalent static load acting on the associated exposed hull surface.

4.2.6.6. The effect of green water on the deck structure is considered along the entire vessel's length. The green water loads on fore and parallel mid bodies of a ship are determined based on model tests, ship motion analysis and service experience. For the fore and mid body green sea loads, the green sea loads for the aft body are consistent with the derivation.

4.2.7. Accidental loads

4.2.7.1. In accordance with the assumptions made in IMO regulations, the accidental load scenarios cover loads acting on local structure as a consequence of flooding which in turn relates to the assessment of the watertight subdivision boundaries.

4.2.7.2. In the flooded condition, only static loads corresponding to the draught are considered.

4.2.8. Deformation loads

Within the limits specified by the design basis, thermal loads are considered negligible. Assumptions are made that care is taken to account and allow for expected thermal expansion.

4.3. Structural Capacity Assessment

4.3.1. General

4.3.1.1. The basic principle of structural design is to apply the defined design loads, identify possible failure modes and employ appropriate capacity models in order to determine the required structural scantlings.

4.3.2. Capacity models for strength

4.3.2.1. The strength assessment method is required to be capable of analysing the failure mode in addition to the required degree of accuracy. Application of several assessment methods may be done for the same failure modes.

4.3.2.2. The following aspects are the basis for selection of strength capacity models:

a) Whether the structural member is assessed at a higher level in the hierarchy and/or at a later stage by more accurate methods or by more accurate response calculations,
b) Simplified capacity models always gives conservative results where some of the stress components are neglected,
c) Appropriate methodology to assess the failure mode,
d) Probability level of the load,
e) Capability of response calculations to represent the physical behavior of the structure up to the given load level,
f) Complexity of structure,
g) Complexity of loads,
h) Criticality of the structural member. Primarily this will consist of an impact on the assessment criteria, but it is requisite to be considered in

conjunction with selection of the appropriate methodology for structural assessment.

4.3.2.3. The structural capacity assessment methods are performed in two ways, either a prescriptive format or require the use of more advanced calculations such as finite element analysis methods.

4.3.2.4. The formulae utilized to determine stresses, deformations and capacity are appropriate for the selected capacity assessment method and the type and magnitude of the design load set.

4.3.3. Capacity models for fatigue

4.3.3.1. The fatigue assessment method provides Rule requirements in order to safeguard structural details against fatigue failure.

4.3.3.2. The basis of the fatigue capacity model is on a linear cumulative damage summation (Palmgren-Miner's rule) in combination with S-N curves, a characteristic stress range and an assumed long-term stress distribution curve.

4.3.3.3. The fatigue capacity assessment models are in either a prescriptive format or require the utilization of more advanced calculations such as finite element analysis methods. These methods are utilized for the combined effects of global and local dynamic loads.

4.3.4. Net thickness approach.

4.3.4.1. The philosophy behind the net thickness approach is to:

a) Provide a direct link between the thickness utilized for strength calculations during the new building stage and the minimum thickness accepted during the operational phase
b) Enable the status of the structure with respect to corrosion to be clearly ascertained throughout the life of the ship.

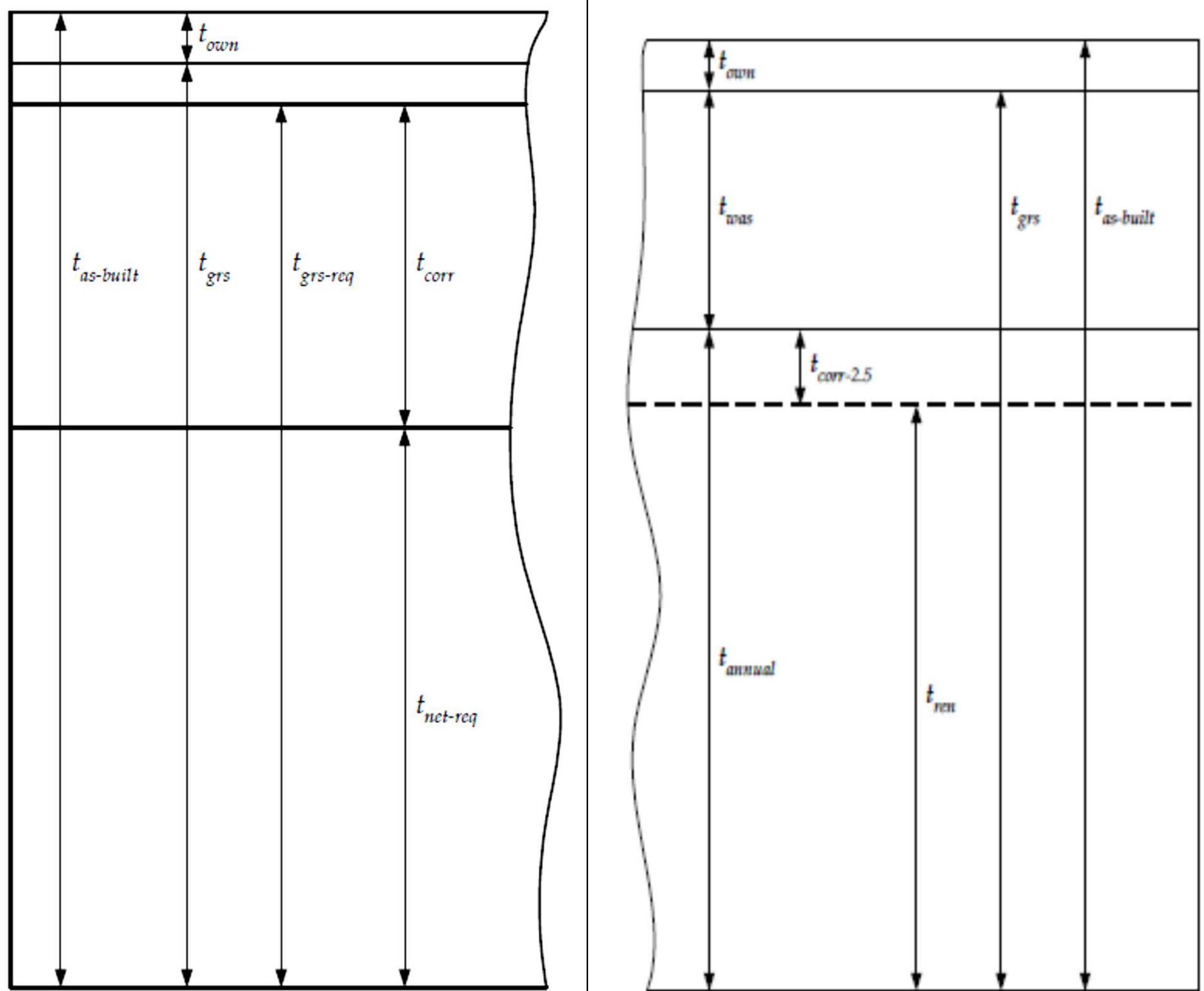
4.3.4.2. The net thickness approach provides a distinction between local and global corrosion. Local corrosion is defined as uniform corrosion of local structural elements, such as a single plate or stiffener. The overall average corrosion of larger areas such as primary support members and the hull girder is defined as Global corrosion. Both the local and overall corrosion are used as a basis for the new building review and are to be confirmed during operation of the vessel.

4.3.4.3. The net thickness approach for the local corrosion is presented in Figure 1.2.2 (a) and is in terms of new building thicknesses, which is given by:

a) The local strength requirements are given by the net thickness ($t_{net-req}$) after rounding
b) The required gross thickness ($t_{grs-req}$) is given by adding the corrosion addition (t_{corr}) to the required rounded net thickness ($t_{net-req}$)
c) The gross thickness (t_{grs}) is the actual thickness selected by the designer to fulfill the gross required thickness($t_{grs-req}$) and is to be equal or greater than the required gross thickness ($t_{grs-req}$)
d) Theas-built thickness is equal to the gross thickness (t_{grs}) plus any additional owners extra margin (t_{own})
e) Any additional thicknesses specified by the owner, such as owners extra margin (t_{own}) are not to be included in the assessment of the required gross thickness ($t_{grs-req}$).

Figure 1.2.2: Net Thickness Approach for Local Wastage

(a) Application to scanting requirements **(b) Application to ship in operation requirements**



4.3.4.4. Shown in Figure 1.2.2 (b) isthe net thickness approach for determining the local renewal thickness during the operation phase of the ship and is given by:

a). The thickness at which annual surveys are required, t_{annual}, is achieved by subtracting the total wastage allowance (t_{was}) and the owners extra margin (t_{own}) from the as-built thickness ($t_{as\text{-}built}$),

b). Thickness at which renewal is required, t_{ren}, is achieved by subtracting the total wastage allowance (t_{was}), the thickness $t_{corr\text{-}2.5}$ and the owners extra margin (t_{own}) from the as-built thickness ($t_{as\text{-}built}$). Where ($t_{corr\text{-}2.5}$)is the wastage allowance in reserve for corrosion occurring in the two and half years between Intermediate and Special surveys,

c). The rule specified the required wastage allowance (t_{was}) available before annual surveys is obtained by deducting the thickness ($t_{corr\text{-}2.5}$) from the corrosion addition (t_{corr}).

The approach calls for a general 2.5 year survey interval when the gauged thickness is greater than the “thickness at which annual surveys are required" (t_{annual}), and a 1 year survey interval when the gauged thickness is lesser than the "thickness at which annual surveys are required" (t_{annual}).

4.3.4.5. The overall average corrosion for primary support members and the hull girder cross-section is provided by deducting half the local corrosion addition ($0.5t_{corr}$) from all the structural elements comprising the respective cross-sections.

4.3.4.6. Based on the hull girder stresses given by the net hull girder properties, e.g. based on a global overall average corrosion of the hull girder, and the local stresses based on the net thickness of the local member under consideration, e.g. based on full local corrosion, the assessment of local scantlings is performed. Assumptions are made that the structure may corrode locally to the maximum allowed and reduction of the hull girder may be done to the maximum allowed overall hull girder corrosion.

4.3.4.7. The basis of the assessment of global (hull girder and primary support member) scantlings is on the overall global corrosion, e.g. half the full local corrosion for all structural members simultaneously. Assumptions are made that the full local corrosion will not occur globally and hence a lesser average value of assumed corrosion is appropriate. Individual structural elements may corrode to the maximum corrosion addition and this in turn taken into account in the buckling assessment.

4.3.4.8. The scantlings and stresses used for the assessment are to be taken as the representative mean value over the design life as fatigue is an accumulative assessment. The mean corrosion over the design life is given as half the corrosion assumed for scantling strength assessment. Calculations of the local stresses are thus based on half the full local corrosion addition and calculations of hull girder stresses are based on half the overall global corrosion. Half the global overall corrosion is found by deduction of one quarter of the full local corrosion addition of all structural elements simultaneously.

4.3.4.9. The actual amount of wastage allowed in service is taken as:

a). Locally: the full corrosion addition less an amount for typical wastage between the survey periods,

b). Globally: the full global overall corrosion addition less an amount for typical wastage between the survey periods. The global wastage is monitored in service by evaluating the current global characteristics of the vessel.

4.3.5. Intact structure

4.3.5.1. On the basis of the assumption that the structure is intact,all strength calculations are done. Assessment of the residual strength of the ship is not considered in a structurally damaged condition.

4.3.5.2. No benefit is provided in the assessment of structural capability for the presence of coatings or similar corrosion protection systems.

4.4. Materials and Welding

4.4.1. Materials

4.4.1.1. The basis of the rule requirements associated with the selection of materials for structural components is on the location, design temperature (see 3.1.7.4 and 3.1.8.4), membrane, through thickness forces and criticality of the component.

4.4.2. Welding

4.4.2.1. The basis of Rule requirements for weld type, size and materials are on the following considerations:

a). Joint type,
b). Criticality of the joint,
c). Magnitude, type and direction of the stresses in the joint,
d). Material properties of the parent and weld material
e). Weld gap size.

4.5. Assessment/Acceptance Criteria

4.5.1. Design methods

4.5.1.1. The criteria for the assessment of the scantlings are based on one of the following design methods:

a) Working Stress Design (WSD) method, also known as the permissible or allowable stress method,

b) Partial safety Factor (PF) method, also known as Load and Resistance Factor Design (LRFD).

4.5.1.2. Two design assessment conditions and corresponding acceptance criteria are given, for both WSD and PF. These conditions are associated with the probability level of the combined loads, A and B:

a) Condition A is applicable to design load combinations based on 'expected' characteristic load values, typically covered by the static design load combinations
b) Condition B is applicable to design load combinations based on 'extreme' characteristic load values, typically covered by the static plus dynamic load combinations.

4.5.1.3. The WSD method has the following composition:

$W \leq \eta_1 R$ for condition A

$W_{stat} + W_{dyn} \leq \eta_2 R$ for condition B

where:

W_{stat} = simultaneously occurring static loads (or load effects in terms of stresses)
W_{dyn} = simultaneously occurring dynamic loads. The dynamic loads are typically a combination of local and global load components
R = characteristic structural capacity (e.g. yield stress or buckling capacity)
η_i = Permissible utilisation factor (resistance factor). The utilisation factor includes consideration of uncertainties in loads, structural capacity and the consequence of failure.

4.5.1.4. The PF method has the following composition:

$$\gamma_{stat-}\ W_{stat} + \gamma_{dyn-}\ W_{dyn} \leq \frac{R}{\gamma_R} \text{ for condition A}$$

$$\gamma_{stat}\quad W_{stat} + \gamma_{dyn-2}\, W_{dyn} \leq \frac{R}{\gamma_R} \qquad \text{for condition B}$$

y_{stat-} = partial safety factor that accounts for the uncertainties related to static loads
W_{stat} = simultaneously occurring static loads (or load effects in terms of stresses)
y_{dyn-i} =partial safety factor that accounts for the uncertainties related to dynamic loads

W_{dyn} = simultaneously occurring dynamic loads. The dynamic loads are typically a combination of local and global load components.

R = characteristic structural capacity (e.g. yield stress, ultimate hull girder stress)

y_R =partial safety factor that accounts for the uncertainties related to structural capacity

4.5.1.5. In order to achieve the consistent and acceptable safety level for all combinations of static and dynamic load effects,the acceptance criteria for both the WSD method and PF method are required to be calibrated for the various requirements.

4.6. Principle of Safety Equivalence

4.6.1. General

4.6.1.1. As per the rules, Novel designs deviating from the design basis or structural arrangements will be subject to special consideration. The principle of equivalence is to be applied to the novel design, hence it must be mentioned that the structural safety of the novel design is at least equivalent to that intended by the Rules.

4.6.1.2. Application of the principle of equivalence may be done to alternative calculation methods.

4.6.1.3. A systematic review process was undertaken in developing these Rules which identified and evaluated the likely consequences of hazards due to operational and environmental influences on tanker structural configurations and arrangements covered by these Rules. For novel designs, dependent on the nature of the deviation, it may be necessary to conduct an independent systematic review to document equivalence with the Rules.

5. Application of Principles

5.1. Overview of the Application of Principles

5.1.1. General

5.1.1.1. This Sub-Section shows how the design principles (depicted in Sub-Section 4), have been applied in the development of the rule requirements.

5.2. Structural Design Process

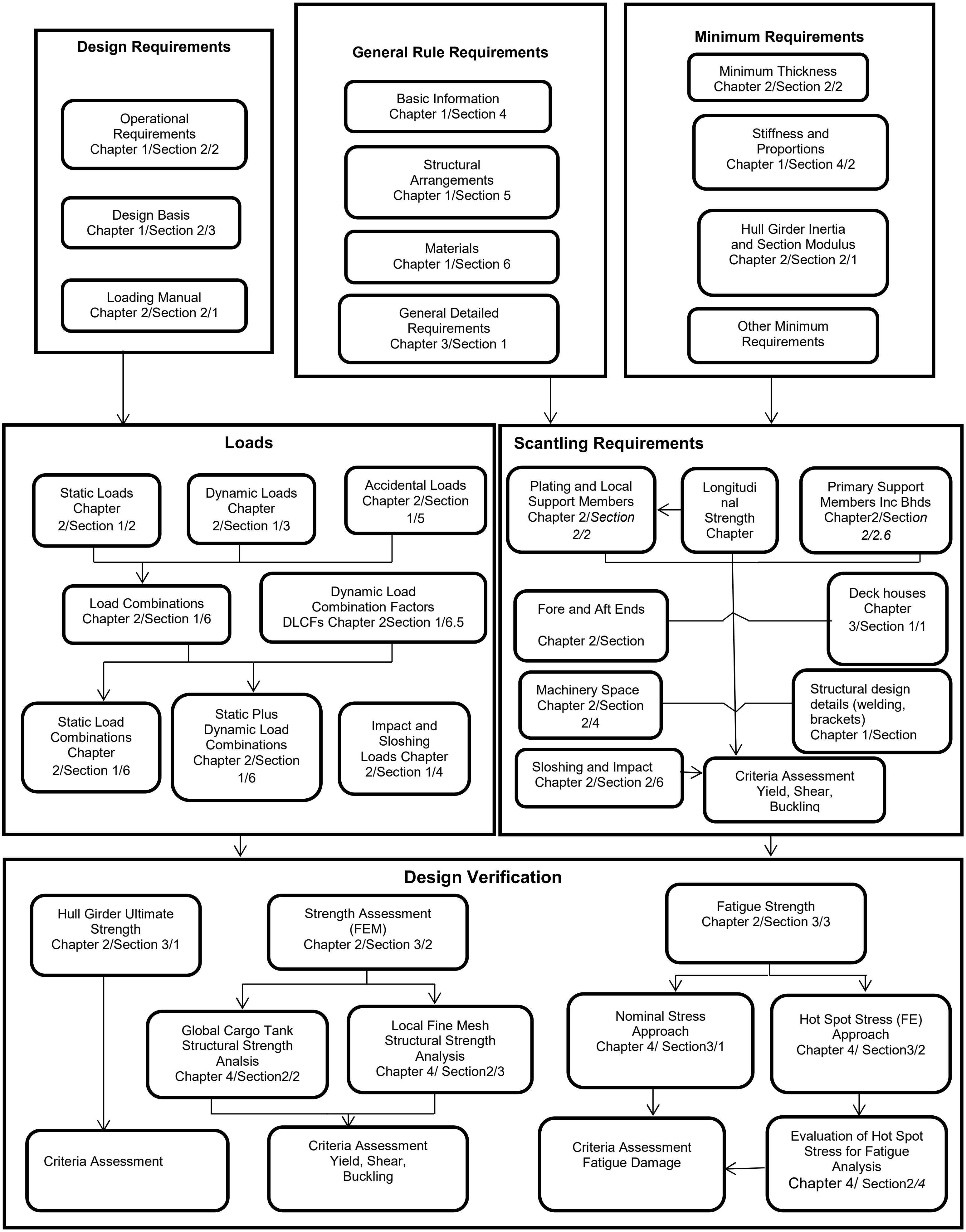
5.2.1. Overview of the structural design process

5.2.1.1. An overview of the structural design process applied in the Rules is shown in Figure 1.2.3.

5.2.1.2. The strength and acceptable safety of the hull and the structural elements is verified through the application of the following Rule requirements:

a) Prescriptive scantling requirements
- minimum requirements
- load-capacity based requirements

b) Design verification requirements based on load-capacity methods:
- hull girder ultimate strength
- strength assessment using the Finite Element (FE) analysis
- fatigue assessment



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Nominal Stress Approach Chapter 4/ Section3/1
Hot Spot Stress (FE) Approach Chapter 4/ Section3/2
Criteria Assessment
Criteria Assessment Yield, Shear, Buckling
Criteria Assessment Fatigue Damage
Evaluation of Hot Spot Stress for Fatigue Analysis Chapter 4/ Section2/4

5.3. Minimum Requirements

5.3.1. General

5.3.1.1. The minimum requirements are usually in one of the following forms:

a) Minimum thickness, which is not dependent of the yield stress, these are based on service experience and are usually expressed in the following format:

$$t = A + B\,L$$

Where;
A, B = Constant
L = rule length, as defined in Section 4/1.[1.1.1]

b) Minimum stiffness and proportion, which are based on prescriptive buckling requirements

5.4. Load-capacity Based Requirements

5.4.1. General

5.4.1.1. Generally, application of the Working Stress Design (WSD) method is applied in the requirements, except for the hull girder ultimate strength criteria where the Partial safety Factor (PF) method is applied. The partial safety factor format is applied for highly critical failure mode to better account for uncertainties related to static loads, dynamic loads and capacity formulations.

5.4.1.2. As given in Table 1.2.4, the identified load scenarios are addressed by the Rules in terms of design loads, design format and acceptance criteria set. The table is schematic and is only intended to give an overview.

5.4.1.3. The Rules cover operations addresses the load scenarios such as seagoing conditions, loading and unloading, tank testing conditions, ballast water exchange situations, special operations in harbour (e.g. propeller inspection afloat condition) and accidental flooding.

5.4.1.4. The design load combinations that represent the identified load scenarios are given in Chapter 2 Section 1/6 and are denoted by S (static loads), S+D (static + dynamic loads), and A (accidental loads). In addition, the Rules address impact loads and sloshing loads as given in Chapter 2 Section 1/4 and fatigue loads as given in Chapter 2 Section 1/3.

5.4.1.5. The considered loads, for the strength requirements, cover the most severe operational loads that occur; hence the cargo tank finite element analysis and load-capacity based scantling requirements are based on rule loadingconditions which simulate the worst possible loading conditions within the operating limits of the vessel.

5.4.1.6. The considered loads, for the fatigue requirements, cover an expected load history and representative loading conditions covering the ships' intended service are applied.

5.4.1.7. The acceptance criteria has been categorised into three acceptance criteria sets. These are explained below and shown in Tables 1.2.3 and 1.2.4. The specific acceptance criteria set that have been applied in the WSD rule requirements is dependent on the probability level of the characteristic combined load.

5.4.1.8. The acceptance criteria set AC1 is applied when the combined characteristic loads are frequently occurring, typically for the static design load combinations, but also applied for the sloshing design loads. This means that the loads come about on a frequent or regular basis. The permissible stress for a frequent load is lower than for an extreme load to take into account effects of:

a) Repeated yield
b) Allowance for some dynamics
c) Margins for operational mistakes

5.4.1.9. The acceptance criteria set AC2 is typically applied when the combined characteristic loads are extreme values, e.g. typically for the static + dynamic design load combinations. High utilisation (η_i in Table 1.2.2) of the structural capacity (R_i in Table 1.2.2) is permitted in such cases because the considered loads are extreme loads with a low probability of occurrence.

5.4.1.10. For capacity formulations, the acceptance criteria set AC3 is typically applied based on the plastic collapse models such as those that are applied to address bottom slamming and bow impact loads.

Table 1.2.2: Load Scenarios and Corresponding Rule Requirements

Load Scenarios		**Rule Requirements**			
Operation	Loads (that the vessel is exposed to and is to withstand)	Design Load Combination (specified in Chapter 2 Section 1/6)		Design Format (specified in Chapter 2 Section 2&3) see Note 1	Acceptance Criteria Set (specified in Chapter 2 Section 2&3)
		Ref. no	Notation		
Seagoing operations					
Transit	Static and dynamic loads inheavy weather	1	S + D	1. $S_G + S_L + D_G + D_L \leq \eta_2 R_1$	AC2
				2. $\gamma_S S_G + \gamma_D D_G \leq R_2 / \gamma_{R2}$	AC2
	Impact loads in heavy weather	2	Impact	$S_L + D_{imp} \leq \eta_3 R_p$	AC3
	Internal sloshing loads	3	Sloshing	$S_G + D_{slh} \leq \eta_1 R_1$	AC1
	Cyclic wave loads	4	Fatigue	$D_M \leq \sum \eta_i / N_i$	-
BWE by flow through or sequential methods	Static and dynamic loads inheavy weather	5	S + D	$S_G + S_L + D_G + D_L \leq \eta_2 R_1$	AC2
Harbour and sheltered operations					
Loading, unloading and ballasting	Typical maximum loads During loading, unloading and ballasting operations	6	S	$S_G + S_L \leq \eta_1 R_1$	AC1
Tank testing	Typical maximum loads	7	S	$S_G + S_{L1} \leq \eta_1 R_1$	AC1
Special conditions in harbour	Typical maximum loads during special operations inharbour, e.g. propellerinspection afloat or dry-dockingloading conditions	8	S	$S_G + S_L \leq \eta_1 R_1$	AC1
Accidental condition					
Accidental flooding	Typically maximum loads on internal watertight subdivision structure due to accidental flooding	9	A	for water tight boundaries 1. $S_L \leq \eta_2 R_1$	AC2
				for collision bulkhead 2. $S_L \leq \eta_1 R_1$	AC1
Note					

1. The symbols defined in this column are defined in the text of 5.4
Where: D_G = dynamic global load D_L = dynamic local load D_M = cumulative fatigue damage ratio S_G = static global load S_L = static local load R_i = structural capacity

5.4.2. Design loads for scantling requirements and strength assessment (FEM)

5.4.2.1. The structural assessment of compartment boundaries, e.g. bulkheads, is on the basis of the worst possible loading; hence conditions are assessed with a full tank on one side and an empty tank on the other side. The situation with the tank content reversed is also to be measured. Similarly the shell envelope is assessed for conditions at the deepest draught without internal filling and at the lowest draught with internal filling.

5.4.2.2. For tankers with two oil-tight longitudinal bulkheads and one centre-line oil-tight longitudinal bulkhead respectively, the standard loading patterns to be utilized in the strength assessment (FEM) are given in Chapter 4 Section 2, Tables 4.2.3 and 4.2.4. The corresponding information for the scantling requirements is provided in Chapter 2 Section 2.

5.4.2.3. Standardized rule values for parameters such as GM, R_{roll}, T_{sc} and C_b. are applied to calculate the rule load values, to ensure consistency of approach.

5.4.2.4. The probability level of the dynamic global and local loads (D_G, D_L and D_{imp} in Table 1.2.2) is 10^{-8} and is derived utilizing the long term statistical approach mentioned in 4.2.6.2.

5.4.2.5. The probability level of the sloshing loads (D_{slh} in Table 1.2.2.) is 10^{-4} which occurs frequently.

5.4.2.6. The design load combinations corresponding to the identified load scenarios produce realistic design load sets that are suitable for the design and verification of the structural capability. For the design of a particular or group of structural members, design load sets apply for all the applicable simultaneously acting static and dynamic local load components (S_L and D_L in Table 1.2.2, which are generally pressure load components) and static and dynamic global load components (S_G and D_G in Table 1.2.2., which is usually hull girder bending moment). The relevant design load sets for the scantling requirements are provided in Section 4 to 8/5. The design load sets for the Finite Element analysis are mentioned to as load cases and are given in Chapter 4 Section 2

5.4.2.7. The simultaneously occurring dynamic loads are indicated by applying a dynamic load combination factor to the envelope dynamic load values given in Chapter 2 Section 1/3. The dynamic load combination factors that define the dynamic load cases are given in Chapter 2 Section 1/6.4 for the structural strength assessment (FE) and in Chapter 2 Section 1/6.5 for the scantling requirements.

5.4.2.8. The dynamic load combination factors are derived utilizing the equivalent design wave approach to provide realistic simultaneously occurring dynamic loads components suitable for structural assessment.

5.4.2.9. The operational loads (i.e. ship loading conditions) and the environmental loads (i.e. hull girder wave bending moments) are maximised for sagging conditions for seagoing conditions, for the determination of design loads for the hull girder ultimate strength requirement as given in Chapter 4 Section 1/1. The characteristic value for the still water hull girder sagging bending moments M_{sw} is based on the maximum value from the seagoing conditions that has been specified in Chapter 2 Section 2/1. The characteristic value for the wave hull girder sagging bending moments M_{WV} is provided in Chapter 2 Section 7/3.

5.4.3. Design loads for fatigue requirements

5.4.3.1. The load assessment is based on the expected load history and an average approach is applied, for the fatigue requirements as given in Chapter 2 Section 3/3 and Chapter 4 Section 3. The expected load history for the design life is characterised by the 10^{-4} probability level of the dynamic load value; for each structural member the load history is represented by Weibull probability distributions of the corresponding stresses.

5.4.3.2. The considered wave-induced loads include:

a) Hull girder loads (i.e., vertical and horizontal bending moments)
b) Dynamic wave pressures
c) Dynamic tank pressures

5.4.3.3. For two representative loading conditions, the fatigue analysis is calculated covering the ship's intended operation. These two conditions are:

a) Full load homogeneous conditions at design draught
b) Normal ballast condition.

The proportion of the sailing life of the ship in the full load condition is 50% and in ballast 50%. It is assumed that 15% of the life of the ship is in harbour/sheltered water. It is consequently assumed that the ship will be sailing in open waters in full load condition for 42.5% of the life of the ship and in the ballast condition for 42.5% of the ship's life.

5.4.3.4. Corresponding to the applied loading conditions, the load values are based on actual parameters, e.g.GM, C_b, etc., and the applicable draughts at amidships is utilized. The actual values are taken from specified loading conditions in the loading manual.

5.4.3.5. By combination of stresses due to the various dynamic load components, the simultaneously occurring dynamic loads are accounted for. The stress combination procedure is provided in Chapter 4 Section 3.

5.4.3.6. Still water loads and static sea and tank pressures from the actual loading conditions are utilized to determine the mean stress effect.

5.4.4. Structural response analysis

5.4.4.1. The following approaches are applied, in general, for determination of the structural response to the applied design load combinations.

a) Beam theory
   - used for prescriptive requirements

b) FE analysis
   - Coarse mesh for cargo hold model
   - Fine mesh for local models
   - Very fine mesh for fatigue assessment

5.4.5. Structural capacity assessment

5.4.5.1. The considered failure modes in the Rules are yield (plastic deformation), buckling, brittle fracture and fatigue. Structural failure due to yield and buckling is primarily controlled by the strength requirements, brittle fracture is primarily controlled by the requirements for material selection and welding, and fatigue failure is primarily controlled by the high cycle fatigue requirements.

5.4.5.2. Normally, application of the capacity models in the prescriptive rules, i.e., the scantling requirements in Chapter 2 Section 2, are based on simple beam theory and include elastic yield and plastic capacity models. The buckling capacity is assessed utilizing simplified buckling capacity models or by a more theoretical non-linear analysis procedure.

5.4.5.3. The basis of the design verification requirements are on a linear elastic finite element analysis, a detailed prescriptive fatigue assessment procedure and a simplified ultimate strength assessment procedure. For some structural members, there is also a finite element based fatigue assessment method, such as the hopper knuckle.

5.4.5.4. The application of the net thickness approach to assess the structural capacity is specified in Section 6/3.3.

5.4.6. Acceptance criteria

5.4.6.1. The acceptance criteria applied in the working stress design requirements are provided as acceptance criteria sets shown in Tables 1.2.3 and 1.2.4. There are slight variations within each set depending on the relative contribution of local and global loads, static and dynamic loads and the structural member being considered. The specific acceptance criteria are provided in the detailed rule requirements in Chapter 2 Section 2 and 3/2.

Table 1.2.3: Principal Acceptance Criteria - Rule Requirements

	Plate panels and Local Support Members		**Primary Support Members**		**Hull girder members**	
Acceptance criteria set	**Yield**	**Buckling**	**Yield**	**Buckling**	**Yield**	**Buckling**
AC1:	70-80% of yield stress	Control of stiffness and proportions. Usage factor typically 0.8	70-75% of yield stress	Control of stiffness and proportions. Pillar buckling	75% of yield stress	NA
AC2:	90-100% of yield stress	Control of stiffness and proportions. Usage factor typically 1.0	85% of yield stress	Control of stiffness and proportions. Pillar buckling	90-100% of yield stress	Usage factor typically 0.9
AC3:	Plastic criteria	Control of stiffness and proportions	Plastic criteria	Control of stiffness and proportions	NA	NA

Table 1.2.4: Principal Acceptance Criteria - Design Verification - FE Analysis

	Global cargo tank analysis		**Local fine mesh analysis**
Acceptance criteria set	**Yield**	**Buckling**	**Yield**
AC1:	60-80% of yield stress	Control of stiffness and proportions. Usage factor typically 0.8	local mesh as 136% of yield stress averaged stresses as global analysis
AC2:	80-100% of yield stress	Control of stiffness and proportions. Usage factor typically 1.0	local mesh as 170% of yield stress averaged stresses as global analysis

5.4.6.2. The purpose of applying different sets is to obtain a consistent and acceptable safety level for all combinations of static and dynamic loads and to account for different capacity models.

5.5. Materials

5.5.1. General

5.5.1.1. Higher material properties are carefully chosen for highly critical structural elements which are subjected to high loads in order to reduce the risk of propagation of brittle fracture.

5.6. Application of Rule Requirements

5.6.1. Minimum requirements

5.6.1.1. These specify the minimum scantling requirements whose application shall be done, irrespective of all other requirements, hence thickness below the minimum are not allowed.

5.6.2. Load based prescriptive requirements

5.6.2.1. These provide scantling requirements for all plating, local support members, most primary support members and the hull girder and also cover all structural elements including deckhouses, foundations for deck equipment, etc.

5.6.2.2. These requirements explicitly control one particular failure mode in general, and hence application of several requirements is done to assess one particular structural member.

5.6.3. Design verification - hull girder ultimate strength

5.6.3.1. The requirements for the ultimate strength of the hull girder depends upon a Partial safety Factor (PF) method, see 4.5. A safety factor is assigned to each of the basic variables, the still water bending moment, wavebending moment and ultimate capacity. The safety factors were determined using a structural reliabilityassessment approach; the long term load history distribution of the wave bending moment was derived usingship motion analysis techniques suitable for determining extreme wave bending moments.

5.6.3.2. The purpose of the hull girder ultimate strength verification method is to demonstrate that one of most critical failure modes of a double hull tanker is controlled.

5.6.4. Design verification - global finite element analysis

5.6.4.1. The global finite element analysis is utilized to verify the scantlings given by the load-capacity based prescriptive requirements. The analysis is essential because the prescriptive requirements do not take into account the complex interactions between the ship’s structural components, complex local structural geometry, change in thicknesses and member section properties as well as the complex load regime with sufficient accuracy. Hence the global finite element analysis is necessary to verify the proposed scantlings.

5.6.4.2. A linear elastic three dimensional finite element analysis of the cargo region (a FE model length of three tanks is necessary) is carried out to assess and verify the structural response of the proposed hull girder and primary support members and assist in specifying the scantling requirements for the primary support members.The purpose with the finite element analysis is to verify that the stresses and buckling capability of the primary support members are within acceptable limits for the applied design loads.

5.6.5. Design verification - fatigue assessment

5.6.5.1. The fatigue assessment is necessary to verify that the fatigue life of critical structural details is satisfactory. A prescriptive fatigue requirement is applied to details such as end connections of longitudinal stiffeners utiliziing an SN curve approach based on geometric details, i.e. Class F, F2, etc. A hot spot fatigue assessment procedure utilizing finite element analysis is applied to details such as the hopper knuckle. In both cases, the fatigue assessment method is based on the Palmgren-Miner linear damage model.

5.6.6. Relationship between the prescriptive scantling requirements and the strength assessment (FEM)

5.6.6.1. The minimum acceptable scantlings are defined by the prescriptive minimum requirements. These may not to be reduced by any form of alternative calculations such as load-capacity prescriptive requirements or strength analysis such as FEM.

5.6.6.2. The section modulus and/or shear area of a primary support member and/or the cross sectional area of a primary support member cross tie may be lessened to 85% of the prescriptive requirements provided that the reduced scantlings conform to the strength assessment (FEM).

5.6.6.3. The philosophy is that a coarse approach shall be more conservative than a detailed approach. Hence, the prescriptive requirements are generally more conservative than the corresponding requirement based on strength assessment (FEM).

SECTION 3 RULE APPLICATION

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1. Notations

1.1. Notations

1.1.1. General

1.1.1.1. Ships fully equipped with the requirements of these Rules and the specific requirements of the IRS relating to construction, survey and equipment will be eligible to be assigned with character symbols and a ship type notation appropriate to the IRS.

2. Documentation, Plans and Data Requirements

2.1. Documentation and Data Requirements

2.1.1. Loading information

2.1.1.1. Loading guidance information which has adequate information to enable the master of the ship to maintain the ship within the stipulated operational limitations shall be provided onboard the ship. The loading guidance information shall include an approved loading manual and loading computer system complying with the requirements given in Chapter 2 Sections 2/1.1.2 and 1.1.3 respectively.

2.1.2. Submission of calculation data and results

2.1.2.1. Where calculations are carried out according to the procedures given in these Rules and regulations, one copy of the following supporting information is to be submitted as applicable:

a) Reference to the calculation procedure and technical program used,
b) A description of the structural modeling,
c) A summary of the analysis parameters including properties and boundary conditions,
d) Details of the loading conditions and the means of applying loads,
e) A comprehensive summary of calculation results,
f) Sample calculations where appropriate.

2.1.2.2. In general, submission of large volumes of input and output data associated with programs, such as finite element analysis, shall not be necessary.

2.1.2.3. The responsibility for specification without any error and input of program data and the subsequent correct transpose of output resides with the designer.

2.1.3. Use of computer software for rule calculations

2.1.3.1. In general, any rule computation program familiar to IRS may be employed to determine scantlings according to these Rules provided the implementation given in 5.1 is complied with.

2.1.3.2. A computer program that is demonstrated to produce reliable results to the satisfaction of IRS is regarded as a recognised program. Full particulars of the computer program, including example calculation output, are to be submitted, where the computer programs employed are not supplied or recognised by IRS. It is recommended that the designers consult the IRS on the suitability of the computer programs intended to be utilized prior to the commencement of any analysis work.

2.2. Submission of Plans and Supporting Calculations

2.2.1. General

2.2.1.1. In general, the main categories and lists of information requisite are provided in 2.2.2. Additional requirements for some items are also provided in subsequent sections as applicable.

2.2.1.2. Plans are usually taken to be submitted in triplicate, but one copy only is required for supporting documents and calculations. Additional copies can be required in accordance with the IRS requirements.

2.2.1.3. Plans are to consist of all necessary information to fully define the structure, which includes construction details, materials, welding and loads imposed on the structure by equipment and systems as appropriate.

2.2.1.4. Plans shall include information related to the renewal thickness as specified in Chapter 3 Section 2.

2.2.2. Plans and supporting calculations

2.2.2.1. In general, plans covering the following items are to be submitted:

a) Main scantling plans:

- midship sections showing longitudinal and transverse structural members,
- Construction profiles/plans showing all main longitudinal structural elements along the ships length including decks, inner bottom, bulkheads, double side stringers and double bottom girders,
- Shell expansion,
- Main oil-tight and watertight transverse bulkheads including primary support members.

b) Loading guidance information:

- preliminary loading manual,
- final loading manual,
- details of the design basis, see Ch 2 Section 2/1.1.2,
- test conditions for the loading instrument.

c) Detailed construction plans:

- Cargo tank construction plans showing the variations in detail arrangements and scantlings of double bottom floors, double side webs and other transverse primary support members,
- Fore end,
- Aft end,
- Engine room construction including the engine and thrust bearing seating,
- Deckhouses and superstructures.

d) Detail design plans except where the information is already included on plans listed in (a) and (c):

- Stern frame,
- Hull penetration plans,
- Welding ,
- Bilge keels,
- Booklet of standard design details,
- Anchoring and mooring equipment,
- Pillar and girder support arrangements for decks,
- Access arrangements through double bottom and side skin spaces in the cargo tank region,

- Details and arrangements of openings and attachments to the hull structure for means of access for inspection purposes.

e) plans detailing support structures except where the information is already included on plans listed in (a) to(d):

- Anchoring windlass and chain stopper,
- Mooring winches,
- Masts, derrick posts or cranes,
- Emergency towing equipment,
- Other deck equipment or fittings.

2.2.2.2. The following supporting documents are to be submitted:

a) General arrangement,
b) capacity plan,
c) lines plan or equivalent,
d) dry-docking plan, where developed,
e) Freeboard plan or equivalent, showing freeboards and items relative to the conditions of assignment.

2.2.2.3. The following supporting calculations are to be submitted:

a) Calculation for Stiil water bending moments, Wave bending moments, Sea pressures etc. for determination of scantlings for structural components of the vessel.

b) Calculation of the equipment number

2.2.2.4. Plans of items not covered by these Rules are to be submitted according to the IRS requirements.

2.2.3. Plans to be supplied onboard the ship

2.2.3.1. One copy of the following plans indicating the new-building and renewal thickness for each structural item:

a) Main scantling plans as given in 2.2.2.1(a),
b) One copy of the final approved loading manual, see 2.1.1,
c) One copy of the final loading instrument test conditions, see Chapter 2 Section 2/1.1.3,
d) Detailed construction plans as given in 2.2.2.1(c),
e) Welding,
f) Details of the extent and location of higher tensile steel together with details of the specification and mechanical properties, and any recommendations for welding, working and treatment of these steels,
g) Details and information on use of special materials, such as aluminum alloy, used in the hull construction,
h) Towing and mooring arrangements plan, see Chapter 3 Section 2/3.1.6.16.

3. Scope of Approval

3.1. General

3.1.1. Rule application

3.1.1.1. Further to the information contained in Chapter 1 Section 1/1.1.2 and Section 1/1.2.1, the Rules cover the scantling requirements for the classification of new double hull tankers of 150m or greater in length.

3.1.1.2. In addition to or in excess of the classification requirements, the attention of owners, designers, and builders are directed to the regulations of international, national, canal, and other authorities dealing with those requirements which may affect structural aspects.

3.1.1.3. Other aspects of the structural design not covered by these Rules shall be addressed utilizing the rules of the IRS.

3.2. Classification

3.2.1. General

3.2.1.1. Submission of the documentation plans and data requirements specified in 2 are required to be submitted. In order to verify compliance with the requirements, such documentation can be reviewed by IRS.

3.2.1.2. An appropriate term can be used to indicate that the plans, reports or documents have been reviewed for compliance with these Rules according to the procedures of the IRS.

3.3. Requirements of National and International Regulations

3.3.1. Responsibility

3.3.1.1. It is the responsibility of the designer to make sure that the design complies with the current National and International regulations applicable to the vessel.

3.3.1.2. IRS cannot be made responsible for assessing compliance with International and National regulations as part of the general classification approval process. However, IRS may enter into an agreement under which they are explicitly instructed to review and approve a vessel design for compliance with specified regulations. This approval may be accepted as proof of compliance on behalf of a Flag Administration provided IRS has been designated as a suitable recognised by that Flag Administration in accordance with SOLAS Regulations XI/1.

3.3.2. Review procedure

3.3.2.1. The vessel is to be issued with certificates indicating compliance with National and International regulations by the Flag Administration, when compliance is reviewed by the Flag Administration. For ships with arrangements and equipment that are essential to conform to the following requirements, and applicable amendments thereto, and where not issued by the Flag Administration, the applicable convention certificates are to be issued by IRS when authorised:

a) *International Convention on Load Lines, 1966*
b) *International Convention for the Safety of Life at Sea, 1974, and its Protocol of 1978*
c) *International Convention for the Prevention of Pollution from Ships, 1973, and as modified by the Protocol of 1978 relating thereto.*

Convention certificates may be issued by either IRS with which the ship is classed, for dual class ships, provided this is recognised in a formal dual class agreement with the other Society classing the ship and that both societies are authorised by the Flag Administration.

4. Equivalence Procedure

4.1. General

4.1.1. Rule applications

4.1.1.1. Application of these Rules can be done in general to double hull oil tankers of normal form, proportions, speed and structural arrangements. Relevant design parameters defining the assumptions made are given in Chapter 1 Section 2/3.

4.1.1.2. Application of these Rules can be done to steel ships of welded construction. Other materials for use in hull construction can be specially considered.

4.1.1.3. Special consideration will be provided to the application of the Rules incorporating design parameters which are outside the design basis of Chapter 1 Section 2/3, for example:

a) Increased fatigue life
b) Increased corrosion additions
c) Increased cargo density.

4.1.2. Novel designs

4.1.2.1. Ships of novel design, i.e. those of unusual form, proportions, speed and structural arrangements outside those reflected in Chapter 1 Section 2/3.1.2 of these Rules will be specially considered in accordance with the contents of this sub-section.

4.1.2.2. Submission of the information is to be done to IRS to demonstrate that the structural safety of the novel design is at least equivalent to that intended by the Rules.

4.1.2.3. IRS is to be contacted in such cases, at an early stage in the design process to establish the applicability of the Rules and additional information is required for submission.

4.1.2.4. A systematic review may be required to document equivalence with the Rules, dependent on the nature of the deviation.

4.1.3. Alternative calculation methods

4.1.3.1. Alternative calculation methods to those shown in the Rules may be accepted where indicated in specific sections of the Rules, provided it is demonstrated that the scantlings and arrangements are of at least equivalent strength to those derived utilizing the Rule calculation method.

5. Calculation and Evaluation of Scantling Requirements

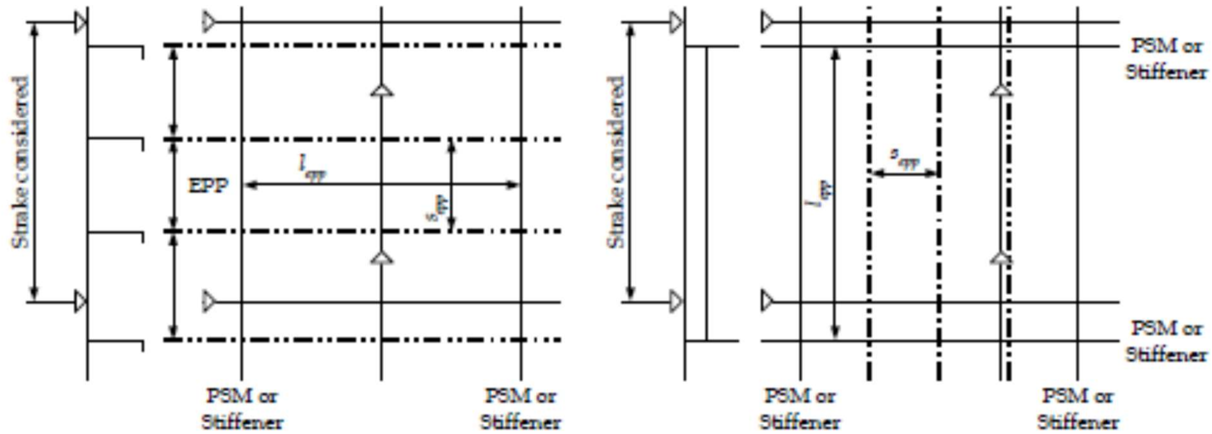
5.1. Determination of Scantling Requirements for Plates

5.1.1. Determination of scantlings of plate strakes - idealisation of plate panels

5.1.1.1. Based on the idealisation of the as-built structure as a series of Elementary Plate Panels (EPP), scantlings of plate strakes are to be derived.

5.1.1.2. An EPP is the unstiffened part of the plating between stiffeners. The plate panel length, as shown in Figure 1.3.1, l_{epp}, and breadth, s_{epp}, of the EPP are defined in relation to the longest and shortest plate edges respectively.

5.1.1.3. The idealisation of EPP may be different for strength assessment, and may be taken into account the mesh arrangement in the FEM model.



Longitudinal/horizontal framing | Transverse/vertical framing

Figure 1.3.1: Elementary Plate Panel Definition

5.1.1.4. The required scantling of a plate strake is to be taken as the greatest value necessary for each EPP within that strake as given by:

a) An EPP positioned entirely within the strake boundaries, e.g. EPP2 in Figure 1.3.2

b) An EPP with a strake boundary weld seam bisecting it predominantly in the direction of the long edge of the EPP, e.g. EPP1, 3, 4 and 6 in Figure 1.3.2

c) An EPP with a strake boundary weld seam bisecting it predominantly in the direction of the short edge of the EPP within more than half the EPP breadth, s_{epp}, from the edge, e.g. EPP1 and EPP2 in Figure 1.3.3(a).

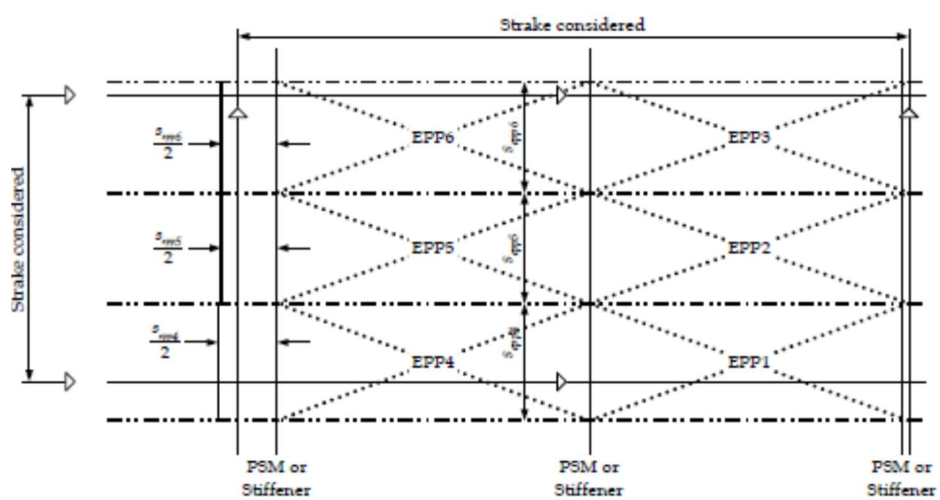


Figure 1.3.2: Determining Elementary Plate Panels for a Strake

5.1.2. Determination of scantlings of elementary plate panels for scantling requirements

5.1.2.1. The scantling that is required of each elementary plate panel shall be calculated based on a Load Calculation Point (LCP) defined as:

a) For longitudinal framing, at the mid length of the EPP is to be measured along the global x-axis at its lower edge. For horizontal plating the load calculation point is to be taken at the outboard y-value of the EPP. See Figure 1.3.3.(a)
b) For transverse framing, at the mid length of the EPP measured along the global x-axis at the lower edge of strake. For horizontal plating the load calculation point is to be taken at the outboard y-value of the EPP. See Figure 1.3.3(b)
c) For horizontal framing on vertical transverse structure, at the lower edge of the elementary plate panel at the point of outboard y-value of the EPP. See Figure 1.3.3(c),
d) For vertical framing on vertical transverse structure, at the greatest y-value of the lower edge of the EPP or at the lower edge of strake. See Figure 1.3.3(d)

5.1.2.2. Both the local pressure and hull girder stress utilized for the calculation of the local scantling requirements shall be taken at the LCP.

5.1.3. Determination of scantlings of elementary plate panels for hull girder strength

5.1.3.1. The needed scantlings of the elementary plate panels shall satisfy the hull girder bending and hull girder shear requirements as stated in Chapter 2 Section 2/1.

5.1.3.2. The thickness which is needed in each elementary plate panel, with respect to buckling, is to be calculated based on stresses which are taken at the mid length of the EPP measured along the global x-axis.

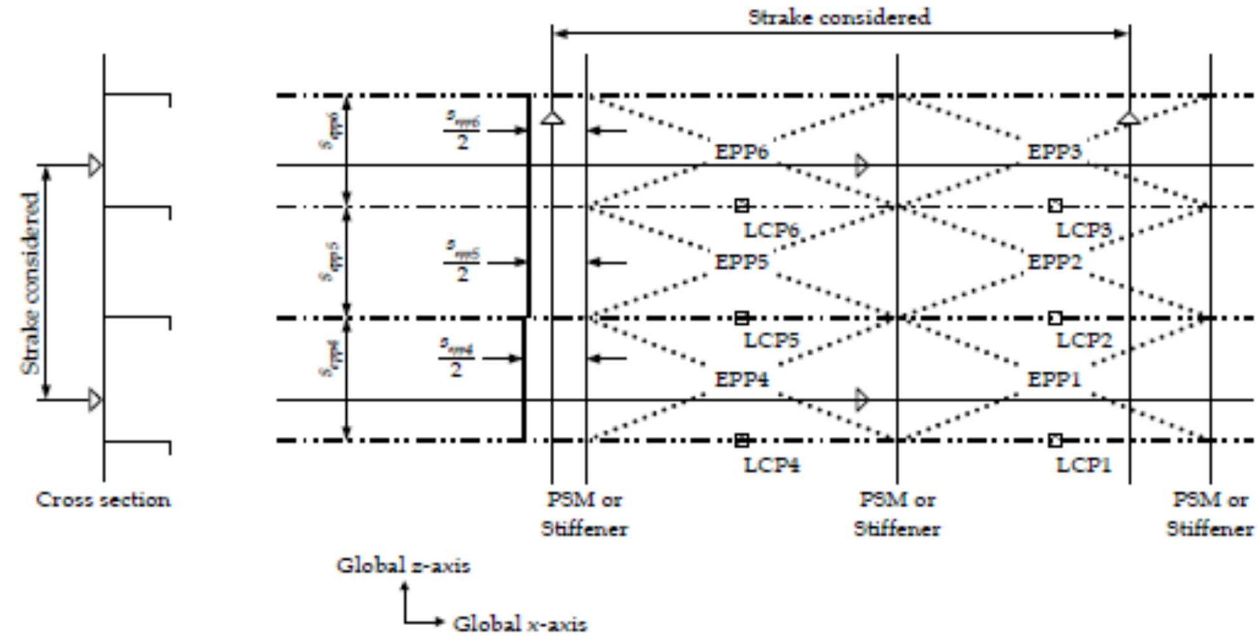
5.1.3.3. The stress distribution can be used to calculate the buckling evaluation across the width of the panel defined with a reference stress taken at the edge with maximum stress and reduced stress at the other edge given as a fraction, Ψ, as it is defined in Table 2.4.4, of the reference stress.

5.1.3.4. The required scantling of a plate strake shall be taken as the greatest value needed for each EPP within that strake as given by:

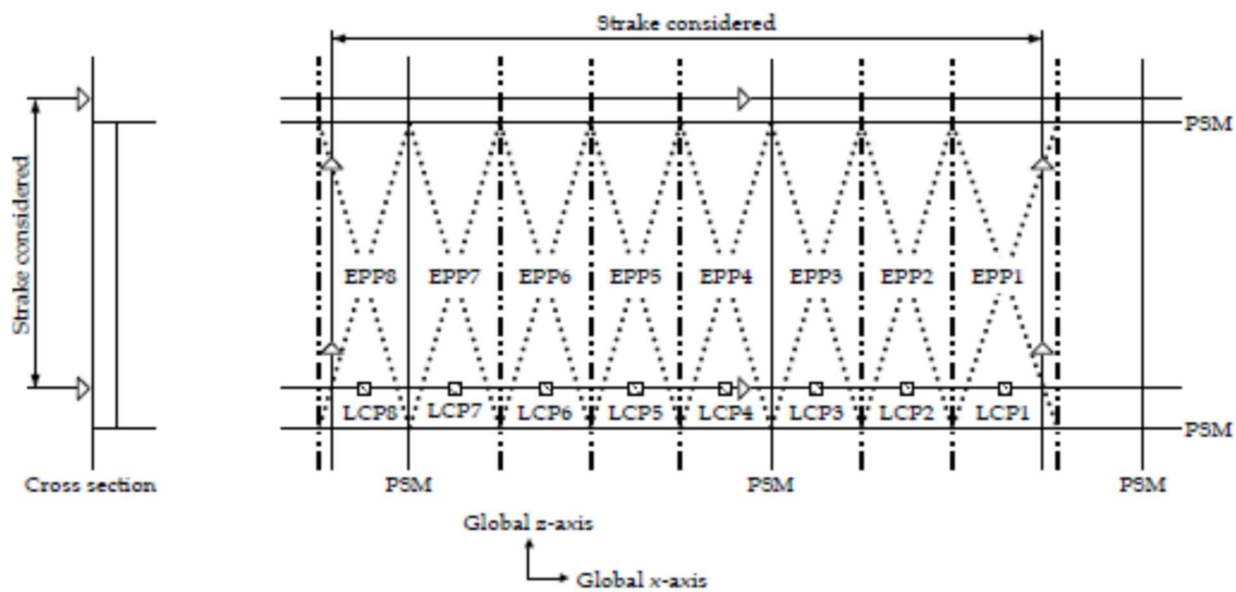
a) An EPP positioned entirely within the strake boundaries, e.g. EPP2 in Figure 1.3.2,
b) An EPP with a strake boundary weld seam bisecting it predominantly in the direction of the long edge of the EPP, e.g. EPP 1, 3, 4 and 6 in Figure 1.3.2,
c) An EPP with a strake boundary weld seam bisecting it predominantly in the direction of the short edge of the EPP within more than half the EPP breadth, s_{epp}, from the edge, e.g. EPP 1 and 2 in Figure 1.3.3(a).

5.1.4. Determination of scantlings of elementary plate panels for FEM strength assessment

5.1.4.1. The required scantlings of elementary plate panels can be derived from the plate mesh element with maximum utilisation see Chapter 2 Section 3/2.

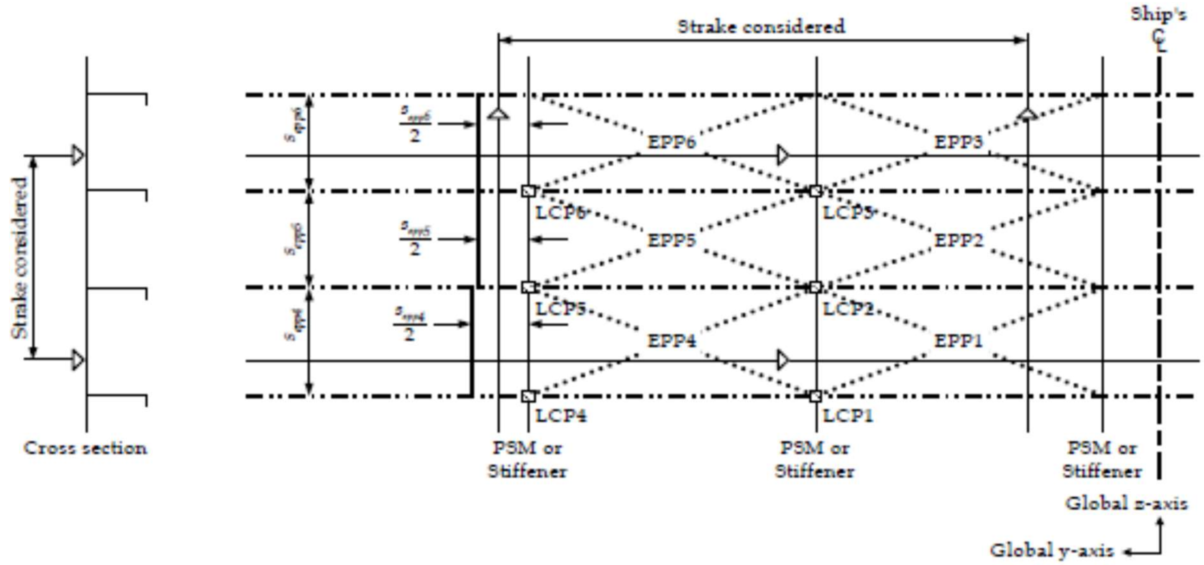


(a) Longitudinal Framing

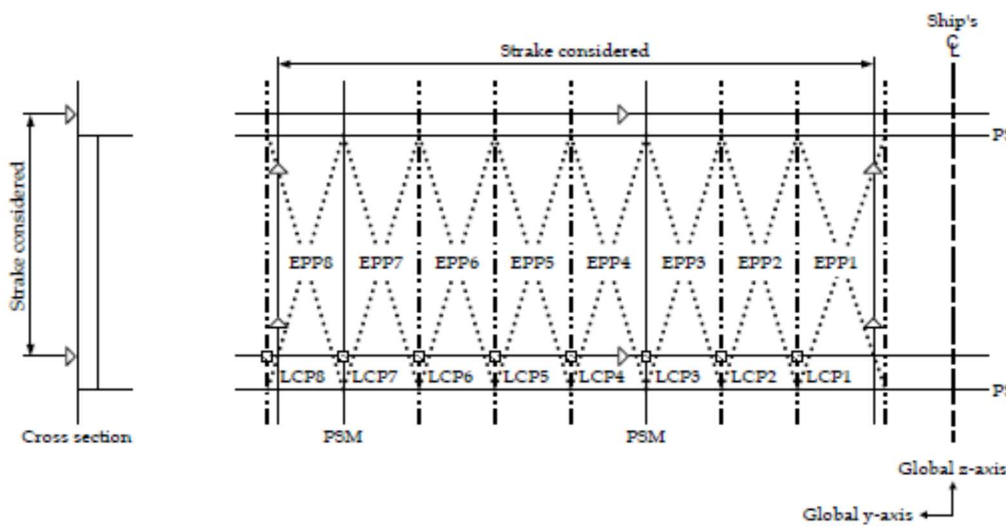


(b) Transverse Framing

Figure 1.3.3: Example of Load Calculation Point for Typical Structural Configurations



(c) Horizontal Framing on Transverse Structure



(d) Vertical Framing on Transverse Structure

Figure 1.3.3: Example of Load Calculation Point for Typical Structural Configurations (Continued)

5.2. Determination of Scantlings of Stiffeners

5.2.1. Determination of scantlings of stiffeners - idealisation of stiffeners

5.2.1.1. Idealisation of the as built structure can be used for the scantlings of individual stiffeners as a series of stiffened panels.

5.2.1.2. A stiffened panel consists of a single idealized stiffener profile and effective plate flange that supports a boundary of one or more elementary plate panels. The stiffened panels are arranged on the idealisation of the structure in accordance with the elementary plate panel definition in 5.1.1.

5.2.1.3. As it is stated in Chapter 2 Section 2, scantlings of stiffeners may be decided based on the concept of grouping designated sequentially placed stiffeners of equal scantlings. The scantling of the group is to be taken as the greater of the following:

a) The average of the required scantling of all stiffeners within a group
b) 90% of the maximum scantling that is required for any one stiffener within the group. The concept of grouping is not applicable to fatigue requirements as given in Chapter 2 Section 3/3 and Chapter 4 Section 3.

5.2.2. Determination of scantlings of stiffened panels for scantling requirements and fatigue

5.2.2.1. The required scantling of a stiffened panel should be based on a pressure load calculation point defined as:

a) Midpoint of the overall span, l_{full}, of the stiffener between primary support members, see Figure 1.3.4,

b) The point where the stiffener connects to the plating.

Double Skin Construction

Single Skin Construction

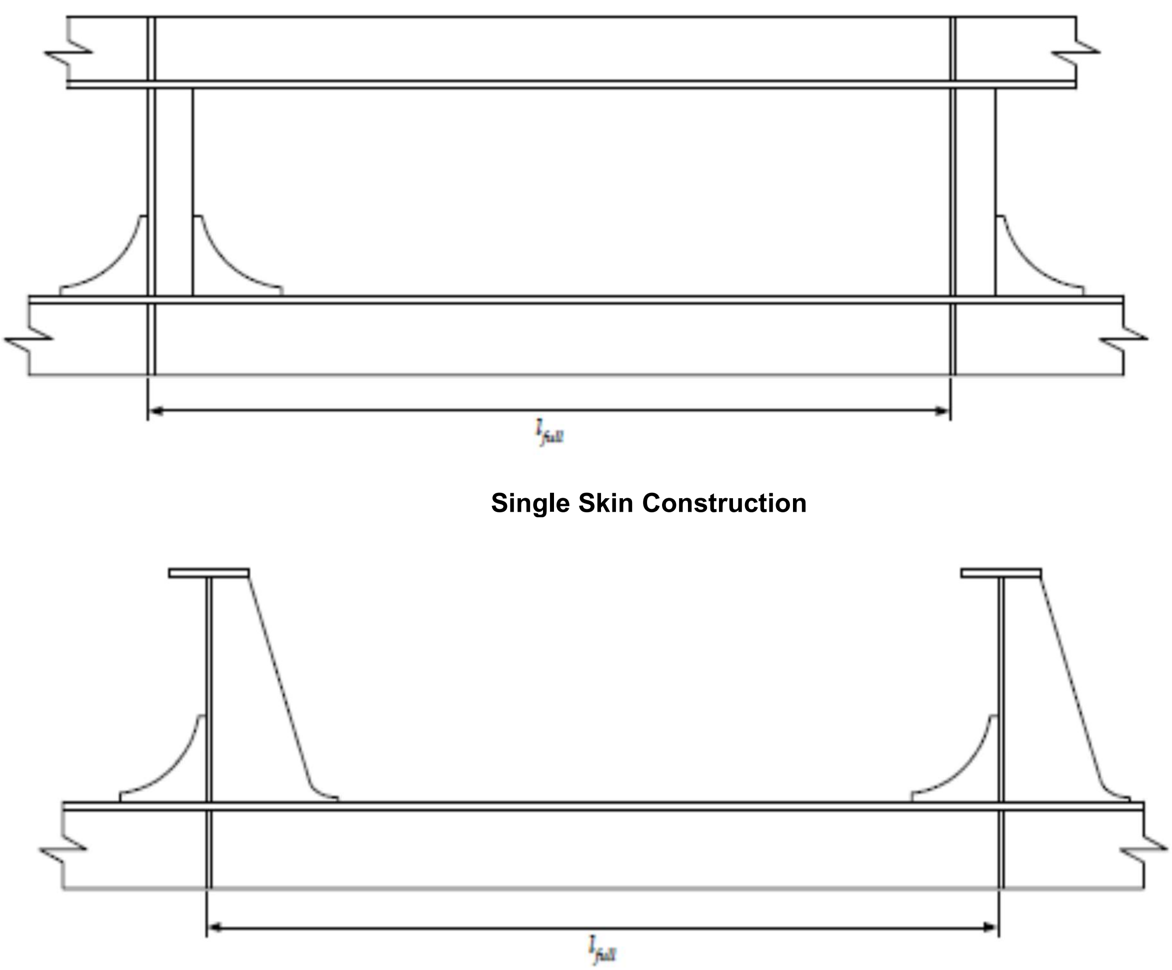


Figure 1.3.4: Definition of Overall Span of Stiffeners, l_{full}

5.2.2.2. The design pressure should be taken as the pressure at the midpoint of the overall span for longitudinal and horizontal framing.

5.2.2.3. The design pressure is to be taken as the greater of the following for transverse and vertical framing:

P_{ms} kN/m^2

$$\frac{(P_{end-1} + P_{end-2})}{2} \quad kN/m^2$$

where:

P_{ms}= calculated pressure at midpoint of overall span, l_{full}, in kN/m^2
P_{end-1}= calculated pressure at 1st end of overall span, in kN/m^2
P_{end-2}= calculated pressure at 2nd end of overall span, in kN/m^2
l_{full}= overall span, in m, see Figure 1.3.4

5.2.2.4. The requirements of section modulus given in these Rules relate to the reference point giving the minimum section modulus. Generally, this will be on the outer surface of the faceplate. Figure 1.3.5 shows the reference point for calculation of section modulus for typical profiles.

5.2.2.5. The hull girder stress which is normally used for calculation of local scantling requirements for stiffeners is to be taken at the reference point as shown in Figure 1.3.5.

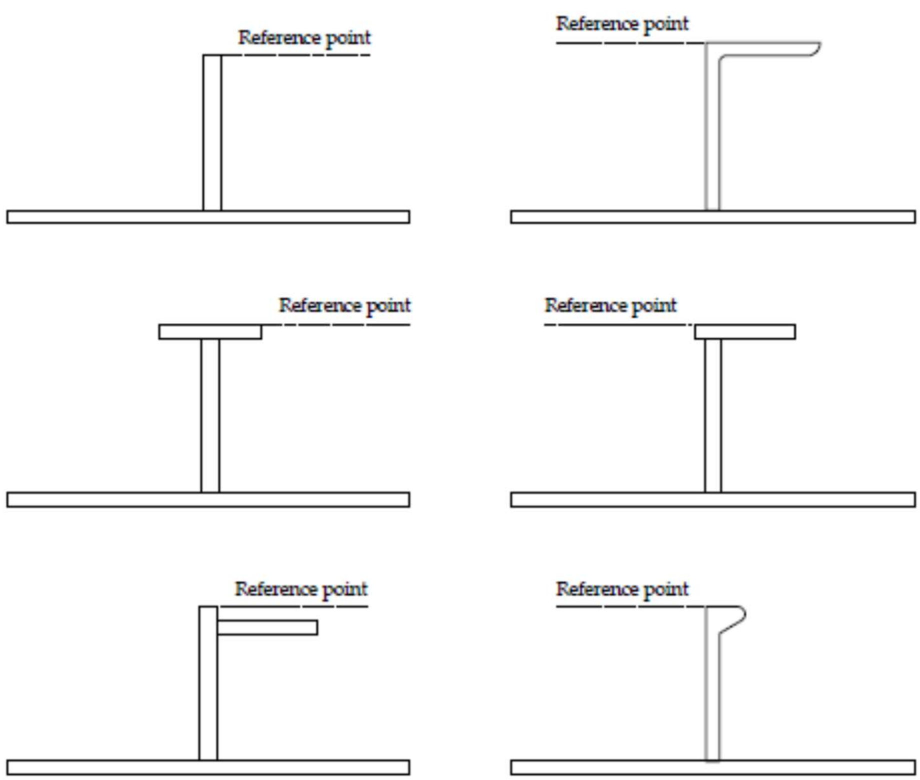


Figure 1.3.5: Reference Point for Calculation of Section Modulus and Hull Girder Stress for Local Scantling Assessment

5.2.3. Determination of scantlings of stiffened panels for hull girder buckling strength

5.2.3.1. The scantling that is required in a stiffened panel, with respect to buckling, is to be based on the axial stress which is calculated at the pointwhere the stiffener gets attached to the plate and at the mid length of the stiffener measured along the global x-axis.

5.2.3.2. The scantling which is necessary as given in 5.2.3.1 applies to stiffeners outside of a distance from the support, where the stiffener is spacing.

5.2.4. Determination of scantlings of stiffened panels for FEM strength assessment

5.2.4.1. The required scantlings of the stiffened panel are mainly based on the derivation of applied stresses as it is stated in Chapter 2 Section 3/2.

5.2.5. Shear area requirements of stiffeners

5.2.5.1. Chapter 2 Section 2 states the requirements for the shear area and/or web thickness of stiffeners.

5.2.5.2. The requirements that are mentioned in Chapter 2 Section 2 shall be calculated based on the load point that are defined in 5.2.2 and the effective span as it is given in Chapter 1 Section 4/2.1.2.

5.2.5.3. The things that needs to be matched with the requirements in Chapter 1 Section 2 are to be evaluated against the actual shear area of the stiffener, and this whole thing will be based on the effective shear height of the stiffener as it is said in Chapter 1 Section 4/2.4.2 and based on the specified minimum yield of the stiffener.

5.2.5.4. The calculation of the effective span may sustain the effect of brackets, but no part of the bracket is to be included in the calculation of the actual shear area.

5.2.6. Bending requirements of stiffeners

5.2.6.1. Chapter 2 Section 2 states all the requirements for the section modulus and moment of inertia of stiffeners.

5.2.6.2. The things that are needed in Chapter 2 sectio 2 can be calculated based on the load point which can be located in 5.2`.1 and the effective span as it is stated in Chapter 2 Section 4/2.1.1

5.2.6.3. All the things that are required in Chapter 2 Section 2 can be used for evaluation against the actual section modulus/moment of inertia of the stiffener. In the calculation of actual sectional properties, the stiffener web and flanges can also be included.

5.2.6.4. In the calculation of the effective span, the effects of bracket can be included, but no part of the bracket is to be included in the calculation of section modulus/moment of inertia.

5.2.6.5. When the material of the stiffener is of a higher strength material than the material of the attached plate, the yield stress used for the calculation of the section modulus requirements in Chapter 2 Section 2 is generally should not be greater than 1.35 times the minimum specified yield stress of the attached plate. If in any case the yield stress of the stiffener exceeds this limitation, the following criterion is to be satisfied:

$$\sigma_{yd-stf} \le \left(\sigma_{yd-plt} - |\sigma_{hg}|\right)\frac{Z_{net-p}}{Z_{net}} + |\sigma_{hg}| \qquad N/mm^2$$

where:
$\sigma_{yd\text{-}stf}$= specified minimum yield stress of the material of the stiffener, in N/mm^2
$\sigma_{yd\text{-}plt}$= specified minimum yield stress of the material of the attached plate, in N/mm^2
σ_{hg}maximum hull girder stress of sagging and hogging (S+D), in N/mm^2, as defined in Table 2.2.11 and Table 2.2.32 for stiffeners in cargo tank

region and machinery spaces respectively and not to be taken as less than 0.4 $\sigma_{yd\text{-}plt}$

Z_{net} = net section modulus, in way of face plate/free edge of the stiffener, in cm^3

$Z_{net\text{-}plt}$ =net section modulus, in way of the attached plate of stiffener, in cm^3

5.2.7. Evaluation of slanted stiffeners

5.2.7.1. The shear area and section modulus that are required for local support members are valid about an axis parallel to the plate flange. If the angle ϕ_w between the stiffener web and the attached plating is less than 75^0, see Figure 1.4.18, then the actual shear area and section modulus can be adjusted according to the Chapter 1 Sections 4/2.4.2 and 2.4.3. The stiffener web, ϕ_w, and the attached plating create an angle which is not to be less than 50^0 .

5.3. Calculation and Evaluation of Scantling Requirements for Primary Support Members

5.3.1. Load application point for primary support members

5.3.1.1. The midpoint of the load area generally takes the design pressure for primary support members. The design pressures for the primary support members are defined for individual members as given in Chapter 2 Section 2

5.3.2. Shear requirements of primary support members

5.3.2.1. Chapter 2 Section 2 states clearly the requirements for shear area and/or web thickness of primary support members.

5.3.2.2. These requirements of these things can be calculated on the basis of the load point defined in 5.3.1 and the effective span as it is stated in Chapter 1 Section 4/2.1.5.

5.3.2.3. These requirements can be utilized for the evaluation against the actual shear area and the specified minimum yield of the web plate of the primary support member. The quantity of the shear area which a primary support member has is defined in Ch 1Section 4/2.5.1. The calculation of effective span may use the effect of brackets, but the brackets are not to be included in the calculation of actual shear area.

5.3.3. Bending requirements of primary support members

5.3.3.1. Chapter 2 Section 2 and Section 4 states all the requirements for section modulus and moment of inertia of primary support members, respectively.

5.3.3.2. These requirements shall be calculated based on the load point defined in 5.3.1 and the effective span as given in Chapter 1 Section 4/2.1.4.

5.3.3.3. These requirements shall be evaluated against the actual section modulus/moment of inertia of the primary support member. In calculation of the actual sectional properties, web and flanges can be included. In the calculation of effective span, the effects of brackets can be included, but the brackets shall not be included in the calculation of section modulus/moment of inertia.

5.3.3.4. Where fitting a primary support member with the required web depth is almost impracticable; it is permissible to fit a member with reduced depth only if the fitted member has equivalent moment of inertia or deflection to the required member. The equivalent moment of inertia that are needed is to be based on an equivalent section which is given by the effective width of plating at mid span with required plate thickness, web of required depth and thickness and face plate of sufficient width and thickness to satisfy the required mild steel section modulus. All other rule requirements, such as minimum thicknesses, slenderness ratio, section modulus and shear area, are to be satisfied for the member of reduced depth. An equivalent member may also show the equivalent moment of inertia that is having the same deflection as the required member.

5.4. Rounding of Calculated Thickness

5.4.1. Required gross thickness

5.4.1.1. The minimum gross thickness that is needed of any member to be fitted at the new-building stage, exclusive of any owners' extras, can be taken as the rounded net thickness needed plus the appropriate corrosion addition.

5.4.1.2. The calculated net thickness can be rounded off to give the required net thickness to the nearest half millimeter. For example:

a) For $10.75 \le t_{calc\text{-}net} < 11.25$ mm the Rule required thickness is 11mm
b) For $11.25 \le t_{calc\text{-}net} < 11.75$ mm the Rule required thickness is 11.5mm.

SECTION 4 BASIC INFORMATION

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1. Definitions

1.1. Principal Particulars

1.1.1. L, rule length

1.1.1.1. The rule length that is defined by L is the distance on the waterline at the scantling draught that is measured from the forward side of the stem to the centerline of the rudder stock, in metres. L should not be shorter than 96%, and not required to be greater than 97%, of the extreme length on the summer load waterline. In ships with an unusual stern and bow arrangement the length, L, will be specially considered.

1.1.2. L_L, load line length

1.1.2.1. L_L, the load line length is stated in the International Convention on Load Lines.

1.1.3. Moulded breadth

1.1.3.1. B is used to indicate the moulded breadth, which is the maximum breadth of the ship, measured amidships to the moulded line of the frame, in metres.

1.1.4. Moulded depth

1.1.4.1. D, which is used to mark the moulded depth, is the vertical distance, in metres, amidships, from the moulded baseline to the moulded deck line of the uppermost continuous deck measured at deck at side. D shall be measured to the continuation of the moulded deck line on vessels with a rounded gunwale.

1.1.5. Draughts

1.1.5.1. T, the draught in metres, which is measured from the moulded baseline at amidships, is the summer load line draught for the ship in operation. It is to be noted that this may be less than the maximum permissible summer load waterline draught.

1.1.5.2. The strength requirements for the scantlings of the ship are met with T_{bal}, which is the minimum design ballast draught, in metres, the minimum draught of ballast condition which includes ballast water exchange operation are to be greater than the minimum design ballast draught, which is measured from the moulded base line at amidships, for any ballast loading condition in the loading manual that also includes both departure and arrival conditions.

1.1.5.3. For the normal balance condition in the loading manual, T_{bal-n}, the normal ballast draught in metres, which is the draught at departure is given, which is measured from the moulded base line at amidships, stated clearly in Chapter 2 Section2 /1.1.2.3. The normal ballast condition is the ballast condition in compliance with condition specified in Section 2/1.1.2.2 (a).

1.1.5.4. T_{full}, the full load design draught in metres, is the draught at departure given for the homogeneous full load condition in the loading manual, measured from the moulded base line at amidships, see Chapter 2 Section 2/1.1.2.3.

1.1.5.5. The strength which is needed for the scantlings of the ship is met at T_{sc}, which is the maximum design draught, in metres.

1.1.6. Amidships

1.1.6.1. Amidships is to be taken as the middle of the rule length, L.

1.1.7. Moulded displacement

1.1.7.1. Δ, the moulded displacement, in tonnes, corresponding to the underwater volume of the ship, at draught T_{sc}, in sea water having a density of $1.025 t/m^3$.

1.1.8. Maximum service speed

1.1.8.1. V, the maximum ahead service speed, in knots, means the greatest speed which the ship is designed to maintain in service at her deepest sea-going draught at the maximum propeller RPM and corresponding engine MCR (Maximum Continuous Rating).

1.1.9. Block coefficient

1.1.9.1. C_b, the block coefficient at the scantling draught, is defined as:

$$C_b = \frac{\nabla}{L B_{WL} T_{SC}}$$

where;

∇ moulded displacement volume at the scantling draught, in m^3

L rule length, as defined in 1.1.1.1

B_{WL} moulded breadth measured amidships, in m, at the scantling draught waterline

T_{sc} scantling draught, as defined in 1.1.5.5

1.1.9.2. C_{b-LC}, the block coefficient at considered loading condition, is defined as:

$$C_{b-LC} = \frac{\nabla_{LC}}{L B_{WL} T_{LC}}$$

Where:

∇_{LC} = moulded displacement volume at the T_{LC}, in m^3

L= rule length, as defined in 1.1.1.1

B_{WL}= moulded breadth measured amidships, in m, at the T_{LC}

T_{LC}= draught at amidships, in m, in the loading condition being considered.

1.1.10. Length between perpendiculars

1.1.10.1. L_{pp}, the length between perpendiculars, is the distance, in metres, on the scantling draught waterline from the fore side of the stem to the after side of the rudder post, or to the centre of the rudder stock if there is no rudder post.

1.1.11. The forward perpendicular

1.1.11.1. F.P., the forward perpendicular, is the perpendicular at the intersection of the scantling draught waterline with the fore side of the stem. The F.P. is the forward end of the rule length, L.

1.1.12. The aft perpendicular

1.1.12.1. A.P., the aft perpendicular, is the perpendicular at the aft end of the rule length, L, measured from the F.P.

1.1.13. Load line block coefficient

1.1.13.1. C_{bL}, the load line block coefficient, is defined in the *International Convention on Load Lines* as follows:

$$C_{bL} = \frac{\nabla_L}{L_L B T_L}$$

Where:
∇_L moulded displacement volume at the moulded draught, T_L, in m^3
L_L load line length, as defined in 1.1.2.1
B moulded breadth, in m, as defined in 1.1.3.1
T_L the moulded draught measured to the waterline at 85 per cent of the least moulded depth, in m

1.1.14. Deadweight

1.1.14.1. DWT is the deadweight of the ship, in tonnes, floating in water with a specific gravity of 1.025, at the summer load line draught.

1.2. Position 1 and Position 2

1.2.1. Position 1

1.2.1.1. Any location upon exposed freeboard is defined as Position 1 and raised quarterdecks, and exposed superstructure decks within the forward $0.25L_L$ from FP.

1.2.2. Position 2

1.2.1.2. Any location upon exposed superstructure desk is defined as Position 2, abaft of $0.25L_L$ from FP and at least one standard height of supertstructure above freeboard deck also forward of 0.25 L_{LL} from FP and at least two standard height of superstructure above freeboard deck.

1.3. Type ‘A’ and Type ‘B’ Freeboard Ships

1.3.1. ICLL definition

1.3.1.1. A Type ‘A’ or Type ‘B’ freeboard ship is as defined in the *International Convention on Load Lines*.

1.4. Coordinate System

1.4.1. Origin and orientation

1.4.1.1. Figure 1.4.1 states the coordinate system used within these Rules. Motions and displacements are considered positive in the forward, up and to port direction. Angular motions are considered positive in the clockwise direction about the x, y or z axis.

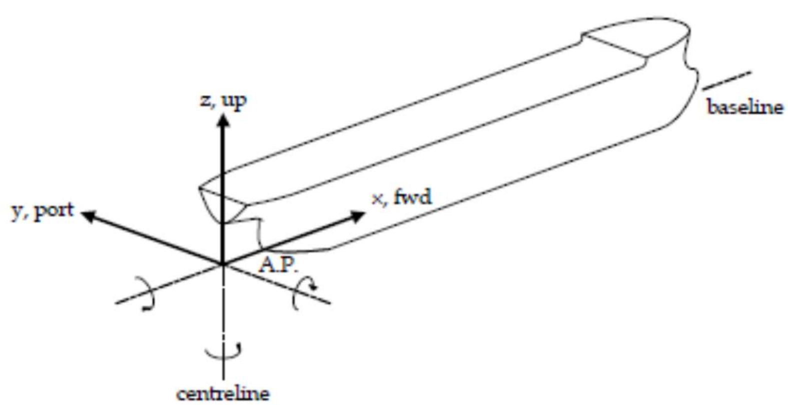


Figure 1.4.1: Corrugated Transverse Bulkhead Nomenclature

1.5. Naming Convention

1.5.1. Bulkhead nomenclature

1.5.1.1. Figures 1.4.2, 1.4.3 and 1.4.4 show the common structural nomenclature used within these Rules.

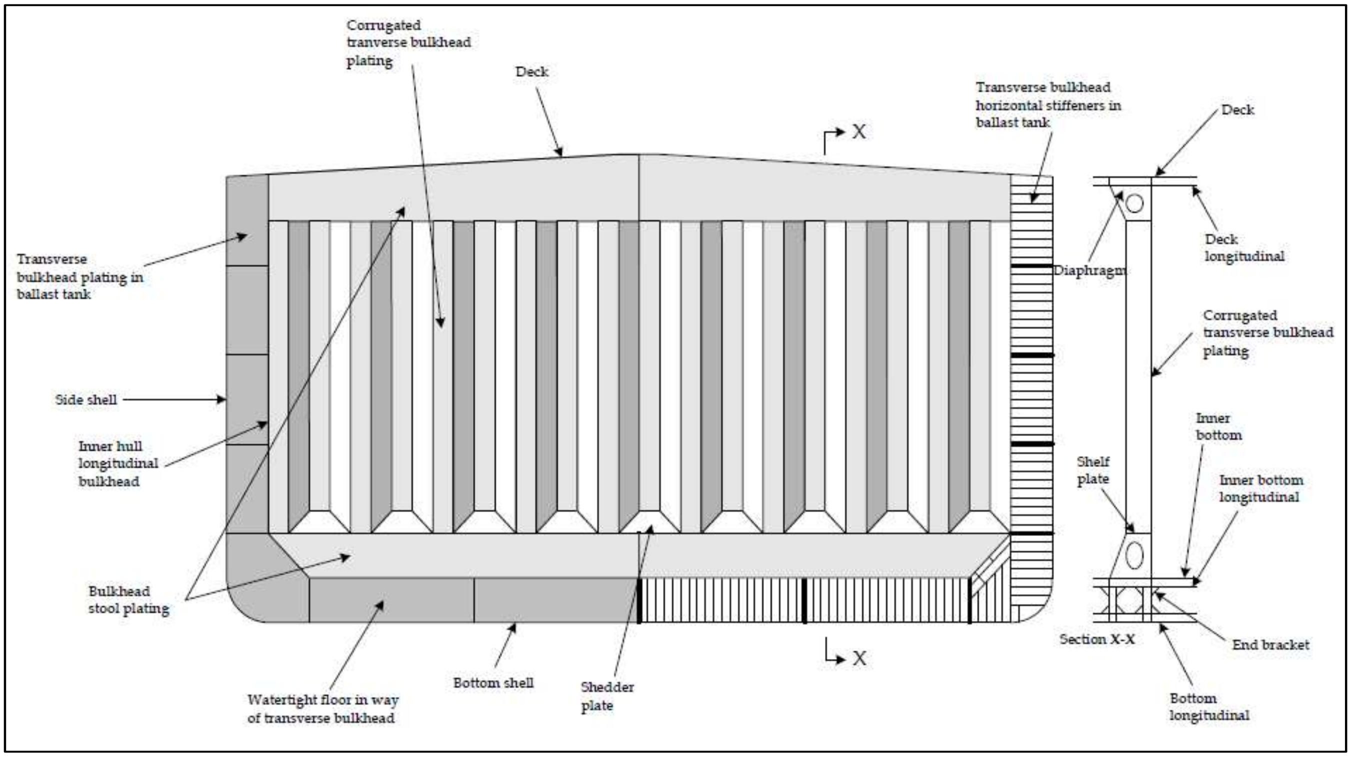


Figure 1.4.2 Corrugated Transverse Bulkhead Nomenclature

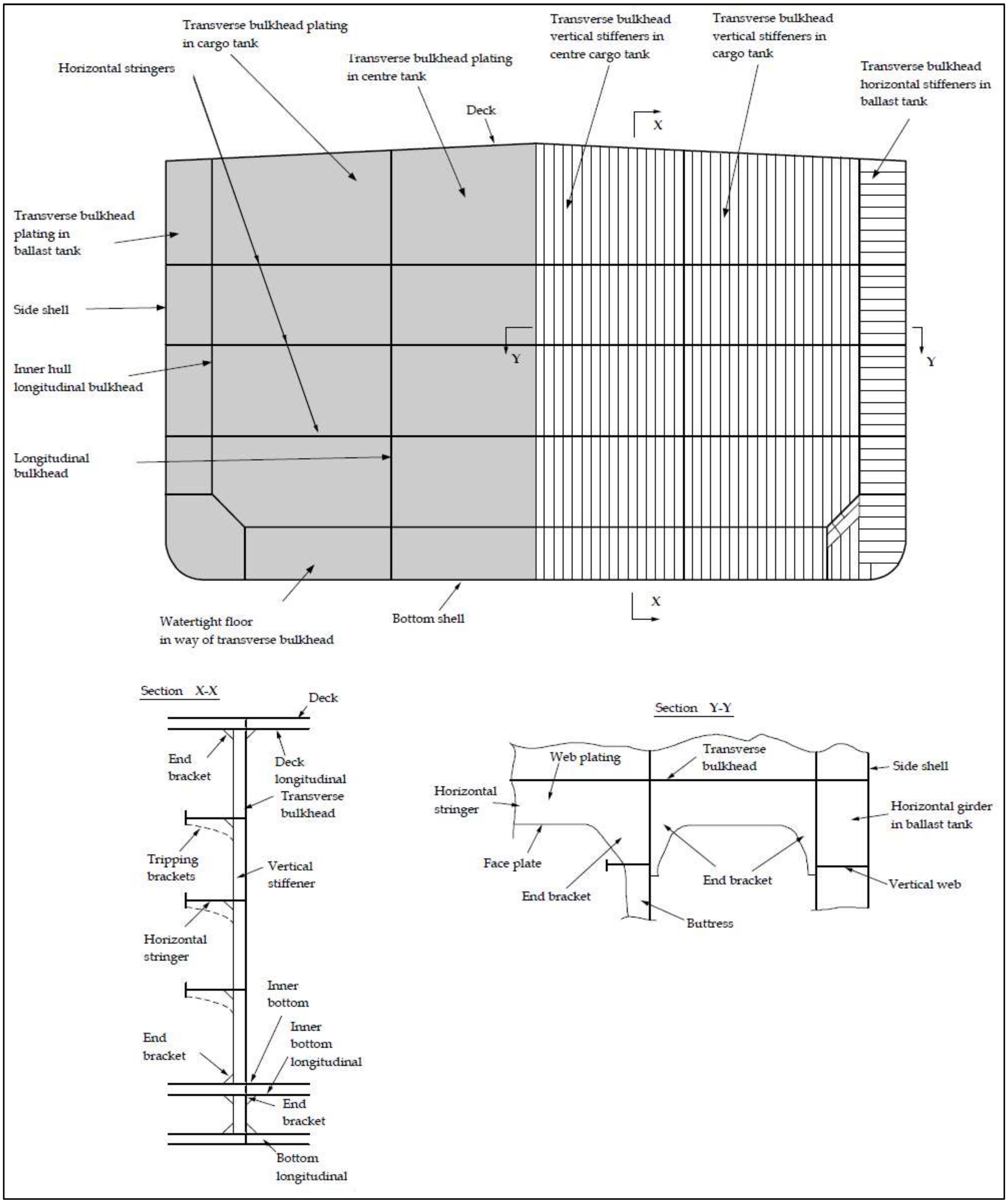


Figure 1.4.3 : Flat Transverse Bulkhead Nomenclature

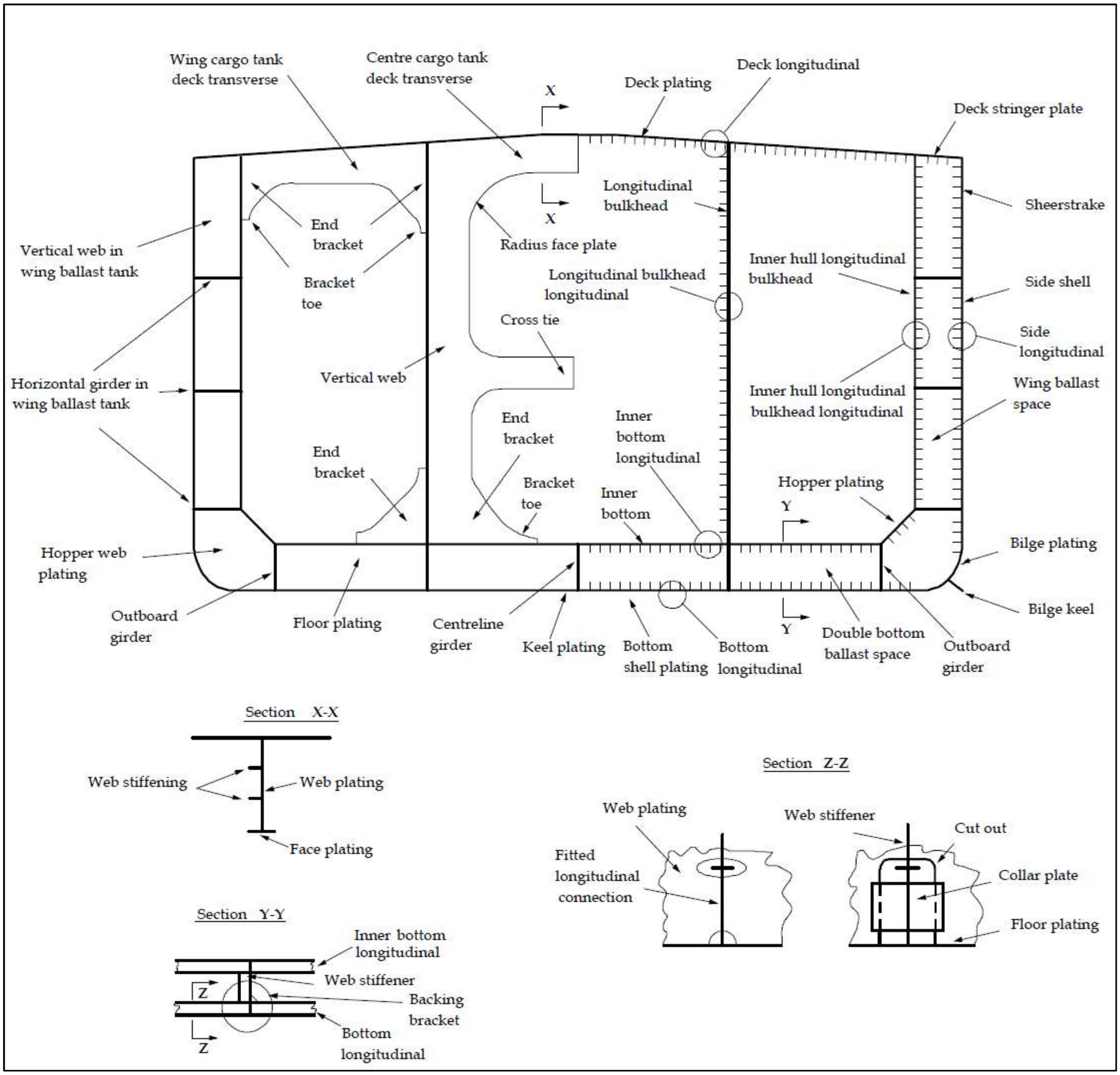


Figure 1.4.4: Mid Cargo Hold Transverse Section

1.6. Symbols

1.6.1. General

1.6.1.1. The symbols and subscripts utilized within these Rules have been defined locally. The principal particulars, as defined in 1.1, may be used within text without reference.

1.7. Units

1.7.1. General

1.7.1.1. The following units are utilized within these Rules. The units to be utilized within equations are given locally:

a) General:
- dimensions/distances, m
- primary spacings, m
- secondary spacings, mm
- area, m^2
- volume, m^3
- mass, t
- velocity, m/s
- acceleration, m/s^2

b) Hull girder properties:
- Dimensions, m
- Area, m^2
- section modulus, m^3
- moment of inertia, m^4
- moment of area, m^3

c) Stiffener properties:
- Dimensions, mm
- Area, cm^2
- section modulus, cm^3
- inertia, cm^4
- length/effective length, m
- Span, m

d) Plating dimensions:
- Breadth, mm
- Length, m
- Thickness, mm

e) Loads:
- Pressures, kN/m^2
- Loads, kN
- bending moment, kNm
- shear force, kN

f) Miscellaneous:
- yield strength, N/mm^2
- stress, N/mm^2
- deflections, mm
- modulus of elasticity, N/mm^2
- density, t/m^3
- displacement, t
- angle, deg
- calculated angle, rad
- period, s
- frequency, Hz
- ship speed, knots

1.8. Glossary

1.8.1. Definitions of terms

1.8.1.1. The terms in Table 1.4.1 are used within these Rules to describe the items which their respective definitions describe.

Table 1.4.1: Definitions of Terms

Terms	Definition
Accommodation deck	A deck used primarily for the accommodation of the crew
Accommodation ladder	A portable set of steps on a ship’s side for people boarding from small boats or from a pier
Aft peak	The area aft of the aft peak bulkhead
Aft peak bulkhead	The first main transverse watertight bulkhead forward of the stern
Aft peak tank	The compartment in the narrow part of the stern aft of the aft peak bulkhead
Anchor	a device which is attached to anchor chain at one end and lowered into the sea bed to hold a ship in position; it is designed to grip the bottom when it is dragged by the ship trying to float away under the influence of wind and current; usually made of heavy casting or casting
Ballast tank	A compartment used for the storage of water ballast
Bay	The area between adjacent transverse frames or transverse bulkheads
Bilge keel	A piece of plate set perpendicular to a ship’s shell along the bilges to reduce the rolling motion
Bilge plating	The area of curved plating between the bottom shell and side shell. To be taken as follows: From the start of the curvature at the lower turn of bilge on the bottom to the lesser of, the end of curvature at the upper turn of the bilge on the side shell or 0.2D above the baseline/local centerline elevation
Bilge strake	The lower strake of bilge plating
Boss	The boss of propeller is the central part to which propeller blades are attached and through which the shaft end passes
Bottom shell	The shell envelope plating forming the predominantly flat bottom portion of the shell envelope including the keel plate
Bow	The structural arrangement and form of the forward end of the ship
Bower Anchor	An anchor carried at the bow of the ship
Bracket	An extra structural component used to increase the strength of a joint between two structural members
Bracket toe	The narrow end of a tapered bracket
Breakwater	Inclined and stiffened plate structure on a weather deck to break and deflect the flow of water coming over the bow
Breast hook	A triangular plate bracket joining port and starboard side structural members at the stem
Bridge	An elevated superstructure having a clear view forward and at each side, and from which a ship is steered
Bulb profile	A stiffener utilizing an increase in steel mass on the outer end of the web instead of a separate flange
Bulkhead	A structural partition wall sub-dividing the interior of the ship into compartments
Bulkhead deck	The uppermost continuous deck to which transverse watertight bulkheads and shell are carried
Bulkhead stool	The lower or upper base of a corrugated bulkhead
Bulkhead structure	The transverse or longitudinal bulkhead plating with stiffeners and girders
Bulwark	The vertical plating immediately above the upper edge of the ship’s side surrounding the exposed deck(s)
Bunker	A compartment for the storage of fuel oil used by the ship's machinery
Cable	A rope or chain attached to the anchor

Camber	The upward rise of the weather deck from both sides towards the centerline of the ship
Cargo tank bulkhead	A boundary bulkhead separating cargo tanks
Cargo area	The part of the ship that contains cargo tanks and cargo/slop tanks and adjacent areas including ballast tanks, fuel tanks, cofferdams, void spaces and also including deck areas throughout the entire length and breadth of the part of the ship over the mentioned spaces. It includes the collision bulkhead and the transverse bulkhead at the aft end of the cargo block.
Carlings	A stiffening member used to supplement the regular stiffening arrangement
Casing	The covering or bulkhead around or about any space for protection
Cellular construction	A structural arrangement where there are two closely spaced boundaries and internal diaphragm plates arranged in such a manner to create small compartments
Centreline girder	A longitudinal member located on the centreline of the ship
Chain	Connected metal rings or links used for holding anchor, fastening timber cargoes, etc...
Chain locker	A compartment usually at the forward end of a ship which is used to store the anchor chain
Chain pipe	A section of pipe through which the anchor chain enters or leaves the chain locker
Chain stopper	A device for securing the chain cable when riding at anchor as well as securing the anchor in the housed position in the hawse pipe, thereby relieving the strain on the windlass
Coaming	The vertical boundary structure of a hatch or skylight
Cofferdams	The spaces between two bulkheads or decks primarily designed as a safeguard against leakage of oil from one compartment to another
Collar plate	A patch used to, partly or completely, close a hole cut for a longitudinal stiffener passing through a transverse web
Collision bulkhead	The foremost main transverse watertight bulkhead
Companionway	A weather tight entrance leading from a ship’s deck to spaces below
Compartment	An internal space bounded by bulkheads or plating
Confined space	A space identified by one of the following characteristics: limited openings for entry and exit, unfavourable natural ventilation or not designed for continuous worker occupancy
Corrugated bulkhead	A bulkhead comprised of plating arranged in a corrugated fashion
Cross ties	Large transverse structural members joining longitudinal bulkheads and used to support them against hydrostatic and hydrodynamic loads
Deck	A horizontal structure element that defines the upper or lower boundary of a compartment
Deck house	A decked structure other than a superstructure, located on the freeboard deck or above
Deck structure	The deck plating with stiffeners, girders and supporting pillars
Deep tank	any tank which extends between two decks or the shell/inner bottom and the deck above or higher
Discharges	Any piping leading through the ship’s sides for conveying bilge water, circulating water, drains etc….
Docking bracket	A bracket located in the double bottom to locally strengthen the bottom structure for the purposes of docking
Double bottom structure	The shell plating with stiffeners below the top of the inner bottom and other elements below and including the inner bottom plating
Doubler	Small piece of plate which is attached to a larger area of plate that requires strengthening in that location. Usually at the attachment point of a stiffener
Double skin member	Double skin member is defined as a structural member where the idealized beam comprises webs, with top and bottom flanges formed by

	attached plating
Duct keel	A keel built of plates in box form extending the length of the cargo tank. It is used to house ballast and other piping leading forward which otherwise would have to run through the cargo tanks
Enclosed superstructure	The superstructure with bulkheads forward and/or aft fitted with weather tight doors and closing appliances
Engine room bulkhead	A transverse bulkhead either directly forward or aft of the engine room
Face plate	The section of a stiffening member attached to the plate via a web and is usually parallel to the plated surface
Flange	The section of a stiffening member, typically attached to the web, but is sometimes formed by bending the web over. It is usually parallel to the plated surface
Flat bar	A stiffener comprising only of a web
Floor	A bottom transverse member
Forecastle	A short superstructure situated at the bow
Fore peak	The area of the ship forward of the collision bulkhead
Fore peak deck	A short raised deck extending aft from the bow of the ship
Freeboard deck	Generally the uppermost complete deck exposed to weather and sea, which has permanent means of closing all exposed openings
Freeing port	An opening in the bulwarks to allow water shipped on deck to run freely overboard
Gangway	The raised walkway between superstructure, such as between the forecastle and bridge, or between the bridge and poop
Girder	A collective term for primary supporting structural members
Gudgeon	A block with a hole in the centre to receive the pintle of a rudder; located on the stern post, it supports and allows the rudder to swing
Gunwale	The upper edge of the ship’s sides
Gusset	A plate, usually fitted to distribute forces at a strength connection between two structural members
Hatch ways	Openings, generally rectangular, in a ship’s deck affording access into the compartment below
Hawse pipe	Steel pipe through which the hawser or cable of anchor passes, located in the ship's bow on either side of the stem, also known as spurling pipe
Hawser	Large steel wire or fiber rope used for towing or mooring
Hopper plating	Plating running the length of a compartment sloping between the inner bottom and vertical portion of inner hull longitudinal bulkhead
HP	Holland Profile
Independent tank	A self-supporting tank
Inner hull	The innermost plating forming a second layer to the hull of the ship
Intercostal	Longitudinal member between the floors or frames of a ship; it is non-continuous
JIS	Japanese industrial standard profile
Keel	The main structural member or backbone of a ship running longitudinal along centreline of bottom. Usually a flat plate stiffened by a vertical plate on its centreline inside the shell
Knuckle	A discontinuity in a structural member
Lightening hole	A hole cut in a structural member to reduce its weight
Limber hole	A small drain hole cut in a frame or plate to prevent water or oil from collecting
Local support members	Local support members are defined as local stiffening members which only influence the structural integrity of a single panel, e.g. deck beams
Longitudinal centreline bulkhead	A longitudinal bulkhead located on the centreline of the ship
Longitudinal hull girder	Structural members that contribute to the longitudinal strength of the hull

structural members	girder, including: deck, side, bottom, inner bottom, inner hull longitudinal bulkheads including upper sloped plating where fitted, hopper, bilge plate, longitudinal bulkheads, double bottom girders and horizontal girders in wing ballast tanks
Longitudinal hull girder shear structural members	Structural members that contribute to strength against hull girder vertical shear loads, including: side, inner hull longitudinal bulkheads, hopper, longitudinal bulkheads and double bottom girders
Manhole	A round or oval hole cut in decks, tanks, etc., for the purpose of providing access
Margin plate	The outboard strake of the inner bottom and when turned down at the bilge the margin plate (or girder) forms the outer boundary of the double bottom
Notch	A discontinuity in a structural member caused by welding
Oil fuel tank	A tank used for the storage of fuel oil
Pillar	A vertical support placed between decks where the deck is unsupported by the shell or bulkhead
Pintle	Vertical pin on a rudder's forward edge that enables the rudder to hang onto the stern post and swing when it fits into the gudgeon
Pipe tunnel	The void space running in the midships fore and aft lines between the inner bottom and shell plating forming a protective space for bilge, ballast and other lines extending from the engine room to the tanks
Poop	The space below an enclosed superstructure at the extreme aft end of a ship
Poop deck	The first deck above the shelter deck at the aft end of a ship
Primary support members	Members of the beam, girder or stringer type which ensure the overall structural integrity of the hull envelope and tank boundaries, e.g. double bottom floors and girders, transverse side structure, deck transverses, bulkhead stringers and vertical webs on longitudinal bulkheads
Rudder	A device, usually of an aero foil or flat section that is used to steer a ship. A common type has a vertical fin at the stern and is able to move from 35 degrees port to 35 degrees starboard; rudders are characterised by their area, aspect ratio, and shape
Scallop	A hole cut into a stiffening member to allow continuous welding of a plate seam
Scarfing bracket	A bracket used between two offset structural items
Scantlings	The physical dimensions of a structural item
Scupper	Any opening for carrying off water from a deck, either directly or through piping
Scuttle	A small opening in a deck or elsewhere, usually fitted with a cover or lid or a door for access to a compartment
Shedder plates	Slanted plates that are fitted to minimize pocketing of residual cargo in way of corrugated bulkheads
Sheer strake	The top strake of a ship's side shell plating
Shelf plate	A horizontal plate located on the top of a bulkhead stool
Shell envelope plating	The shell plating forming the effective hull girder
Side shell	The shell envelope plating forming the side portion of the shell envelope above the bilge plating
Single skin member	Single skin member is defined as a structural member where the idealized beam comprises a web, with a top flange formed by attached plating and a bottom flange formed by a face plate
Skylight	A deck opening fitted with or without a glass port light and serving as a ventilator for engine room, quarters, etc.
Slop tank	A tank in an oil tanker which is used to collect the oil and water mixtures from cargo tanks after tank washing
Spaces	Separate compartments including tanks
Stay	Bulwark and hatch coaming brackets

Stem	The piece of bar or plating at which a ship's outside plating terminates at forward end
Stern frame	The heavy strength member in single or triple screw ships, combining the rudder post
Stern tube	A tube through which the shaft passes to the propeller; and acts as an after bearings for the shafting and may be water or oil lubricated
Stiffener	A collective term for secondary supporting structural members
Stool	A structure supporting tank bulkheads
Strake	A course, or row, of shell, deck, bulkhead, or other plating
Strength deck	The uppermost continuous deck
Stringer	Horizontal girders linking vertical web frames
Stringer plate	The outside strake of deck plating
Superstructure	A decked structure on the freeboard deck, extending from side to side of the ship or with the side plating not being inboard of the shell plating more than 0.04B
Tank top	The horizontal plating forming the bottom of a cargo tank
Towing pennant	A long rope which is used to effect the tow of a ship
Transom	The structural arrangement and form of the aft end of the ship
Transverse ring	All transverse material appearing in a cross-section of the ship's hull, in way of a double bottom floor, vertical web and deck transverse girder
Transverse web frame	The primary transverse girders which join the ships longitudinal structure
Tripping bracket	A bracket used to strengthen a structural member under compression, against torsional forces
‘Tween deck	An abbreviation of between decks, placed between the upper deck and the tank top in the cargo tanks
Ullage	The quantity represented by the unoccupied space in a tank
Void	An enclosed empty space in a ship
Wash bulkhead	A perforated or partial bulkhead in a tank
Watertight	Watertight means capable of preventing the passage of water through the structure under a head of water for which the surrounding structure is designed
Weather deck	A deck or section of deck exposed to the elements which has means of closing Weather tight, all hatches and openings
Weather tight	Weather tight means that in any sea conditions water will not penetrate into the ship
Web	The section of a stiffening member attached perpendicular to the plated surface
Wind and water strakes	The strakes of a ship's side shell plating between the ballast and the deepest load Waterline
Windlass	A machine for lifting and lowering the anchor chain
Wing tank	The space bounded by the inner hull longitudinal bulkhead and side shell

2. Structural Idealisation

2.1. Definition of Span

2.1.1. Effective bending span of local support members

2.1.1.1. The effective bending span, l_{bdg}, of a stiffener is defined for typical arrangements in 2.1.1.3 to 2.1.1.7. Span definition may be specially considered, where arrangements differ from those shown in Figure 1.4.5 through Figure 1.4.12.

2.1.1.2. The presence of brackets may reduce the effective bending span, only if the brackets are effectively supported by the adjacent structure, otherwise the effective bending span can be taken as the full length of the stiffener between primary member supports.

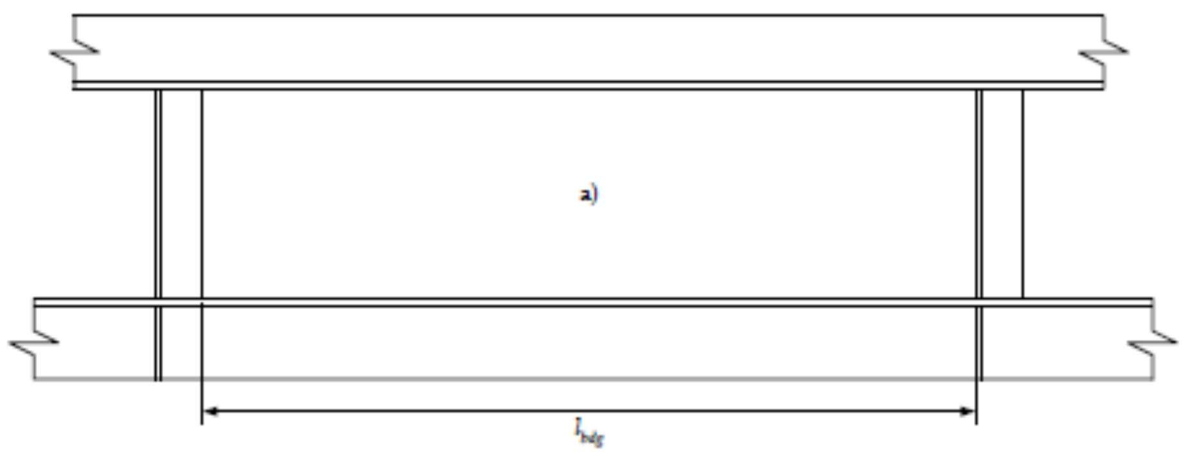
2.1.1.3. The effective bending span can be taken at the full length between primary member supports unless a backing bracket is fitted, if the web stiffener is sniped at the end or not attached to the stiffener under consideration, see Figure 1.4.6.

2.1.1.4. The effective bending span may only be lessened where brackets are fitted to the flange or free edge of the stiffener. Brackets fitted to the attached plating on the side opposite to that of the stiffener shall not be considered as effective in reducing the effective bending span.

2.1.1.5. The effective bending span, l_{bdg}, for stiffeners forming part of a double skin arrangement is to be taken as presented in Figure 1.4.5.

2.1.1.6. The effective bending span, l_{bdg}, for stiffeners forming part of a single skin arrangement shall be taken as depicted in Figure 1.4.6.

2.1.1.7. The effective bending span is to be taken as the full distance between primary support members as shown in Figure 1.4.6(a), for stiffeners supported by a bracket on one side of primary support members. The effective bending span is to be taken as in Figures 1.4.6(b), (c) and (d), if brackets are fitted on both sides of the primary support member.



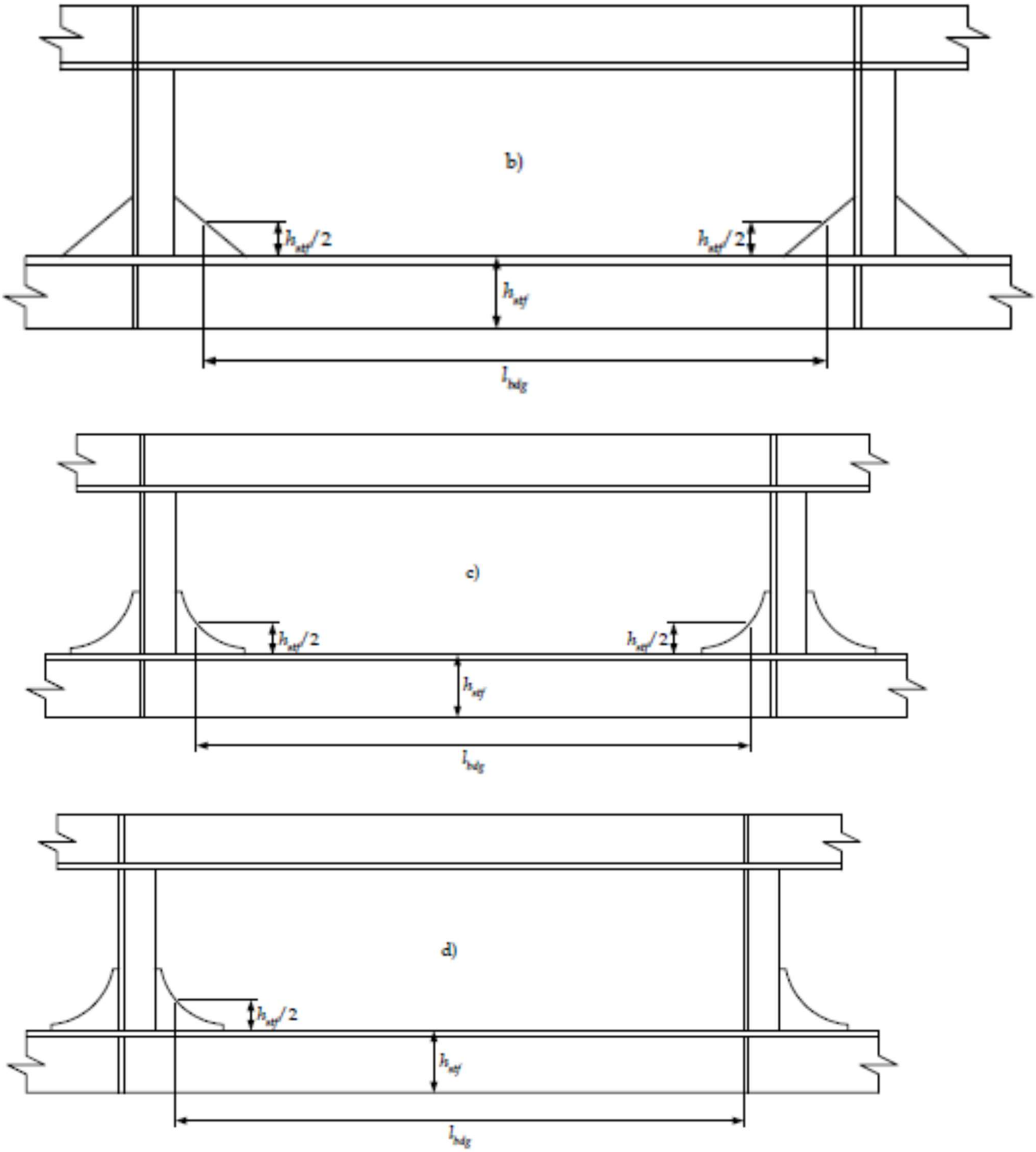


Figure 1.4.4: Effective Bending Span of Stiffeners Supported by Web Stiffeners (Double Skin Construction)

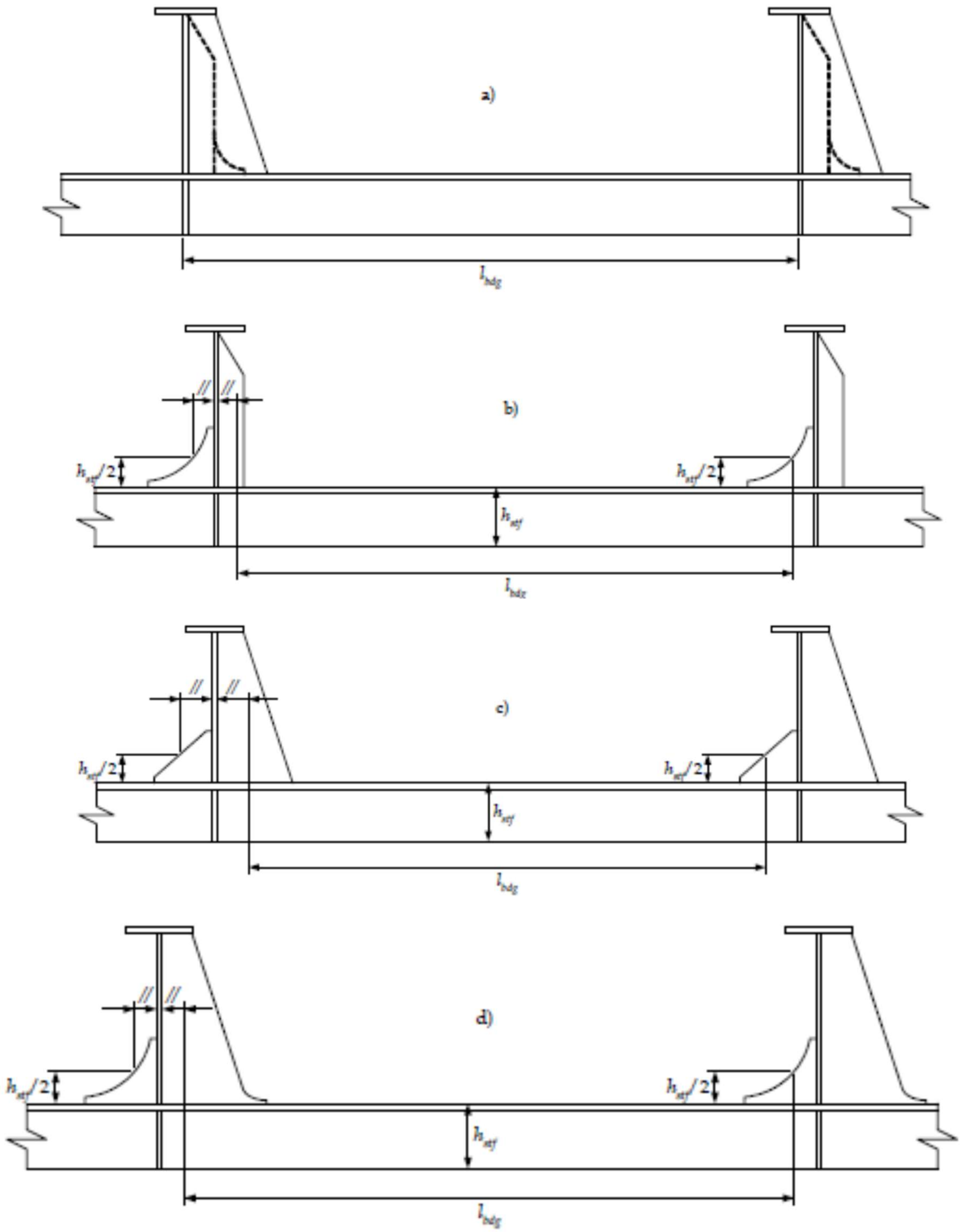


Figure 1.4.6: Effective Bending Span of Stiffeners Supported by Web Stiffeners (Single Skin Construction)

2.1.1.8. The effective bendingspan is to be taken to the position where the depth of the bracket is equal to one quarter of the depth of thestiffener, see Figure 1.4.6, where the face plate of the stiffener is continuous along the edge of the bracket.

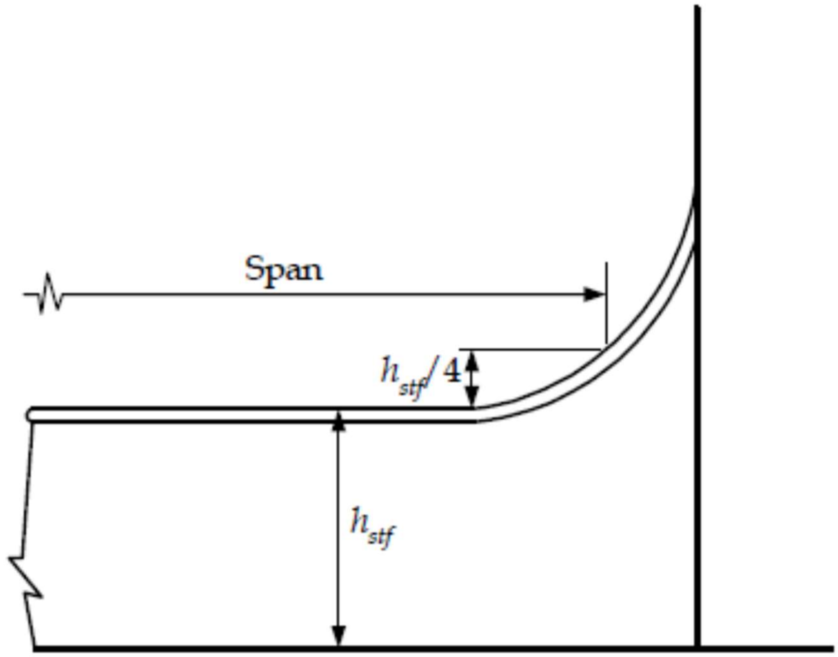


Figure 1.4.7: Effective Bending Span for Local Support Members with Continuous Face Plate along Bracket Edge

2.1.1.9. The bracket length is not to be taken greater than 1.5 times thelength of the arm on the bulkhead or base, for the calculation of the span point.

2.1.2. Effective shear span of local support members

2.1.2.1. The effective shear span, l_{shr}, of a stiffener is defined for typical arrangements in 2.1.2.5 to 2.1.2.7. For other arrangements, effective bending span will be specially considered.

2.1.2.2. The effective shear span may be lessened due to the presence of brackets provided the brackets are effectively supported by the adjacent structure, otherwise the effective shear span is to be as the full length as given in 2.1.2.4.

2.1.2.3. The effective shear span may be reduced for brackets fitted on either the flange or the free edge of the stiffener, or for brackets fitted to the attached plating on the side opposite to that of the stiffener. The effective shear span may be calculated using the longer effective bracket arm, if brackets are fitted at both the flange and free edge of the stiffener, and to the attached plating on the side opposite to that of the stiffener.

2.1.2.4. The effective shear span may be reduced by a minimum of s/4000 m at each end of the member, regardless of support detail, hence the effective shear span, l_{shr}, is not to be taken greater than:

$$l_{shr} \leq l - \frac{s}{2000} \qquad m$$

Where:
l =full length of the stiffener between primary support members, in m
s= stiffener spacing, in mm, as defined in 2.2.1.

2.1.2.5. The effective shear span, l_{shr}, for stiffeners forming part of a double skin arrangement shall be taken as projected in Figure 1.4.8.

2.1.2.6. The effective shear span, l_{shr}, for stiffeners forming part of a single skin arrangement shall be taken as shown in Figure 1.4.9.

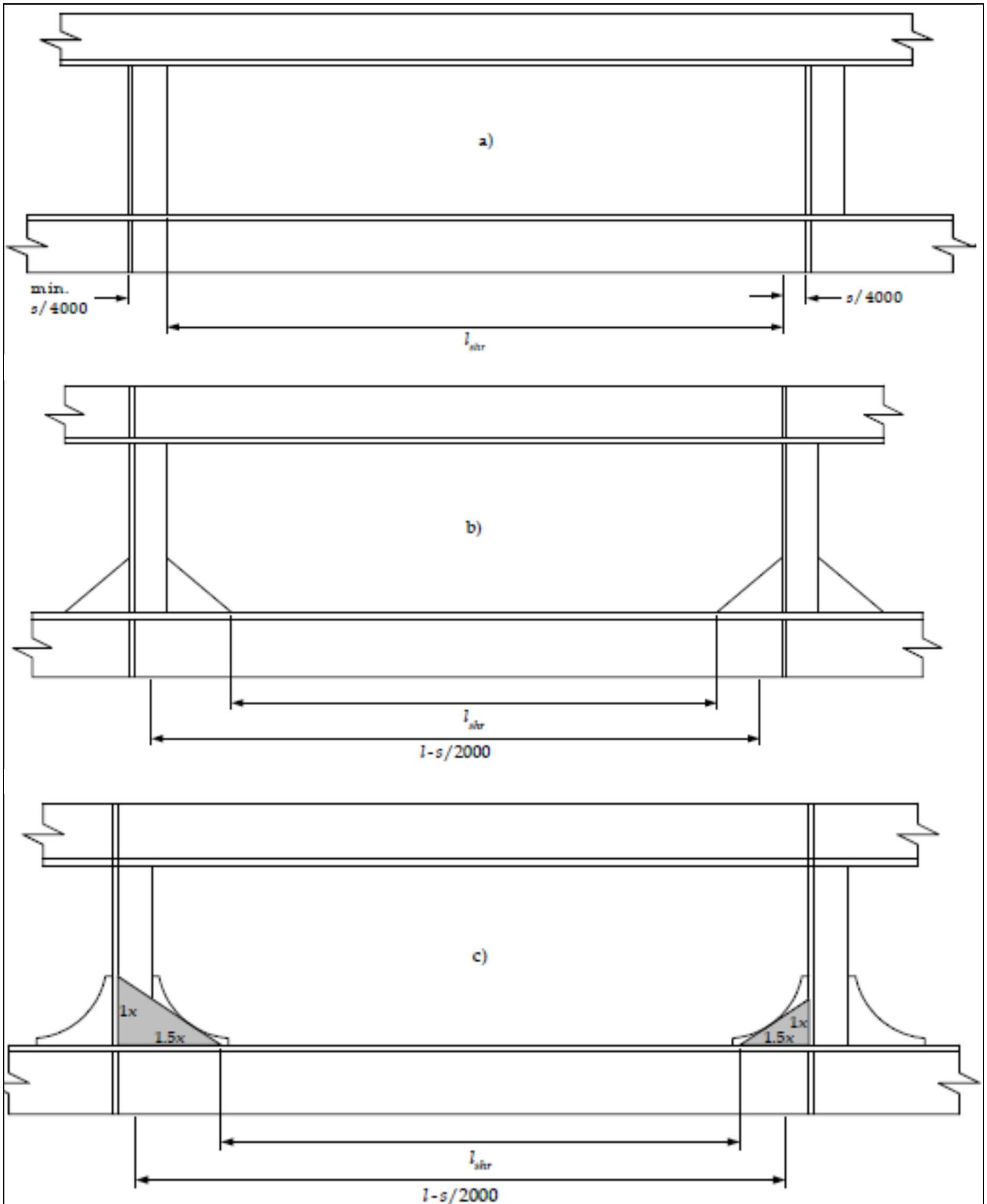


Figure 1.4.8: Effective Shear Span of Stiffeners Supported by Web Stiffeners (Double Skin Construction)

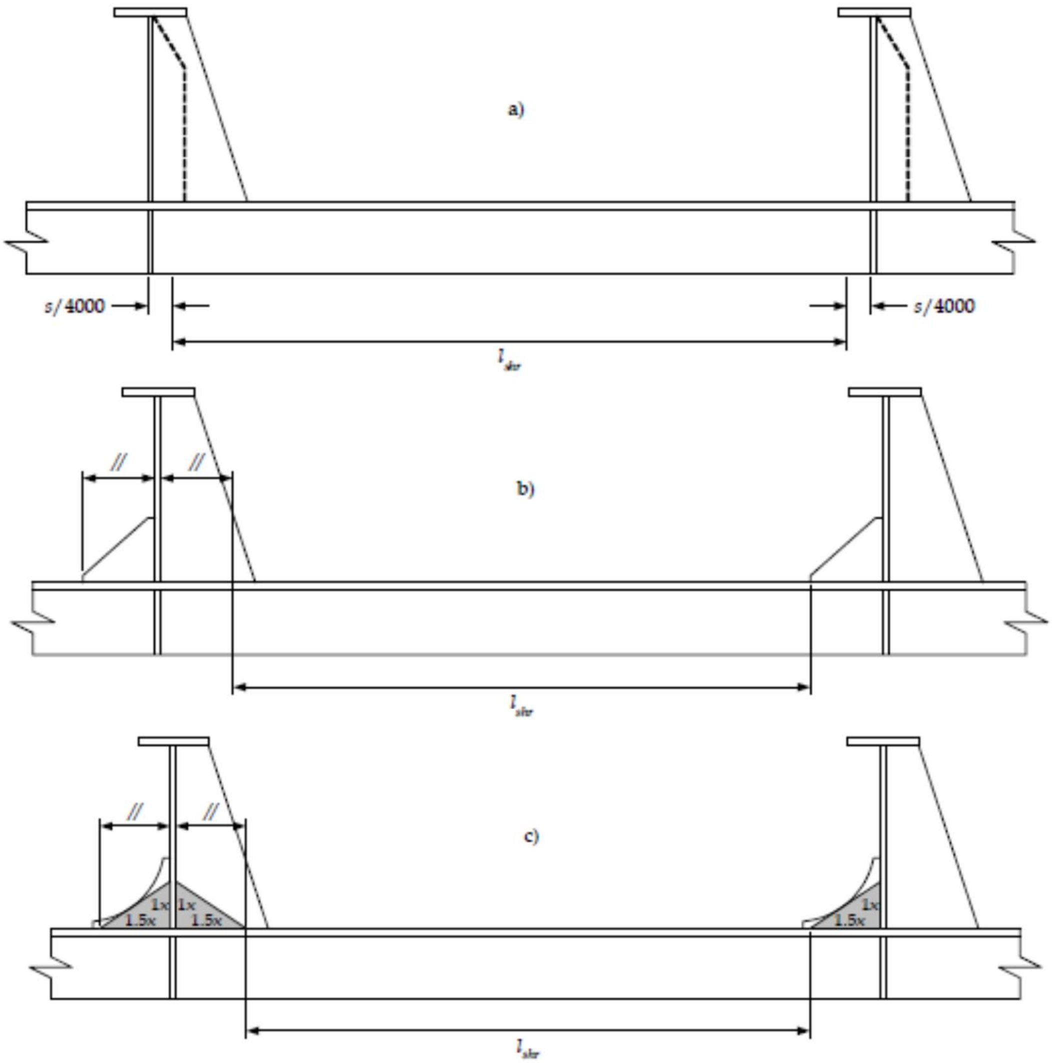


Figure 1.4.9: Effective Shear Span of Stiffeners Supported by Web Stiffeners (Single Skin Construction)

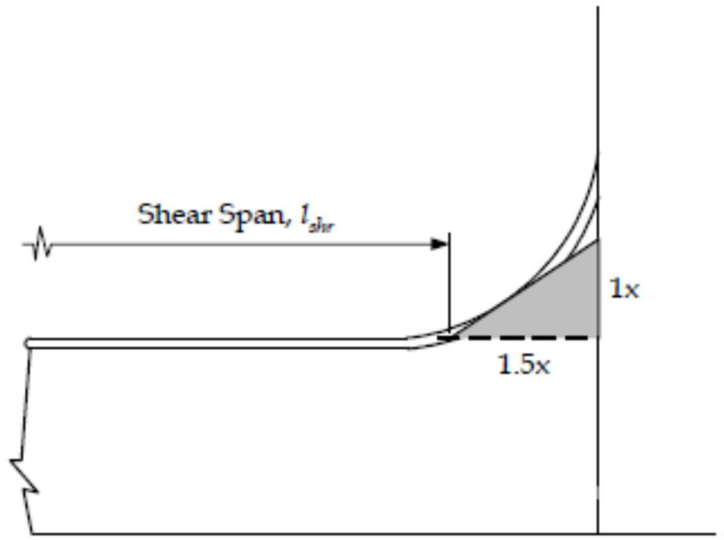


Figure 1.4.10: Effective Shear Span for Local Support Members with Continuous Face Plate along Bracket Edge

2.1.2.7. The effective shear span is to be taken as shown in Figure 1.4.10, where the face plate of the stiffener is continuous along the curved edge of the bracket.

2.1.2.8. The effective bracket length is to be taken as the maximum inscribed 1:1.5 bracket for curved and/or long brackets (high length/height ratio) as shown in Figure 1.4.8(c) and Figure 1.4.9 (c).

2.1.3. Effect of hull form shape on span of local support members

2.1.3.1. For flat bar stiffeners, the full length of the stiffener between primary support members, *l*, is to be measured along the flange for stiffeners with a flange, and along the free edge. The span is defined as the chord length between span points for curved stiffeners. The calculation of the effective span is to be according to requirements given in 2.1.1.

2.1.4. Effective bending span of primary support members

2.1.4.1. The effective bending span, l_{bdg}, of a primary support member shall be taken as less than the full length of the member between supports as long as suitable end brackets are fitted.

2.1.4.2. Where the primary support member face plate is not carried continuously around the edge of the bracket, i.e. the bracket is welded to the primary support member, the span point at each end of the member, between which the effective bending span is measured, is to be taken at the point where the depth of end bracket measured from the face of the member is equal to one half the depth of the member, as shown in Figure 1.4.11(b) for arrangements. The effective bracket utilized to define the span point is to be taken as given in 2.1.4.4.

2.1.4.3. For brackets where the face plate of the primary support member is continuous along the face of the bracket, i.e. the bracket is integral part of the primary support member, the span point is to be taken at the position where the depth of the bracket is equal to one quarter the depth of the member, see Figures 1.4.11(a), (c) and (d). The effective bracket used to define the span point is to be taken as given in 2.1.4.4.

2.1.4.4. The effective bracket is defined as the maximum size of triangular bracket with a length to height ratio of 1.5 that just fits inside the as fitted bracket, for curved brackets the tangent point shall be utilized to define the fit, see Figure 1.4.11 for examples.

2.1.4.5. The span point is to be taken to the effective bracket, for straight brackets with a length to height ratio greater than 1.5; for steeper brackets the span point is to be taken to the as fitted bracket.

2.1.4.6. The span point is to be measured for curved brackets, taken to the fitted bracket at span positions above the tangent point between fitted bracket and effective bracket. The span point should be measured to the effective bracket, for span positions below the tangent point.

2.1.4.7. Where the primary support member face plate is carried on to the bracket and backing brackets are fitted for arrangements, the span point need not be taken greater than to the position where the total depth reaches twice the depth of the primary support member. Arrangements with small and large backing brackets are shown in Figure 1.4.11(e) and (f).

2.1.4.8. Where the height of the primary support member is maintained and the face plate width is increased towards the support for arrangements, the effective bending span may be taken to a position where the face plate breadth reaches twice the nominal breadth.

2.1.5. Effective shear span of primary support members

2.1.5.1. The span point at each end of the primary support member, between which the shear span is measured, shall be taken at the toe of the effective brackets supporting the member, where the toes of effective brackets are as projected in Figure 1.4.12. The effective bracket utilized to define the toe point is given in 2.1.4.4.

2.1.5.2. Some arrangements where the effective bracket is smaller than the effective backing bracket in way of face plate, the shear span is to be taken as the mean distance between toes of the effective brackets as shown in Figure 1.4.12 (f).

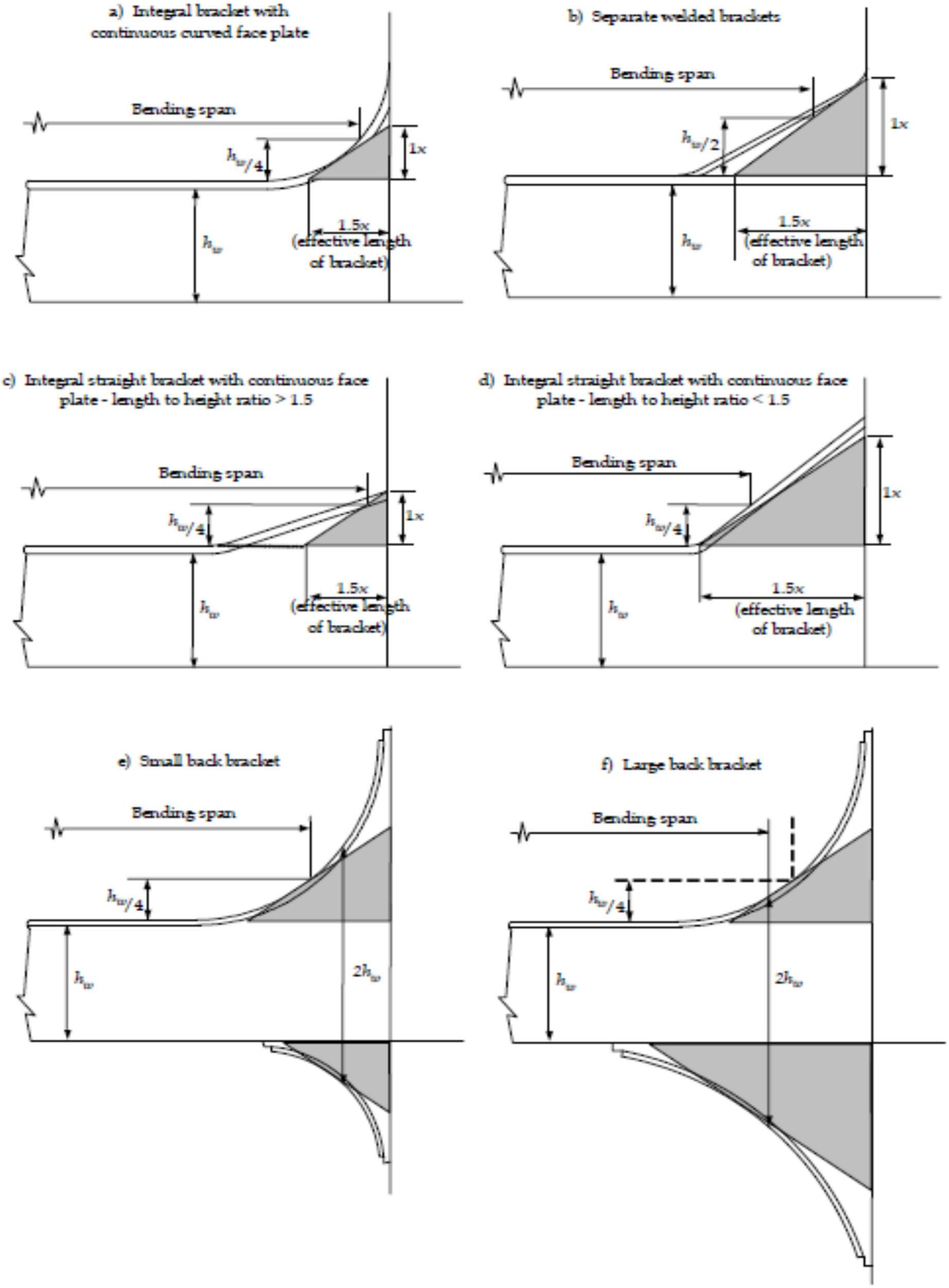


Figure 1.4.11 : Effective Span of Primary Support Member for Bending Assessment

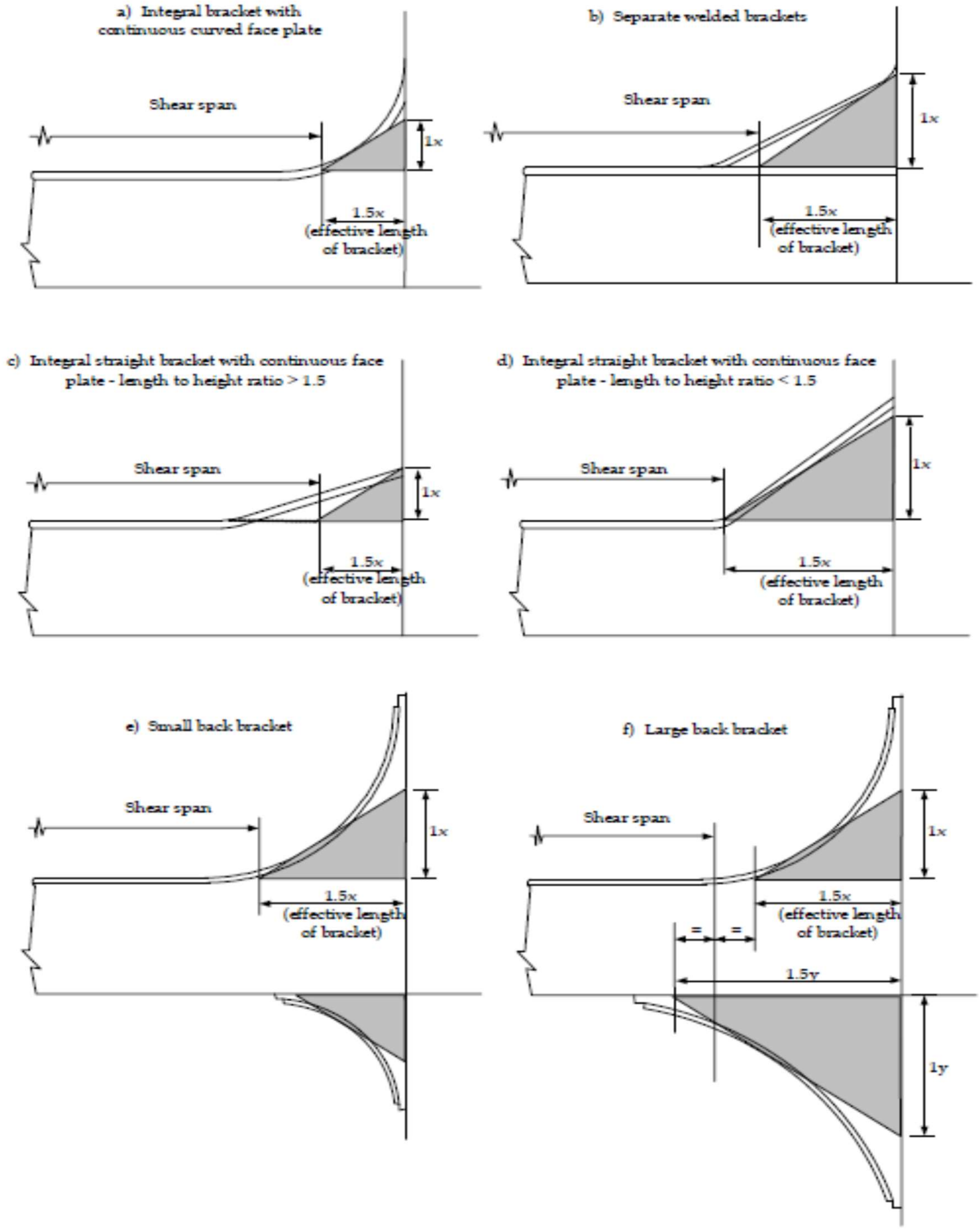


Figure 1.4.11: Effective Span of Primary Support Member for Shear Assessment

2.2. Definition of Spacing and Supported Breadth

2.2.1. Supported load breadth of local support members

2.2.1.1. The mean of the stiffener spacings on each side shall be utilized for the calculation of the effective plate flange of stiffeners and the load breadth supported by a stiffener, s, see Figure 1.4.13

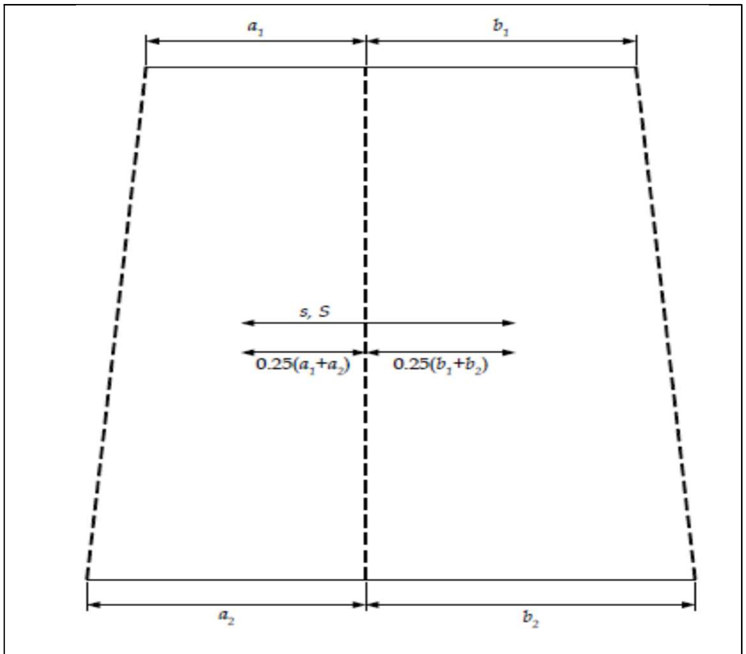
2.2.2. Spacing and supporting load breadth of primary support members

2.2.2.1. Primary support member spacing, S, for the calculation of the effective plate flange of primary support members shall be taken as the mean spacing between adjacent primary support members, as depicted in Figure 1.4.13.

2.2.2.2. The loading breadth supported by a girder is defined as half the sum of the primary support member spacing on each side, unless specifically defined elsewhere in the Rules, see Figure 1.4.13.

2.2.3. Effective spacing of curved plating

2.2.3.1. The stiffener spacing or the primary support member spacing, s or S, for curved plating, is to be measured on the mean chord between members.



Note

1. The mean breadth is to be taken as 0.25 (a_1 + a_2 + b_1 + b_2), where a_1, a_2, b_1, b_2 are the spacings between local and primary support members at ends as appropriate

Figure 1.4.13: Supported Load Breadth and Breadth of Attached Plating for Local and Primary Support Members

2.3. Effective Breadth of Plating

2.3.1. Effective breadth of attached plate of local support members for strength evaluation

2.3.1.1. The effective breadth as defined in 2.3.1.2 is applicable to the scantling requirements of stiffeners as provided in Chapter 2 Section 2.

2.3.1.2. The effective breadth of the attached plate, b_{eff}, to be utilized for calculating the combined section modulus of the stiffener and attached plate is to be taken as the mean stiffener spacing, s, as given in 2.2.1. However, where the attached plate net thickness, $t_{p\text{-}net}$, is less than 8mm, the effective breadth is not to be taken greater than 600mm.

2.3.2. Effective breadth of attached plate and flanges of primary support members for strength evaluation

2.3.2.1. The effective breadths as defined in 2.3.2.2 to 2.3.2.4 are applicable to the scantling requirements of primary support members as provided in Chapter 2 Section 2.

2.3.2.2. At the end of the span where no effective end bracket is fitted, the effective breadth of attached plate, b_{eff}, for calculating the section modulus and/or moment of inertia of a primary support member is to be taken as:

$$b_{eff} = 0.67\, S\, sin\left[\frac{\pi}{6}\left(\frac{l_{bdg}\left(1-\frac{1}{\sqrt{3}}\right)}{2\, S}\right)\right] \text{m} \quad \text{for} \left(\frac{l_{bdg}\left(1-\frac{1}{\sqrt{3}}\right)}{2\, S}\right) \le 3$$

$$b_{eff} = 0.67\, S \quad m \quad \text{for}\left(\frac{l_{bdg}\left(1-\frac{1}{\sqrt{3}}\right)}{2\, S}\right) \le 3$$

where:
S= mean spacing of primary support member as it is stated in 2.2.2 at position considered, in m
l_{bdg}= effective bending span, as it depicts in 2.1.4, in m
Note:
Sin () is to be calculated in radians

2.3.2.3. At mid span, the effective breadth of attached plate, b_{eff}, for calculating the section modulus and/or moment of inertia of a primary support member is to be taken as:

$$b_{eff} = S \sin\left[\frac{\pi}{18}\left(\frac{l_{bdg}}{S\sqrt{3}}\right)\right] \text{m for } \left(\frac{l_{bdg}}{S\sqrt{3}}\right) \le 9$$

$$b_{eff} = 1.0S \quad \text{m for } \left(\frac{l_{bdg}}{S\sqrt{3}}\right) \le 9$$

Where:
S= mean spacing of primary support member as defined in 2.2.2 at position considered, in m
l_{bdg} = effective bending span, as it depicts in 2.1.4, in m
Note:
Sin () is to be calculated in radians

2.3.2.4. The effective breadth of attached plate, b_{eff}, for calculating the section modulus of a primary support member is to be taken as the mean values of those given by 2.3.2.2 and 2.3.2.3, at the end of the span where an effective end bracket is fitted. A bracket is considered effective when the length as defined in Figure 1.4.10 is equal or greater than $0.1l_{bdg}$.

2.3.2.5. The free flange of primary support members of single skin construction may generally be considered fully effective provided tripping bracket arrangements are fitted as required in Section Chapter 2 ,4/2.3.3. For curved face plates see 2.3.4.

2.3.3. Effective breadth of attached plate of local support members for fatigue strength evaluation

2.3.3.1. The effective breadths as defined in 2.3.3.2 and 2.3.3.3 are applicable to the fatigue strength evaluation of local support members as given in Chapter 2 Section 3/3 and Chapter 4 Section 3

2.3.3.2. At the ends of the span and in way of end brackets and supports, the effective breadth of attached plating, b_{eff}, shall be utilized for calculating the combined section modulus of the stiffener and attached plate is to be taken as:

$$b_{eff} = 0.67\ s\ \sin\left[\frac{\pi}{6}\left(\frac{1000 l_{bdg}\left(1-\frac{1}{\sqrt{3}}\right)}{2s}\right)\right] \text{mm}$$

$$\text{for } \left(\frac{1000\ _{bdg}\left(1-\frac{1}{\sqrt{3}}\right)}{2s}\right) \le 3$$

$$b_{eff} = 0.67\ s \text{ mm} \quad \text{for} \quad \left(\frac{1000 l_{bdg}\left(1-\frac{1}{\sqrt{3}}\right)}{2s}\right) > 3$$

Where:
s = stiffener spacing, in mm, as defined in 2.2.1
l_{bdg}= effective bending span, as defined in 2.1.1, in m
Note
Sin () is to be calculated in radians

2.3.3.3. At mid span, the effective breadth of attached plate, b_{eff}, shall be utilized for calculating the combined section modulus of the stiffener and attached plate is to be taken as:

$$b_{eff} = s\ \sin\left[\frac{\pi}{18}\left(\frac{1000\ _{bdg}}{s\sqrt{3}}\right)\right] \text{mm} \quad \text{for } \left(\frac{1000 l_{bdg}}{s\sqrt{3}}\right) \le 9$$

$$b_{eff} = 1.0 s \text{m for } \left(\frac{1000\ _{bdg}}{s\sqrt{3}}\right) > 9$$

where:
s= stiffener spacing, in mm, as defined in 2.2.1
$l_{bdg} =$ Effective bending span, as defined in 2.1.1, in m
Note
Sin() is to be calculated in radians

2.3.4. Effective area of curved face plates or attached plating of primary support members

2.3.4.1. The effective area as defined in 2.3.4.2 and 2.3.4.3 is applicable to primary support members as follows:

a) Deriving the effective net area of curved face plates and curved attached plating for calculating the sectionmodulus of primary support members for the scantling requirements in Chapter 2 Section 2
b) Deriving the effective net area of curved face plates, modeled by beam elements, for the strengthassessment (FEM) in Chapter 2 Section 3/2 and. Chapter 4 Section 2

2.3.4.2. The effective net area of curved face plates or attached plating of primary support members, $A_{eff\text{-}net50}$, is to be taken as:

$A_{eff\text{-}net50} = C_f\ t_{f\text{-}net50}\ b_f$ mm^2
Where:
C_f=flange efficiency coefficient as it is depicted in Figure 1.4.14
$C_{f1} \frac{\sqrt{r_f t_{f-net}}}{b_1}$but not to be taken greater than 1.0

$$C_{f1} = \frac{0.643(\sinh\beta\cosh\beta + \sin\beta\cos\beta}{sinh^2\beta + sin^2\beta}$$

For symmetrical and unsymmetrical face plates, see Curve 1 in Figure 1.4.14

$$= \frac{0.78(\sinh\beta + \sin\beta)(\cosh\beta - \cos\beta)}{\sinh^2\beta + \sin^2\beta}$$

For attached plating of box girders with two webs, see Curve 2 in Figure 1.4.14

$$= \frac{1.56(\cosh\beta - \cos\beta)}{\sinh\beta + \sin\beta}$$

For attached plating of box girders with multiple webs, see Curve 3 in Figure 1.4.14

$$\beta = \frac{1.285 b_1}{\sqrt{r_f t_{f-net}}} \qquad rad$$

b_1 = 0.5 (b_f – $t_{w\text{-}net50}$) for symmetrical face plates
= b_f for unsymmetrical face plates
= s_w – $t_{w\text{-}net50}$ for attached plating of box girders
s_w= spacing of supporting webs for box girders, in mm
$t_{f\text{-}net50=}$ net flange thickness
= $t_{f\text{-}grs}$ – 0.5t_{corr} mm
For calculation of C_f and β for unsymmetrical face plates $t_{f\text{-}net50}$ is not to be taken greater than $t_{w\text{-}net50}$
$t_{f\text{-}grs}$= gross flange thickness, in mm
$t_{w\text{-}net50}$ =net web plate thickness
= $t_{w\text{-}grs}$ – 0.5t_{corr} mm
$t_{w\text{-}grs}$= gross web thickness, in mm
t_{corr}= corrosion addition, as given in Section 6/3.2
r_f= radius of curved face plate or attached plating, in mm
b_f= breadth of face plate or attached plating, in mm

2.3.4.3. The effective net area of curved face plates supported by radial brackets, or attached plating supported by cylindrical stiffeners, $A_{eff\text{-}net50}$, is provided by:

$$A_{eff-net50} = \left(\frac{3r_f t_{f-net50} + C_f s_r^2}{3r_f t_{f-net} \quad + s_r^2}\right) t_{f-net} \quad b_f mm^2$$

Where:

C_f= as defined in 2.3.4.2
$t_{f\text{-}net50}$= net flange thickness, as defined in 2.3.4.2
s_r= spacing of tripping brackets or web stiffeners or stiffeners normal to the web plating, in mm, see Figure 1.4.15
b_f= breadth of face plate or attached plating, in mm, see Figure 1.4.15
r_f = radius of curved face plate or attached plating, in mm, see Figure 1.4.15

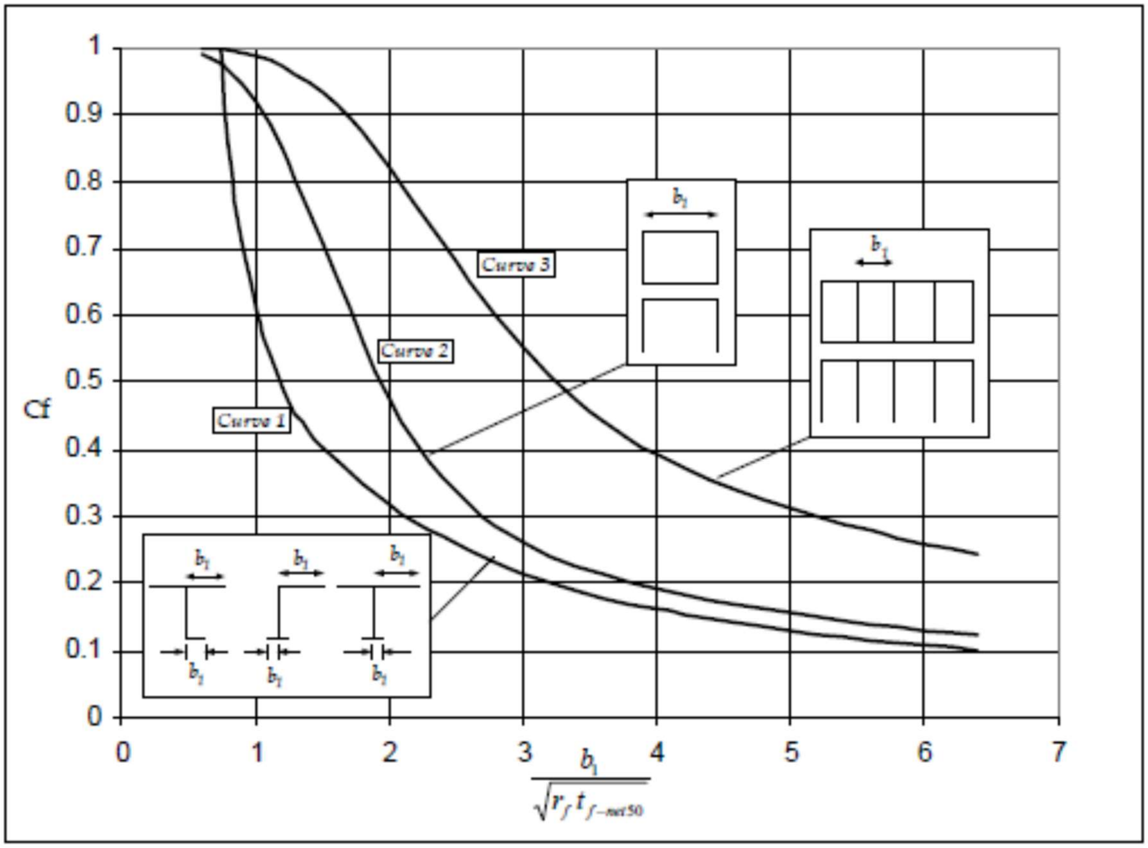


Figure 1.4.14: Effective Width of Curved Face Plates for Alternative Structural Configurations

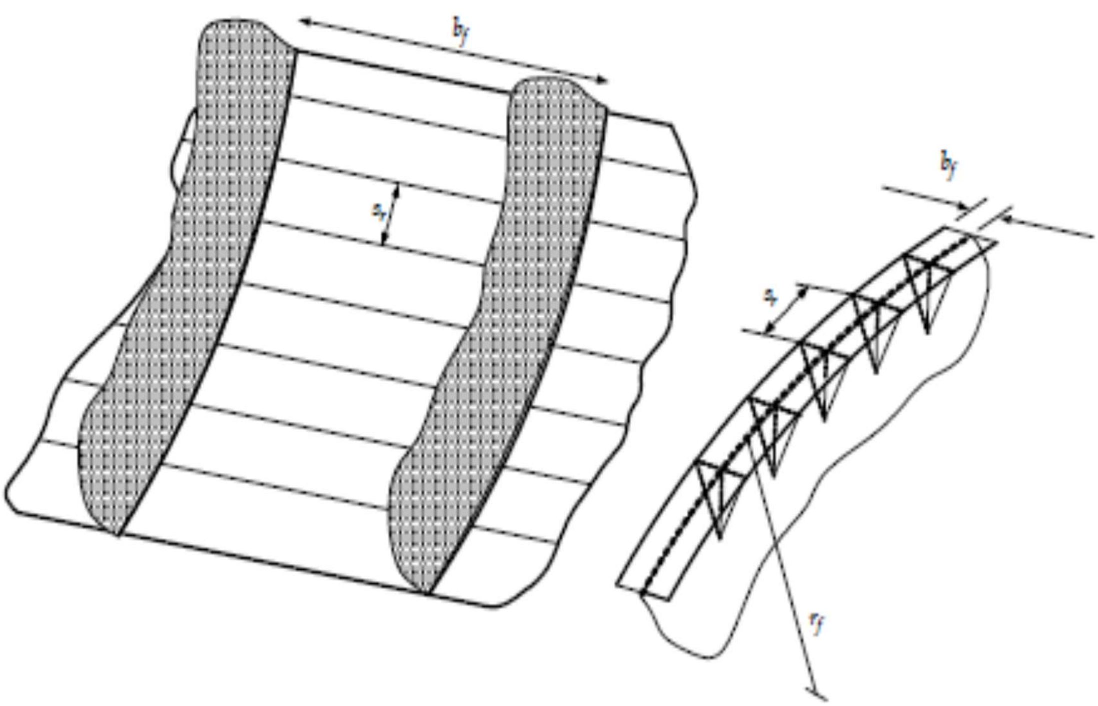


Figure 1.4.15: Curved Shell Panel and Face Plate

2.3.4.4. The effective area given in 2.3.4.2 and 2.3.4.3 is only applicable to faceplates and attached plating of primary support members. This is not to be applied for the area of web stiffeners parallel to the face plate.

2.4. Geometrical Properties of Local Support Members

2.4.1. Calculation of net section properties for local support members

2.4.1.1. The net section modulus, moment of inertia and shear area properties of local support members shall be calculated utilizing the net thicknesses of the attached plate, web and flange.

2.4.1.2. Figure 1.4.16 shows the description of the net dimensions for typical profiles.

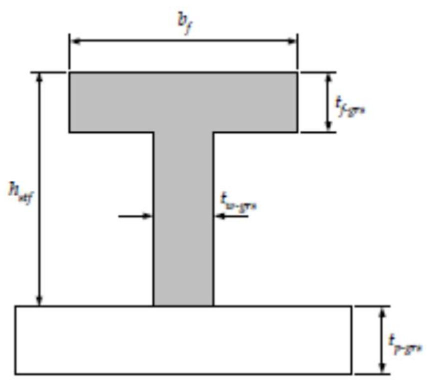
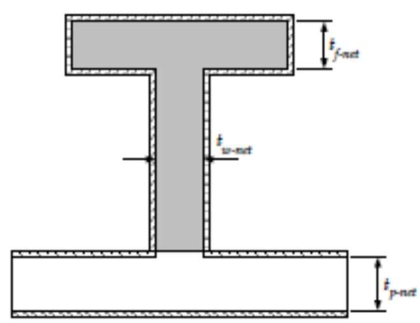
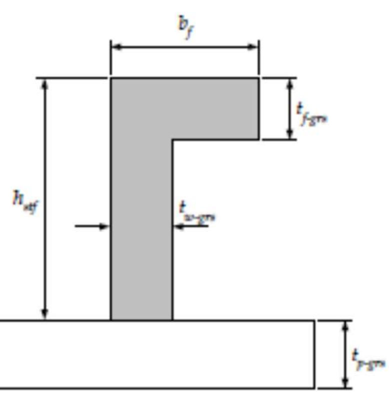
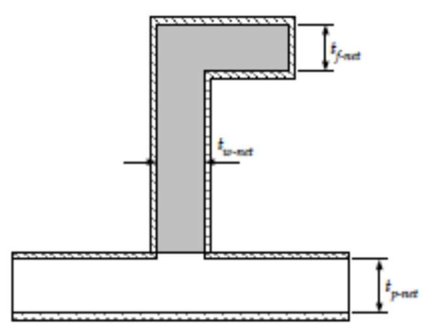
PROFILE	REDUCTION METHODOLOGY
	LOCAL SUPPORT MEMBERS
 T- PROFILE	
 L- PROFILE	

Figure 1.4.16 : Net Sectional Properties of Local Support Members

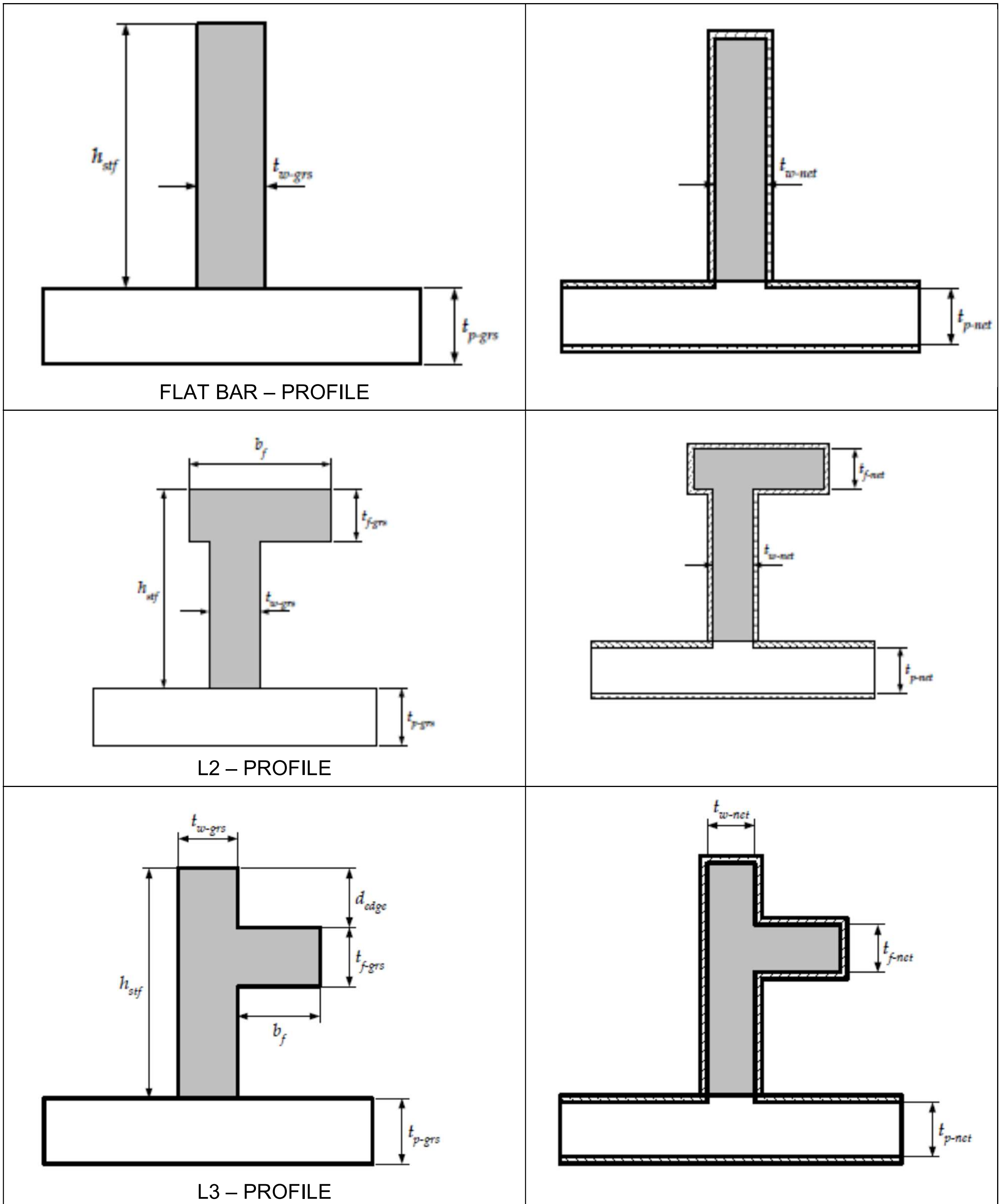


Figure 1.4.16 : Net Sectional Properties of Local Support Members (Continued)

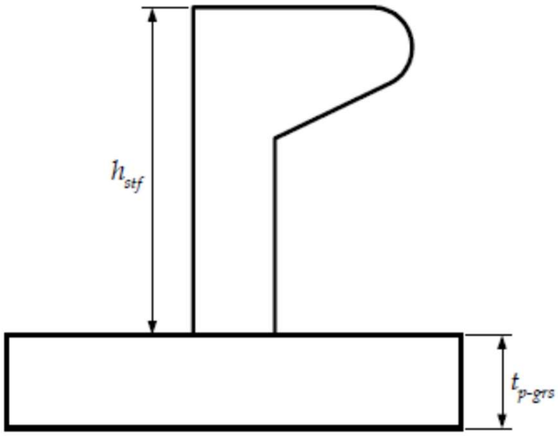
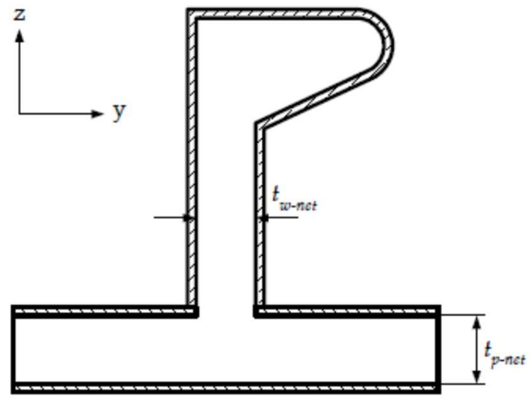
 BULB PROFILE AND SIMILAR PROFILES	 The net cross-sectional area, the moment of inertia aboutthe y-axis and the associated neutral axis position of the profile is to be determined assuming the corrosion magnitude $0.5t_{corr}$ deducted from the surface of the profile cross-section.

Figure 1.4.16 : Net Sectional Properties of Local Support Members(Continued)

2.4.2. Effective elastic sectional properties of local support members

2.4.2.1. The net elastic shear area, $A_{shr\text{-}el\text{-}net}$, of local support members is to be taken as:

$$A_{shr-el-net} = \frac{(h_{stf} + t_{p-net})t_{w-net}\sin\varphi_w}{100} cm^2$$

where:

h_{stf}= stiffener height, including face plate, in mm. See also 2.4.1.2
$t_{p\text{-}net}$ = net thickness of attached plate, in mm
$t_{w\text{-}net}$ = net web thickness, in mm
ϕ_w = angle between the stiffener web and attached plating; see Figure 1.4.18, in degrees. ϕ_w is to be takenas 90^0 if the angle is greater than or equal to 75^0

2.4.2.2. The effective shear depth of stiffeners, d_{shr}, is to be taken as:

$$d_{shr} = \left(h_{stf} + t_{p-net}\right)\sin\varphi_w \qquad mm$$

where:
h_{stf}= stiffener height, including face plate, in mm. 2.4.1.2 can be consulted
$t_{p\text{-}net}$= net thickness of attached plate, in mm
ϕ_w= angle between the stiffener web and attached plating; see Figure 1.4.18, in degrees. $\phi_w$is to be taken as 90^0 if the angle is greater than or equal to 75^0

2.4.2.3. The elastic net section modulus, $Z_{el\text{-}\phi\text{-}net}$ of local support members is to be taken as:

where:

$Z_{stf\text{-}net}$ = net section modulus of corresponding upright stiffener, i.e. when ϕ_w is equal to 90^0, in cm^3.See also 2.4.1.2

ϕ_w = angle between the stiffener web and attached plating; see Figure 1.4.18, in degrees. ϕ_w is to be taken as 90^0 if the angle is greater than or equal to 75^0.

2.4.3. Effective plastic section modulus and shear area of stiffeners

2.4.3.1. The net plastic shear area, $A_{shr\text{-}pl\text{-}net}$, of local support members is to be taken as:

$$A_{shr-pl-net} = \frac{(h_{stf} + t_{p-net})t_{w-net}\sin\varphi_w}{100} cm^2$$

where:

h_{stf}= stiffener height, including face plate, in mm. 2.4.1.2can be consulted

$t_{p\text{-}net}$= net thickness of attached plate, in mm

$t_{w\text{-}net}$= net web thickness, in mm

ϕ_w= angle between the stiffener web and the plate flange; see Figure 1.4.18,, in degrees. ϕ_w is to be taken as 90 degrees if the angle is greater than or equal to 75 degrees

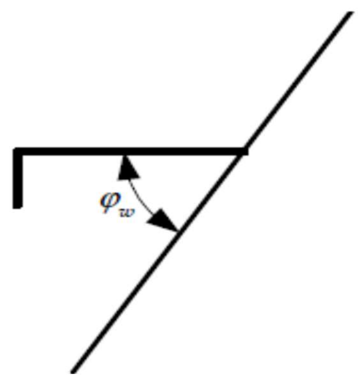


Figure 1.4.18: Angle between Stiffener Web and Plate Flange

2.4.3.2. The effective net plastic section modulus, $Z_{pl\text{-}net}$, of local support members is to be taken as:

$$Z_{pl-net} = \frac{f_w d_w^2 t_{w-net}\sin\varphi_w}{2000} + \frac{(2\gamma - 1)A_{f-net}(h_{f-ctr}\sin\varphi_w - b_{f-ctr}\cos\varphi_w)}{1000} cm^3$$

where:

f_w= web shear stress factor

= 0.75 for flanged profile cross-sections with n = 1 or 2

= 1.0 for flanged profile cross-sections with n = 0 and for flat bar stiffeners

n = number of moment effective end supports of each member = 0, 1 or 2

A moment effective end support may be considered where:

a. The stiffener is continuous at the support
b. Thestiffener passes through the support plate while it is connected at its termination point by a carling (or equivalent) to adjacent stiffeners
c. The stiffener is attached to a abutting stiffener effective in bending (not a buckling stiffener) or bracket. The bracket is assumed to be

bending effective when it is attached to another stiffener (not a buckling stiffener).

d_w= depth of stiffener web, in mm:

= h_{stf} − t_{f-net} for T, L (rolled and built up) and L2 profiles

= h_{stf} for flat bar and L3 profiles

To be taken as given in Table 1.4.2 and Table 1.4.3 for bulb profiles

h_{stf}= stiffener height, in mm, see Figure 1.4.18

$$\gamma = 0.25\left(1 + \sqrt{3 + 12\beta}\right)$$

β = 0.5 for all cases, except L profiles without a mid-span tripping bracket

$$= \frac{10^6 t_{w-n}^2 \;\; f_b l_f^2}{80 b_f^2 t_{f-net} h_{f-ctr}} + \frac{t_{w-ne}}{2b_f}$$

but not to be taken greater than 0.5 for L (rolled and built-up) profiles without a midspan tripping bracket.

A_{f-net}= net cross-sectional area of flange, in mm^2:

= b_f t_{f-net} in general

= 0 for flat bar stiffeners

b_f= breadth of flange, in mm, see Figure 1.4.16. For bulb profiles, see Table 1.4.2and Table 1.4.3

b_{f-ctr}= distance from mid thickness of stiffener web to the centre of the flange area:

= $0.5(b_f - t_{w-grs})$ for rolled angle profiles

= 0 for T profiles

as given in Table 1.4.2 and Table 1.4.3 for bulb profiles

h_{f-ctr}= height of stiffener measured to the mid thickness of the flange:

= h_{stf} – 0.5 t_{f-net} for profiles with flange of rectangular shape except for L3 profiles

= h_{stf} – d_{edge} – 0.5 t_{f-net} for L3 profiles

as given in Table 1.4.2 and 1.4.3 for bulb profiles

d_{edge}= distance from upper edge of web to the top of the flange, in mm. For L3 profiles, see Figure 1.4.16.

f_b = 1.0 in general

= 0.8 for continuous flanges with end bracket(s). A continuous flange is defined as a flange that is not sniped and continuous through the primary support member

= 0.7 for non-continuous flanges with end bracket(s). A non-continuous flange is defined as a flange that is sniped at the primary support member or terminated at the support without aligned structure on the other side of the support

l_f= length of stiffener flange between supporting webs, in m, but reduced by the arm length of end bracket(s) for stiffeners with end bracket(s) fitted

t_{f-net}= net flange thickness, in mm

= 0 for flat bar stiffeners

as given in Table 1.4.2 and Table 1.4.3 for bulb profiles

t_{w-net} = net web thickness, in mm

ϕ_w= angle between the stiffener web and the plate flange; see Figure 1.4.18, in degrees. ϕ_w is to be taken as 90 degrees if the angle is greater than or equal to 75 degrees.

Table 1.4.2: Characteristic Flange Data for HP Bulb Profiles (see Figure 1.4.19**)**

h_{stf} (mm)	d_w (mm)	b_{f-grs}* (mm)	t_{f-grs}* (mm)	b_{f-ctr} (mm)	h_{f-ctr} (mm)
200	171	40	14.4	10.9	188
220	188	44	16.2	12.1	206
240	205	49	17.7	13.3	225
260	221	53	19.5	14.5	244
280	238	57	21.3	15.8	263
300	255	62	22.8	16.9	281
320	271	65	25.0	18.1	300
340	288	70	26.4	19.3	318
370	313	77	28.8	21.1	346
400	338	83	31.5	22.9	374
430	363	90	33.9	24.7	402

Note

1. Characteristic flange data converted to net scantlings are given as:
   $b_f \cong b_{f-grs}* + 2\ t_{w-net}$
   $t_{f-net} = t_{f-grs}* - t_{corr}$
   $t_{w-net} = t_{w-grs} - t_{cor}$

Table 1.4.3: Characteristic Flange Data for Bulb Profiles (see Figure 1.4.19)

h_{stf} (mm)	d_w (mm)	b_{f-grs}* (mm)	t_{f-grs}* (mm)	b_{f-ctr} (mm)	h_{f-ctr} (mm)
180	156	34	11.9	9.0	170
200	172	39	13.7	10.4	188
230	198	45	15.2	11.7	217
250	215	49	17.1	12.9	235

Note

1. Characteristic flange data converted to net scantlings are given as:
   $b_f \cong b_{f-grs}* + 2\ t_{w-net}$
   $t_{f-net} = t_{f-grs}* - t_{corr}$
   $t_{w-net} = t_{w-grs} - t_{cor}$

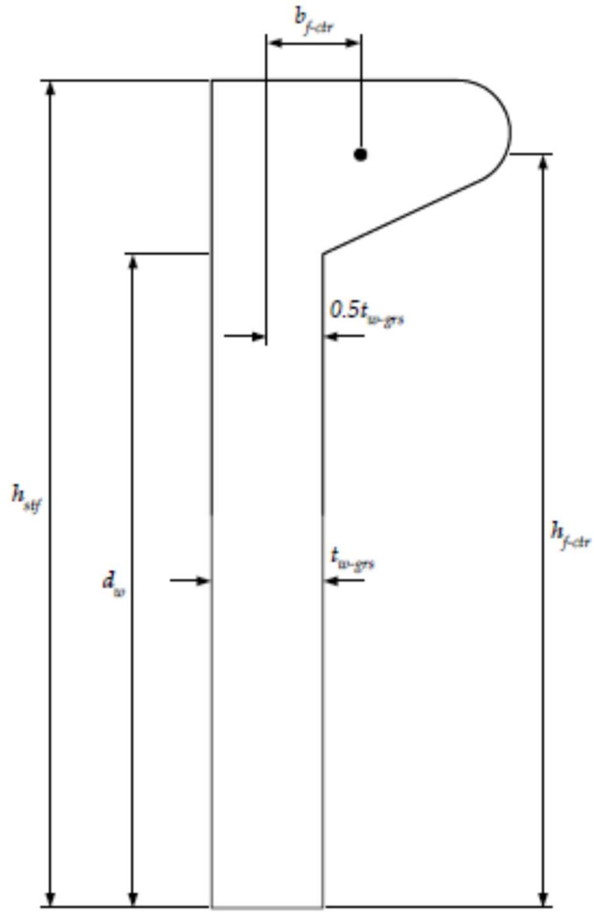


Figure 1.4.19: Characteristic Data for Bulb Profiles

2.5. Geometrical Properties of Primary Support Members

2.5.1. Effective shear area of primary support members

2.5.1.1. The web height, h_w, shall be taken as the moulded height of the primary support member, for calculation of the shear area of primary support members.

2.5.1.2. For single and double skin primary support members, the effective net shear area, $A_{shr\text{-}net50}$, is to be taken as:

$A_{shr\text{-}net50} = 0.01\ h_n\ t_{w\text{-}net50}\ cm^2$

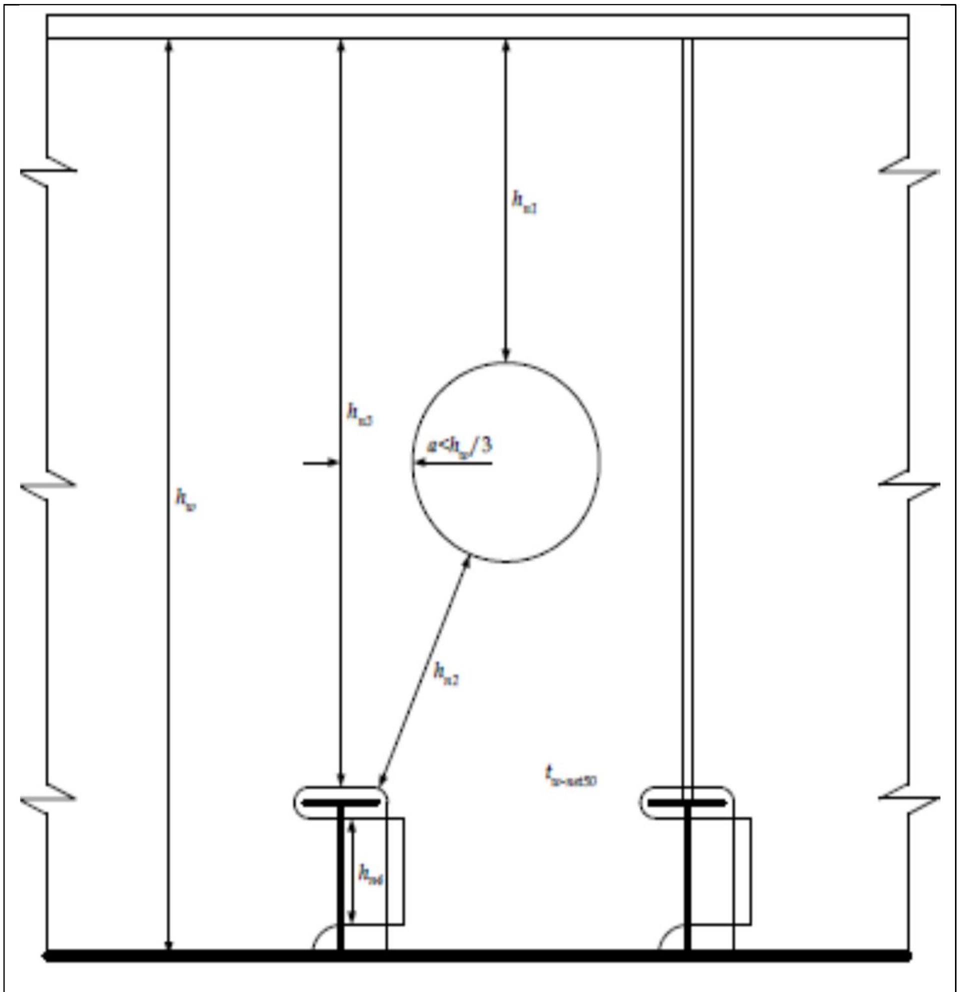
Where:
h_n for a single skin primary support member, see Figure 1.4.20,, the effective web height, in mm, is to be taken as the lesser of:

a. h_w
b. $h_{n3} + h_{n4}$
c. $h_{n1} + h_{n2} + h_{n4}$

For a double skin primary support member, the same principle is to be adopted in determining the effective web height.

h_w= web height of primary support member, in mm
h_{n1}, h_{n2}, h_{n3}, h_{n4} as shown in Figure 1.4.20,
$t_{w\text{-}net50}$= net web thickness
= $t_{w\text{-}grs} – 0.5\ t_{corr}$ mm

$t_{w\text{-}grs}$= gross web thickness, in mm
t_{corr}= corrosion addition, as given in Section 6/3.2, in mm
ϕ_w = angle between the web and attached plating; see Figure 1.4.18,, in degrees. ϕ_w is to be takenas 90^0 if the angle is greater than or equal to 75^0



Note
The figure shows effective web height for a single skin primary support member. The effective web height of a double skin primary support member follows the same principles

Figure 1.4.20: Effective Shear Area in way of Openings

2.5.1.3. Where an opening is positioned at a distance less than $h_w/3$ from the cross-section considered, h_n is to betaken as the smaller of the net height and the net distance through the opening. See Figure 1.4.20.

2.5.1.4. Where a girder flange of a single skin primary support member is not parallel to the axis of the attached plating, the effective net shear area, $A_{shr\text{-}net50}$, is to be taken as:

$A_{shr\text{-}net50} = 0.01\, h_n\, t_{w\text{-}net50} + 1.3\, A_{f\text{-}net50} \sin 2\theta \sin \theta$ cm^2
where:
$A_{f\text{-}net50}$= net flange/face plate area
= 0.01 bf $t_{f\text{-}net50}$ cm^2
b_f= breadth of flange or face plate, in mm
$t_{f\text{-}net50}$= net flange thickness
= $t_{f\text{-}grs} – 0.5t_{corr}$ mm
$t_{f\text{-}grs}$= gross flange thickness, in mm

t_c = corrosion addition, as given in Chapter 1 Section 6/3.2, in mm
θ = angle of slope of continuous flange, Figure 1.4.21 can be consulted
$t_{w-net50}$ = net web thickness, as stated in 2.5.1.2, in mm
h_n=effective web height, as depicted in Figure 1.4.20,, in mm

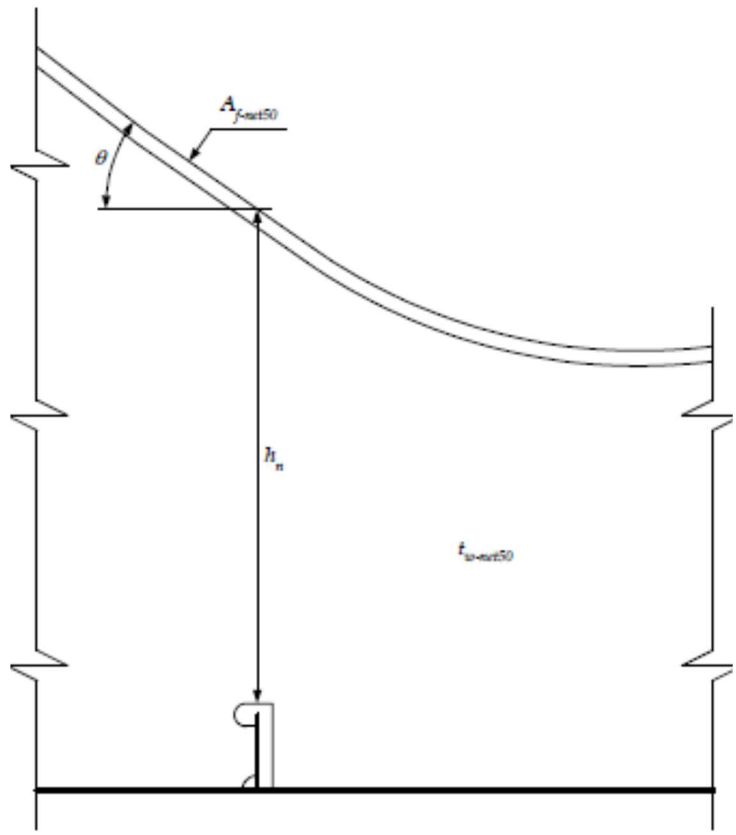


Figure 1.4.19: Effective Shear Area in way of Brackets

2.5.2. Effective section modulus of primary support members

2.5.2.1. The net section modulus of primary support members is to be calculated using the net thicknesses of the attached plate, web and face plate (or top attached plate for double skin girders), where the net thicknesses are to be taken as:

$t_{w-net50}$= t_{w-grs} – 0.5t_{corr} mm, for the net web thickness

$t_{p-net50}$= t_{p-grs} – 0.5t_{corr} mm, for the net lower attached plate thickness

$t_{f-net50}$= t_{f-grs} – 0.5t_{corr} mm, for the net upper attached plate or face plate

where:

tw-grs= gross web thickness, in mm

tp-grs=gross thickness of lower attached plate, in mm

tf-grs= gross thickness of upper attached plate or face plate, in mm

tc= corrosion addition, as given in Section 6/3.2, in mm

Note

See 2.3.4 for curved face plates of primary support members

Where angle between the primary support member web and the plate flange is less than 75^0, the section modulus is to be directly calculated.

2.6. Geometrical Properties of the Hull Girder Cross-Section

2.6.1. Vertical hull girder section modulus

2.6.1.1. The effective vertical hull girder section modulus, Z_v, at any vertical distance, z, above the baseline is defined by:

$$Z_v = \frac{I_v}{|z - z_{NA}|} m^3$$

where:

I_v= vertical hull girder moment of inertia, of all longitudinally continuous members in cross section under consideration, after deduction of openings as given in 2.6.3, in m^4

z= distance from the structural member under consideration to the baseline, in m

z_{NA}= distance from the baseline to the horizontal neutral axis of the hull girder cross-section, in m

2.6.1.2. For calculation of the vertical net hull girder section modulus for the strength assessment, $Z_{v\text{-}net50}$, needed by Chapter 2 Section 2, the vertical net hull girder moment of inertia and position of horizontal neutral axis shall be calculated based on gross thickness minus the corrosion addition $0.5t_{corr}$ of all effective structural members comprising the hull girder section, where tcorr is as defined in Section 6/3.2.

2.6.1.3. For calculation of vertical net hull girder section modulus for the fatigue assessment, $Z_{v\text{-}net75}$, required by Chapter 2 Section 3/3, the vertical net hull girder moment of inertia and position of horizontal neutral axis is to becalculated based on gross thickness minus the corrosion addition $0.25t_c$ of all effective structural members comprising the hull girder section, where t_c is as defined in Section 6/3.2.

2.6.2. Horizontal hull girder section modulus

2.6.2.1. The effective horizontal hull girder section modulus, Z_h, at any transverse coordinate, y, is to be taken as:

$$Z_h = \frac{I_h}{|y - y_{NA}|} m^3$$

where;

I_h= horizontal hull girder moment of inertia, of all longitudinally continuous members in cross section under consideration, after deduction of openings as given in 2.6.3, in m^4

y = transverse coordinate, in m

y_{NA}= distance from the centreline to the vertical neutral axis of the hull girder cross section, in m

2.6.2.2. For calculation of the horizontal net hull girder section modulus for the strength assessment, $Z_{h\text{-}net50}$, required by Chapter 2 Section 2, the horizontal net hull girder moment of inertia and position of vertical neutral axis shall be calculated based on gross thickness minus the corrosion addition $0.5t_c$ of all effective structural members comprising the hull girder section, where t_{corr} is as defined in Section 6/3.2.

2.6.2.3. For calculation of the horizontal net hull girder section modulus for fatigue assessment, $Z_{h\text{-}net75,}$ as required in Chapter 2 Section 3/3, the net horizontal hull girder moment of inertia and position of vertical neutral axis shall be calculated based on gross thickness minus the corrosion addition $0.25t_c$ of all effective structural members comprising the hull girder section, where t_{corr} is as defined in Section 6/3.2.

2.6.3. Effective area for calculation of hull girder moment of inertia and section modulus

2.6.3.1. After deduction of openings, the effective hull girder sectional area includes all the longitudinally continuous structural members. The structural members given in 2.6.3.2 shall not be included in the effective hull girder sectional area. The definition of openings to be deducted and deduction free openings are provided in 2.6.3.4 – 2.6.3.9. The definition of effective area in way of non-continuous bulkheads and decks is given in 2.6.3.10.

2.6.3.2. The following structural members shall not be considered as effectively contributing to the hull girder sectional area as they do not provide adequate structural continuity and are therefore to be excluded in the calculation:

a) superstructures which do not form a strength deck,
b) deck houses,
c) vertically corrugated bulkheads,
d) bulwarks and gutter plates,
e) bilge keels,
f) sniped or non-continuous longitudinal stiffeners if the cross-section under consideration is closer thantwice the height of the stiffener from the end of the stiffener.

2.6.3.3. The following definitions of opening are to be applied:

a) Large openings are openings exceeding 2.5m in length and/or 1.2m in breadth, where the length is measured along the global x-axis of the ship as it is depicted in Figure 1.4.1
b) Small openings are openings that are not large openings i.e. manholes, lightening holes, etc.
c) Isolated openings are openings spaced not less than 1m apart in the ship's transverse/vertical direction

2.6.3.4. Large openings and small openings that are not isolated shall be deducted from the sectional area utilized in the section modulus calculation.

2.6.3.5. Isolated small openings in longitudinal stiffeners or girders shall be deducted if their depth surpasses 25% of the web depth.

2.6.3.6. When several openings are positioned in or adjacent to the same cross-section, the total equivalent breadth of the combined openings, Σb_{ded}, is to be deducted, see 2.6.3.7 to 2.3.6.8 and Figure 1.4.22.

2.6.3.7. Isolated small openings need not be withheld provided that the sum of their breadths, or shadow area breadths, in one transverse section does not lessen the hull girder section modulus at deck or baseline by more than 3%. Alternatively isolated small openings need not to be deducted provided the total equivalent breadth of small openings, Σb_{sm}, is less than:

$\sum b_{sm} = 0.06(B_{sect} - \sum b_{ded})$ m
where:
Σb_{sm}= total equivalent breadth of small openings, see Figure 1.4.22
$= b_{sm1} + b_{sm2} + b_{sm3}$ m
B_{sect}= the breadth of the ship at the section being considered, in m
Σb_{ded}=total equivalent breadth of combined openings specified in 2.6.3.7, in m
The effect of the shadow area of deductible openings is to be taken into account

2.6.3.8. Each opening is assumed to have a longitudinal shadow area, when calculating the total equivalent breadth of small openings, Σb_{sm}, see Figure 1.4.22. This shadow area is achieved by drawing two tangent lines with an angle of 15^0 to the longitudinal axis of the ship.

2.6.3.9. Full or partial compensation of openings may be provided by increasing the sectional area of the plating, longitudinal stiffeners or girders, or other suitable structure. The compensation area is to prolong well beyond the forward and aft end of the opening. Any local edge reinforcement of the opening is not to be included in the effective area of the hull girder section modulus calculations. Compensation is not required for openings which are not required to be deducted in accordance with 2.6.3.7.

2.6.3.10. The effective area is to be taken as shown in Figure 1.4.23, when calculating the ineffective area in way of large openings and in way of non-continuous decks and longitudinal bulkheads. The shadow area, which indicates the area that is not effective, is obtained by drawing two tangent lines with an angle of 15^0 to the longitudinal axis of the ship.

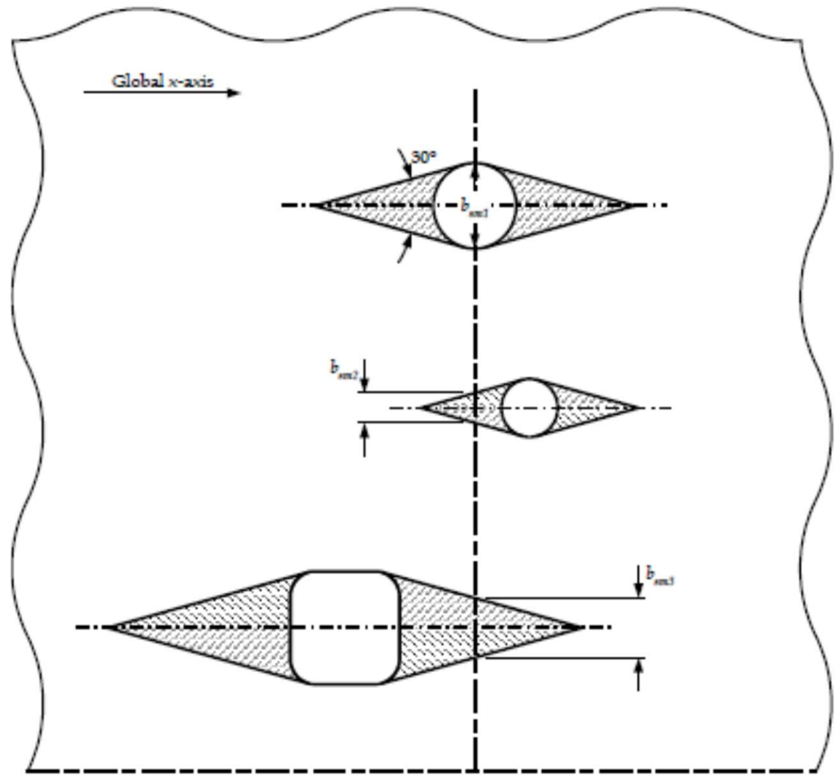


Figure 1.4.22: Calculation of equivalent Breadth

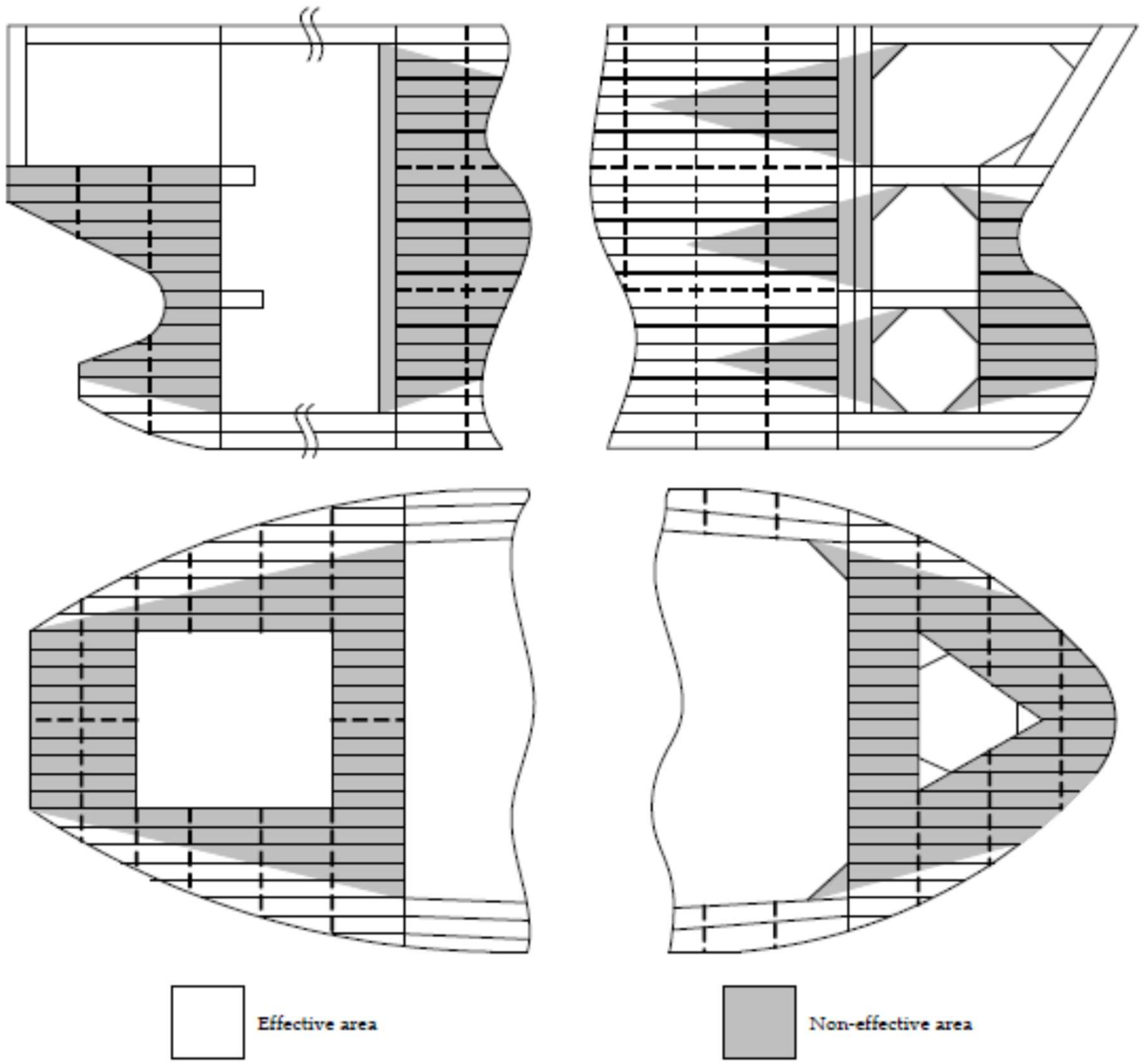


Figure 1.4.23 : Effective Area in way of Non-Continuous Decks and Bulkheads

2.6.4. Effective vertical hull girder shear area

2.6.4.1. The effective net hull girder vertical shear area includes the net plating area of the side shell that includes the bilge, the inner hull including the hopper side and the outboard girder under and the longitudinal bulkheads comprising the double bottom girders in line.

2.6.4.2. The net plating area is to be calculated based on the net thickness, t_{net50}, for calculation of the net hull girder vertical shear area, given by the gross thickness minus the corrosion addition $0.5t_c$ of all effective structural members given in 2.6.4.1. Where t_{corr} is as defined in Section 6/3.2.

2.6.4.3. The area of the member to be included in the shear force calculation is to be based on the projected area onto the vertical plane for longitudinal strength members forming the web of the hull girder which are inclined to the vertical. See Figure 1.4.24.

2.6.4.4. The calculation of the net effective shear area for vertical and horizontal corrugated bulkheads shall be based on the net effective equivalent thickness, $t_{cg\text{-}net50}$, provided by:

$$t_{cg-net50} = \left[0.5\left(t_{w-grs} + t_{f-grs}\right)\frac{b_{cg}}{b_{w-cg} + b_{f-c}}\right] - 0.5t_{corr} \quad mm$$

where:
t_{w-grs}= gross corrugation web thickness, in mm
t_{f-grs}= gross corrugation flange thickness, in mm
b_{cg}= projected length of one corrugation, in mm, as defined in Figure 1.4.24
b_{w-cg}= breadth of corrugation web, in mm, as defined in Figure 1.4.24
b_{f-cg}= breadth of corrugation flange, in mm, as defined in Figure 1.4.24
t_c = corrosion addition, as defined in Section 6/3.2

2.6.4.5. The equivalent net corrugation thickness, $t_{cg-net50}$, is only applicable for the calculation of the effective area, $A_{eff-net50}$, and shear force distribution factor, f_i, as defined in Chapter 2 Section 2/1.3.2.2.

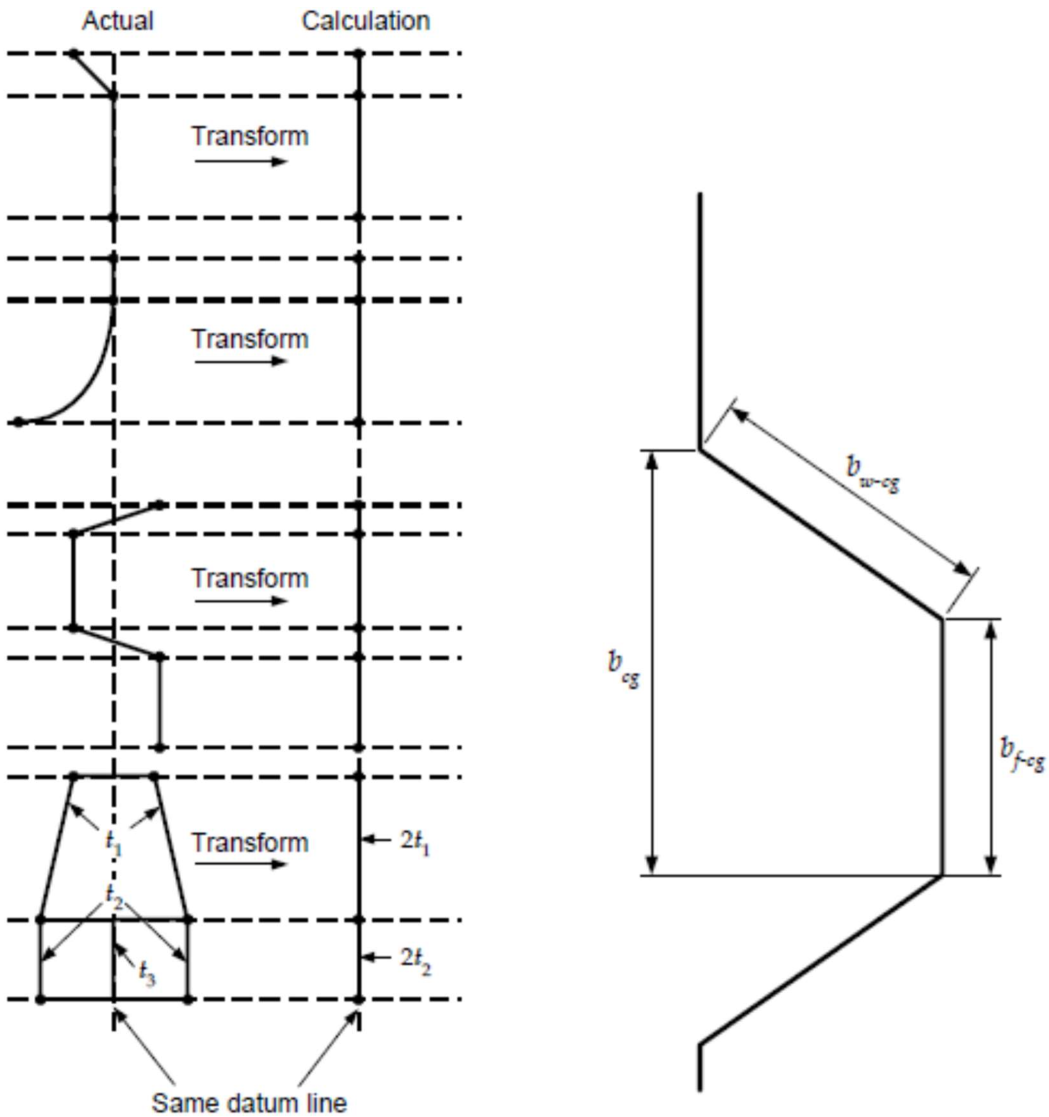


Figure 1.4.24: Effective Shear Area

3. Structure Design Details

3.1. Standard Construction Details

3.1.1.Details to be submitted

3.1.1.1. A booklet of standard construction details is to be submitted for review. which is to include the following:

a) The proportions of built-up members to demonstrate compliance with established standards for structural stability, Chapter 2 Section 4 can be consulted
b) The design of structural details which reduce the harmful effects of stress concentrations, notches and material fatigue; such as:
   - Details of the ends, at the intersections of members and associated brackets,
   - Shape and location of air, drainage, and/or lightening holes,
   - Shape and reinforcement of slots or cut-outs for internals,
   - Elimination or closing of weld scallops in way of butts, ‘softening’ of bracket toes, reduction of abruptchanges of section or structural discontinuities,
   - Proportion and thickness of structural members to reduce fatigue response due to engine, propeller or waveinduced cyclic stresses, particularly for higher strength steels.

3.2. Termination of Local Support Members

3.2.1. General

3.2.1.1. In general, to avoid hard spots, notches and stress concentrations, structural members shall be effectively connected to adjacent structures.

3.2.1.2. Structural continuity is to be maintained by suitable backup structure fitted in way of the end connection of frames, or the end connection is to be effectively extended with additional structure and integrated with an adjacent beam, stiffener, etc, where a structural member is terminated.

3.2.1.3. Connection of all types of stiffeners (longitudinals, beams, frames, bulkhead stiffeners) is to be done at their ends. However, in special cases sniped ends may be allowed. Requirements for the various types of connections (bracketed, bracket less or sniped ends) are given in 3.2.3 to 3.2.5.

3.2.2. Longitudinal members

3.2.2.1. All longitudinals shall be kept continuous within the 0.4L amidships cargo tank region. In special cases, in way of large openings, foundations and partial girders, the longitudinals may be terminated, but end connection and welding is to be specially considered.

3.2.2.2. The correct alignment of the brackets on each side of the primary support member is to be ensured, where continuity of strength of longitudinal members is provided by brackets, and the scantlings of the brackets are to be such that the combined stiffener/bracket section modulus and effective cross-sectional area are not less than those of the member.

3.2.3. Bracketed connections

3.2.3.1. At bracketed end connections, continuity of strength shall be maintained at the stiffener connection to the bracket and at the connection of the bracket to the supporting member. The brackets are to consist of scantlings adequate to compensate for the non-continuous stiffener flange or non-continuous stiffener.

3.2.3.2. The arrangement of the connection between the stiffener and the bracket is to be such that at no point in the connection, the section modulus is less than that required for the stiffener.

3.2.3.3. Minimum net bracket thickness, $t_{bkt\text{-}net}$, is to be taken as:

$$t_{bkt-n} = \left(2 + f_{bkt}\sqrt{Z_{rl-ne}}\right)\left(\sqrt{\frac{\sigma_{yd-s}}{\sigma_{yd-bkt}}}\right) \quad mm$$

but is not to be less than 6 mm and need not be greater than 13.5mm

where:

f_{bkt}= 0.2 for brackets with flange or edge stiffener

= 0.3 for brackets without flange or edge stiffener

$Z_{rl\text{-}net}$ = net rule section modulus, for the stiffener, in cm^3. In the case of two stiffeners connected, it need not be taken as greater than that of the smallest connected stiffener

$\sigma_{yd\text{-}stf}$= specified minimum yield stress of the material of the stiffener, in N/mm^2

$\sigma_{yd\text{-}bkt}$= specified minimum yield stress of the material of the bracket, in N/mm^2

3.2.3.4. Brackets to provide fixity of end rotation are to be fitted at the ends of discontinuous local support members, except as otherwise permitted by 3.2.4. The end brackets are to have arm lengths, l_{bkt}, not less than:

3.2.3.4 bis In case of different arm lengths the lengths of the arms, measured from the plating to the toe of thebracket, are to be such that the sum of them is greater than 2l_{bkt} and each arm not to be less than 0.8l_{bkt}, wherel_{bkt} is as defined in 3.2.3.4.

$$l_{bkt} = c_{bkt}\sqrt{\frac{Z_{rl-ne}}{t_{bkt-net}}} \quad mm$$

1.8 times the depth of the stiffener web for connections where the end of the stiffener web is supported and the bracket is welded in line with the stiffener web or with offset necessary to enable welding. See Figure 1.4.25 (c).

2.0 times for other cases, see Figure 1.4.25

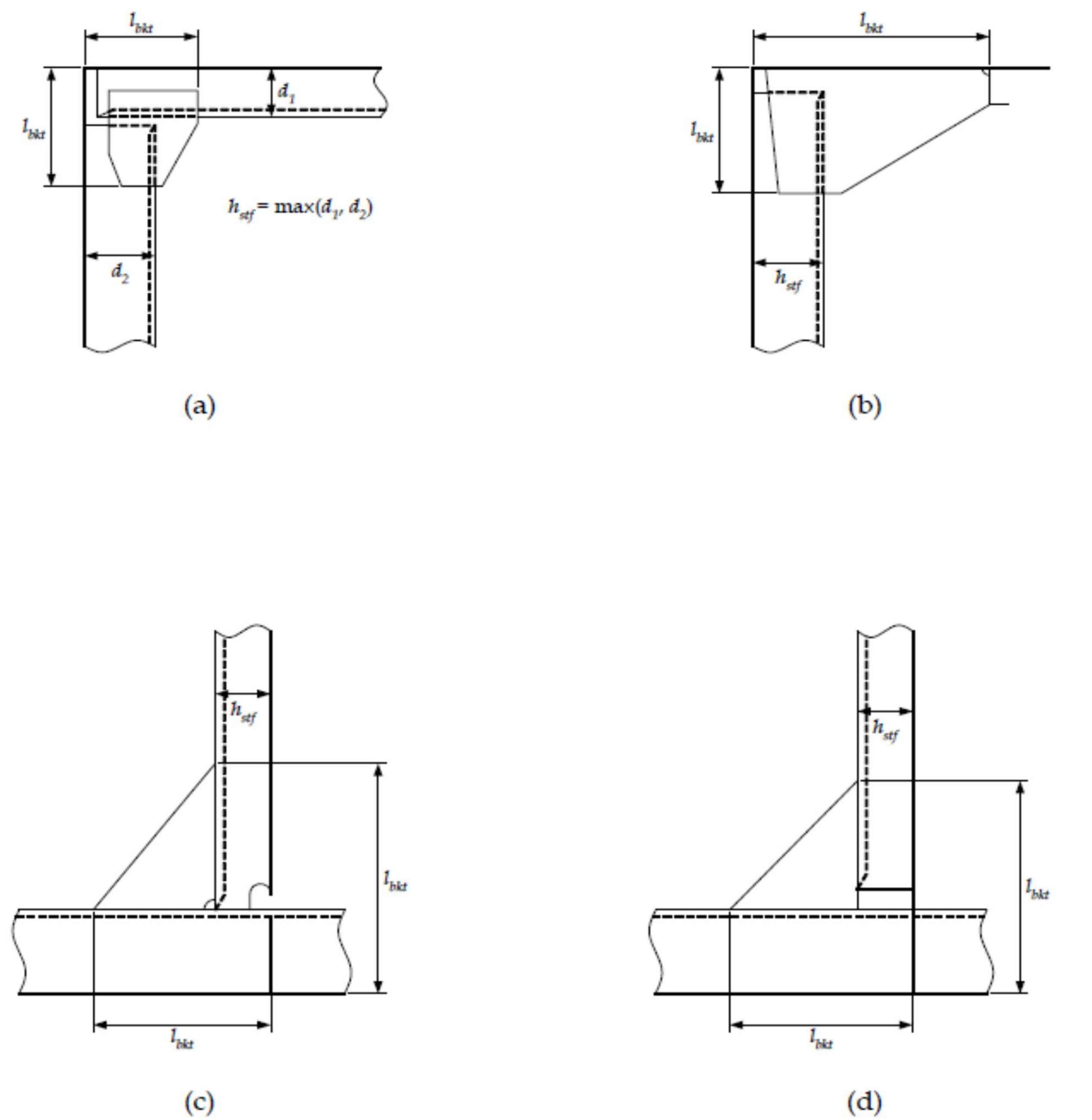
where:

c_{bkt}= 65 for brackets with flange or edge stiffener

= 70 for brackets without flange or edge stiffener

$Z_{rl\text{-}net}$=net rule section modulus, for the stiffener, in cm^3. In the case of two stiffeners connected, it need not be taken as greater than that of the smallest connected stiffener

$t_{bkt\text{-}net}$= minimum net bracket thickness, as depicted in 3.2.3.3



Note:

- For stiffeners of configuration (b) that are not lapped, the bracket arm length l_{bkt} is not to be less than the stiffener height h_{stf}.
- For stiffener arrangements similar to (c) and (d) where the smaller attached stiffener, labeled as h_{stf}, is connected to a primary support member or bulkhead, the height of the bracket is not to be less than the height of the attached stiffener, h_{stf}

Figure 1.4.25: Bracket Arm Length

3.2.3.5. The proportions and edge stiffening of brackets are to be according to the requirements of Chapter 2 Section 4/2.4. Where an edge stiffener is requisite, the depth of stiffener web, d_w, is not to be less than:

$$d_w = 45\left(1 + \frac{Z_{rl-ne}}{2000}\right) \quad mm$$

but is not to be less than 50 mm

where:

Z_{rl-net}= net rule section modulus, for the stiffener, in cm^3. In the case of two stiffeners connected, it need not be taken as greater than that of the smallest connected stiffener.

3.2.4. Bracket less connections

3.2.4.1. Local support members are usually to be connected at their ends, for example longitudinals, beams, frames and bulkhead stiffeners forming part of the hull structure, according to the requirements of 3.2.2 and 3.2.3.

3.2.4.2. The proposed arrangements will be specially considered, where alternative connections are adopted.

3.2.4.3. The design of end connections and their supporting structure shall be such as to provide sufficient resistance to rotation and displacement of the joint.

3.2.5. Sniped ends

3.2.5.1. Stiffeners with sniped ends may be utilized where dynamic loads are small and where the incidence of vibration is considered to be small, i.e. structure not in the stern area and structure not in the vicinity of engines or generators, on condition that the net thickness of plating supported by the stiffener, t_{p-net}, is not less than:

$$t_{p-net} = c_1\sqrt{\left(1000l - \frac{s}{2}\right)\frac{sPK}{10^6}} \qquad mm$$

where:

l = stiffener span, in m

s = stiffener spacing, in mm, as depicted in 2.2

P = design pressure for the stiffener for the design load set being considered, in kN/m². The design load sets and method to derive the design pressure are to be taken in accordance with the following criteria, which define the acceptance criteria set to be used:

a) Table 2.2.11 in the cargo tank region
b) Chapter 2 Section 2/3.9.2.2 in the area forward of the forward cargo tank, and in the aft end
c) Chapter 2 Section 2/4.8.1.2 in the machinery space

k = higher strength steel factor, as defined in Section 6/1.1.4 and Part 3 Chapter 2

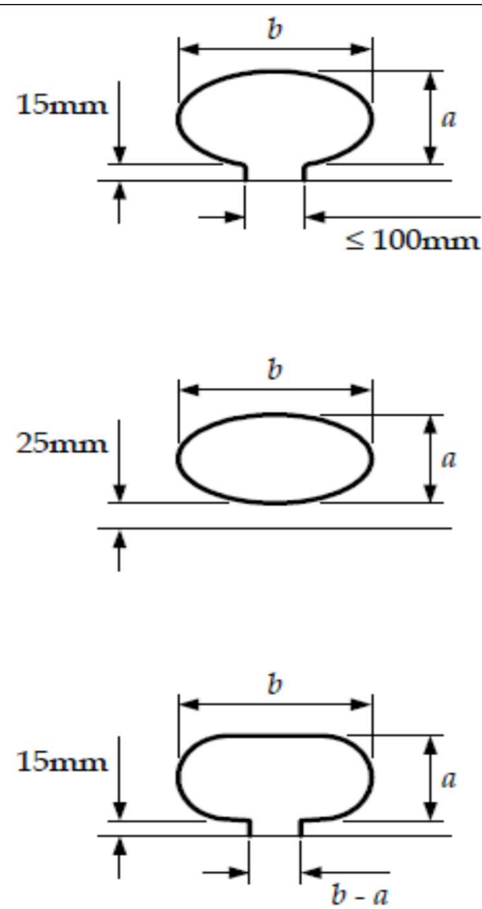
c_1= coefficient for the design load set being considered, to be taken as:
= 1.2 for acceptance criteria set AC1
= 1.1 for acceptance criteria set AC2

3.2.5.2. In general, bracket toes and sniped end members are, to be kept within 25mm of the adjacent member. The maximum distance is not to exceed 40mm unless the bracket or member is supported by another member on the opposite side of the plating. Special attention is to be provided to the end taper by using a sniped end of not more than 30^0. The depth of toe or sniped end is, generally, not to exceed the thickness of the bracket toe or sniped end member, but need not be less than 15mm.

3.2.5.3. The end attachments of non-load bearing members may be snipe ended. The sniped end shall be not more than 30^0 and is generally to be kept within 50mm of the adjacent member unless it is supported by a member on the opposite side of the plating. The depth of the toe is normally not to exceed 15mm.

3.2.6. Air and drain holes and scallops

3.2.6.1. Air, drain holes, scallops and block fabrication butts shall be kept at least 200mm clear of the toes of end brackets, end connections and other areas of high stress concentration measured along the length of the stiffener toward the mid-span and 50mm measured along the length in the opposite direction. Consult Figure 1.4.26(b). Alternative arrangements may be accepted, in areas where the shear stress is less than 60 percent of the allowable limit. Openings are to be well-rounded. Figure 1.4.26 (a) shows some examples of air and drain holes and scallops. In general, the ratio of a/b, as defined in Figure 1.4.26 (a), is to be between 0.5 and 1.0. In fatigue sensitive areas further consideration may be required with respect to the details and arrangements of openings and scallops.



Note
The details shown in this figure are for guidance and illustration only.

Figure 1.4.26(a): Examples of Air and Drain Holes andScallops

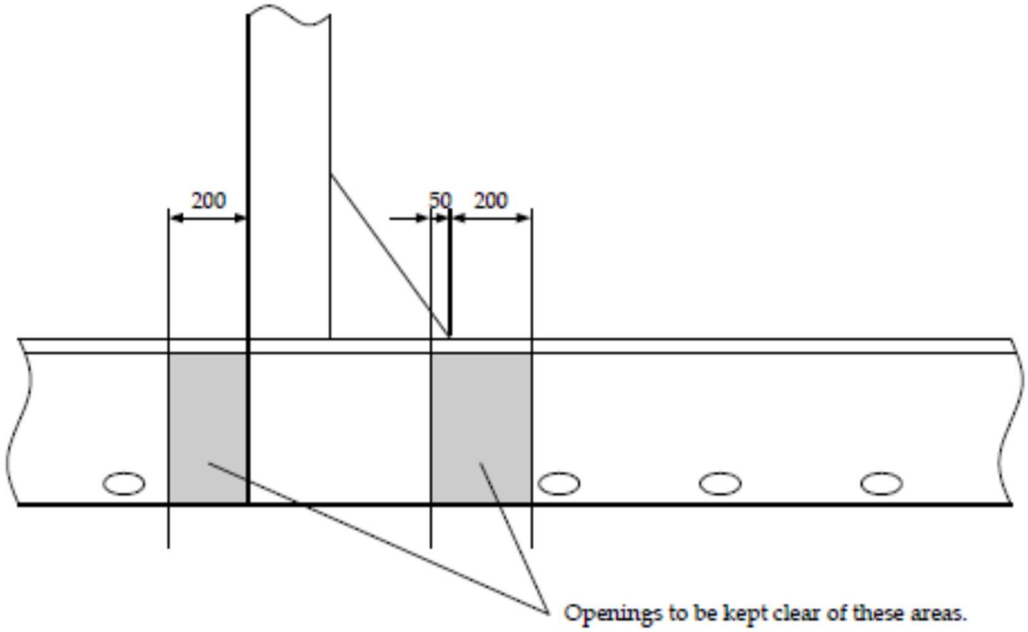


Figure 1.4.26(b): Location of Air and Drain Holes

3.2.7. Special requirements

3.2.7.1. The scallops that are closely shaped or drain holes, i.e. where the distance between scallops/drain holes is less than twice the width b as shown in Figure 1.4.26 (a),are not permitted in longitudinal strength members or within20% of the stiffener span measured from the end of the stiffener. Widely spaced air or drain holes may be permitted only if they are of elliptical shape or equivalent to minimise stress concentration and are, in general, cut clear of the weld connection.

3.3. Termination of Primary Support Members

3.3.1. General

3.3.1.1. Arrangement of Primary support members are to be done to ensure effective continuity of strength. Abrupt changes of depth or section shall be avoided. Primary support members in tanks are to form a continuous line of support and, wherever possible, a complete ring system.

3.3.1.2. The members are to consist of sufficient lateral stability and web stiffening, and the arrangement of the structure is to be done to minimise hard spots and other sources of stress concentration. Openings are to consist of well-rounded corners and are to be situated considering the stress distribution and buckling strength of the panel.

3.3.2. End connection

3.3.2.1. Primary support members are to be provided with satisfactory end fixity by brackets or equivalent structure. The design of end connections and their supporting structure shall provide adequate resistance to rotation and displacement of the joint and effective distribution of the load from the member.

3.3.2.2. The ends of brackets are normally to be soft-toed. The free edges of the brackets shall be stiffened. Scantlings and details are provided in 3.3.3.

3.3.2.3. Where primary support members are subject to concentrated loads, particularly if these are out of line with the member web, additional strengthening may be required.

3.3.2.4. In general, ends of primary support members or connections between primary support members forming ring systems shall be provided with brackets. Bracket less connections may be applied on condition that there is adequate support of the adjoining face plates.

3.3.3. Brackets

3.3.3.1. In general, the arm lengths of brackets connecting primary support members shall not be less than the web depth of the member, and need not be taken as greater than 1.5 times the web depth. In general, the thickness of the bracket is not to be less than that of the girder web plate.

3.3.3.2. For a ring system where the end bracket is integral with the webs of the members and the face plate is carried continuously along the edges of the members and the bracket, the full area of the largest face plate shall be maintained close to the midpoint of the bracket and gradually tapered to the smaller face plates. Butts in face plates shall be kept well clear of the bracket toes.

3.3.3.3. Where a wide face plate abuts a narrower one, the taper is generally not to be greater than 1 in 4. The taper of the thickness is not to be greater than 1 in 3, where a thick face plate abuts against a thinner one and the difference in thickness is greater than 4mm.

3.3.3.4. Face plates of brackets (typical brackets similar to those indicated in Figure 1.4.11 (b) are to consist of a net cross-sectional area, $A_{f\text{-}net}$, which is not to be less than:

$A_{f-net} = l_{bkt-edge} t_{bkt-net}$ cm^2

where:

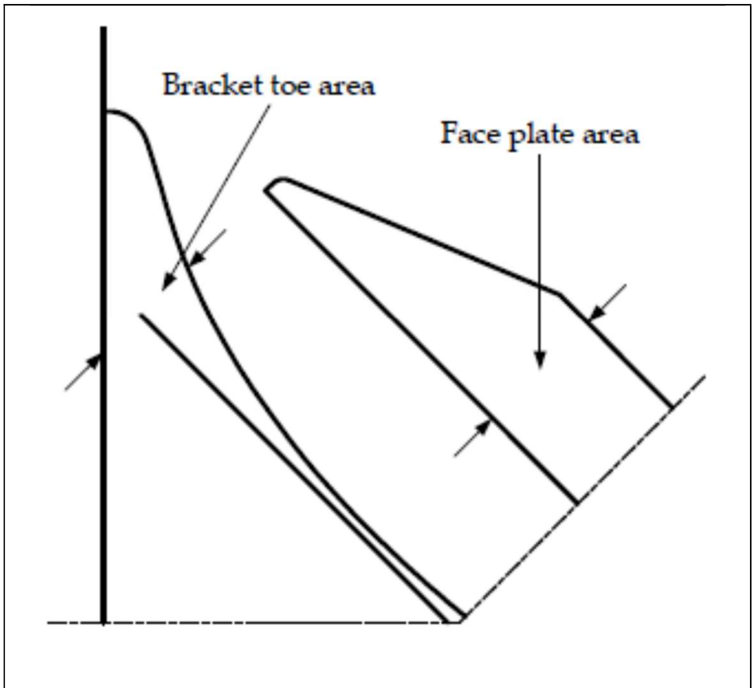
$l_{bkt\text{-}edge}$= length of free edge of bracket, in m. For brackets that are curved the length of the free edge may be taken as the length of the tangent at the midpoint of the free edge. If $l_{bkt\text{-}edge}$ is greater than 1.5 m, 40 percent of the face plate area is to be in a stiffener fitted parallel to the free edge and a maximum 0.15 m from the edge

$t_{bkt\text{-}net}$ =minimum net bracket thickness, in mm, as it is depicted in 3.2.3.3

3.3.4. Bracket toes

3.3.4.1. The toes of brackets shall be a little higher than the unstiffened plating. Notch effects at the toes of brackets may be reduced by making the toe concave or otherwise tapering it off. In general, the toe height is not to be greater than the thickness of the bracket toe, but need not be less than 15mm. The end brackets of large primary support members are to be soft-toed. Where any end bracket has a face plate, it is to be sniped and tapered at an angle not greater than 30°.

3.3.4.2. Particular attention is to be paid to the design of the end bracket toes in order to minimize stress concentrations, where primary support members are constructed of higher strength steel. Sniped face plates, whichare welded onto the edge of primary support member brackets, are to be carried well around the radiusedbracket toe and are to incorporate a taper not greater than 1 in 3. Where sniped face plates are welded adjacent to the edge of primary support member brackets, adequate cross-sectional area shall be provided through the bracket toe at the end of the snipe. In general, this area, measured perpendicular to the face plate is to be notless than 60 percent of the full cross-sectional area of the face plate, see Figure 1.4.27.



Note
The details shown in this figure are only used to illustrate items described in the text and are not intended to represent design guidance or recommendations

Figure 1.4.27: Bracket Toe Construction

3.4. Intersections of Continuous Local Support Members and Primary Support Members

3.4.1. General

3.4.1.1. Cut-outs for the passage of stiffeners through the web of primary support members, and the related collaring arrangements, shall be designed to minimize stress concentrations around the perimeter of the opening and on the attached web stiffeners.

3.4.1.2. Cut-outs in way of cross-tie ends and floors under bulkhead stools or in high stress areas shall be fitted with “full” collar plates, consult Figure 1.4.28.

3.4.1.3. Lug type collar plates shall be fitted in cut-outs where required for compliance with the requirements of 3.4.3, and in areas of significant stress concentrations, e.g., in way of primary support member toes. See Figure 1.4.29 for typical lug arrangements.

3.4.1.4. When, in the following locations, the calculated direct stress, σ_w, in the primary support member web stiffener in accordance with 3.4.3.5 exceeds 80% of the permissible values a soft heel is to be provided in way of the heel of primary support member web stiffeners:

a). Connection to shell envelope longitudinals below the scantling draught, T_{sc}
b). Connection to inner bottom longitudinals.

Where a back bracket is fitted or where the primary support member web is welded to the stiffener face plate, a soft heel is not required at the intersection with watertight bulkheads. The soft heel is to have a keyhole, similar to that shown in Figure 1.4.30 (c).

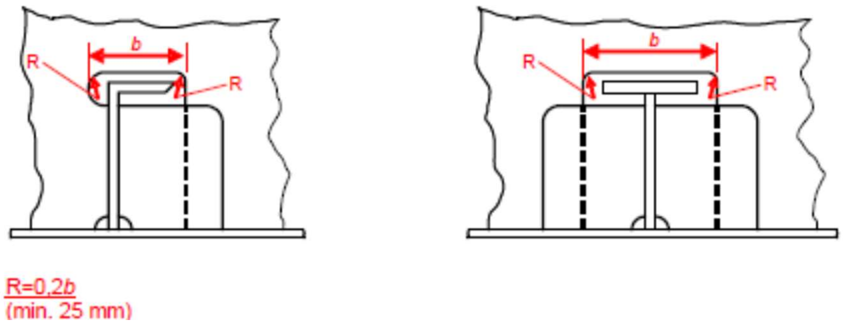


Figure 1.4.28: Collars for Cut-outs in Areas of High Stress

3.4.2. Details of cut-outs

3.4.2.1. In general, cut-outs are to consist of rounded corners and the corner radii, *R*, shall be as large as practicable, with a minimum of 20 percent of the breadth, *b*, of the cut-out or 25 mm, whichever is greater, but need not be greater than 50 mm, see Figure 1.4.28. Consideration will be given to other shapes on the basis of maintaining equivalent strength and minimizing stress concentration.

3.4.3. Connection between primary support members and intersecting stiffeners (local support members)

3.4.3.1. The cross-sectional areas of the connections shall be determined from the proportion of load transmitted through each component in association with its appropriate permissible stress.

3.4.3.2. The total load, W, transmitted through the connection to the primary support member is provided by:

$$W = Ps\left(S - \frac{s}{2000}\right)10^{-3} \quad kN$$

where:

P = design pressure for the stiffener for the design load set being considered, in kN/m². The design load sets, method to derive the design pressure and applicable acceptance criteria set are to be taken in accordance with the following criteria, which define the Acceptance Criteria Set to be used:

Table 2.2.11 in the cargo tank region

Chapter 2 Section 2/3.9.2.2 in the area forward of the forward cargo tank

Chapter 2 Section 2/3.9.2.2 in the aft end

Chapter 2 Section 2/4.8.1.2 in the machinery space

Chapter 2 Section 2/6.2.4.1 when subjected to sloshing loads

Chapter 2 Section 2/6.3.5.1 when subjected to bottom slamming loads

Chapter 2 Section 2/6.4.5.1 when subjected to bow impact loads

S = primary support member spacing, in m, as defined in Section 4/2.2

s = stiffener spacing, in mm, as defined in Section 4/2.2

For stiffeners having different primary support member spacing, S, and/or different pressure, P, at each side of the primary support member, the average load for the two sides is to be applied, e.g. vertical stiffeners at transverse bulkhead.

3.4.3.3. The load, W_1, transmitted through the shear connection is to be taken as follows.If the web stiffener is connected to the intersecting stiffener:

$$W_1 = W\left(\alpha_a + \frac{A_{1-net}}{4f_c A_{w-n} \quad + A_{1-net}}\right) \quad kN$$

If the web stiffener is not connected to the intersecting stiffener:

W_1 =W

where:

W the total load, in kN, as projected in 3.4.3.2

α_a= panel aspect ratio, not to be taken greater than 0.25

$$= \frac{s}{1000\, S}$$

S = primary support member spacing, in m

s = stiffener spacing, in mm

A_{1-net}=effective net shear area of the connection, to be taken as the sum of the components of the connection:

$A_{1d-net} + A_{1c-net}$ cm^2

In case of a slit type slot connections area, A_{1-net}, is given by:

$A_{1-net} = 2 l_d t_{w-net}\, 10^{-2}$ cm^2

In case of a typical double lug or collar plate connection area, A_{1-net}, is given by:

$A_{1-net} = 2 f_1 l_c t_{c-net}\, 10^{-2}$ cm^2

A_{1d-net} = net shear connection area excluding lug or collar plate, as given by the following and Figure 1.4.29

$A_{1d-ne} \; = l_d t_{w-net}\, 10^{-2}$ cm^2

l_d= length of direct connection between stiffener and primary support member web, in mm

t_{w-net}= net web thickness of the primary support member, in mm

A_{1c-net} = net shear connection area with lug or collar plate, given by the following and Figure 1.4.29:

$A_{1c-ne} \; = f_1 l_c t_{c-net}\, 10^{-2}$ cm^2

l_c = length of connection between lug or collar plate and primary support member, in mm

t_{c-net}= net thickness of lug or collar plate, not to be taken greater than the net thickness of the adjacent primary support member web, in mm

f_1= shear stiffness coefficient:

= 1.0 for stiffeners of symmetrical cross section

= 140/w for stiffeners of asymmetrical cross section but are not to be taken as greater than 1.0

w = the width of the cut-out for an asymmetrical stiffener, measured from the cut-out side of the stiffener web, in mm, as indicated in Figure 1.4.29.

A_{w-net} = effective net cross-sectional area of the primary support member web stiffener in way of the connection including backing bracket where fitted, as shown in Figure 1.4.30, in cm^2. If the primary support member web stiffener incorporates a soft heel ending or soft heel and soft toe ending, A_{w-net}, is to be measured at the throat of the connection, as it is stated in Figure 1.4.30

f_c= the collar load factor defined as follows:

for intersecting stiffeners of symmetrical cross section:

= 1.85 for $A_{w-net} \leq 14$

= 1.85 – 0.0441 (A_{w-net} – 14) for 14 < $A_{w-net} \leq 31$

= 1.1 – 0.013 (A_{w-net} – 31) for 31 < $A_{w-net} \leq 58$

= 0.75 for A_{w-net}> 58

for intersecting stiffeners of asymmetrical cross section:

$$= 0.68 + 0.0172 \frac{l_s}{A_{w-net}}$$

where:

l_s = l_c for a single lug or collar plate connection to the primary support member

= l_d for a single sided direct connection to the primary support member

= mean of the connection length on both sides, i.e., in the case of a lug or collar plus a direct connection, ls = 0.5(l_c + l_d)

3.4.3.4. The load, W_2, transmitted through the primary support member web stiffener is to be taken as follows.If the web stiffener is connected to the intersecting stiffener:

$$W_2 = W\left(1 - \alpha_a - \frac{A_{1-net}}{4f_c A_{w-net} + A_{1-net}}\right) \quad kN$$

If the web stiffener is not connected to the intersecting stiffener:

$W_2 = 0$

where:

W = the total load, in kN, as it is shown in 3.4.3 2

α_a= panel aspect ratio

$$= \frac{s}{1000S}$$

S = primary support member spacing, in m

s = stiffener spacing, in mm

A_{1-net} = effective net shear area of the connection, in cm², as defined in 3.4.3.3

f_c= collar load factor, as defined in 3.4.3.3

A_{w-net} = effective net cross-sectional area of the primary support member web stiffener, in cm², asdefined in 3.4.3.3

3.4.3.5. The values of A_{w-net}, A_{wc-net} and A_{1-net} are to be such that the calculated stresses satisfy the following criteria:

for the connection to the primary support member web stiffener away from the weld:

$\sigma_w \le \sigma_{perm}$

for the connection to the primary support member web stiffener in way of the weld:

$\sigma_{wc} \le \sigma_{perm}$

for the shear connection to the primary support member web:

$\tau_w \le \tau_{perm}$

where:

σ_w= direct stress in the primary support member web stiffener at the minimum bracket area away from the weld connection:

$$= \frac{10W_2}{A_{w-net}} \quad N/mm^2$$

σ_{wc} = direct stress in the primary support member web stiffener in way of the weld connection:

$$= \frac{10W_2}{A_{wc-net}} \quad N/mm^2$$

τ_c = shear stress in the shear connection to the primary support member

$$= \frac{10W_1}{A_{1-net}} \quad N/mm^2$$

A_{w-net} effective net cross-sectional area of the primary support member web stiffener, in cm², as depicted in 3.4.3.3

$A_{wc\text{-}net}$ effective net area of the web stiffener in way of the weld as projected in Figure 1.4.30, in cm^2

$A_{1\text{-}net}$ effective net shear area of the connection, in cm^2, as it is stated in 3.4.3.3

W_1 load transmitted through the shear connection, in kN, as it is shown in 3.4.3.3

W_2 load transmitted through the web stiffener, in kN, as indicated in 3.4.3.4.

σ_{perm} = permissible direct stress shown in Table 1.4.4 for the applicable acceptance criteria, see 3.4.3.2, in N/mm^2

τ_{perm} = permissible shear stress indicated in Table 1.4.4 for the applicable acceptance criteria, 3.4.3.2 can be consulted, in N/mm^2

3.4.3.5 bis 1 When total load, W, is bottom slamming or bow impact loads the following criteria apply in lieu of 3.4.3.3-3.4.3.5:

$$0.9W \leq \frac{A_{1-net}\tau_{perm} + A_{w-net}\sigma_{perm}}{10} \qquad kN$$

$A_{1\text{-}net}$ = effective net shear area in cm^2 of the connection, as indicated in 3.4.3.3.

$A_{w\text{-}net}$ = effective net cross-sectional area in cm^2 of the primary support member web stiffener in way of the connection including backing bracket where fitted, as depicted in 3.4.3.3.

σ_{perm}= permissible direct stress shown in Table 1.4.4 for AC-3, in N/mm^2

τ_{perm}= permissible shear stress shown in Table 1.4.4 for AC-3, in N/mm^2

3.4.3.6. In addition to the primary support member web stiffener where a backing bracket is fitted, it is to be arranged on the opposite side to, and in alignment with the web stiffener. The arm length of the bracket is to be not less than the depth of the web stiffener and its net cross-sectional area through the throat of the bracket is to be included in the calculation of $A_{w\text{-}net}$ as indicated in Figure 1.4.30

3.4.3.7. Lapped connections of primary support member web stiffeners or tripping brackets to local support members are not allowed in the cargo tank region, e.g., lapped connections between transverse and longitudinal local support members.

3.4.3.8. Fabricated stiffeners having their face plate welded to the side of the web, leaving the edge of the web exposed, are not recommended for side shell and longitudinal bulkhead longitudinals. A symmetrical arrangement of connection to the transverse members is to be incorporated, where such sections are connected to the primary support member web stiffener. This may be implemented by fitting backing brackets on the opposite side of the transverse web or bulkhead. In way of the cargo tank region, the primary support member web stiffener and backing brackets are to be butt welded to the intersecting stiffener web.

3.4.3.9. The offset primary support member web stiffener may be located as shown in Figure 1.4.29, where the web stiffener of the primary support member is parallel to the web of the intersecting stiffener, but not connected to it. The offset primary support member web stiffener is to be situated in close proximity to the slot edge. Figure 1.4.29 can also be consulted. The ends of the offset web stiffeners are to be suitably tapered and softened.

3.4.3.10. Alternative arrangements will be specially considered on the basis of their ability to transmit load with equivalent effectiveness. Submission of details of calculations made and/or testing procedures and results are to be done.

3.4.3.11. The size of the fillet welds is to be calculated in accordance with Section 6/5 based on the weld factors given in Table 1.4.24. For the welding in way of the shear connection the size is not to be less than that required for the primary support member web plate for the location under consideration.

Table 1.4.4: Permissible Stresses for Connection between Stiffeners and Primary Support Members

Item	Direct Stress, σ_{perm}, in N/mm^2			Shear Stress, τ_{perm}, in N/mm^2		
	Acceptance Criteria Set See 3.4.3.2			Acceptance Criteria Set See 3.4.3.2		
	AC1	AC2	AC3	AC1	AC2	AC3
Primary support member web stiffener	$0.83\sigma_{yd}$ (3)	σ_{yd}	σ_{yd}			
Primary support member web stiffener to intersecting stiffener in way of weld connection:						
double continuous fillet	$0.58\ \sigma_{yd}$(3)	$0.70\ \sigma_{yd}$(3)	σ_{yd}			
partial penetration weld	$0.83\ \sigma_{yd}$(2)(3)	σ_{yd}(2)	σ_{yd}			
Primary support member stiffener to intersecting stiffener in way of lapped welding	$0.50\ \sigma_{yd}$	$0.60\ \sigma_{yd}$	σ_{yd}			
Shear connection including lugs or Collarplates:						
single sided connection				$0.71\ \tau_{yd}$	$0.85\ \tau_{yd}$	τ_{yd}
double sided connection				$0.83\ \tau_{yd}$	τ_{yd}	τ_{yd}

where:

τ_{perm} permissible shear stress, in N/mm^2

σ_{perm} permissible direct stress, in N/mm^2

σ_{yd} minimum specified material yield stress, in N/mm^2

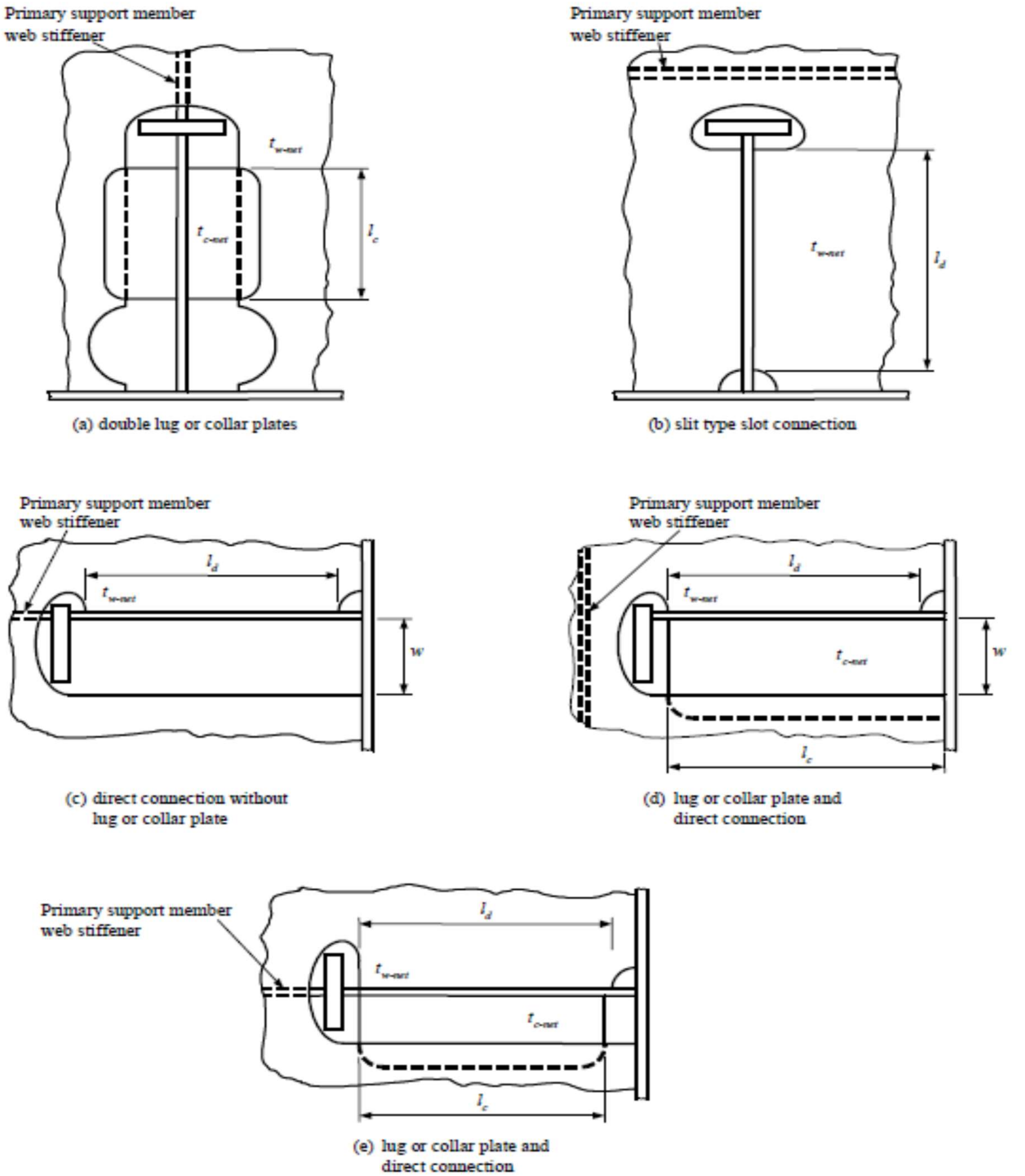
$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}}$ in N/mm^2

Note

1) The stress computation on plate type members is to be performed on the basis of net thicknesses, whereas gross values are to be used in weld strength assessments, see 3.4.3.11.
2) The root face is not to be greater than one third of the gross thickness of the primary support member stiffener.
3) Allowable stresses may be increased by 5 percent where a soft heel is provided in way of the heel of the primary support member web stiffener.

Table 1.4.5: Weld Factors for Connection between Stiffeners and Primary Support Members

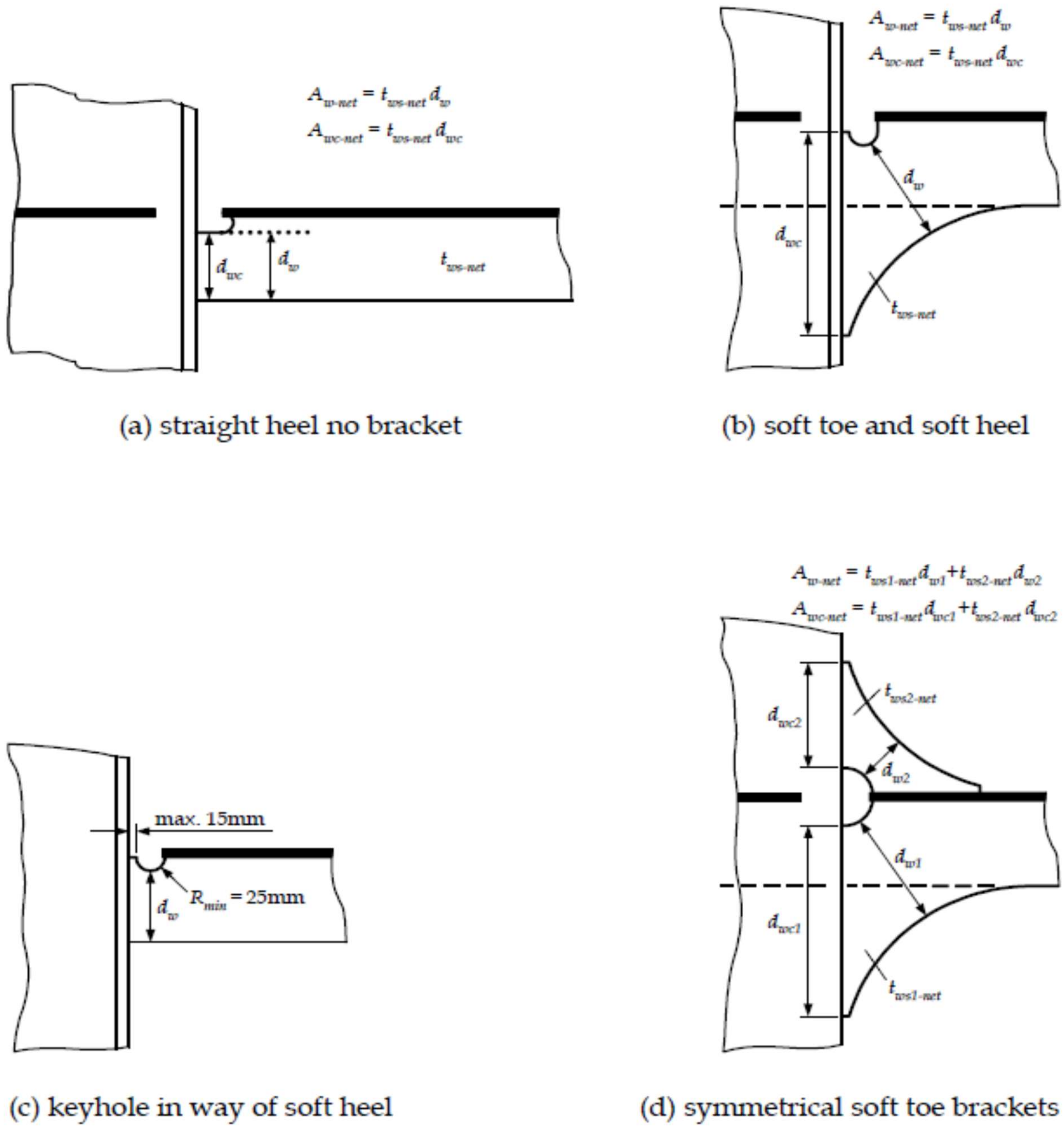
Item	Weld factor
Primary support member stiffener to intersecting stiffener	$0.6\ \sigma_{wc}/\sigma_{perm}$ not to be less than 0.38
Shear connection inclusive lug or collar plate	0.38
Shear connection inclusive lug or collar plate, where the web stiffener of the primary support member is not connected to the intersection stiffener	$0.6\ \tau_w/\tau_{perm}$ not to be less than 0.44
where: τ_w shear stress, as defined in 3.4.3.5 σ_w as defined in 3.4.3.5 τ_{perm} permissible shear stress, in N/mm^2, see Table 1.4.4 σ_{perm} permissible direct stress, in N/m^{m2} see Table 1.4.4	



Note

The details shown in this figure are only used to illustrate symbols and definitions and are not intended to represent designguidance or recommendations.

Figure 1.4.29: Symmetric and Asymmetric Cut outs



where:

$t_{ws\text{-}net}$, $t_{ws1\text{-}net}$ and $t_{ws2\text{-}net}$ = net thickness of the primary support member web stiffener/backing bracket, in mm

d_w, d_{w1} and d_{w2} = minimum depth of the primary support member web stiffener/backing bracket, in mm

d_{wc}, d_{wc1} and d_{wc2} = length of connection between the primary support member web stiffener/backing bracket and the local support stiffener, in mm

Note

Except where specific dimensions are noted for the details of the keyhole in way of the soft heel,3.4.1.4can be consulted, the details shown in this figure are only used to illustrate symbols and definitions and are not intended to represent design guidanceor recommendations

Figure 1.4.30: Primary Support Member Web Stiffener Details

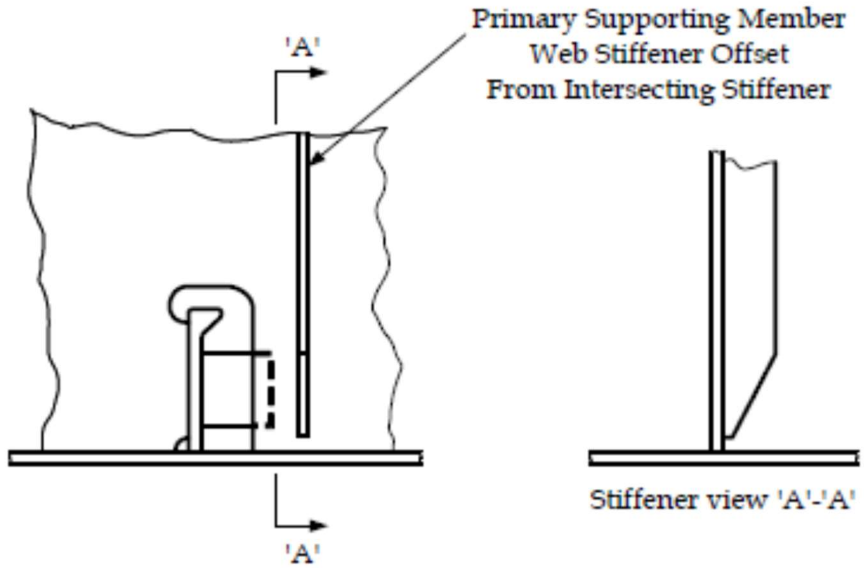


Figure 1.4.31: Offset Primary Support Member Web Stiffeners

3.5. Openings

3.5.1. General

3.5.1.1. Openings are to have well rounded corners

3.5.1.2. In way of concentrated loads, manholes, lightening holes and other similar openings should be avoided, and areas of high shear. To be precise, manholes and similar openings are to be avoided in high stress areas unless the stresses in the plating and the panel buckling characteristics have been calculated and found satisfactory.

Examples of high stress areas include:

a) In vertical or horizontal diaphragm plates in narrow cofferdams/double plate bulkheads within one-sixth oftheir length from either end
b) In floors or double bottom girders close to their span ends
c) Above the heads and below the heels of pillars.
Where larger openings than given by 3.5.2 or 3.5.3 are proposed, the arrangements and compensation that are neededwill be specially considered.

3.5.2. Manholes and lightening holes in single skin sections not requiring reinforcement

3.5.2.1. Openings cut in the web with depth of opening not exceeding 25 percent of the web depth and positioned so that the edges are not less than 40 percent of the web depth from the faceplate do not generally require reinforcement. The length of opening shall not be greater than the web depth or 60 percent of the local support member spacing, whichever is greater. The ends of the openings are to be equidistant from the corners of cut outs for local support members.

3.5.3. Manholes and lightening holes in double skin sections not requiring reinforcement

3.5.3.1. Where openings are cut in the web and are clear of high stress areas, reinforcement of these openings is not requisite provided that the depth of the opening does not exceed 50 percent of the web depth and is located so that the edges are well clear of cut outs for the passage of local support members.

3.5.4. Manholes and lightening holes requiring reinforcement

3.5.4.1. Manholes and lightening holes are to be stiffened as necessary by 3.5.4.2 and 3.5.4.3. The stiffening requirements of 3.5.4.2 and 3.5.4.3 may be improved where alternative arrangements are demonstrated as satisfactory with regards to stress and stability, according to analysis methods described in Chapter 2 Section 3/2.

3.5.4.2. The web plate shall be stiffened at openings when the mean shear stress, as determined by application of the requirements of Chapter 2 Section 2 or Section 3/2, is greater than 50N/mm² for acceptance criteria set AC1 or greater than 60N/mm² for acceptance criteria set AC2. The stiffening arrangement is to ensure buckling strength as required by Chapter 2 Section 4 under application of the loading as necessary in Chapter 2 Section 2 or Section 3/2.

3.5.4.3. Stiffeners are to be fitted along the free edges of the openings parallel to the vertical and horizontal axis of the opening, on members contributing to longitudinal strength. Stiffeners may be omitted in one direction if the shortest axis is less than 400mm and in both directions if length of both axes is less than 300mm. Edge reinforcement may be used as an alternative to stiffeners. See Figure 1.4.32.

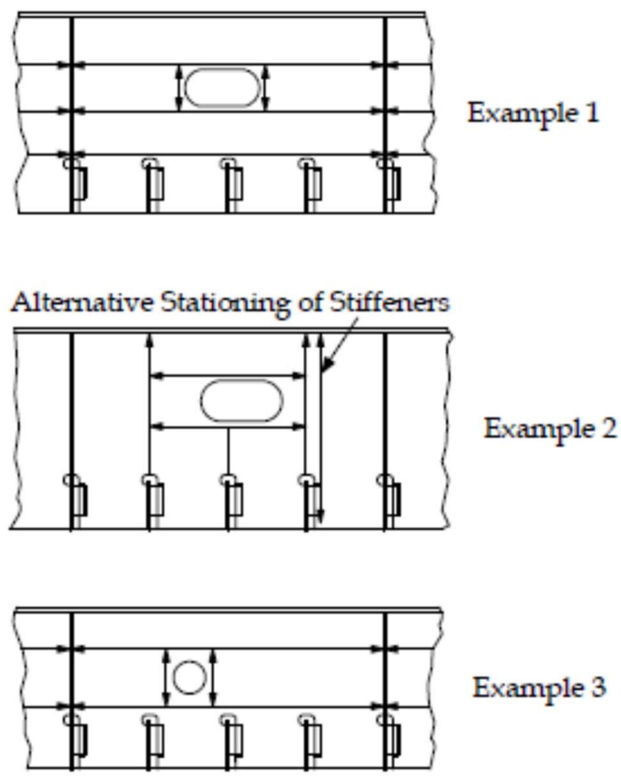


Figure 1.4.32: Web Plate with Large Openings

3.6. Local Reinforcement

3.6.1. Reinforcement at knuckles

3.6.1.1. Adequate stiffening shall be fitted at the knuckle to transmit the transverse load, whenever a knuckle in a main member (shell, longitudinal bulkhead etc.) is arranged. This stiffening, in the form of webs, brackets or profiles, is to be connected to the transverse members to which they are to transfer the load (in shear). See Figure 1.4.33

3.6.1.2. In general, for longitudinal shallow knuckles, closely spaced carlings are to be fitted across the knuckle, between longitudinal members above and below the knuckle. Carlings or other types of reinforcement need not be fitted in way of shallow knuckles that are not subject to high lateral loads and/or high in-plane loads across the knuckle, such as deck camber knuckles.

3.6.1.3. Generally, the distance between the knuckle and the support stiffening described in 3.6.1.1 is not to be greater than 50mm.

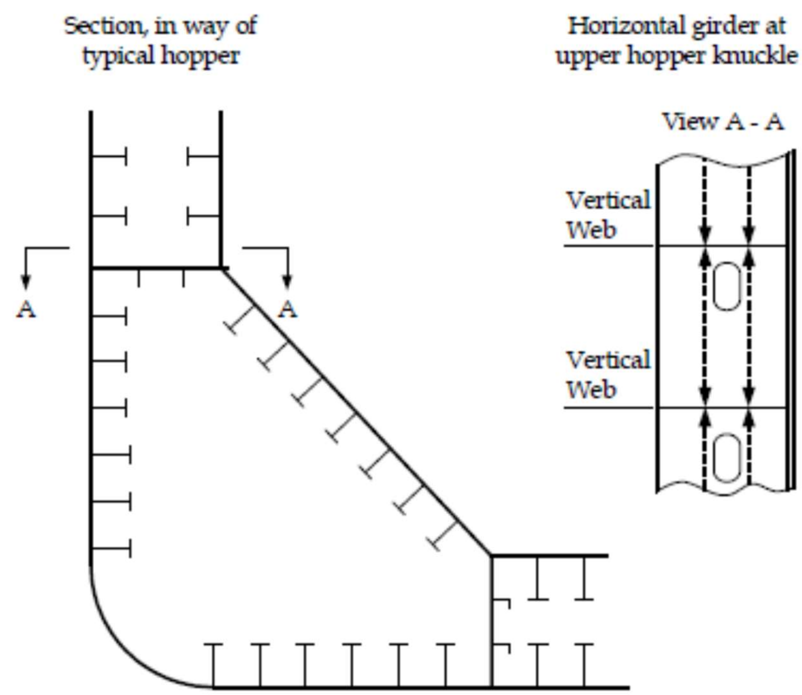


Figure 1.4.33: Example of Reinforcement at Knuckles

3.6.2. Reinforcement for openings and attachments associated with means of access for inspection purposes

3.6.2.1. Local reinforcement should be given according to the proper location and strength of all attachments to the hull structure for access for inspection purposes.

3.7. Fatigue Strength

3.7.1. General

3.7.1.1. Structural details shall be designed for compliance with the requirements of fatigue strength as specified in Chapter 2 Section 3/3.

SECTION 5 STRUCTURAL ARRANGEMENT

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1. General

1.1. Introduction

1.1.1. Scope

1.1.1.1. On the basis or as derived from National and International regulations, the general structural arrangement requirements for the ship is covered in this section, see Sections 2/2.1.1 and 3/3.3.

2. Watertight Subdivision

2.1. Watertight Bulkhead Arrangement

2.1.1. General

2.1.1.1. According to the following requirements, all ships are to be provided with watertight bulkheads arranged to subdivide the hull into watertight.

2.1.2. Minimum number and disposition of watertight bulkheads

2.1.2.1. On all ships fitting of the following watertight bulkheads are to be done:

a) A collision bulkhead, see 2.2.1.1
b) An aft peak bulkhead
c) A bulkhead at each end of the machinery space.

2.1.2.2. As far as practicable, the bulkheads in the cargo tank region are to be spaced at uniform intervals.

2.1.2.3. In order to suit to the requirements for subdivision, flood-ability and damage stability, arrangement of the applicable number and disposition of bulkheads are to be done and are required to be in accordance with the requirements of National regulations.

2.1.2.4. In watertight bulkheads, the number of openings is to be kept to a minimum. In order to maintain the watertight integrity, arrangements are to be made where penetrations of watertight bulkheads and internal decks are necessary for access, piping, ventilation, electrical cables, etc. In Chapter 2 Section 2/3.6.2, additional requirements apply to collision bulkheads.

2.2. Position of Collision Bulkhead

2.2.1. General

2.2.1.1. Fitting of a collision bulkheadon all ships is to be done and extended up to the freeboard deck.It is to be located between $0.05L_L$ or 10m, whichever is less, and $0.08L_L$ aft of the reference point, where the load line length, L_L, is as defined in Section 4/1.1.2.1 and the reference point is as defined in 2.2.1.2. Proposals for location of the collision bulkhead aft of $0.08L_L$ will be specially considered.

2.2.1.2. The reference point is to be taken for ships without bulbous bows where the forward end of L_L coincides with the forward side of the stem on the waterline which L_L is measured. For ships with bulbous bows, measurement from the forward end of L_L a distance x forward is to be done; where x is to be taken as the lesser of the following:

a) half the distance, from the forward end of L_L and the extreme forward end of the bulb extension
b) $0.015L_L$
c) 3.0m.

2.2.1.3. As the limits prescribed in 2.2.1.1 and 2.2.1.2, the collision bulkhead in general is to be in one plane, however, the bulkhead may have steps or recesses provided they are in compliance with these limits.

2.3. Position of Aft Peak Bulkhead

2.3.1. General

2.3.1.1. An aft peak bulkhead, enclosing the stern tube and rudder trunk in a watertight compartment, shall be provided. Special consideration of the alternative arrangements is to be considered where the shafting arrangements enclosing the stern tube in a watertight compartment is impractical. Special consideration shall also be given for the aft peak bulkhead location on ships powered and/or controlled by equipment that do not require the fitting of a stern tube and/or rudder trunk.

2.3.1.2. Provided that this deck is made watertight to the stern or to a watertight transom floor, the aft peak bulkhead may terminate at the first deck above the summer load waterline.

3. Double Hull Arrangement

3.1. General

3.1.1. Protection of cargo tanks

3.1.1.1. In accordance with 3.2 and 3.3, every tanker is to be provided with double bottom tanks and spaces, and double side tanks and spaces. Protection of the cargo tanks or spaces are to be done by the double bottom and double side tanks and spaces and are not to be used for the carriage of oil cargoes.

3.1.2. Capacity of ballast tanks

3.1.2.1. The capacity of the segregated ballast tanks shall be so determined that the ship may operate safely on ballast voyages without recourses to the use of cargo tanks for water ballast. The capacity of ballast shall be at least such that, in any ballast condition at any part of the voyage, including the conditions consisting of lightweight plus segregated ballast only, the ships draught and trim can meet the requirements in 3.1.2.2 to 3.1.2.4.

3.1.2.2. The moulded draught amidships, T_{mid}, excluding any hogging or sagging correction, is not to be less than:

$$T_{mid} = 2.0 + 0.02L \text{m}$$

Where:

L rule length, as defined in Section 4/1.1.1.1, in m

3.1.2.3. As given in 3.1.2.2, the draughts at the F.P. and A.P. are to correspond to those determined by the draught amidships, and in association with a trim by the stern not greater than 0.015L (m).

3.1.2.4. In order to obtain full immersion of the propeller(s), the draught at the A.P. is to benot less than that required.

3.1.3. Limitation of size and arrangement of cargo tanks

3.1.3.1. In order to limit the hypothetical oil outflow from side and bottom damage, anywhere along the length of the ship, arrangement and size of the Cargo tanks are to be considered.

3.2. Double Bottom

3.2.1. Double bottom depth

3.2.1.1. The minimum double bottom depth, d_{db}, is to be taken as the lesser of:

$d_{db} = \frac{B}{15}$ m, but not less than 1.0 m
d_{db}= 2.0 m
where:

B moulded breadth, in m, as defined in Section 4/1.1.3.1

3.3. Double Side

3.3.1. Double side width

3.3.1.1. The minimum double side width, w_{ds}, is to be taken as the lesser of:

$w_{ds} = 0.5 + \frac{DWT}{20000}$ m, but not less than 1.0 m

w_{ds} = 2.0 m

where:

DWT = deadweight of the ship, in tonnes, as defined in Section 4/1.1.14.1.

4. Separation of Spaces

4.1. Separation of Cargo Tanks

4.1.1. General

4.1.1.1. The cargo pump room, cargo tanks, slop tanks and cofferdams shall be positioned forward of machinery spaces. The positioning of main cargo control stations, control stations, accommodation and service spaces shall be aft of cargo tanks, slop tanks, and spaces so as to keep cargo or slop tanksisolated from machinery spaces, but not essentially aft of the oil fuel bunker tanks and ballast tanks.

4.2. Cofferdam Spaces

4.2.1. General

4.2.1.1. Cofferdam spaces are to be kept gas-tight. In accordance with 5.3, access requirements to permit internal inspections are to be conducted wherever applicable.

5. Access Arrangements

5.1. Access Into and Within Spaces in, and Forward of, the Cargo Tank Region

5.1.1. General

5.1.1.1. Satisfaction of the International Convention for the Safety of Life at Sea, 1974, as amended, Chapter II-1, Part A-1, Regulation 3-6, as required by the Flag Administration, for details and arrangements of openings and attachments to the hull structure access into and within spaces in, and forward of, the cargo tank region is to be provided. Reviewing in conjunction with the structural requirements shall be conducted.. Additionally, the requirements of 5.1.1.2 to 5.1.1.5 are to be complied with.

5.1.1.2. Provision is to be made for at least two exits to the open deck arranged at a maximum distance from each other where a duct keel or pipe tunnel is fitted. The duct keel or pipe tunnel is not to pass through machinery spaces. The aft access may lead from the pump room to the duct keel.The access opening from the pump room to the duct keel is to be provided with an oil-tight cover plate or a watertight door, where an aft access is provided from the pump room to the duct keel. Sufficient ventilation of such spaces prior to entry shall be provided and mechanical ventilation is to be installed. At each entrance, a notice board is to be fitted to the pipe tunnel which shall state that the ventilating fan must have been in operation for a sufficient periodbefore making any attempt to enter.Additionally, sampling of the atmosphere in the tunnel is to be obtained by a gas monitor, and an oxygen monitor is to be provided where an inert gas system is fitted in cargo tanks.

5.1.1.3. The scantlings of the watertight door are to conform to the requirements of the IRS where a watertight door is fitted in the pump room for access to the duct keel and the following additional requirements are:

a) In addition to bridge operation, the watertight door is to be capable of being manually closed from outside the main pump room entrance. In order to note whether the door is open or closed, a means is to be provided locally and on the bridge.
b) During normal operations of the ship, a notice is to be affixed at each operating position to the effect that the watertight door is to be kept closed, except when access to the pipe tunnel is required.

5.1.1.4. In order to assist in rescue operation, at least one horizontal access opening of 600mm by 800mm clear opening is to be fitted in each horizontal girder in the vertical wing ballast space and weather deck. Acceptance of a 600mm by 600mm clear opening shall be provided where an opening of 600mm by 800mm is not permitted due to structural arrangements.

5.1.1.5. In order to fit permanent repair/maintenance access openings with oil-tight covers in cargo tank bulkheads, special consideration will be given to any proposals. National regulations concerning load line and oil outflow aspects of such arrangements, attention is required to be drawn.

5.1.1.6. Ref. IACS Rec.No:132 Human Element Recommendations for structural design of lighting, ventilation, vibration, noise, access and egress arrangements

Table 1.5.1 - Means of access for ballast and cargo tanks of oil tankers

1 Water ballast tanks, except those specified in the right column, and cargo oil tanks	**2 Water ballast wing tanks of less than 5 m width forming double side spaces and their bilge hopper sections**
Access to the underdeck and vertical structure	
1.1 For tanks of which the height is 6 m and over containing internal structures, permanent means of access shall be provided in accordance with.1 to .6: .1 continuous athwartship permanent accessarranged at each transverse bulkhead on the stiffened surface, at a minimum of 1.6 m to a maximum of 3 m below the deck head; .2 at least one continuous longitudinal permanent means of access at each side of the tank. One of these accesses shall be at a minimum of 1.6 m to a maximum of 6 m below the deck head and the other shall be at a minimum of 1.6 m to a maximum of 3 m below the deck head; .3 access between the arrangements specified in .1 and .2 and from the main deck to either .1 or .2; .4 continuous longitudinal permanent means of access which are integrated in the structural member on the stiffened surface of alongitudinal bulkhead, in alignment, where possible, with horizontal girders oftransverse bulkheads are to be provided for access to the transverse webs unless permanent fittings are installed at theuppermost platform for use of alternativemeans, as defined in paragraph 3.9 of the Technical provisions, for inspection atintermediate heights; .5 for ships having cross-ties which are 6 m or more above tank bottom, a transversepermanent means of access on the cross-ties providing inspection of the tie flaringbrackets at both sides of the tank, with access from one of the longitudinal permanent means of access in .4; and .6 alternative means as defined inparagraph 3.9 of the Technical provisions may be provided for small ships as an alternative to .4 for cargo oil tanks of which the height is less than 17 m.	2.1 For double side spaces above the upper knuckle point of the bilge hopper sections, permanent means of access are to be provided in accordance with .1 to .3: .1 where the vertical distance between horizontal uppermost stringer and deck head is 6 m or more, one continuous longitudinal permanent means of access shall be provided for the full length of the tank with a means to allow passing through transverse webs installed at a minimum of 1.6 m to a maximum of 3 m below the deck head with a vertical access ladder at each end of the tank; .2 continuous longitudinal permanent means of access, which are integrated in the structure, at a vertical distance not exceeding 6 m apart; and .3 plated stringers shall, as far as possible, be in alignment with horizontal girders of transverse bulkheads.
1.2 For tanks of which the height is less than 6 m, alternative means as defined in paragraph 3.9 of the Technical provisions or portable means may be utilized in lieu of the permanent means of access.	2.2 For bilge hopper sections of which the vertical distance from the tank bottom to the upper knuckle point is 6 m and over, one longitudinal permanent means of access shall be provided for the full length of the tank. It shall be accessible by vertical permanent means of access at each end of the tank. 2.2.1 The longitudinal continuous permanent means of access may be installed at a minimum 1.6 m to maximum 3 m from the top of the bilge hopper section. In this case, a platform extending the longitudinal continuous permanent means of access in way of the webframe may be used to access the identified structural critical areas. 2.2.2 Alternatively, the continuous longitudinal permanent means of access may be installed at a minimum of 1.2 m below the top of the clear opening of the web ring allowing a use of portable means of access to reach identified structural critical areas.
Fore peak tanks 1.3 For fore peak tanks with a depth of 6 m or more at the centre line of the collision bulkhead, a suitable means of access shall be provided for access to critical areas such as the underdeck structure,stringers, collision bulkhead and side shell structure. 1.3.1 Stringers of less than 6 m in vertical distance from the deck head or a stringer immediately above are considered to provide suitable access in combination with portable means of access. 1.3.2 In case the vertical distance between the deck head and stringers, stringers or the loweststringer and the tank bottom is 6 m or morealternative means of access as defined in paragraph 3.9 of the Technical provisions shall be provided.	2.3 Where the vertical distance referred to in 2.2 is less than 6 m, alternative means as defined in paragraph 3.9 of the Technical provisions or portable means of access may be utilised in lieu of the permanent means of access. To facilitate the operation of the alternative means of access, in-line openings in horizontal stringers shall be provided. The openings shall be of an adequate diameter and shall have suitable protective railings.

6. Venting arrangements

6.1. Principle

Cargo tanks are to be provided with venting systems entirely distinct from the air pipes of the other compartments of the ship. The arrangements and position of openings in the cargo tank deck from which emission of flammable vapours can occur are to be such as to minimise the possibility of flammable vapours being admitted to enclosed spaces containing a source of ignition, or collecting in the vicinity of deck machinery and equipment which may constitute an ignition hazard.

6.2. Design of venting arrangements

The venting arrangements are to be so designed and operated as to ensure that neither pressure nor vacuum in cargo tanks exceeds design parameters and be such as to provide for:

- the flow of the small volumes of vapour, air or inert gas mixtures caused by thermal variations in a cargo tank in all cases through pressure/vacuum valves, and
- the passage of large volumes of vapour, air or inert gas mixtures during cargo loading and ballasting, or during discharging,
- a secondary means of allowing full flow relief of vapour, air or inert gas mixtures to prevent overpressure or underpressure in the event of failure of the arrangements in b). Alternatively, pressure sensors may be fitted in each tank protected by the arrangement required in b), with a monitoring system in the ship's cargo control room or the position from which cargo operations are normally carried out. Such monitoring equipment is also to provide an alarm facility which is activated by detection of overpressure or underpressure conditions within a tank.

Note 1 : A pressure / vacuum valve fitted on the inert gas main may be utilised as the required secondary means of venting. Where the venting arrangements are of the free flow type and the masthead isolation valve is closed for the unloading condition, the inert gas system will serve as the primary underpressure protection with the pressure / vacuum breaker serving as the secondary means.

6.3. Combination of venting arrangements

- The venting arrangements in each cargo tank may be independent or combined with other cargo tanks and may be incorporated into the inert gas piping.
- Where the arrangements are combined with other cargo tanks, either stop valves or other acceptable means are to be provided to isolate each cargo tank. Where stop valves are fitted, they are to be provided with locking arrangements which are to be under the control of the responsible ship's officer. There is to be a clear visual indication of the operational status of the valves or other acceptable means. Where tanks have been isolated, it is to be ensured that relevant isolating valves are opened before cargo loading or ballasting or discharging of those tanks is commenced. Any isolation must continue to permit the flow caused by thermal variations in a cargo tank in accordance with [4.2.2].

Note 1 : Inadvertent closure or mechanical failure of the isolation valves need not be considered in establishing the secondary means of venting cargo tanks required in [4.2.2].

- If cargo loading and ballasting or discharging of a cargo tank or cargo tank group is intended, which is isolated from a common venting system, that cargo tank or cargo tank group is to be fitted with a means for overpressure or underpressure protection as required in [4.2.2].

6.4. Arrangement of vent lines

The venting arrangements are to be connected to the top of each cargo tank and are to be self-draining to the cargo tanks under all normal conditions of trim and list of the ship.

Where it may not be possible to provide self-draining lines, permanent arrangements are to be provided to drain the vent lines to a cargo tank.Plugs or equivalent means are to be provided on the lines after the safety relief valves.

6.5. Openings for pressure release

Openings for pressure release required by [4.2.2] are to:

- have as great a height as is practicable above the cargo tank deck to obtain maximum dispersal of flammable vapours but in no case less than 2 m above the cargo tank deck,
- be arranged at the furthest distance practicable but not less than 5 m from the nearest air intakes and openings to enclosed spaces containing a source of ignition and from deck machinery and equipment which may constitute an ignition hazard.

Note 1 : The provisions of item a) are not applicable to the pressure / vacuum valve fitted on the inert gas main (see [4.2.2] Note 1) provided its settings are above those of the venting arrangements required by items a) and b) of [4.2.2].
Note 2 : Anchor windlass and chain locker openings constitute an ignition hazard. They are to be located at the distances required by b) above.

6.6. **Pressure/vacuum valves**

- Pressure/vacuum valves are to be set at a positive pressure not exceeding 0,021 N/mm^2 and at a negative pressure not exceeding 0,007 N/mm^2.
  Note 1 : Higher setting values not exceeding 0,07 N/mm^2 may be accepted in positive pressure if the scantlings of the tanks are appropriate.
- Pressure/vacuum valves required by [4.2.2] may be provided with a bypass when they are located in a vent main or masthead riser. Where such an arrangement is provided, there are to be suitable indicators to show whether the bypass is open or closed.
- Pressure/vacuum valves are to be of a type approved by the Society in accordance with Ch 7, App 1.
- Pressure/vacuum valves are to be readily accessible.
- Pressure/vacuum valves are to be provided with a manual opening device so that valves can be locked on open position. Locking means on closed position are not permitted.

Vent outlets

Vent outlets for cargo loading, discharging and ballasting required by [4.2.2] are to:

- permit:
  The free flow of vapour mixtures, or the throttling of the discharge of the vapour mixtures to achieve a velocity of not less than 30 m/s,
- be so arranged that the vapour mixture is discharged vertically upwards,
- where the method is by free flow of vapour mixtures, be such that the outlet is not less than 6 m above the cargo tank deck or fore and aft gangway if situated within 4 m of the gangway and located not less than 10 m measured horizontally from the nearest air intakes and openings to enclosed spaces containing a source of ignition and from deck machinery and equipment which may constitute an ignition hazard,
- where the method is by high velocity discharge, be located at a height not less than 2 m above the cargo tank deck and not less than 10 m measured horizontally from the nearest air intakes and openings to enclosed spaces containing a source of ignition and from deck machinery which may constitute an ignition hazard. These outlets are to be provided with high velocity devices of a type approved by the Society,
- be designed on the basis of the maximum designed loading rate multiplied by a factor of at least 1,25 to take account of gas evolution, in order to prevent the pressure in any cargo tank from exceeding the design pressure. The Master is to

be provided with information regarding the maximum permissible loading rate for each cargo tank and in the case of combined venting systems, for each group of cargo tanks.

Note 1 : The height requirements of items c) and d) above are not applicable to the pressure / vacuum valve fitted on the inert gas main (see [4.2.2] Note 1) provided its settings are above those of the venting arrangements required by items a) and b) of [4.2.2].

Note 2: Anchor windlass and chain locker openings constitute an ignition hazard. They are to be located at the distances required by c) and d) above.

6.7. High velocity valves

- High velocity valves are to be readily accessible.
- High velocity valves not required to be fitted with flame arresters are not to be capable of being locked on open position.

6.8. Prevention of the passage of flame into the tanks

- The venting system is to be provided with devices to prevent the passage of flame into the cargo tanks..
  Note 1 : The above requirement is not applicable to the pressure / vacuum valve fitted on the inert gas main provided its settings are above those of the venting arrangements required by 6.2.2.
- A flame arresting device integral to the venting system may be accepted.
- Flame screens and flame arresters are to be designed for easy overhauling and cleaning.

6.9. Prevention of liquid rising in the venting system

- Provisions are to be made to prevent liquid rising in the venting system;.
- Cargo tanks gas venting systems are not to be used for overflow purposes.
- Spill valves are not considered equivalent to an overflow system.

6.10. Additional provisions for ships fitted with an inert gas system

- On ships fitted with an inert gas system, one or more pressure/vacuum-breaking devices are to be provided to prevent the cargo tanks from being subject to:
  1. a positive pressure in excess of the test pressure of the cargo tank if the cargo were to be loaded at the maximum rated capacity and all other outlets are left shut, and
  2. a negative pressure in excess of 700 mm water gauge if cargo were to be discharged at the maximum rated capacity of the cargo pumps and the inert gas blowers were to fail.
     Such devices are to be installed on the inert gas main unless they are installed in the venting system required by 6.2 or on individual cargo tanks.
- The location and design of the devices referred to in paragraph a) above are to be in accordance with requirements 6.2 to 6.10.

SECTION 6 MATERIALS AND WELDING

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1. Steel Grades

1.1. Hull Structural Steel

1.1.1. Scope

1.1.1.1. During construction, Materials that are used are required to conform to the Rules for Materials for IRS. Special consideration shall be given in case of use of other materials and the corresponding scantlings.

1.1.2. Strength

1.1.2.1. Normal strength hull structural steel is regarded as those steel which have a specified minimum yield stress of 235N/mm^2. Steel having a higher specified minimum yield stress is regarded as higher strength hull structural steel.

1.1.3. Material grades

1.1.3.1. Material grades of hull structural steels are referred to as follows:

a) A, B, D and E denote normal strength steel grades

b) AH, DH and EH denote higher strength steel grades.

1.1.4. Higher strength steel factor

1.1.4.1. In order to determine the hull girder section modulus, where higher

Strength hull structural steel is used, a higher strength steel factor, as given in Part 3 Table 2.2.1.

Table 1.6.1: Values of k

Specified Minimun Yield Stress,N/mm^2	k
235	1.00
265	0.93
315	0.78
340	0.74
355	0.72
390	0.68

Note:Intermediate values are to be calculated by linear interpolation

1.1.5. Through thickness property

1.1.5.1. In accordance with the Rules for Materials of the IRS, where tee or cruciform connections employ partial or full penetration welds, and the plate material is subject to significant tensile strain in a direction perpendicular to the rolled surfaces, consideration is to be given to the use of special material with specified through thickness properties. Designing of these steels are to be done on basis of the approved plan by the required steel strength grade followed by the letter Z (e.g. EH36 Z).

1.1.6. Steel castings and forgings

1.1.6.1. In accordance with the Rules for Materials of the IRS, steel castings or forgings that are used for stern frames, rudder frames, rudder stocks, propeller shaft brackets and other major structural items are required to be compiled.

1.2. Application of Steel Materials

1.2.1. Selection of material grades

1.2.1.1. Steel materials for particular locations are not to be of lower grades than those given in Table 1.6.2 for the material class given in Table 1.6.3.

1.2.2. Applicable thickness

1.2.2.1. For application of Table 1.6.2 and Table 1.6.3, the steel grade is required to correspond to the as-built thickness.

1.2.3. Operation in areas with low air temperature

1.2.3.1. Special considerations for ships intended to operate for long periods in areas with a lowest daily mean air temperature below –10°C (i.e. regular service during winter to Arctic or Antarctic waters) the materials in exposedstructures shall be observed.

Table 1.6.2: Material Grades

Thickness, t in mm	Material Class		
	I	II	III
t ≤15	A, AH	A, AH	A, AH
15 < t ≤ 20	A, AH	A, AH	B, AH
20 < t ≤ 25	A, AH	B, AH	D, DH
25 < t ≤ 30	A, AH	D, DH	D, DH
30 < t ≤ 35	B, AH	D, DH	E, EH
35 < t ≤ 40	B, AH	D, DH	E, EH
40 < t ≤ 51	D, DH	E, EH	E, EH

Table 1.6.3: Material Class or Grade of Structural Members

Structural member category	Material Class or Grade	
	Within 0.4L Amidships	Outside 0.4L
Secondary Longitudinal bulkhead strakes, other than those belonging to primary category Deck plating exposed to weather other than that belonging to primary or special category Side plating	Class I	Grade A(6)/AH
Primary Bottom plating including keel plate Strength deck plating, excluding that belonging to the special category (8)(9) Continuous longitudinal members above strength deck, excluding longitudinal hatch coamings (9) Uppermost strake in longitudinal bulkheads (8) Vertical strake (hatch side girder) and upper sloped strake in top wing tank	Class II	Grade A(6) /AH
Special Sheer strake at strength deck (1)(2)(3)(8)(9) Stringer plate in strength deck (1)(2)(3)(8)(9) Deck strake at longitudinal bulkhead (2)(4)(8)(9) Strength deck plating at outboard corners of cargo hatch openings (9) Bilge strake (2)(5) Continuous longitudinal hatch coamings (9)	Class III	Class II (Class I outside 0.6L amidships)
Other Categories Plating for stern frames, rudder horns and shaft brackets	– Grade B/AH	Class II –

Longitudinal strength members of strength deck plating for ships with single strength deck (9) Strength members not referred to in above categories (7)	Grade A(6) /AH	Grade A(6) /AH

Note
(1) Not to be less than E/EH within 0.4L amidships in vessels with length, L, exceeding 250m.
(2) Single strakes required to be of material class III or E/EH are, within 0.4L amidships, to have breadths not less than 800 + 5L mm, but need not be greater than 1800mm.
(3) A radius gunwale plate may be considered to meet the requirements for both the stringer plate and the sheer strake, provided it extends generally 600mm inboard and vertically.
(4) For tankers having a breadth, B, exceeding 70m, the centreline strake and the strakes in way of the longitudinal bulkheads port and starboard, are to be class III.
(5) To be not lower than D/DH within 0.6L amidships of vessels with length, L, exceeding 250m.
(6) Grade B/AH to be used for plate thickness more than 40mm. However, engine foundation heavy plates outside 0.6L amidships may be of Grade A/AH.
(7) The material class used for reinforcement and the quality of material (i.e. whether normal or higher strength steel) used for weldedattachments, such as spill protection bars and bilge keel, is to be similar to that of the hull envelope plating in way. Where attachments are made to round gunwale plates, special consideration will be given to the required grade of steel, taking account of the intended structural arrangements and attachment details.
(8) The material class for deck plating, sheer strake and upper strake of longitudinal bulkhead within 0.4L amidships is also to be applied at structural breaks of the superstructure, irrespective of position.
(9) To be not lower than B/AH within 0.4L amidships for ships with single strength deck.

1.2.4. Guidance for repairs

1.2.4.1. For constructing, materials that are used, which are not in accordance with the Rules for Materials of IRS, a set of plans showing the following information, for each material, is required to be placed aboard the vessel in addition to those normally retained on the vessel:

a. Material specification and applicable thickness
b. Welding procedure
c. Location and extent of application.

1.3. Aluminum Alloys

1.3.1 General

1.3.1.1 Special consideration of the use of aluminum alloys in superstructures, deckhouses, hatch covers, helicopter platforms, or other local components will be given. Submission of a specification of the proposed alloys and their proposedmethod of fabrication are to be provided for approval.

1.3.1.2 Submission of the details of the proposed method of joining any aluminum and steel structures are to be provided for approval.

1.3.1.3 Material requirements and scantlings are to conform to the Rules for Materials of IRS.

1.3.2 Incendiary sparking on impact with steel

1.3.2.1 Under certain circumstances, aluminum may give rise to incendiary sparking on impact with oxidised steel. When dragging or rubbing of an aluminum component is done against the uncoated steel structure creating a thin smear of aluminum on the surface, a particular risk is involved. Generation of an incendiary spark which is capable of igniting any surrounding inflammable gas shall happen by the subsequent high energy impact by a rusted component on that smear. The following requirements are therefore to be complied with:

a) The aluminum fittings in tanks used for the carriage of oil, and in cofferdams and pump rooms are to be avoided.

b) Satisfaction of the requirements of 2.1.2 for aluminum anodes are to be compiled where aluminum fittings, units and supports are fitted, in tanks used for the carriage of oil, cofferdams and pump rooms.

c) In order to avoid the creation of smears, protection of the underside of heavy portable aluminum structures such as gangways, etc., is to be given by means of a hard plastic or wood cover, or other approved means. Such protection is required to be permanently and securely attached to the structures.

2. Corrosion Protection Including Coatings

2.1. Hull Protection

2.1.1. General

2.1.1.1. As required by SOLAS Reg. II-1/3-2, see Section 2/2.1.1, all dedicated seawater ballast tanks are required to have an efficient corrosion prevention system.

2.1.1.2. For ships contracted for construction on or after the date of IMO adoption of the amended SOLAS Regulation II-1/3-2, by which an IMO “Performance standard for protective coatings for ballast tanks and void spaces” will be made mandatory, the coatings of internal spaces subject to the amended SOLAS Regulation are to satisfy the requirements of the IMO performance standard.

2.1.1.3. The shipbuilder, coating system supplier and the owner, in consultation with IRS shall agree with IMO Resolution A.798 (19), the selection of the coating system, including coating selection, specification, and inspection plan, prior to commencement of construction. Documentation of the specification for the coating system for these spaces is to be done and verification of this document is to be conducted by IRS and is required to be in full compliance with the coating performance standard

2.1.1.4. Demonstration shall be given by the shipbuilder that the selected coating system with associated surface preparation and application methods is compatible with the manufacturing processes and methods.

2.1.1.5. The shipbuilder is to demonstrate that the coating inspectors have proper qualification as required by the IMO standard.

2.1.1.6. Verification of the application of the coatings will not be carried out by the attending surveyor of IRS but will review the reports of the coating inspectors in order to verify that the specified shipyard coating procedures have been followed.

2.1.1.7. Submission of the ballast tank anode distribution drawings are to be provided for approval where anodes are fitted in ballast tanks. Details of the connections to the hull, e.g. welding details are to be included in such drawings.

2.1.2. Internal cathodic protection systems

2.1.2.1. Submission of a plan of the fitting arrangement is to be provided for approval when a cathodic protection system is to be fitted to steel structures in tanks used for liquid cargo with flash point below 60°C. Consideration of the arrangements will be given for safety against fire and explosion. Application of this approval is also done to adjacent tanks.

2.1.2.2. Permanent anodes in tanks made of, or alloyed with magnesium are not acceptable, except in tanks solely intended for water ballast that are not adjacent to cargo tanks. In order to avoid explosion that can happen due to the development of chlorine and hydrogen, impressed current systems are not to be used in cargo tanks. Aluminum anodes are accepted, however, in tanks with liquid cargo with flash point below 60°C and in adjacent ballast tanks, aluminum anodes are to be located so that a kinetic energy of not more than 275J is developed in the event of their loosening and becoming detached.

2.1.2.3. In order to protect Aluminum anodes from falling objects, they are required to be located in proper way. Unless protected by adjacent structure,they shall not to be located under tank hatches or Butterworth openings.

2.1.2.4. For them to remain securely fastened both initially and during service,all anodes are to be attached to the structure in a proper way. The following methods are acceptable:

a. Steel core connected to the structure by continuous fillet welds of sufficient cross section
b. Attachment by properly secured through-bolts or other positive locking devices. Attachment by clamps fixed with setscrews is to be by approved means.

2.1.2.5. Anode steel cores bent and directly welded to the steel structure are to be of a material complying with the requirements for grade A of the Rules for Materials of IRS.

2.1.2.6. Anodes are to be attached to stiffeners or aligned in way of stiffeners on plane bulkhead plating, but they are not to be attached to the shell. The two ends are not to be attached to separate members which are capable of relative movement.

2.1.2.7. Where cores or supports are welded to local support members or primary support members, they are to be kept clear of end supports, toes of brackets and similar stress raisers. Where they are welded to asymmetrical members, the welding is to be at least 25mm away from the edge of the web. In the case of stiffeners or girders with symmetrical face plates, the connection may be made to the web or to the centreline of the face plate, but well clear of the free edges. Generally, anodes are not to be fitted to a face plate of higher strength steel.

2.1.2.8. Tanks in which anodes are installed are to have sufficient holes for the circulation of air to prevent gas from collecting in pockets.

2.1.3. Paint containing aluminum

2.1.3.1. Where cargo vapors may accumulate, paint containing aluminum is not to be used in positions unless it has been shown by appropriate tests that the paint to be used does not increase the incendiary sparking hazard. With less than 10 percent aluminum by weight, tests need not be performed for coatings.

3. Corrosion Additions

3.1. General

3.1.1. Introduction

3.1.1.1. As specified in this Sub-Section,the required net thickness of steel structures is to be increased by the corrosion addition.

3.1.1.2. Application of the corrosion additions given in this Sub-Section are to be done to carbon-manganese steels, see 1.1. In accordance with the requirements of IRS,application of corrosion additions for other materials, such as stainless steel, is required to be considered.

3.1.1.3. The application of the corrosion additions in rule calculations is given in 3.3.

3.2. Local Corrosion Additions

3.2.1. General

3.2.1.1. The local corrosion additions, tcorr, for structural members are to be taken as:

$t_{corr} = t_{was} + 0.5$ mm

where:

t_{was} = total wastage allowance of the considered structural member, in mm, as given in Chapter 3 Section 2/1.4.2.2

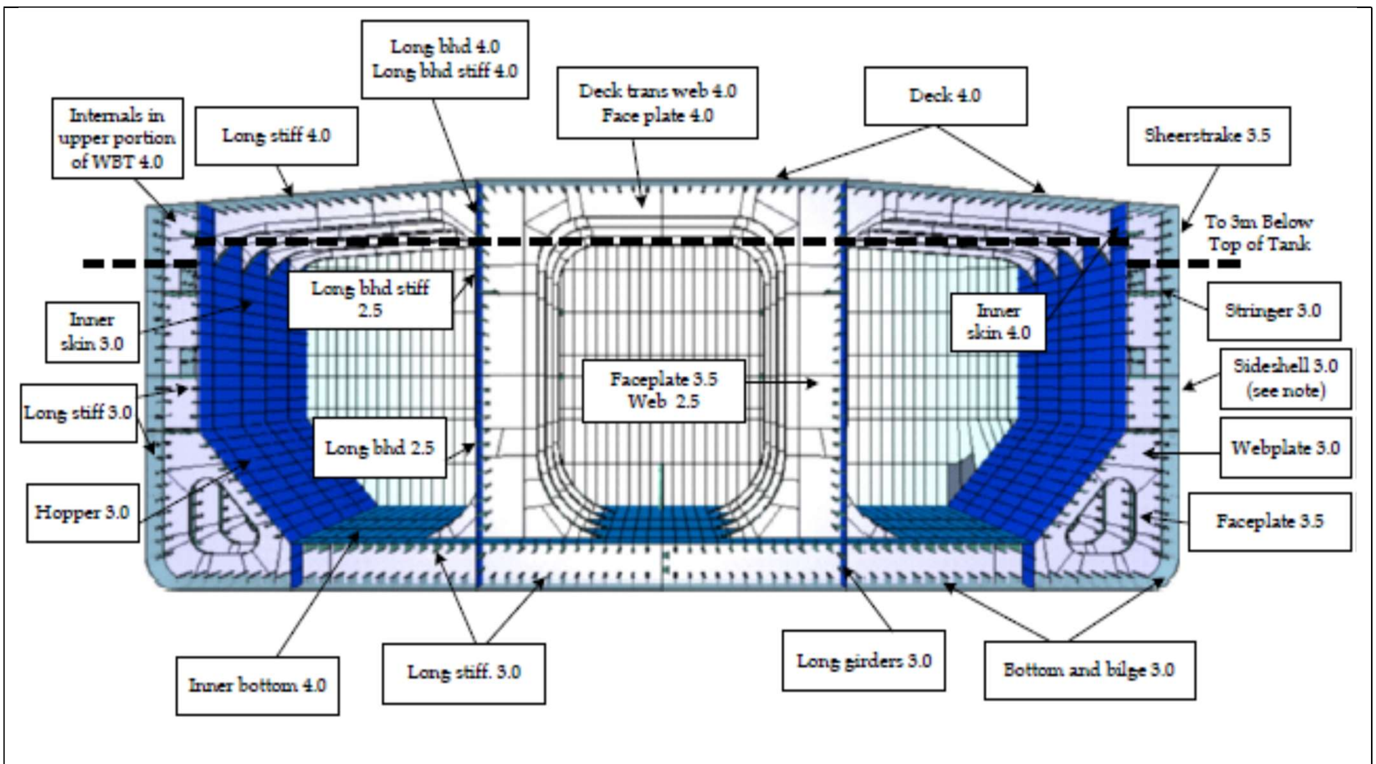
The local corrosion additions, t_{corr}, for typical structural elements in the cargo tank region are given in Table 1.6.4 and Figure 1.6.1

Table 1.6.4: Corrosion Addition, t_{corr}, for Typical Structural Elements within the Cargo Tank Region

Category of contents			Corrosion Addition t_{corr}, in mm
Internal members and plate boundary between spaces with the same category of contents			
In and between ballast water tanks	Face plate of PSM	Within 3m below top of tank (1)	4.5
		Elsewhere	3.5
	Other members	Within 3m below top of tank (1)	4
		Elsewhere	3
	Stiffeners on boundaries to heated cargo tanks	Within 3m below top of tank (1)	4.5
		Elsewhere	3.5
In and between cargo oil tanks	Face plate of PSM	Within 3m below top of tank (1)	4
		Elsewhere	3.5
	Other members	Within 3m below top of tank (1)	4
		Elsewhere	2.5
Exposed to atmosphere on both sides	Support members on deck		2.5
In and between void spaces	Spaces not normally accessed, e.g. access only via bolted manhole openings, pipe tunnels, etc.		2
In and between dry spaces	Internals of deckhouses, machinery spaces, pump room, store rooms, steering gear space, etc.		1.5

Plate boundary between spaces having a different category			
Boundary between ballast tank and cargo oil tank	Unheated cargo tank	Within 3m below top of tank (1)	4
		Inner bottom plating	4
		Elsewhere	3
	Heated cargo tank	Within 3m below top of tank (1)	4.5
		Inner bottom plating	4.5
		Elsewhere	3.5
Boundary between ballast tank and atmosphere or sea	Weather deck plating		4
	Other members(2)	Within 3m below top of tank (1)	3.5
		Elsewhere	3
Boundary between ballast tank and void or dry space	Within 3m below top of tank(1)		3
	Elsewhere		2.5
Boundary between cargo tank and atmosphere	Weather deck plating		4
Boundary between cargo tank and void spaces	Within 3m below top of tank (1)		3
	Elsewhere		2.5
Boundary between cargo tank and dry spaces	Within 3m below top of tank (1)		3
	Elsewhere		2

Note
(1) Only applicable to cargo and ballast tanks with weather deck as the tank top
(2) 0.5mm to be added for side plating in the quay contact region defined in Chapter 2 section 2/Figure 2.2.11. Heated cargo oil tanks are defined as cargo tanks arranged with any form of heating capability



Note
1) Corrosion additions are given for a standard configuration and without heated cargo
2) 0.5mm to be added for side plating in the quay contact region defined in Chapter 2 section 2/Figure 2.2.11

Figure 1.6.1: Corrosion Addition, t_{corr}, for Typical Structural Elements within the Cargo Tank

3.3. Application of Corrosion Additions

3.3.1. General

3.3.1.1. Unless otherwise specified in the specific rule requirements,the application of corrosion additions described in 3.3.2 to 3.3.7 is required to be applied.

3.3.1.2. Compliance with the Rules may be performed either by:

a) Comparison of the proposed gross scantling with the gross required, in which case the applicable corrosion addition is added to the net requirement of the Rules

b) Comparison of the proposed net scantling with the net required, in which case the applicable corrosion addition is deducted from the gross proposed.

Methods (a) and (b) are suitable for assessment of thickness. Method (b) is the most suitable for assessment of section properties, e.g. section modulus, area and moment of inertia.

3.3.1.3. The gross scantlings specified in 3.3.2 to 3.3.7 used to derive the net scantlings are to exclude any owner's extra thicknesses, see also Section 2/4.3.4.3.

3.3.2. Application for hull girder longitudinal strength calculations

3.3.2.1. As given in Chapter 2 Section2/1, the calculation of hull girder stresses for the assessment of longitudinal strength is to be based on the net hull girder sectional properties calculated by deducting half the corrosion addition, i.e. -0.5t_{corr}, from the gross thickness of all structural elements comprising the hull girder cross-section.

3.3.2.2. As given in Chapter 2 Section2/1.4.2, the local buckling capacity of plates and stiffeners subject to hull girder stresses are to be calculated based on the net scantlings. The net scantling is calculated by deducting the full corrosion addition, i.e. -1.0t_{corr}, from the gross thickness.

3.3.3. Application for scantling assessment of plates and local support members

3.3.3.1. The required gross thickness for plates and local support members are calculated by adding the full corrosion addition, i.e. +1.0t_{corr}, to the net thickness required in accordance with the scantling requirements in Section 4/3.4 and Chapter 2 Sections 2/2 to 2/7.

3.3.3.2. The net sectional properties of local support members are calculated by deducting the full corrosionaddition, i.e. -1.0t_{corr}, from the web, flange and attached plate gross thicknesses as described in Section 4/2.4.1 and are to conform to required section modulus, moment of inertia and shear area as given in Section 4/3.4and Chapter 2 Sections 2/2 to 2/7.

3.3.3.3. The calculation of hull girder stresses for the strength assessment of members under combined localand global loading is to be based on the net hull girder sectional properties calculated by deducting half thecorrosion addition, i.e. -0.5t_{corr}, from the gross thickness of all structural elements comprising the hull girdercross-section.

3.3.3.4. The required minimum gross thickness of plates and local support members is calculated by addingthe full corrosion addition, i.e. $+1.0t_{corr}$, to the minimum net thickness requirements given in Chapter 2 Section2/2.1.5.

3.3.4. Application of corrosion additions for scantling strength assessment of primary support members

3.3.4.1. Calculation of the required gross thickness of primary support members is done by adding half the corrosionaddition, i.e. $+0.5t_{corr}$, to the net thickness required in accordance with the strength requirements in Chapter 2 Sections 2/2.6 and 2/3 to2/7.

3.3.4.2. Calculation of the net sectional properties of primary support members are to be done by deducting half thecorrosion addition, i.e. $-0.5t_{corr}$, from the web and flange gross thicknesses, and are to conform to the requiredsection modulus, moment of inertia and area as given in Sections 8/2.6 and 8/3 to 8/7.

3.3.4.3. Calculation of the required minimum gross thickness of primary support members is to be done by adding the fullcorrosion addition, i.e. $+1.0t_{corr}$, to the minimum net thickness requirement given in Chapter 2 Sections 2/2.1.6.1, 2/3.1.4.1,2/4.1.5.1, 2/5.1.4.1, 2/6.3.7.5, 2/6.4.5.4 and 4/2.3.

3.3.5. Application of corrosion additions for hull girder ultimate strength analysis

3.3.5.1. The calculation of the hull girder ultimate capacity, M_u, as given in Chapter 2 Section 3/1, is to be based on thenet hull girder sectional properties calculated by deducting half the corrosion addition, i.e. $-0.5t_{corr}$, from thegross thickness of all structural elements comprising the hull girder cross-section.

The buckling capacity of the structural elements used to derive the hull girder ultimate capacity is to be calculated by deducting half the corrosion addition, i.e. $-0.5t_{corr}$, from the gross thicknesses of the plates and stiffener webs and flanges.

3.3.6. Application of corrosion additions for strength assessment by finite element analysis

3.3.6.1. As given in Chapter 2 Section 3/2.2 and Chapter 4 Section 2/2, for the cargo tank structural strength analysis, the finite element model is to be modeled with thicknesses calculated by deducting half the corrosion addition, i.e. $-0.5t_{corr}$, from the gross thickness of all structural elements.

3.3.6.2. The local buckling capacity of plates and stiffeners are to be calculated by deducting the full corrosion addition, i.e. $-1.0t_{corr}$, from the gross thickness.

3.3.6.3. The local fine mesh structural strength analysis models, as given in Chapter 2 Section 3/2.3 and Chapter 4 Section 2/3, are to be modeled with thicknesses calculated by deducting half the corrosion addition, i.e. $-0.5t_{corr}$, from the gross thickness. The specified fine mesh areas are to be modeled by deduction of the full corrosion addition, i.e. -1.0tcorr, from the gross thickness.

3.3.7. Application of corrosion additions for fatigue strength assessment

3.3.7.1. The calculation of hull girder stresses for the fatigue strength assessment, as given in Chapter 2 Section 3/3 and Chapter 4 Section 3/1 is to be based on the net fatigue hull girder sectional properties, which is calculated by deducting a quarter of the corrosion addition, i.e. $-0.25t_{corr}$ from the gross thickness of all structural elements comprising the hull girder cross section.

3.3.7.2. As given in Chapter 2 Section 3/3 and Chapter 4 Section 3/1, the calculation of stresses in local support members from lateral load for the fatigue strength assessment are to be based on deducting half the corrosion addition, i.e. -0.5t_{corr}, from the stiffener web, flange and attached plate.

3.3.7.3. As given in Chapter 2 Section 3/3 and Chapter 4 Section 3/2, for hot spot stress (FE based) approach, the FE model of the hopper knuckle is required to be modeled with thickness calculated by deducting a quarter of the corrosion addition, i.e. -0.25t_{corr}, from the gross thicknesses. The very fine mesh areas are to be modeled by deduction of half the corrosion addition, i.e. -0.5t_{corr}, from the gross thickness.

3.3.7.4. As an alternative to 3.3.7.3, the hopper fatigue FE model may be made in accordance with requirements for FE strength model, i.e. all areas at -0.5t_{corr}, as described in 3.3.6.1. However the calculated stress range is then to be corrected by the factor f_{model} as described in Chapter 4 Section 3/2.4.2.7.

4. Fabrication

4.1. General

4.1.1. Workmanship

4.1.1.1. The Surveyor shall accept all workmanship which is required to be of commercial marine quality. In accordance with the requirements of Sub-Section 5, welding is to be carried out. Before the material is covered with paint, cement or any other composition, any defect is required to be rectified to the satisfaction of theSurveyor.

4.1.2. Fabrication standard

4.1.2.1. In accordance with 'Shipbuilding and Repair Quality Standard for New Construction' or a recognised fabrication standard which has been accepted by IRS prior to the commencement of fabrication/construction,structural fabrication is required to be carried out.

4.1.2.2. The fabrication standard to be used during fabrication/construction is to be made available to the attending representative of IRS, prior to the commencement of the fabrication/ construction.

4.1.2.3. The fabrication standard is to include information, to establish the range and the tolerance limits, for the items specified as follows:

a. Cutting edge
   - The slope of the cut edge and the roughness of the cut edges

b. Flanged longitudinals and brackets and built-up sections
   - The breadth of flange and depth of web, angle between flange and web, and straightness in plane of flange or at the top of face plate

c. Pillars
   - The straightness between decks, and cylindrical structure diameter

d. Brackets and small stiffeners
   - The distortion at the free edge line of tripping brackets and small stiffeners

e. Sub-assembly stiffeners
   - Details of snipe end of secondary face plates and stiffeners

f. Plate assembly

- For flat and curved blocks the dimensions (length and breadth), distortion and squareness, and the deviation of interior members from the plate

g. Cubic assembly

- In addition to the criteria for plate assembly, twisting deviation between upper and lower plates, for flat and curved cubic blocks

h. Special assembly

- The distance between upper and lower gudgeons, distance between aft edge of propeller boss and aft peak bulkhead, twist of stern frame assembly, deviation of rudder from shaft centreline, twist of rudder plate, and flatness, breadth and length of top plate of main engine bed. The final boring out of the propeller boss and stern frame, skeg or solepiece, and the fit-up and alignment of the rudder, pintles and axles, are to be carried out after completing the major part of the welding of the aft part of the ship. The contacts between the conical surfaces of pintles, rudder stocks and rudder axles are to be checked before the final mounting.

i. Butt joints in plating
- Alignment of butt joint in plating

j. Cruciform joints
- Alignment measured on the median line and measured on the heel line of cruciform joints

k. Alignment of interior members
- alignments of flange of T longitudinals, alignment of panel stiffeners, gaps in T joints and lap joints, and distance between scallop and cut outs for continuous stiffeners in assembly and in erection joints

l. Keel and bottom sighting
- Deflections for whole length of the ship, and for the distance between two adjacent bulkheads, cocking up of fore body and of aft body, and rise of floor amidships

m. Dimensions
- dimensions of length between perpendiculars, moulded breadth and depth at midship, and length between aft edge of propeller boss and main engine

n. Fairness of plating between frames
- Deflections between frames of shell, tank top, bulkhead, upper deck, superstructure deck, deck house deck and wall plating

o. Fairness of plating in way of frames
- deflections of shell, tank top, bulkhead, strength deck plating and other structures measured in way offrames

4.2. Cold Forming

4.2.1. Special structural members

4.2.1.1. The inside bending radius, in cold formed plating, is not to be less than 10 times the gross plate thickness for carbon-manganese steels (hull structural steels, see 1.1) for highly stressed components of the hull girder where notch toughness is of particular concern (e.g. items required to be Class III in Table

1.6.3, such as radius gunwales and bilge strakes). The allowable inside bending radius may be reduced below 10 times the gross plate thickness, providing the additional requirements stated in 4.2.3 are complied with.

4.2.2. Other members

4.2.2.1. For main structural members, e.g. corrugated bulkheads and hopper knuckles, the inside bending radius, in cold formed plating, is not to be less than 4.5 times the gross plate thickness for carbon-manganese steels (hull structural steels, see 1.1). The allowable inside bending radius may be reduced below 4.5 times the gross plate thickness, providing the additional requirements stated in 4.2.3 are complied with.

4.2.3. Additional requirements

4.2.3.1. A supporting data is required to be provided when steel is formed below 650°C with a radius of less than 10 or 4.5 times the gross plate thickness for special and other members, respectively. As a minimum, the following additional requirements are to be complied with:

a) The steel is to be of grade D/DH or higher

b) The material is impact tested in the strain-aged condition and satisfies the requirements stated herein. The deformation is required to be equal to the maximum deformation to be applied during production, calculated by the formula

$t_{grs}/(2r_{bdg} + t_{grs})$,

where

t_{grs} is the gross thickness of the plate material and r_{bdg} is the bending radius. One sample is to be plastically strained at the calculated deformation or 5%, whichever is greater and then artificially aged at250°C for one hour then subject to Charpy V-notch testing.After strain ageing, the average impact energy is required to meet the impact requirements specified for the grade of steel used.

c) 100% visual inspection of the deformed area is required to be carried out. In addition, random checks by magnetic particle testing are to be carried out.

In no case the bending radius is to be less than twice the gross plate thickness.

4.3. Hot Forming

4.3.1. Temperature requirements

4.3.1.1. Between the upper and lower critical temperatures, steel is not required to be formed. Mechanical tests are to be made to assure that the temperatures have not adversely affected both the tensile and impact properties of the steel if the forming temperature exceeds 650°C for as-rolled, controlled rolled, thermo-mechanical controlled rolled or normalized steels, or is not at least 28°C lower than the tempering temperature for quenched and tempered steels. In accordance with 4.3.2.1, where curve forming or fairing, by line or spot heating is carried out, these mechanical tests are not required.

4.3.1.2. Confirmation is required to demonstrate the mechanical properties after further heating meet the requirements specified by a procedure test using representative material, when considering further heating other than in 4.3.1.1 of thermo-mechanically controlled steels (TMCP plates) for forming and stress relieving.

4.3.2. Line or spot heating

4.3.2.1. In order to ensure that the properties of the material are not adversely affected,curve forming or fairing, by linear or spot heating, is to be carried out using approved procedures. In order not to exceed the maximum allowable limit applicable to the plate grade, heating temperature, on the surface, is required to be controlled.

4.4. Welding

4.4.1. General

4.4.1.1. Approved welders shall carry out all welding, in accordance with approved welding procedures, using approved welding consumables and is required to conform to the Rules for Materials of IRS.

4.4.2. Welding sequence

4.4.2.1. The assembly sequence and the effect on the overall shrinkage of plate panels, assemblies, etc., resulting from the welding processes employed is required to be considered. Without undue interruption,welding is to proceed systematically, with each welded joint being completed in the correct sequence.

4.4.2.2. Where practicable, welding is to commence at the centre of a joint and proceed outwards, or at the centre of an assembly and progress outwards towards the perimeter so that each part has freedom to move in one or more directions.

4.4.2.3. Generally in order to minimise angular distortion of the stiffener, the welding of stiffener members, including transverses, frames, girders, etc., to welded plate panels by automatic processes is to be carried out in a proper way.

4.4.3. Arrangements at junctions of welds

4.4.3.1. Welds are to be made flush in way of the faying surface where stiffening members, attached by continuous fillet welds, cross the completely finished butt or seam welds. Similarly, butt welds in webs ofstiffening members are to be completed and made flush with the stiffening member before the fillet weld is made. Without notches or sudden changes of section, the ends of the flush portion are to run out smoothly. A scallop is to be arranged in the web of the stiffening member where these conditions cannot be complied with. Scallops are to be of a size, and in a position, that a satisfactory return weld can be made.

4.4.4. Leak stoppers

4.4.4.1. Where structural members pass through the boundary of a tank, leakage into the adjacent space could be hazardous or undesirable, and full penetration welding is to be adopted for the members for at least 150mm on each side of the boundary. Alternatively, a small scallop of suitable shape may be cut in the member close to the boundary outside of the compartment, and carefully welded all around.

5. Weld Design and Dimensions

5.1. General

5.1.1. Scope

5.1.1.1. Generally, weld sizes are based on the Rule gross thickness values.

5.1.1.2. Requirements for welding sequence, qualification of welders, welding procedures and welding consumables are given in 4.4.

5.1.2. Plans and specifications

5.1.2.1. Submission of the plans and/or specifications showing weld sizes and weld details are required to be done for approval for each new construction project.

5.1.2.2. Where reductions in weld sizes are proposed the requirements given in 5.9 are to be applied and the following details are to be included in the welding specification:

a. Proposed weld gap size

b. Proposed welding consumable.

5.1.3. Tolerance requirements

5.1.3.1. The gaps between the faying surfaces of members being joined are to be kept either to a minimum or in accordance with approved specification.

5.1.3.2. Where the gap between the members joined by fillet welds exceeds 2mm, the weld size is to be increased in accordance with 5.7.1.6.

5.1.4. Special precautions

5.1.4.1. Welding is required to be based on approved welding procedure specifications where small fillets are used to attach heavy plates or sections. Acceptance of the special precautions, such as the use of preheating, low-hydrogen electrodes or low-hydrogen welding processes, are to be carried out.

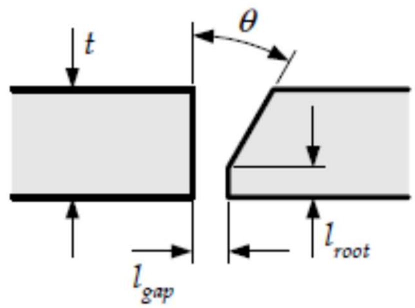
5.1.4.2. When heavy structural members are attached to relatively light plating, the weld size and sequence may require modification.

5.2. Butt Joints

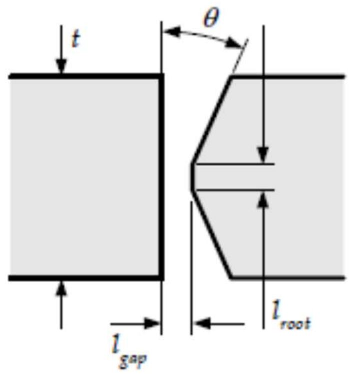
5.2.1. General

5.2.1.1. Joints in the plate components of stiffened panel structures are generally to be joined by butt welds. Typical types of butt welds with corresponding edge preparation are shown in Figure 1.6.2.

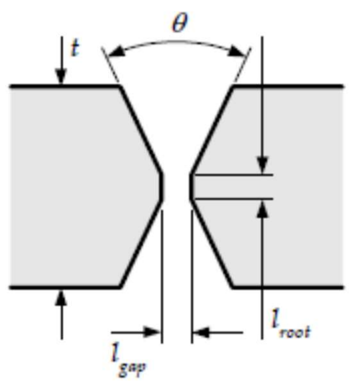
5.2.1.2. All types of butt joints are to be welded from both sides. Before welding is carried out on the second side, unsound weld metal is to be removed at the root by a suitable method. Butt welding from one side will only be permitted for specific applications with an approved welding procedure specification.



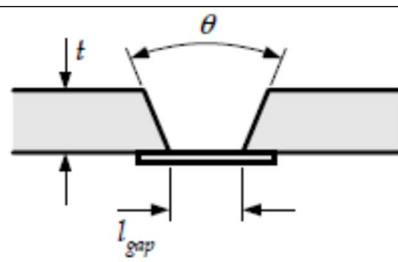
Single bevel butt



Double bevel butt



Double Vee butt, uniform bevels



Single Vee butt, one side welding with backing strip (temporary or permanent)

Note

1) The above figures are shown for guidance only. Actual details and dimensions are to be in accordance with a recognized fabrication standard. See 4.1.2.1

Figure 1.6.2: Typical Butt Welds

5.2.2. Thickness difference in butt welds

5.2.2.1. Where plates of different thicknesses are butt welded,abrupt change of section is required to be avoided.

5.2.2.2. A suitable transition taper is to be provided where plates to be joined differ in thickness by more than 4mm. The transition may be formed by tapering the thicker member, or by specifying a weld joint design which provides the required transition.

5.2.2.3. The transition taper length is to be not less than three times the offset for the transverse butts in longitudinal strength members.

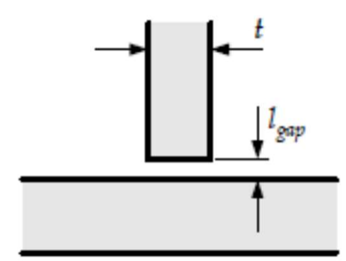
5.2.2.4. Differences in thickness greater than 4mm and without transition taper may be accepted for specific applications.

5.3. Tee or Cross Joints

5.3.1. General

5.3.1.1. In accordance with 5.7 and Figure 1.6.3, the connection of primary support members and stiffener web/end connections and joints formed by plating abutting on another plate panel is generally to be made by fillet welds sized. Examples of other typical tee or cross joint weld arrangements are shown in Figure 1.6.4.

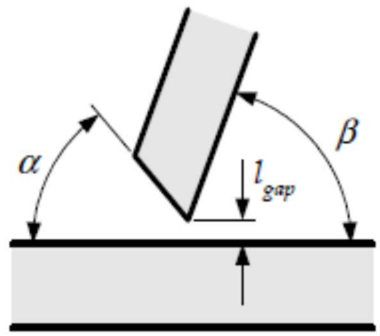
5.3.1.2. A partial or full penetration weld is to be achieved by beveling the edge of the abutting plate where the connection is highly stressed or otherwise considered critical. See 5.3.4 and Figure 1.6.4.



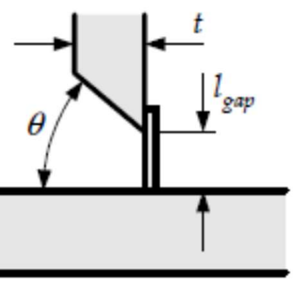
Note
1) The above figure is shown for guidance only. Actual details and dimensions are to be in accordance with a recognized fabrication standard. See 4.1.2.1.

Figure 1.6.3: Typical Tee or Cross Joint Fillet Welds

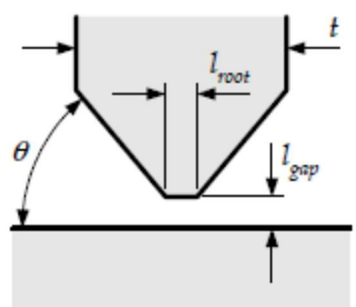
Small angle fillet



Single bevel tee with permanent backing



Double bevel tee symmetrical



Notes
1) The above figures are shown for guidance only. Actual details and dimensions are to be in accordance with a recognised Fabrication standard. See 4.1.2.1.

Figure 1.6.4 Other Typical Tee and Cross Joint Welds

5.3.2. Continuous welding

5.3.2.1. Continuous welding is to be adopted in the following locations:

a. All fillet welds where higher strength steel is used
b. Boundaries of weather tight decks and erections, including hatch coamings, companionways and otheropenings
c. Boundaries of tanks and watertight compartments
d. All structures in ballast and fresh water tanks and the ballast and fresh water tank bulkhead stiffeners
e. All structures in the aft peak and the aft peak bulkhead stiffeners

f. All structures in the fore peak tank/void
g. All welding inside tanks intended for crude oil, petroleum products, chemicals, edible liquids or fresh watercargoes
h. Welding in way of all end connections, including end brackets, lugs, scallops, and at the orthogonalconnections with other members
i. All lap welds in the main hull
j. Primary support members and stiffener members to bottom shell in the 0.3L forward region
k. Flat bar longitudinals to plating
l. The attachment of minor fittings to higher strength steel plating and other connections or attachments.

5.3.3. Intermittent welding

5.3.3.1. Intermittent welding may be applied where continuous welding is not required.

5.3.3.2. There is to be a pair of matched intermittent welds on each side of every intersection where beams, stiffeners, frames, etc., are intermittently welded and pass through slotted girders, shelves or stringers. Additionally, the beams, stiffeners and frames are to be efficiently attached to the girders, shelves and stringers.

5.3.4. Full or partial penetration corner or tee joints

5.3.4.1. Where high tensile stresses act through an intermediate plate (see Figure 1.6.5), increased fillet weldsor penetration welds are to be used as required by 5.8. Examples of such structures are:

a) Connection of hopper to inner hull
b) Longitudinal/transverse bulkhead primary support member end connections to the double bottom
c) Connection of corrugated bulkhead lower stool side plates to shelf plate and inner bottom/hopper tank
d) Connections of gusset plates to corrugated bulkheads
e) Connection of double bottom floors, lower hopper tank webs and double bottom girders below corrugated bulkhead flanges and gusset plates for corrugated bulkheads configured without lower stools
f) Structural elements in double bottoms below bulkhead primary support members and stool plates.

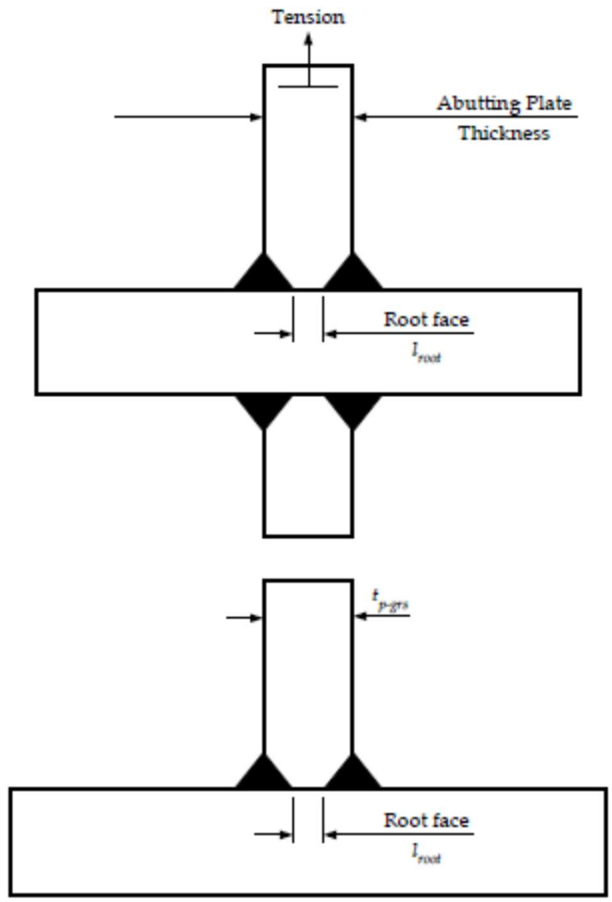


Figure 1.6.5: Abutting Plate Panel

5.3.4.2. Full or partial penetration welds, with maximum root face, $l_{root} = t_{p\text{-}grs}/3$, where l_{root} is the weld root face length and $t_{p\text{-}grs}$ is the gross plate thickness, as shown in Figure 1.6.5, are to be used in the connection of hopper sloped plating to inner bottom.

5.3.4.3. Full penetration welds are to be used in the following connections:

a. lower end of vertical corrugated bulkhead connections
b. lower end of gusset plates fitted to corrugated bulkheads
c. rudder horns and shaft brackets to shell structure
d. rudder side plating to rudder stock connection areas
e. Edge reinforcements within 0.6L amidships to the strength deck, sheer strake, bottom and bilge plating, when the transverse dimension of the opening exceeds 300mm, see Figure 1.6.6.The collar plate is to be welded by a continuous fillet weld where collar plates are fitted in way of pipe penetrations.
f. abutting plate panels with gross plate thickness, $t_{p\text{-}grs}$, as shown in Figure 1.6.5, less than or equal to 12mm, forming outer shell boundaries below the scantling draught, T_{sc}, including, but not limited to; sea chests, rudder trunks, and portions of transoms. For gross plate thickness, $t_{p\text{-}grs}$, greater than 12mm, partial penetration welding with a maximum root face length $l_{root} = t_{p\text{-}grs/3}$ is acceptable.
g. crane pedestals and associated bracketing and support structure, as required by Chapter 3 Section 1/3.1.4.14

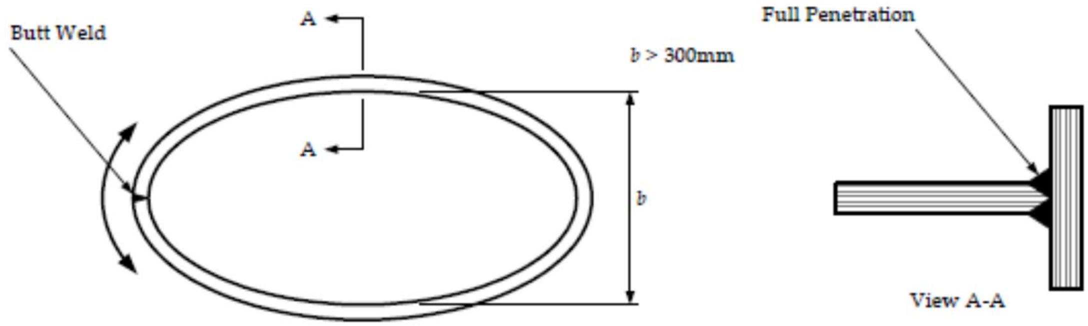


Figure 1.6.6: Examples of Suitable Edge Reinforcements

5.4. Lapped Joints

5.4.1. General

5.4.1.1. Where the connection is not subject to high tensile or compressive loading, overlaps may be adopted for end connections.

5.4.1.2. Where overlaps are adopted, the width of the overlap, w_{lap}, is not to be less than three times, but not greater than four times, the gross thickness of the thinner of the plates being joined. See Figure 1.6.7. The overlap will be subject to special considerationwhere the gross thickness of the thinner plate being joined has a thickness of 25mm or more.

5.4.1.3. The overlaps for lugs and collars in way of cut-outs for the passage of stiffeners through webs and bulkhead plating are not to be less than three times the gross thickness of the lug but need not be greater than50mm. In order to allow adequate access for completion of sound welds, the joints are to be positioned in a proper manner.

5.4.1.4. The faying surfaces of lap joints are to be in close contact and both edges of the overlap are required to have continuous fillet welds.

Fillet weld in lap joint

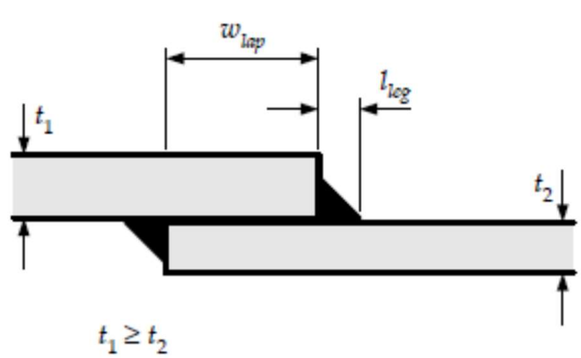


Figure 1.6.7: Lapped Joints

5.4.2. Overlapped end connections

5.4.2.1. Where accepted by the Rules, lapped end connections, are to have continuous welds on each edge with leg length, l_{leg}, as shown in Figure 1.6.7, such that the sum of the two leg lengths is not less than 1.5 times the gross thickness of the thinner plate.

5.4.3. Overlapped seams

5.4.3.1. Overlapped seams are to have continuous welds on both edges, of the sizes required by Table 1.6.5 for the boundaries of tank or watertight bulkheads. In accordance with Table 1.6.5, seams for plates with a gross thickness of 12.5mm or less, which are clear of tanks, may have one edge with intermittent welds for watertight bulkhead boundaries.

5.5. Slot Welds

5.5.1. General

5.5.1.1. Slot welds may be specially approved for particular applications. Typical applications are indicated in 5.5.2 and 5.5.3, and typical arrangements are shown in Figure 1.6.8.

5.5.1.2. Slots are to be well-rounded and have a minimum slot length, l_{slot}, of 75mm and width, w_{slot}, of twice the gross plate thickness. Where used in the body ofdoublers and similar locations, such welds are in general to be spaced a distance, s_{slot}, of $2l_{slot}$ to $3l_{slot}$ but not greater than 250mm

Slot welding

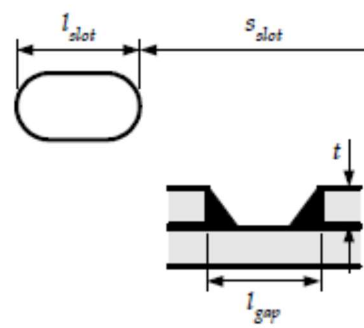


Figure 1.6.8: Slot Welds

5.5.2. Closing plates

5.5.2.1. Where access for welding is not practicable,for the connection of plating to internal websthe closing plating may be attached by slot fillet welds to face plates fitted to the webs.

5.5.2.2. Slots are to be well rounded and have a minimum slot length, $l_{slot,}$ of 90mm and a minimum width, w_{slot}, of twice the gross plate thickness. Slots cut in plating are to have smooth, clean and square edges and are in general to be spaced a distance, s_{slot}, not greater than 140mm. Slots are not to be filled with welding.

5.6. Stud Welds

5.6.1. General

5.6.1.1. Where permanent or temporary studs are to be attached by welding to main structural parts in areas subject to high stress, the proposed location of the studs is to be submitted for approval.

5.7. Determination of the Size of Welds

5.7.1. General

5.7.1.1. The following weld sizes are to be rounded to the nearest half millimeter.

5.7.1.2. The leg length, l_{leg}, as shown in Figure 1.6.9, of continuous, lapped or intermittent fillet welds, in association with the requirements of 5.7.2 to 5.7.5, is not to be taken as less than:

a) $l_{leg} = f_1 t_{p-grs}$
b) $l_{leg} = f_{yd} f_{weld} f_2 t_{p-gr} + t_{gap}$
c) l_{leg} as given in the table 1.6.2

where:

f_1 = 0.30 for double continuous welding
= 0.38 for intermittent welding

t_{p-grs} = the gross plate thickness, in mm. Is generally to be taken as that of the abutting member (member being attached). See 5.7.1.5

f_{yd}= correction factor taking into account the yield strength of the weld deposit:

$$= \left(\frac{1}{k}\right)^{0.5} \left(\frac{235}{\sigma_{weld}}\right)^{0.75}$$

but is not to be taken as less than 0.707

σ_{weld} = minimum yield stress of the weld deposit, and is not to be less than:
305N/mm^2 for welding of normal strength steel
375N/mm^2 for welding of higher strength steels with yield strength of 265 to 355N/mm^2
400 N/mm^2 for welding of higher strength steel with yield strength of 390N/mm^2
See 5.9.4 for additional requirements that are to be applied where the weld size is determined based on a weld deposit yield strength that exceeds the specified minimum value

k =higher strength steel factor, as defined in Section 6 /1.1.4. k is to be based on the material of the abutting member

f_{weld}= weld factor depending on the type of structural member, see 5.7.2, 5.7.3 and 5.7.5

f_2= correction factor for the type of weld:
1.0 for double continuous fillet
$\frac{s_{ctr}}{l_{weld}}$ for intermittent or chain welding

l_{weld} = the actual length of weld fillet, clear of crater, in mm

s_{ctr}= the distance between successive weld fillets, from centre to centre, in mm

t_{gap}= allowance for weld gap (lesser gaps may be permitted, see 5.9.2):
= 2.0 mm for t_{p-grs} > 6.5mm
$= 2\left(1.25 - \frac{1}{f_2}\right)$ mm, for t_{p-grs} > 6.5mm

5.7.1.3. The throat size is not to be less than $l_{leg}/\sqrt{2}$ where the leg length, l_{leg}, is as shown in Figure 1.6.9.

5.7.1.4. The leg size for matched fillet welds either side of an intersection with intermittent welding is not to be greater than $0.62t_{p-grs}$ or 6.5mm, whichever is the lesser.

5.7.1.5. Where the gross web thickness of the abutting longitudinal stiffener is greater than 15mm and exceeds the thickness of the table member (e.g. plating), the welding is to be double continuous and the leg length of the weld is to be not less than the greatest of the following:

a). 0.3 times the gross thickness of the table member. The table member thickness used need not be greater than 30mm

b). 0.27 times the gross thickness of the abutting member plus 1.0mm. The leg size need not be greater than8.0mm

c). As given by Table 1.6.6 for stiffeners to plating.

5.7.1.6. Where the gap between members being joined exceeds 2mm and is not greater than 5mm, the weld leg size is to be increased by the amount of the opening in excess of 2mm. In accordance with an approved welding procedure specification where the opening between members is greater than 5mm, corrective measures are required to be taken.

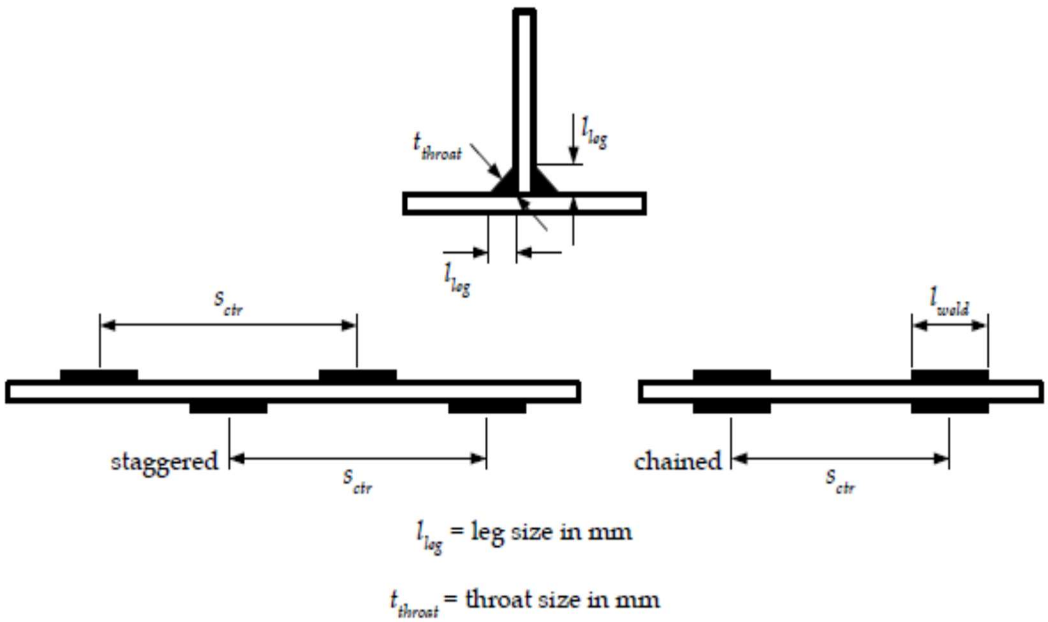


Figure 1.6.9: Weld Definitions

5.7.2. Welding of fillet joints of main structural components

5.7.2.1. General weld factors for the connections of the structural components of the hull are given in Table 1.6.5.

5.7.2.2. Applications of the requirements of 5.7.4 are also to be made where components of the hull form a part of a double skin primary support member.

5.7.2.3. As required by 5.8, increased fillet welds or penetration welds are to be used where high tensile stresses act through an intermediate plate (see Figure 1.6.5).

5.7.3. Welding of primary support members

5.7.3.1. Weld factors for the connections of the web plating of primary support members are given in Table 1.6.8

5.7.3.2. Where the minimum weld size is determined by the requirements of 5.7.1.2(b) the weld connections to shell, decks or bulkheads are to take account of the material lost in the cut out where stiffeners pass through the member. In cases where the web plating and the width of the notch exceeds 15 percent of the stiffener spacing, the size of the weld leg length is to be multiplied by:

$$\frac{0.85s}{l_w}$$

where:
s = stiffener spacing, in mm
l_w= length of web plating between notches, in mm, see Figure 1.6.10

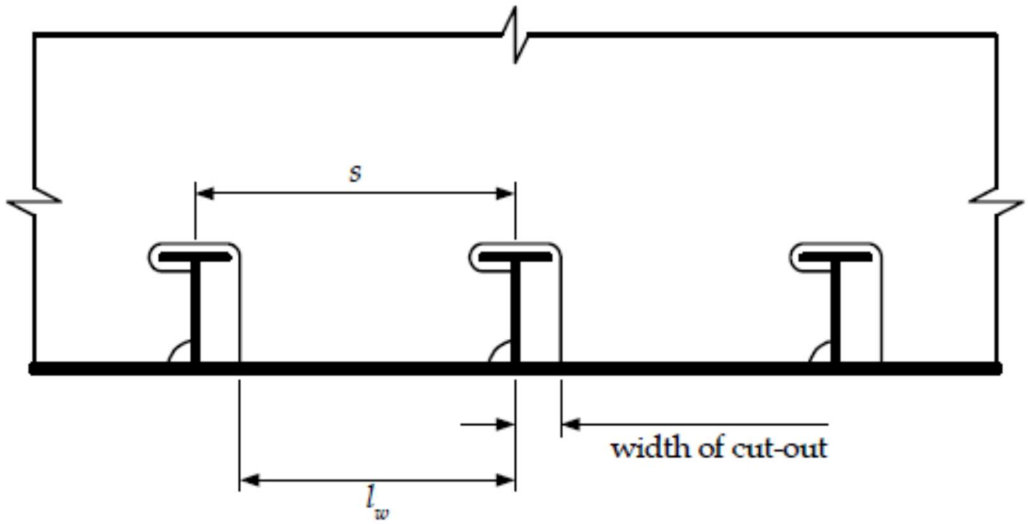


Figure 1.6.10: Lost Material in Web Cut-outs for Stiffeners

5.7.4. Welding of end connections of primary support members

5.7.4.1. Welding of end connections of primary support members (i.e. transverse frames and girders) is to be such that the weld area, A_{weld}, is to be equivalent to the Rule gross cross-sectional area of the member. In terms of weld leg length, l_{leg}, this is to be taken as by:

$$l_{leg} = 1.41 f_{yd} \frac{h_w t_{p-grs}}{l_{dep}} \qquad mm$$

where:

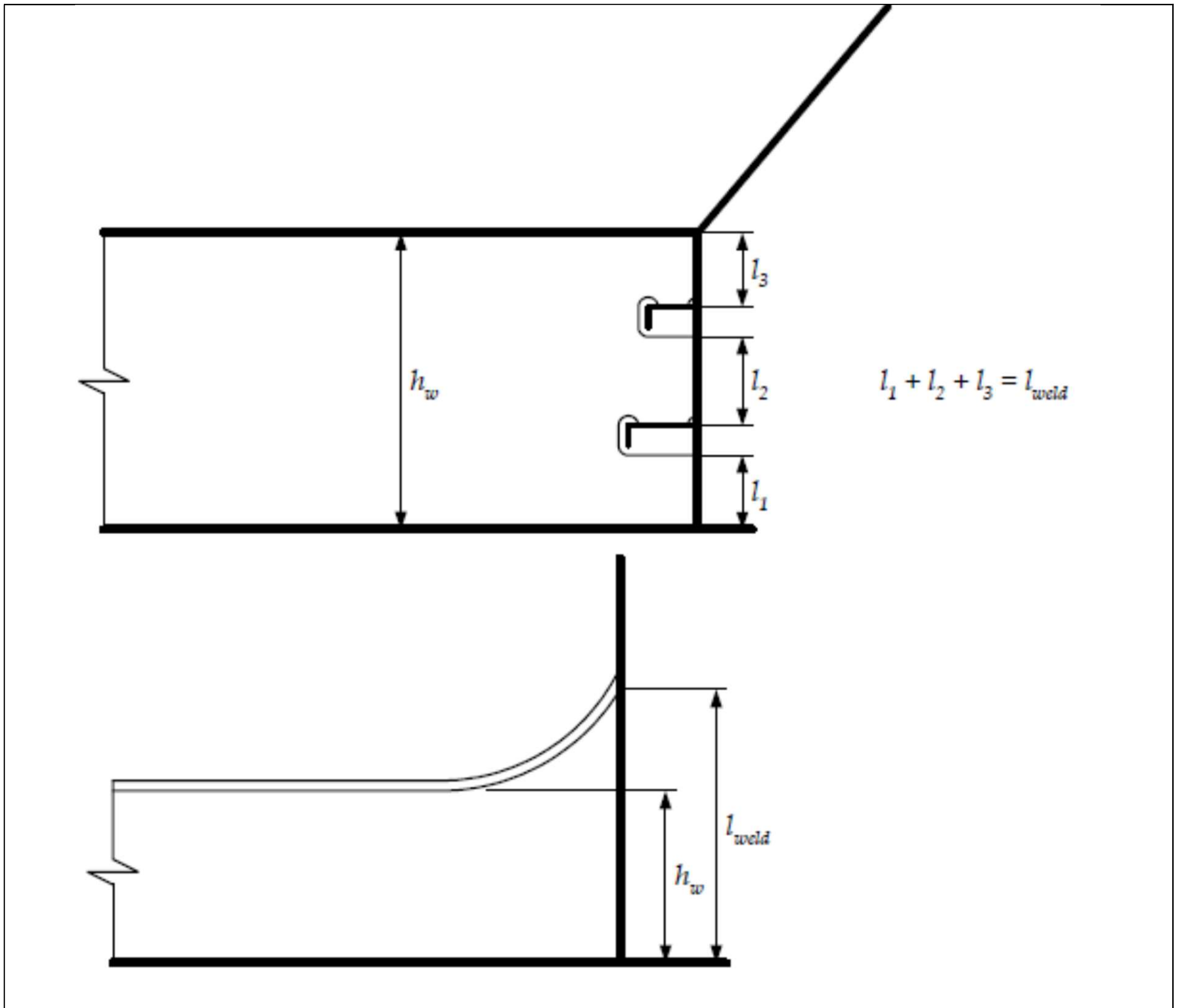
h_w = web height of primary support member, in mm, see Figure 1.6.11

$t_{p\text{-}grs}$= rule gross thickness of the primary support member, in mm

l_{dep}= total length of deposit of weld metal, in mm. Generally this can be taken as twice *l*weld shown in Figure 1.6.11 for a double continuous fillet weld

f_{yd}= correction factor taking into account the yield strength of the weld deposit, as defined in 5.7.1.2

In no case is the size of weld required to be less than that calculated in accordance with 5.7.1.2, using a minimum weld factor, f_{weld}, of 0.48 in tanks or 0.38 elsewhere.



Note

1) The length l_{weld} is the length of the welded connection. The total length of the weld deposit l_{dep} is, for double continuous fillet welds, twice the length of the welded connection l_{weld}

Figure 1.6.11: End Connection of Primary Support Members

5.7.5. Welding at the ends of stiffeners

5.7.5.1. At the ends of the longitudinals, welding of longitudinals to plating is required to be double continuous. In way of transverses the length of the double continuous weld is to be equal the depth of the longitudinal, or the depth of the end bracket, whichever is greater.

5.7.5.2. For deck longitudinals, a matched pair of welds is required at the intersection of longitudinals with transverses.

5.7.5.3. The welding of stiffener (i.e. longitudinals, beams and bulkhead stiffeners) end connections is to be not less than as required by Table 1.6.9. Where two requirements are given, the greater is to be complied with. The area of weld, A_{weld}, indicated in Table 1.6.9, is to be applied to each arm of the bracket or lapped connection.

5.7.5.4. The weld area, A_{weld}, based on the effective throat times the length of theweld is to be not less than the gross cross-sectional area of the member where a longitudinal strength member is cut at a primary support structure and the continuity of strength is provided by brackets. If the longitudinal strength member is of high strength steel, the weld area, A_{weld}, is to be multiplied by f_{yd}, the correction factor taking into account the yield strength of the weld deposit as defined in 5.7.1.2.

5.7.5.5. Theweld connection is to be in accordance with the requirements of Section 4/3.4.3.11where the stiffener member passes through, and is supported by the web of a primary support member.

5.7.5.6. Where intermittent welding is permitted, unbracketed stiffeners of shell, watertight and oil-tight bulkheads, and house fronts are to have double continuous welds for one-tenth of their length at each end. Unbracketed stiffeners of non-tight structural bulkheads, deck house sides and aft ends are to have a pair of matched intermittent welds at each end.

5.8. Weld for Structures Subject to High Tensile Stresses

5.8.1. Minimum leg size

5.8.1.1. Where high tensile stresses act through an intermediate plate, see Figure 1.6.12, the minimum leglength, l_{leg}, of double continuous welds is to be taken as:

$$l_{leg} = 1.92\left(\frac{235}{\sigma_{weld}}\right)^{0.75}\left[0.2 + \left(\frac{\sigma}{270} - 0.25\right)\frac{l_{root}}{t_{p-grs}}\right]$$

where:
σ = maximum tensile stress in plate being attached, in N/mm²
l_{root}= root face length, in mm
t_{p-grs} = gross thickness of plate being attached, in mm
σ_{weld}= as defined in 5.7.1.2, where σ_{weld} is limited to the maximum value permitted by the limits imposed on correction factor taking into account the yield strength of the weld deposit, f_{yd}, as defined in 5.7.1.2

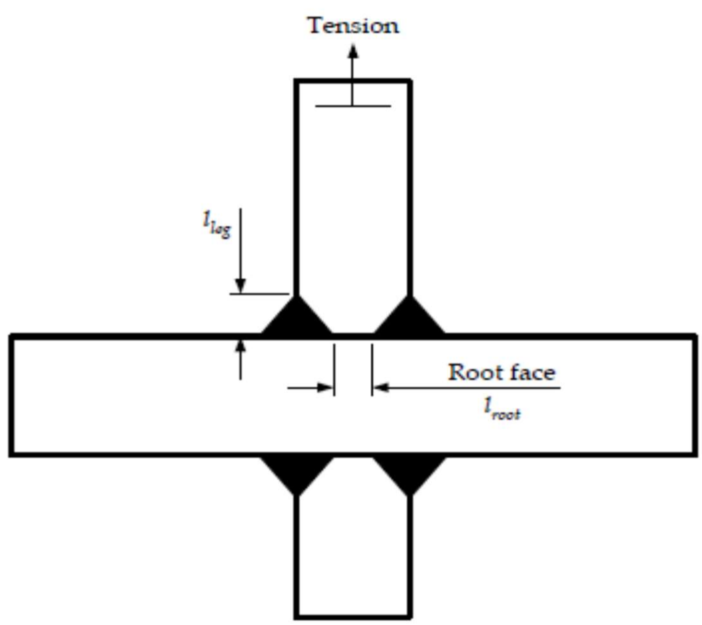


Figure 1.6.12: Welds Subject To High Tensile Stresses

5.9. Reduced Weld Size

5.9.1. General

5.9.1.1. Special approval may be given for reduction in fillet weld sizes that are required by 5.7 in accordance with 5.9.2, 5.9.3 or 5.9.4.

5.9.1.2. The specific requirements giving justification for the reduction are to be indicated on the drawings where any of the methods for reduction of the weld size are adopted. The drawings are to document the weld design and dimensioning requirements for the reduced weld leg length and the required weld leg length given by 5.7 without the permitted leg length reduction. Also, notes are to be added to the drawings to describe the difference in the two leg lengths and the requirements for their application.

5.9.2. Controlled gaps

5.9.2.1. Where quality control facilitates working to a gap between members of 1mm or less, a reduction in fillet weld leg size of 0.5mm is permitted.

5.9.3. Deep penetration welding

5.9.3.1. The weld factors given in Tables 1.6.5, 1.6.6(c) and (d), 1.6.8 and 1.6.9 may be reduced by 15 percent where an approved automatic deep penetration procedure is used and quality control facilitates areworking to a gap between members of 1mm or less. Reductions of up to 20 percent, but not more than the fillet weld leg size of 1.5mm, will be accepted provided that the Shipyard is able to consistently meet the following requirements:

a) The welding is performed to a suitable process selection confirmed by welding procedure tests covering both minimum and maximum root gaps

b) The penetration at the root is at least the same amount as the reduction into the members being attached

c) Demonstrate that an established quality control system is in place.

5.9.4. Controlled welding consumables

5.9.4.1. Where quality control systems are in place which ensure that the grade of welding consumable used is higher than the minimum required for the particular strength steel being welded, the welding consumables that are used may have a weld deposit material yield strength that is greater than the minimums specified in 5.7.1.2 and the size of the weld may be determined based on the yield strength of the higher grade welding consumable.

5.10. End Connections of Pillars and Cross Ties

5.10.1. Effective weld area

5.10.1.1. The end connections of pillars and cross ties are to have an effective fillet weld area (weld throat multiplied by weld length) not less than:

$$A_{weld} = f_3 \left(\frac{235}{\sigma_{weld}}\right)^{0.75} A_{grs} P \qquad \text{cm}^2$$

where:
A_{grs}= gross cross-sectional area, for the pillar or cross tie, in m²

P = design pressure load, for the structure under consideration, in kN/m²

σ_{weld}= minimum yield stress of the deposit, as given in 5.7.1.2, where $\sigma_{weld}$is limited to the maximum value permitted by the limits imposed on f_{yd} in 5.7.1.2

f_3 = 0.05 when pillar or cross tie is in compression only

= 0.14 when pillar or cross tie is in tension

5.11. Alternatives

5.11.1. General

5.11.1.1. The foregoing are considered minimum requirements for electric-arc welding in hull construction, butalternative methods, arrangements and details will be specially considered for approval.

5.11.1.2. The leg length limits given in Table 1.6.6 are to be complied with in all cases.

Table 1.6.5: Weld Factors

Items	Weld Factor f_{weld}	Remarks
(1) General application		except as required by items 2-11
Watertight boundaries	0.43	
Non-tight plate boundaries	0.18	
Strength deck plating to shell	see Table 1.6.7	
Other decks to shell and bulkheads (except where forming tank boundaries)	0.30	generally continuous
Stiffeners to plating (clear of end connections)	0.13	in dry spaces
Stiffeners to plating for 0.1 span at ends	0.18	in tanks
Panel stiffeners	0.21	or extent of end bracket if greater
Overlapped welds generally	0.13	
Longitudinals, with gross web thickness greater than 15mm, to plating	see 5.7.1.5	t_{p-grs} as defined in 5.7.1.5
(2) Bottom construction in cargo tank region		(1)
Non-tight centre girder:		
to keel	0.30	
to inner bottom	0.28	no scallops
Non-tight boundaries of floors and girders	0.15	mid half span
	0.24	end quarters span
Floors and girder to inner bottom in way of:		
vertical primary supporting members	0.43	(1)
Connection between floors and girders	0.36	(1)
End connection of floors and girders	0.43	(1)
Docking brackets	0.30	
(3) Side construction in cargo tank region		including bilge hopper tanks, (1)
Vertical webs to inner hull bulkhead		
in way of deck transverse/bracket	0.43	
in way of cross tie, as applicable	0.36	
Elsewhere	0.24	
Vertical webs to shell	0.24	

Vertical webs end connection	0.43	(1)
(4) Cargo tank bulkhead construction		including pump room and cofferdam, (1)
Longitudinal and transverse oil-tight bulkhead boundaries:		
to deck, inner bottom and bottom shell	0.51	
at sides	0.43	
Vertical corrugation		
at upper end	0.51	
at lower end	see 5.3.4	
Non-tight bulkhead boundaries	0.24	
Primary support members	see Table 1.6.8	
Connection between primary support members	0.49	
(5) Structures in machinery space		
Centre girder to keel and inner bottom	0.36	
Floors to centre girder in way of:		
Engines	0.36	
thrust and boiler bearers	0.36	
Floors to main engine foundation girders	0.36	
Floors/girders to shell and inner bottom	0.24	
Main engine foundation girders to top plate and primary hull structure	Partial penetration	edge to be prepared with maximum root $0.33t_{p\text{-}grs}$ deep penetration
Foundation:		
auxiliary diesels (>350kw)	0.40	
boiler and other auxiliaries	0.35	
Brackets supporting engine foundation	0.21	
(6) Construction in 0.25L forward		
In way of flat of bottom:		
floors to shell and inner bottom	0.18	
girders to shell and inner bottom	0.28	
Bottom longitudinals to shell:		
flat of bottom forward	0.30	
Elsewhere	0.18	
side shell stringers to shell	0.24	
Fore peak construction:		
internal structures	0.18	
(7) Aft peak construction		
Internal structure:		
below water line	0.30	
above waterline	0.18	
(8) Superstructures and deck houses		
Connection of external bulkhead to deck		
first and second tier erections	0.28	
Elsewhere	0.15	
Internal bulkheads	0.12	
(9) Closing Arrangements		
Hatch coaming to deck	0.43	
Cleats and fittings	0.60	Minimum weld factor. Where $t_{p\text{-}grs}$ > 11.5mm, l_{leg} need not exceed 0.62 $t_{p\text{-}grs}$. Penetration welding may be required depending on design

Hatch covers:		
oil-tight joints	0.46	
watertight joints:		
Outside	0.46	
Inside	0.18	
Hatch covers:		
at end of stiffener (unbracketed)	0.38	(2)
at end of stiffener (bracketed)	0.38	
Elsewhere	0.12	
(10) Deck Equipment		(3)
Masts, derrick posts, crane pedestals, etc., to deck	0.43	
Deck machinery seats to deck	0.20	
Mooring equipment seats	0.43	
(11) Miscellaneous fittings and equipment		
Rings for access hole type covers to ship	0.43	
Frames of shell and weather tight doors	0.43	
Stiffening of shell and weather tight doors	0.24	
Ventilators, air pipes, etc., coaming to deck	0.43	
Ventilators, etc., fittings	0.24	
Scuppers and discharge to deck	0.55	
Bulwark stays to deck	0.24	
Bulwark attachment to deck	0.43	
Guard rails, stanchions, etc., to deck	0.43	
Bilge keel ground bars to shell	see Table 3.1.13	
Bilge keels to ground bars	see Table 3.1.13	
Fabricated anchors	full penetration	

Note

(1) The weld size is to be increased for areas with high tensile stress, see 5.8.
(2) Unbracketed stiffeners and webs of hatch covers are to be welded continuously to the plating and to the face plate for a length, at the ends, equal to the end depth of the member.
(3) Weld factors are minimum values.

Table 1.6.6: Leg Size

Item	Minimum Leg Size(1), mm
(a) Gross plate thickness $t_{p-grs} \leq 6.5$ mm (5)	
Hand or automatic welding	4.0
Automatic deep penetration welding	4.0
(b) Gross plate thickness $t_{p-grs} > 6.5$ mm (5)	
Hand or automatic welding	4.5
Automatic deep penetration welding	4.0
(c) Welds within 3m below top of ballast and cargo tanks (2) (4)	6.5
(d) All welds in cargo tank region, except in (c) (4)	6.0

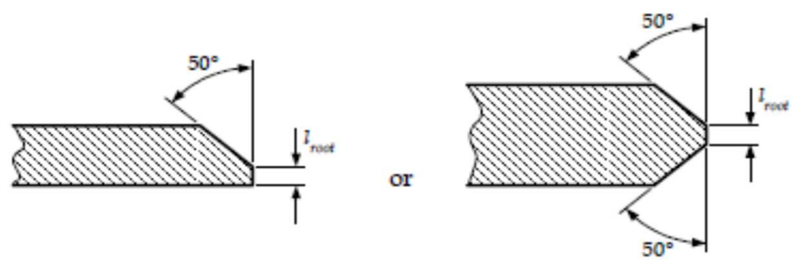
Note

(1) In all cases, the limiting value is to be taken as the greatest of the applicable values given above.
(2) Only applicable to cargo and ballast tanks with weather deck as the tank top.
(3) See 5.9 for provisions to reduce minimum leg size.
(4) A reduction to 5.5 mm leg size for the secondary structural elements such as carling, buckling stiffeners and tripping brackets may be applied without additional gap control.
(5) For superstructure and deck houseGs, the minimum leg length may be taken as 3.5 mm.

Table 1.6.7: Weld Connection of Strength Deck Plating to Sheer Strake

Stringer gross plate thickness, in mm	Weld type
tp-grs ≤ 15	Double continuous fillet weld with a leg size of 0.60 $t_{p\text{-}grs}$ + 2.0mm
15 < tp-grs ≤ 20	Single Vee preparation to provide included angle of 50° with root face length l_{root}< $t_{p\text{-}grs}$/3 in conjunction with a continuous fillet weld with a weld factor of 0.35 or Double Vee preparation to provide included angle of 50° with root face length l_{root}< $t_{p\text{-}grs}$/3
tp-grs > 20	Double Vee preparation to provide included angle of 50° with root face length l_{root}< $t_{p\text{-}grs}$/3, but not to be greater than 10mm

Where $t_{p\text{-}grs}$ = gross thickness of stringer plate, in mm



single vee preparation   double vee preparation

Note

1) Welding procedure, including joint preparation, is to be specified and approved for individual builders.
2) Where structural members pass through the boundary of a tank a leak stopper is to be arranged in accordance with 4.4.4.
3) Special consideration of thealternative connections will be done.

Table 1.6.8: Connection of Primary Support Members

Primary Support Member gross face area, in cm²		Position (1)	Weld factor, f_{weld}			
			In tanks		In dry spaces	
***Greater* than**	***Not greater* than**					
30.0	30.0	At ends	0.20	0.26	0.20	0.20
		Remainder	0.12	0.20	0.12	0.15
65.0	65.0	At ends	0.20	0.38	0.20	0.20
		Remainder	0.12	0.26	0.12	0.15
		At ends	0.42	0.59 (3)	0.20	0.30
95.0	95.0	Remainder	0.30 (2)	0.42	0.15	0.20
		At ends	0.42	0.59 (3)	0.30	0.42
		Remainder	0.30 (2)	0.42	0.20	0.30
130.0	130.0	At ends	0.59 (3)	0.59 (3)	0.42	0.59 (3)
		Remainder	0.42	0.42	0.30	0.42

Note

1) The weld factors ‘at ends’ are to be applied for 0.2 times the overall length of the member from each end, but at least beyond the toe of the member end brackets. On vertical webs, the increased welding may be omitted at the top, but is to extend at least 0.3 times overall length from the bottom.
2) Weld factor 0.38 to be used for cargo tanks.
3) Where the web plate thickness is increased locally to meet shear stress requirements, the weld size may be based on the gross web thickness clear of the increased area, but is to be not less than weld factor of 0.42 based on the increased gross thickness.
4) In regions of high stress, see 5.3.4, 5.7.4 and 5.8.

Table 1.6.9: Stiffener End Connection Welds

Connection	Weld area, A_{weld}, in cm^2	Weld Factor, f_{weld} (1)
(1) Stiffener welded direct to plating	$0.25A_{stf\text{-}grs}$ or 6.5 cm^2 whichever is the greater	0.38
(2) Bracket less connection of stiffeners, stiffener lapped to bracket or bracket lapped to stiffener:		
(a) in dry space	$\sqrt[1.2]{Z_{grs}}$	0.26
(b) in tank	$\sqrt[1.4]{Z_{grs}}$	0.38
(c) main frame to tank side bracket in 0.15L forward	as (a) or (b)	0.38
(3) Bracket welded to face of stiffener and bracket connection to plating	—	0.38

Where:
$A_{stf\text{-}grs}$ = gross cross sectional area of the stiffener, in cm^2
A_{weld}= weld area, in cm2, and is calculated as total length of weld, in cm, times throat thickness, in cm (Where the gap exceeds 2mm the weld size is to be increased. See 5.7.1.6)
Z_{grs} = the gross section modulus required, in cm^3, of the stiffener on which the scantlings of the bracket are based

Note

(1) For minimum weld fillet sizes, see Table 1.6.6.

CHAPTER 2 HULL DESIGN

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SECTION 1 LOADS

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1. Introduction

1.1. General

1.1.1. Application

1.1.1.1. Provided in this section in detail is the loads and load combinations for the scantling calculations. The loads cover load scenarios in harbour and at sea, see Chapter 1 Section 2/5.4, dividing the loads into static load components, dynamic load components, sloshing loads and impact loads.

1.2. Definitions

1.2.1. Coordinate system

1.2.1.1. The applied coordinate system x, y, z is as defined in Chapter 1 Section 4/1.4.1.1.

1.2.1.2. Specification of the direction of the incident waves are found by the angle β between the x-axis and the propagating wave direction as shown in Figure 2.1.1. Examples given:

a. Head sea is waves propagating in the negative x-direction,

b. Beam Sea is waves propagating in the positive or negative y-direction,

c. Oblique sea is waves propagating in a direction between head and beam sea (or following and beam sea), and

d. Following sea is waves propagating in positive x-direction.

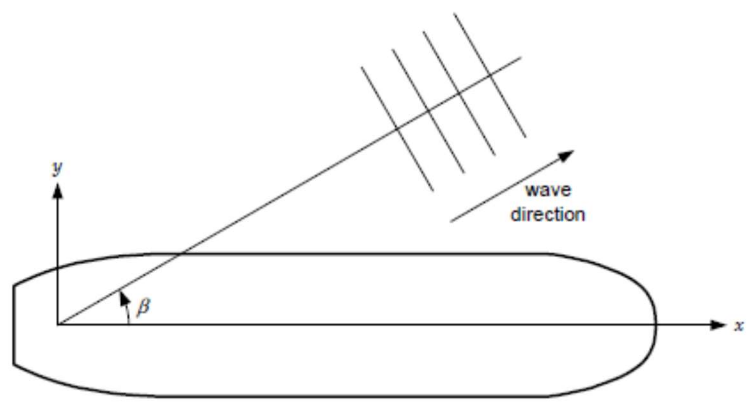
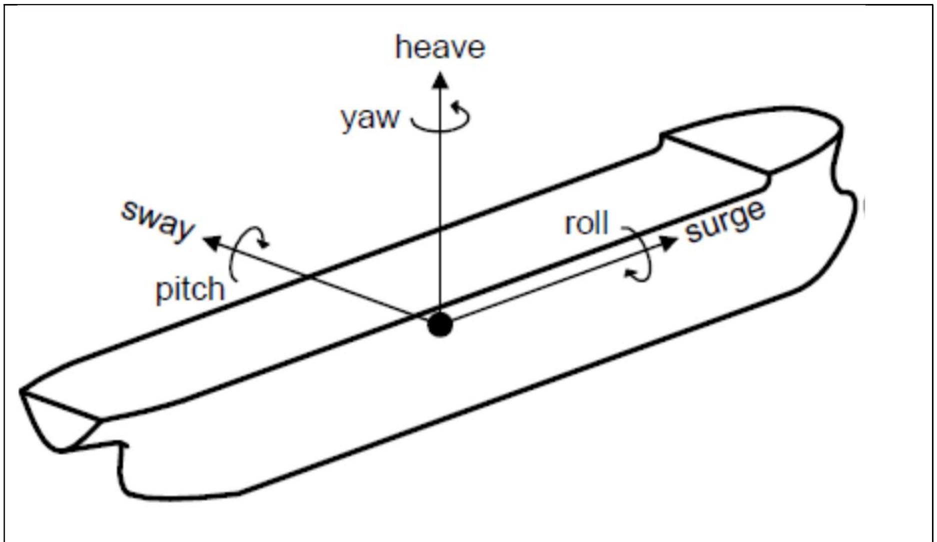


Figure 2.1.1: Definition of Wave Heading

1.2.2. Sign conventions

1.2.2.1. Positive motions, as shown in Figure 2.1.2, are defined as:

a. Positive surge is translation along positive x-axis (forward)
b. Positive sway is translation along positive y-axis (towards port side of vessel)
c. Positive heave is translation along positive z-axis (upwards)
d. Positive roll is starboard down and port side up
e. Positive pitch is bow down and stern up
f. Positive yaw is bow rotating towards portside of vessel and stern towards starboard side.



Note
This figure shows the rotation axis and not the coordinate system.

Figure 2.1.2: Definition of Positive Motions

1.2.2.2. Positive accelerations are defined as:

a. Positive longitudinal acceleration is acceleration along positive x-axis (forward)
b. Positive transverse acceleration is acceleration along positive y-axis (towards portside of vessel)
c. Positive vertical acceleration is acceleration along positive z-axis (upwards).

1.2.2.3. The sign convention of positive vertical hull girder shear force is shown in Figure 2.1.3

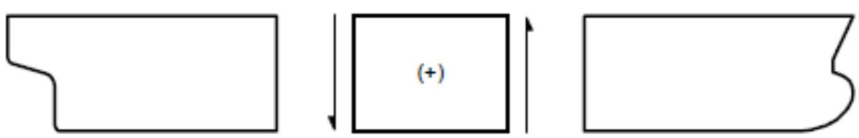


Figure 2.1.3: Positive Vertical Shear Force

1.2.2.4. The sign conventions of positive hull girder bending moments are shown in Figures 2.1.4 and 2.1.5, and are defined as:

a. Positive vertical bending moment is a hogging moment and negative vertical bending moment is a sagging moment

b. Positive horizontal bending moment is tension on the starboard side and compression on the port side.

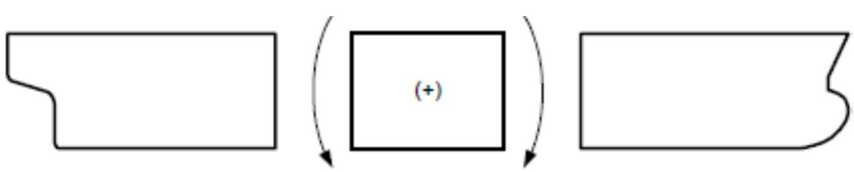


Figure 2.1.4: Positive Vertical Bending Moment

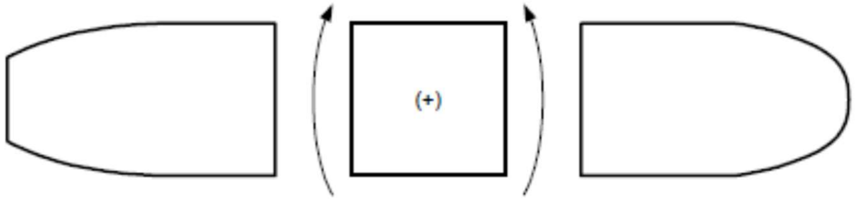


Figure 2.1.5: Positive Horizontal Bending Moment

2. Static Load Components

2.1. Static Hull Girder Loads

2.1.1. Permissible hull girder still water bending moment

2.1.1.1. The permissible hull girder hogging and sagging still water bending moment limits for seagoing, $M_{sw\text{-}perm\text{-}sea}$, and harbour/sheltered water operations, $M_{sw\text{-}perm\text{-}harb}$is to be providedby the designer.

2.1.1.2. The permissible hull girder hogging and sagging still water bending moment limits are to be given at each transverse bulkhead in the cargo area, at the middle of cargo tanks, at the collision bulkhead, at the engine room forward bulkhead and at the midpoint between the f_{wd} and aft engine room bulkhead.

2.1.1.3. The permissible hull girder hogging and sagging still water bending moment envelope is given by linear interpolation between values at the longitudinal positions given in 2.1.1.2.

2.1.1.4. The permissible hull girder hogging and sagging still water bending moment envelopes are to be included in the loading manual as required in Section 2/1.1.2.

2.1.1.5. The permissible hull girder hogging and sagging still water bending moment envelopes for seagoing operations, $M_{sw\text{-}perm\text{-}sea}$, are to envelop the minimum hull girder hogging and sagging still water bending moments given in 2.1.2.1 and 2.1.2.2 and the most severe hogging and sagging hull girder still water bending moments calculated for any seagoing loading condition given in the loading manual. Givenin Section 2/1.1.2are the requirements for the loading conditions.

2.1.1.6. The permissible hull girder hogging and sagging still water bending moment envelopes for harbour/ sheltered water operation, $M_{sw\text{-}perm\text{-}harb}$, are to envelop the minimum hull girder hogging and sagging still water bending moments given in 2.1.2.3 and the most severe hogging and sagging hull girder still water bending moments calculated for any harbour/sheltered water loading condition given in the loading manual and are not to be less than the permissible envelopes for seagoing operation, $M_{sw\text{-}perm\text{-}sea}$.

Note:

Recommendations for initial design are made that the permissible hull girder hogging and sagging still water bending moment envelopes are to be at least 5% above the hull girder still water bending moment envelope from the loading conditions in the loading manual, to account for growth and design margins during the design and construction phase of the ship.

2.1.2. Minimum hull girder still water bending moment

2.1.2.1. The minimum hull girder hogging and sagging still water bending moment for seagoing operations, $M_{sw-min-sea-mid}$, at amidships is to be taken as:

For hogging:

$M_{sw-min-sea-mi} = f_{sea}\,(Z_{v-mi}\ \ \sigma_{perm-sea}\,10^3 - M_{wv-hog})$ kNm

which is identical to

$M_{sw-min-sea-mi} = 0.01\,C_{wv}L^2B\,(11.97 - 1.9C_b)$ kNm

For sagging:

$M_{sw-min-sea-mi} = f_{sea}(Z_{v-m}\ \ \sigma_{perm-sea}10^3 + M_{wv-sa}\ )$m

which is identical to;

$M_{sw-min-sea-mi} = -0.05185\,C_{wv}\,L^2B\,(C_b + 0.7)$ kNm

where:

f_{sea} =0.85 for sagging
1.0 for hogging

Z_{v-min} = rule minimum hull girder section modulus as given in Section 2/1.2.2.2, in m^3

$\sigma_{perm-sea}$ = allowable seagoing hull girder bending stress at midships, as defined in Section 2/1.2.3.2, in N/mm^2

M_{wv-hog} = envelope values of hogging vertical wave bending moment at midships as defined in 3.4.1.1, in kNm

M_{wv-sag} = envelope values of sagging vertical wave bending moment at midships as defined in 3.4.1.1, in kNm

C_{wv} = wave coefficient, as defined in 3.4.1.1

L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1

B = moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.1, in m

C_b= block coefficient, as defined in Chapter 1 Section 4/1.1.9.1

2.1.2.2. At any longitudinal position,the minimum hull girder hogging and sagging still water bending moment for seagoing operations,$M_{sw-min-sea}$, is to be taken as:

$M_{sw-min-sea} = f_{sw}M_{sw-min-sea-mi}$ kNm

where:

f_{sw}= 1.0 within 0.4L amidships

= 0.15 at 0.1L from A.P. or F.P.

= 0 at A.P. and F.P.

Intermediate f_{sw} values are to be obtained by linear interpolation, see Figure 2.1.6

2.1.2.3. At any longitudinal position,the minimum hull girder hogging and sagging still water bending moment for harbour/sheltered water operations, $M_{sw-min-harb}$, is to be taken as:

$M_{sw-min-har} = 1.25M_{sw-min-sea}$ kNm

where:

$M_{sw-min-sea}$corresponding minimum hull girder hogging and sagging still water bending moment for seagoing operation at the section under consideration see 2.1.2.1 and 2.1.2.2

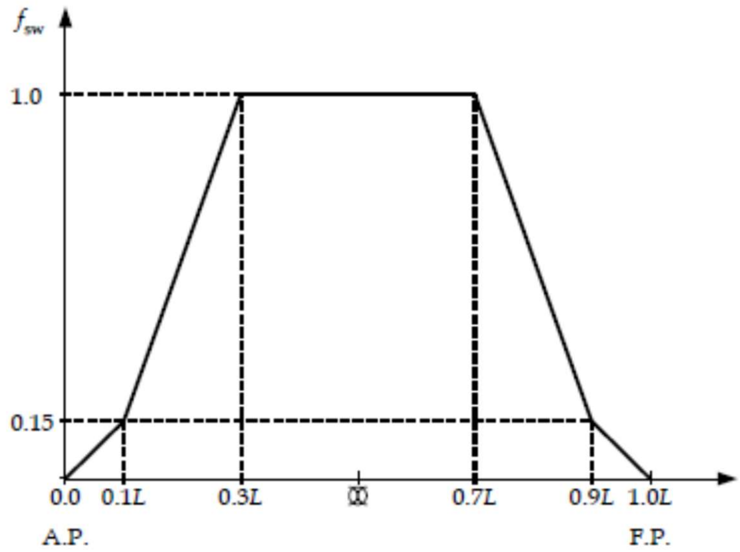


Figure 2.1.6: Still Water Bending Moment Distribution

2.1.3. Still water shear force

2.1.3.1. The permissible hull girder positive and negative still water shear force limits for seagoing, $Q_{sw\text{-}perm\text{-}sea}$, and harbour/sheltered water operations, $Q_{sw\text{-}perm\text{-}harb}$ is to be providedby the designer.

2.1.3.2. At each transverse bulkhead in the cargo area, at the middle of cargo tanks, at the collision bulkhead and at the engine room forward bulkhead, the permissible hull girder positive and negative still water shear force limits are required to be given.

2.1.3.3. The permissible hull girder positive and negative still water shear force envelope is given by linear interpolation between values at the longitudinal positions given in 2.1.3.2.

2.1.3.4. The permissible hull girder positive and negative still water shear force envelopes are to be included in the loading manual as required in Section 2/1.1.2.

2.1.3.5. The permissible hull girder positive and negative still water shear force envelopes for seagoing operation, $Q_{sw\text{-}perm\text{-}sea}$, are to envelope the minimum hull girder positive and negative still water shear forces given in 2.1.4.1, 2.1.4.2 and the most severe positive and negative hull girder still water shear forces for any seagoing loading condition given in the loading manual. The requirements for the loading conditions are given in Section 2/1.1.2.

2.1.3.6. The permissible hull girder positive and negative still water shear force envelopes for harbour operation, $Q_{sw\text{-}perm\text{-}harb}$, are to envelop the minimum hull girder positive and negative still water shear forces given in 2.1.4.3, 2.1.4.4 and the most severe positive and negative hull girder still water shear forces for any harbour/sheltered water loading condition given in the loading manual and are not to be less than the permissible envelopes for seagoing operation, $Q_{sw\text{-}perm\text{-}sea}$.

Note:

It is recommended that, for initial design, the permissible hull girder still water shear force envelopes are at least 10% above the hull girder shear force envelope from the loading conditions in the loading manual, to account for growth and design margins during the design and construction phase of the ship.

2.1.4. Minimum hull girder still water shear force

2.1.4.1. For ships with two longitudinal bulkheads, the minimum hull girder positive and negative still water shear force for seagoing operation, $Q_{sw-min-sea}$, in way of transverse bulkheads between centre cargo tanks, is to be taken as:

$$Q_{sw-min-se} = \pm\max\left\{\begin{matrix} 0.225\rho g\ _{local} l_{tk} T_{sc} \\ 0.5\rho g[0.98(V_{CT} + 2V_{ST}) - 0.7B_{local} l_{tk} T_{sc}] \end{matrix}\right. \text{KN}$$

and taken as the maximum value of $Q_{sw-min-sea}$ calculated for cargo/ballast tanks forward and aft of thetransverse bulkhead

where:

$\boldsymbol{\rho}$ = density of cargo/sea water, not to be taken less than 1.025 tonnes/m^3

g = acceleration due to gravity, 9.81 m/s^2

B_{local} = local breadth at T_{sc} at the middle length of the tank under consideration, in m

l_{tk}= length of cargo tank under consideration, taken at the forward or aft side of the transverse bulkhead under consideration, in m

T_{sc}= scantling draught, in m, as defined in Chapter 1 Section 4/1.1.5.5

V_{CT}= volume of centre cargo tank, taken for the cargo tank on the forward or aft side of the transverse bulkhead under consideration, in m^3

V_{ST} = volume of side cargo tank, taken for the cargo tank on the forward or aft side of the transversebulkhead under consideration, in m^3

2.1.4.2. For ships with centreline longitudinal bulkhead, the minimum hull girder positive and negative still water shear force for seagoing operation, $Q_{sw-min-sea}$, in way of transverse bulkheads between cargo tanks is tobe taken as:

$$Q_{sw-min-sea} = \pm 0.4\rho g B_{local} l_{tk} T_{sc} \text{kN}$$

and taken as the maximum value of $Q_{sw-min-sea}$ calculated for cargo/ballast tanks forward and aft of thetransverse bulkhead
where:
$\boldsymbol{\rho}$ = density of cargo/sea water, not to be taken less than 1.025 tonnes/m^3
g = acceleration due to gravity, 9.81 m/s^2
B_{local} = local breadth at T_{sc} at the middle length of the tank under consideration, in m
l_{tk} = length of cargo tank under consideration, taken at the forward or aft side of the transversebulkhead under consideration, in m
T_{sc}= scantling draught, in m, as defined in Chapter 1 Section 4/1.1.5.5

2.1.4.3. For ships with two longitudinal bulkheads, the minimum hull girder positive and negative still water shear force for harbour/sheltered water operation, $Q_{sw\text{-}min\text{-}harb}$, in way of transverse bulkheads between centre cargo tanks, is to be taken as:

$$Q_{sw-min-harb} = \pm\max\left\{\begin{matrix} 0.275\rho g B_{local} l_{tk} T_{sc} \\ 0.5\rho g[0.98(V_{CT} + 2V_{ST}) - 0.6B_{local} l_{tk} T_{sc}] \end{matrix}\right. \text{kN}$$

and taken as the maximum value of $Q_{sw\text{-}min\text{-}harb}$ calculated for cargo/ballast tanks forward and aft of the transverse bulkhead

where:

ρ = density of cargo/sea water, not to be taken less than 1.025 tonnes/m^3

g acceleration due to gravity, 9.81 m/s^2

B_{local} = local breadth at T_{sc} at the middle length of the tank under consideration, in m

l_{tk} =length of cargo tank under consideration, taken at the forward or aft side of the transverse bulkhead under consideration, in m

T_{sc}= scantling draught, in m, as defined in Chapter 1 Section 4/1.1.5.5

V_{CT} = volume of centre cargo tank, taken for the cargo tank on the forward or aft side of the transverse bulkhead under consideration, in m^3

V_{ST} = volume of side cargo tank, taken for the cargo tank on the forward or aft side of the transverse bulkhead under consideration, in m^3

2.1.4.4. For ships with centreline longitudinal bulkhead, the minimum hull girder positive and negative stillwater shear force for harbour/sheltered water operation, $Q_{sw\text{-}min\text{-}harb}$, in way of transverse bulkheads betweencargo tanks, is to be taken as:

$$Q_{sw-min-har} = \pm 0.45\rho g B_{local} l_{tk} T_{sc} \text{ kN}$$

and taken as the maximum value of $Q_{sw\text{-}min\text{-}harb}$ calculated for cargo/ballast tanks forward and aft of the transverse bulkhead

where:

ρ = density of cargo/sea water, not to be taken less than 1.025 tonnes/m^3

g = acceleration due to gravity, 9.81 m/s^2

B_{local} = local breadth at Tsc at the middle length of the tank under consideration, in m

l_{tk} = length of cargo tank under consideration, taken at the forward or aft side of the transverse bulkhead under consideration, in m

T_{sc} = scantling draught, in m, as defined in Chapter 1 Section 4/1.1.5.5

Local Static Loads

2.2.1. General

2.2.1.1. The following static loads are considered:

a. Static sea pressure

b. Static tank pressure

c. Tank overpressure

d. Static deck load

2.2.2. Static sea pressure

2.2.2.1. The static sea pressure, P_{hys}, is to be taken as:

$$P_{hys} = \rho_{sw} g(T_{LC} - z) \text{ kN/m}^2$$

where:

z =vertical coordinate of load point, in m, and is not to be greater than T_{LC}, see Figure 2.1.7

ρ_{sw}= density of sea water, 1.025 tonnes/m^3

T_{LC}= draught in the loading condition being considered, in m

g = acceleration due to gravity, 9.81m/s^2

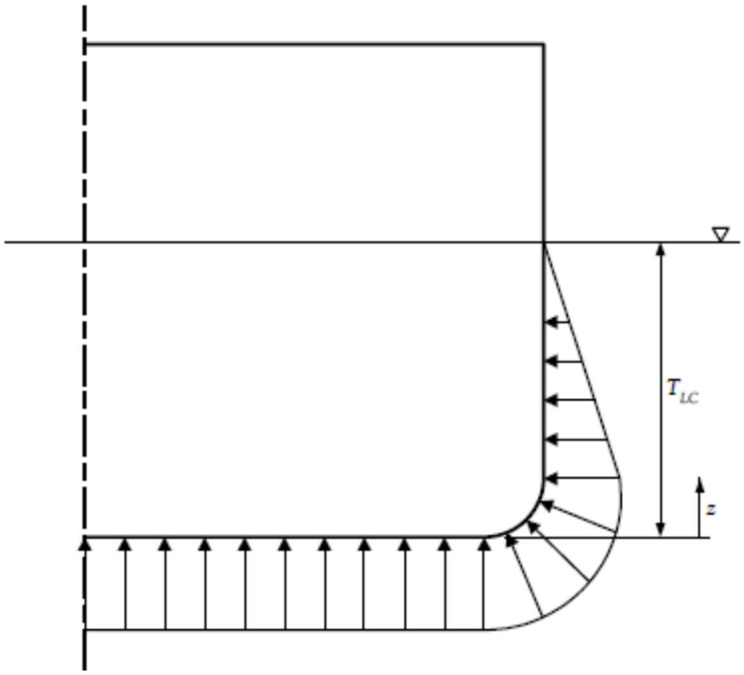


Figure 2.1.7: Static Sea Pressure

2.2.3. Static tank pressure

2.2.3.1. The static tank pressure, P_{in-tk}, is to be taken as:

$$P_{in-tk} = \rho g z_{tk} \text{kN/m}^2$$

where:

z_{tk}= vertical distance from highest point of tank, excluding small hatchways, to the load point, see Figure 2.1.8, in m

ρ = density of liquid in the tank, is not to be taken as less than
= 0.9 for liquid cargo for fatigue strength
= 1.025 otherwise

see Chapter 1 Section 2/3.1.8, in tonnes/m^3

g = acceleration due to gravity, 9.81m/s^2

2.2.3.2. The static tank pressure, P_{in-air}, in the case of overfilling or filling during flow through ballast waterexchange, is to be taken as:

$$P_{in-a} = \rho_{sw} g z_{air} \text{kN/m}^2$$

where:

z_{air} =vertical distance from top of air pipe or overflow pipe to the load point, whichever is the lesser, see Figure 2.1.8, in m

$= = z_{tk} + h_{air}$

ρ_{sw}= density of sea water, 1.025tonnes/m^3

g = acceleration due to gravity, 9.81m/s^2

h_{air} = height of air pipe or overflow pipe, in m, is not to be taken less than 0.76m above highest point of tank, excluding small hatchways. For tanks with tank top below the weather deck the height of air-pipe or overflow pipe is not to be taken less than 0.76m above deck at side unless a lesser height is approved by the flag Administration. See also Figure 2.1.8.

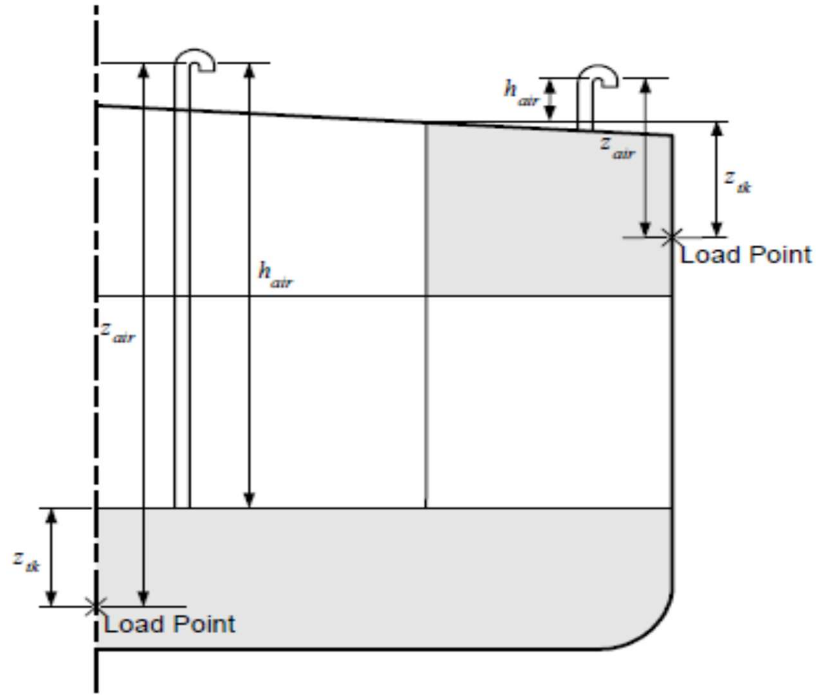


Figure 2.1.8: Pressure-Heads and Distances used for Calculation of Static Tank Pressure

2.2.3.3. The added overpressure due to sustained liquid flow through air pipe or overflow pipe in the case of overfilling or filling during flow through ballast water exchange, P_{drop}, is to be taken as 25 kN/m^2. Additional calculations may be required where piping arrangements may lead to a higher pressure drop, for example long pipes or arrangements such as bends and valves

2.2.3.4. The pressure, $P_{in\text{-}flood}$, in compartments and tanks in a flooded or damaged condition is to be taken as:

$$P_{in-flood} = \rho_{sw} g z_{flood} \text{ kN/m}^2$$

where:

z_{flood}= vertical distance from the load point to the deepest equilibrium waterline in damaged condition obtained from applicable damage stability calculations or to freeboard deck if the damage waterline is not given, in m

ρ_{sw}= density of sea water, 1.025tonnes/m^3

g = acceleration due to gravity, 9.81m/s^2

2.2.3.5. The tank testing pressure, $P_{in\text{-}test}$, is to be taken as the greater of the following, see also the testingrequirements in Table 3.1.16:

2.2.3.6. $P_{in-test} = \rho_{sw}\, g z_{test}$ kN/m²

$P_{in-te} = \rho_{sw}\, g z_{tk} + P_{valve}$ kN/m²

where:

z_{test}= vertical distance to the load point, is to be taken as the greater of the following, in m:

a. top of overflow
b. 2.4 m above top of tank

z_{tk}= vertical distance from highest point of tank, excluding small hatchways, to the load point, see Figure 2.1.8, in m

ρ_{sw} = density of sea water, 1.025 tonnes/m³

g = acceleration due to gravity, 9.81m/s²

P_{valve} = setting of pressure relief valve, if fitted, is not to be taken less than 25 kN/m²

2.2.4. Static deck pressure from distributed loading

2.2.4.1. The pressure on decks and inner bottom, P_{stat}, is to be taken as:

$P_{stat} = P_{deck}$ kN/m²

where:

P_{deck}= uniformly distributed pressure on lower decks and decks within superstructures, including platform decks in the main engine room and for other spaces with heavy machinery components,in kN/m². $P_{deck}$is not to be taken less than 16kN/m². Design pressures for decks of deck houses are provided in Chapter 3 Section 1/1.4.

2.2.5. Static deck loads from heavy units

2.2.5.1. The scantlings of structure in way of heavy units of cargo and equipment are to consider gravity forces acting where the mass is 20 tonnes or greater. The load acting on supporting structures and securing systems for heavy units of cargo, equipment or structural components, F_{stat}, is to be taken as:

$F_{stat} = m_{un} g$ kN
where:
m_{un}= mass of unit, in tonnes
g = acceleration due to gravity, 9.81m/s²

3. Dynamic Load Components

3.1. General

3.1.1. Basic components

3.1.1.1. Formulas for ship motions and accelerations are given in this sub-section.

3.1.1.2. Formulas for the envelope value of the basic dynamic load components are also given. The basic loadcomponents are:

a. Vertical wave bending moment and shear force

b. Horizontal wave bending moment

c. Dynamic wave pressure

d. Dynamic tank pressures.

3.1.2. Envelope load values

3.1.2.1. The envelope loads for scantling requirements and strength assessment are given at a 10^{-8} probability level, while the envelope loads for fatigue strength are given at a 10^{-4} probability level.

3.1.2.2. For scantling requirements and strength assessments, correction factors to account for non-linear effects and operational considerations in heavy weather are given.

3.1.2.3. For fatigue strength a factor adjusts the envelope load from a 10^{-8} probability level to a 10^{-4}probability level. A speed correction factor is applicable where appropriate.

3.1.2.4. The envelope value is the long term value, at a given probability level, taking into consideration the effect of all wave headings.

3.1.3. Metacentric height and roll radius of gyration

3.1.3.1. The metacentric height, GM, and roll radius of gyration, rroll-gyr, associated with the rule loading conditions or specified draughts are specified in Table 2.1.1.

Table 2.1.1: GM and $r_{roll-gyr}$

	T_{LC}	GM	$r_{roll-gyr}$
Loaded at deep draught	between $0.9T_{sc}$ and T_{sc}	0.12B	0.35B
Loaded on reduced draught	0.6Tsc	0.24B	0.40B
In ballast	Tbal	0.33B	0.45B
Where: B moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.1 T_{LC} draught in the loading condition being considered, in m T_{sc} scantling draught, in m, as defined in Chapter 1 Section 4/1.1.5.5 T_{bal} minimum design ballast draught, in m, as defined in Chapter 1 Section 4/1.1.5.2 T_{bal-n} normal ballast draught, in m, as defined in Chapter 1 Section 4/1.1.5.3			

3.1.3.2. For the optional loading conditions, GM is to be taken as the corrected metacentric height given in the loading manual. Where GM for optional loaded or gale/emergency ballast conditions is not specified, GM is to be taken as 0.12B for mean draught greater or equal to $0.9T_{sc}$, and 0.24B for mean draught equal or less than $0.6T_{sc}$. For optional loading conditions with a mean draught other than the values defined, GM is to be obtained by linear interpolation based on values for $0.6T_{sc}$ and $0.9T_{sc}$.

3.1.3.3. $r_{roll-gyr}$ for optional loaded or gale/emergency ballast conditions is, unless provided based on the loading manual, to be taken as 0.35B for mean draught greater or equal to $0.9T_{sc}$, and 0.4B for mean draught equal or less than $0.6T_{sc}$. For optional loading conditions with a mean draught other than the values defined above, $r_{roll-gyr}$ may be obtained by linear interpolation based on values for 0.6Tsc and $0.9T_{sc}$.

3.1.3.4. For the loading conditions used for fatigue strength, GM is to be taken as the corrected metacentric height given in the loading manual. If not available, GM is to be taken as specified in Table 2.1.1. for ballast condition and according to the procedure described in 3.1.3.2 for full load condition. $r_{roll-gyr}$ is, unless based on the loading condition, to be taken as specified in Table 2.1.1 for ballast condition and according to the procedure described in 3.1.3.3 for full load condition.

3.2. Motions

3.2.1. General

3.2.1.1. The envelope values for ship motions are given at a 10^{-8} probability level.

3.2.2. Roll motion

3.2.2.1. The natural roll period, U_{roll}, is to be taken as:

$$U_{roll} = \frac{2.30 r_{roll-gyr}}{\sqrt{GM}} \quad secs$$

where:

GM = metacentric height, in m, as defined in 3.1.3
$r_{roll-gyr}$ = roll radius of gyration, in m, as defined in 3.1.3

3.2.2.2. The roll angle, θ, is to be taken as:

$$\theta = \frac{50}{B+75}(1.25 - 0.025 U_{roll}) f_{bk} \quad rads$$

where:

f_{bk} = 1.2 for ships without bilge keels
= 1.0 for ships with bilge keels
B = moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.1
U_{roll} = roll period, in secs, as defined in 3.2.2.1

3.2.3. Pitch motion

3.2.3.1. The characteristic pitch period, U_{pitch}, is to be taken as

$$U_{\text{pitch}} = f v \sqrt{0.6 \frac{2\pi}{g}(1+f_T)L} \ \text{ s}$$

where:

$$f_V = 1.0 + \frac{V_0}{V}\left(\frac{L}{525} - 0.67\right)$$

$$f_T = \frac{T_{LC}}{T_{sc}}$$

V_0 = vessel speed, in knots, is to be taken as:
= 0 for scantling requirements and strength assessment

= 0.75V for fatigue strength

V = maximum service speed, in knots, as defined in where: Chapter 1`Section 4/1.1.8.1

T_{sc}= scantling draught, in m, as defined in Chapter 1 Section 4/1.1.5.5

T_{LC}= draught in the loading condition being considered, in m

L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1

3.2.3.2. The pitch angle, φ , is to be taken as:

$$\varphi = 960\left(\frac{V_1}{C_b}\right)^{0.25}\frac{1}{L}\frac{\pi}{180} \quad radians$$

where:

V_1= vessel speed, in knots. Is to be taken as V, but not to be taken as less than 10

V = maximum service speed, in knots, as defined in Chapter 1 Section 4/1.1.8.1

C_b= block coefficient, as defined in Chapter 1 Section 4/1.1.9.1

L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1

3.3. Ship Accelerations

3.3.1. General

3.3.1.1. The envelope values for combined translatory accelerations due to motion in six degrees of freedom are given. The transverse and longitudinal components of acceleration include the component of gravity due to roll and pitch.

3.3.2. Common acceleration parameter

3.3.2.1. The common acceleration parameter, a_0, is to be taken as:

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

where:

C_b = block coefficient, as defined in Chapter 1 Section 4/1.1.9.1

L = rule length, in m, as defined in Chapter 1Section 4/1.1.1.1

3.3.3. Vertical acceleration

3.3.3.1. The envelope vertical acceleration, a_0,, at any position, is to be taken as:

$$a_0 = f_{prob}\sqrt{a_{heav}^2 + a_{pitch}^2 + a_{roll-}^2} \quad \text{m/s}^2$$

where:

a_{heave} = vertical acceleration due to heave, is to be taken as:

$$= f v a_0 g \text{m/s2}$$

$a_{pitch-z}$ = vertical acceleration due to pitch, is to be taken as:

$$= \left(0.3 + \frac{L}{325}\right)\varphi\left(\frac{2\pi}{U_{pit}}\right)^2 |x - 0.45L| \text{m/s}^2$$

a_{roll-z} = vertical acceleration due to roll, is to be taken as:

$$= 1.2\theta\left(\frac{2\pi}{U_{pitc}}\right)^2 |y| \text{ m/s}^2$$

a_0 = common acceleration parameter, as defined in 3.3.2.1
g = acceleration due to gravity, 9.81m/s^2
φ = pitch angle, in rads, as defined in 3.2.3.2
U_{pitch}= pitch period, in secs, as defined in 3.2.3.1
L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1
θ = roll angle, in rads, as defined in 3.2.2.2
U_{roll} = roll period, in secs, as defined in 3.2.2.1
x = longitudinal coordinate, in m
y = transverse coordinate, in m
f_{prob} = as defined in 3.3.3.2 and 3.3.3.3 as appropriate
f_V = as defined in 3.3.3.2 and 3.3.3.3 as appropriate

3.3.3.2. For scantling requirements and strength assessment:

f_{prob} = is to be taken as 1.0

f_V = is to be taken as 1.0

3.3.3.3. For fatigue strength:

$f_{prob}$is to be taken as 0.45

$$f_v = \left(\frac{C_{b-Lc}}{C_b}\right)^2 \left(1.2 - \frac{L}{1000}\right)$$

where:

C_{b-LC} = block coefficient for considered loading condition, as defined in Chapter 1 Section 4/1.1.9.2
C_b = block coefficient, as defined in Chapter 1 Section 4/1.1.9.1
L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1

3.3.4. Transverse acceleration

3.3.4.1. The envelope transverse acceleration, at, at any position, is to be taken as:

$$a_t = f_{prob}\sqrt{a_{sway}^2 + \left(g\ sin\theta + a_{roll-y}\right)^2} \text{ m/s}^2$$

where:
a_{sway} = transverse acceleration due to sway and yaw, is to be taken as:
= 0.3ga_0 m/s^2
a_{roll-y} = transverse acceleration due to roll, is to be taken as:

$$= \theta\left(\frac{2\pi}{U_{roll}}\right)^2 R_{roll} \text{ m/s}^2$$

θ = roll angle, in rads, as defined in 3.2.2.2
U_{roll} = roll period, in secs, as defined in 3.2.2.1

$$R_{roll} = z - \left(\frac{D}{4} + \frac{T_{LC}}{2}\right) \quad or\ z - \left(\frac{D}{2}\right)$$

Whichever is the greater, in m
g = acceleration due to gravity, 9.81m/s^2
a_0 = common acceleration parameter, as defined in 3.3.2.1
T_{LC}= draught in the loading condition being considered, in m
D = moulded depth, as defined in Chapter 1 Section 4/1.1.4.1
z = vertical coordinate, in m
f_{prob}= as defined in 3.3.4.2 or 3.3.4.3 as appropriate

3.3.4.2.For scantling requirements and strength assessment:

$f_{prob}$is to be taken as 1.0

3.3.4.3. For fatigue strength

f_{prob} is to be taken as 0.5

3.3.5. Longitudinal acceleration

3.3.5.1. The envelope longitudinal acceleration, a_{lng}, at any position, is to be takenas:

$$a_{lng} = 0.7f_{prob}\sqrt{a_{surge}^2 + \left(\frac{L}{325}\left(g \sin\varphi + a_{pitch}\quad\right)\right)^2} \text{ m/s}^2$$

where:
a_{surge}= longitudinal acceleration due to surge, is to be taken as:
= $0.2ga_0$m/s²

$a_{pitch-x}$ =longitudinal acceleration due to pitch, is to be taken as:

$$= fV\varphi(2\pi\ /U_{pitc}\quad)^2R_{pitch} \text{ m/s}^2$$

φ = pitch angle, in rads, as defined in 3.2.3.2
U_{pitch}= pitch period, in secs, as defined in 3.2.3.1
R_{pitch}= pitch radius and is to be taken as the greater of

$$z - \left(\frac{D}{4} + \frac{T_{LC}}{2}\right) \qquad or\ z - \left(\frac{D}{2}\right), \qquad in\ m$$

g = acceleration due to gravity, 9.81m/s²
a_0 = common acceleration parameter, as defined in 3.3.2.1
T_{LC} = draught in the loading condition being considered, in m
D = moulded depth, in m, as defined in Chapter 1 Section 4/1.1.4.1
L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1
z = vertical coordinate, in m
f_{prob}= as defined in 3.3.5.2 and 3.3.5.3 as appropriate
f_V= as defined in 3.3.5.2 and 3.3.5.3 as appropriate

3.3.5.2. For scantling requirements and strength assessment:

f_{prob} is to be taken as 1.0
$f_V$is to be taken as 1.0

3.3.5.3. For fatigue strength:

f_{prob} is to be taken as 0.5
$f_V$is to be taken as 1.7

3.4. Dynamic Hull Girder Loads

3.4.1. Vertical wave bending moment

3.4.1.1. The envelope hogging and sagging vertical wave bending moments, M_{wv-hog} and M_{wv-sag} , are to be taken as:

$$M_{wv-hog} = f_{prob}0.19f_{wv-v}C_{wv}L^2BC_b$$

$$M_{wv-ho}\quad = -f_{prob}0.11f_{wv-v}C_{wv}L^2B(C_b + 0.7)\text{kNm}$$

where:
f_{wv-v} distribution factor for vertical wave bending moment along the vessel length, see 3.4.1.2 or 3.4.1.3 as appropriate
C_{wv} wave coefficient to be taken as:

$= 10.75 - \left(\frac{300-L}{100}\right)^{\frac{3}{2}}$ for 150 ≤ L ≤ 300
= 10.75 for 300 < L ≤ 350
$=10.75 - \left(\frac{L-350}{150}\right)^{\frac{3}{2}}$ for 350 < L≤ 500
L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1
B = moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.1
C_b = block coefficient, as defined in Chapter 1 Section 4/1.1.9.1

3.4.1.2. For scantling requirements and strength assessment:

f_{wv-v} = distribution factor for vertical wave bending moment along the vessel length, is to be taken as:
= 0.0 at A.P.
= 1.0 for 0.4L to 0.65L from A.P.
= 0.0 at F.P.
Intermediate values to be obtained by linear interpolation, see Figure 2.1.9
f_{prob} is to be taken as 1.0
L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1

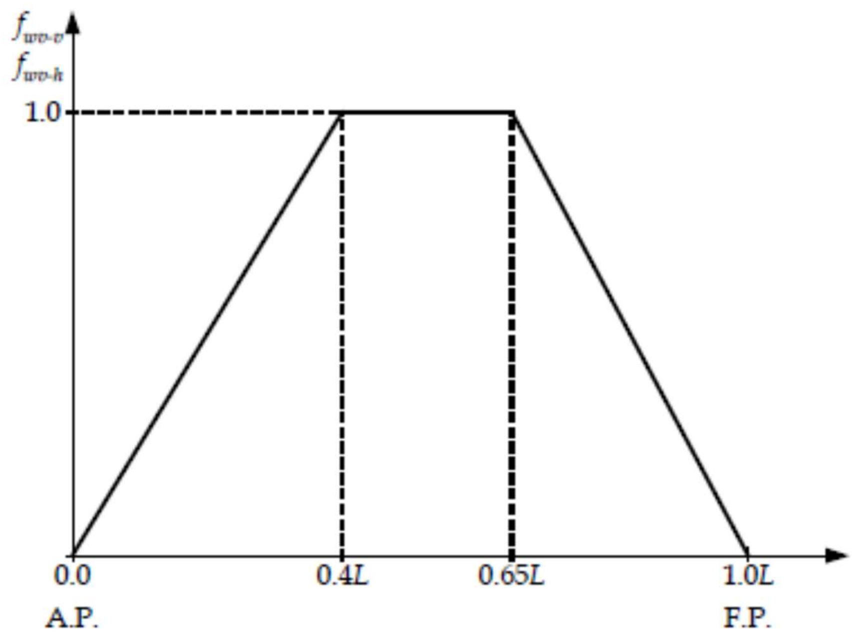


Figure 2.1.9: Vertical and Horizontal Wave Bending Moment Distribution for Scantling Requirements and Strength Assessment

3.4.1.3. For fatigue strength:

f_{wv-v} = distribution factor for vertical wave bending moment along the vessel length, is to be taken as:

0.0 at A.P

0.1 at 0.1L from A.P.
1.0 for 0.4L to 0.65L from A.P.
0.1 at 0.9L from A.P.
0.0 at F.P.
Intermediate values to be obtained by linear interpolation, see Figure 2.1.10

f_{prob} is to be taken as 0.5L rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1

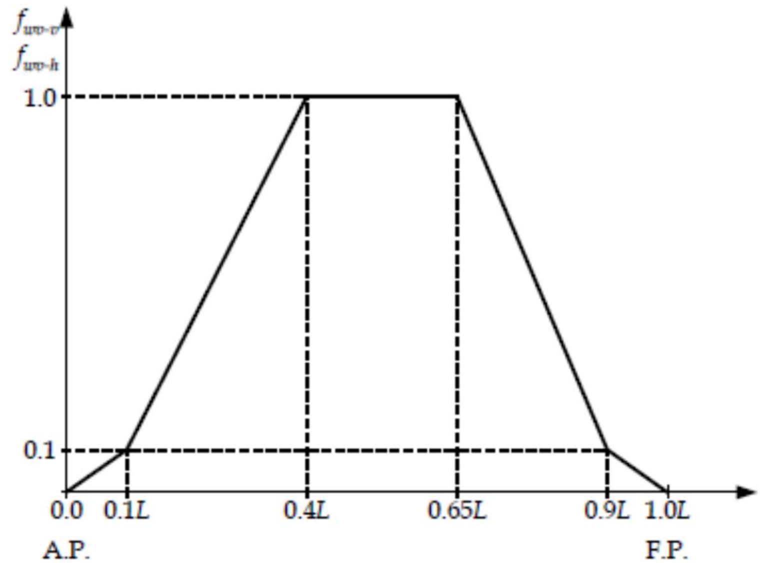


Figure 2.1.10: Vertical and Horizontal Wave Bending Moment Distribution for Fatigue Strength

3.4.2. Horizontal wave bending moment

3.4.2.1. The envelope horizontal wave bending moment, M_{wv-h}, is to be taken as:

$$M_{wv-h} = f_{prob}\left(0.3 + \frac{L}{2000}\right) f_{wv-h} C_{wv} L^2 T_{LC} C_b$$

where:
f_{wv-h} = distribution factor for wave horizontal bending moment along the vessel length, see 3.4.2.2 or 3.4.2.3 as appropriate
C_{wv} = wave coefficient, as defined in 3.4.1.1
L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1
T_{LC}= draught in the loading condition being considered, in m
C_b= block coefficient, as defined in Chapter 1 Section 4/1.1.9.1
For scantling requirements and strength assessment:
f_{wv-h} = distribution factor for wave horizontal bending moment along the vessel length, is to be taken as:
0.0 at A.P.
1.0 for 0.4L to 0.65L from A.P.
0.0 at F.P.
Intermediate values to be obtained by linear interpolation, see Figure 2.1.9
$f_{prob}$is to be taken as 1.0
L rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1
f_{wv-h} = distribution factor for wave horizontal bending moment along the vessel length, is to be taken as:
0.0 at A.P.
0.1 at 0.1L from A.P.
1.0 for 0.4L to 0.65L from A.P.
0.1 at 0.9L from A.P.
0.0 at F.P.
Intermediate values to be obtained by linear interpolation, see Figure 2.1.10

f_{prob} is to be taken as 0.5
L rule length, in m, as defined in Section 4/1.1.1.1

3.4.3. Vertical wave shear force

3.4.3.1. The envelope positive and negative vertical wave shear forces, Q_{wv-pos} and Q_{wv-neg}, are to be taken as:

$$Q_{\mathrm{wv-pos}} = 0.3 f_{qwv-pos} C_{wv} LB(C_b + 0.7) \text{kN}$$

$$Q_{\mathrm{wv-neg}} = -0.3 f_{qwv-n} \quad C_{wv} LB(C_b + 0.7) \text{ kN}$$

where:
$f_{qwv-pos}$ = distribution factor for positive vertical wave shear force along the vessel length and is to be taken as:
0.0 at A.P.
$1.59 \frac{C_b}{C_b+0.7}$ for 0.2L to 0.3L from A.P.

0.7 for 0.4L to 0.6L from A.P.
1.0 for 0.7L to 0.85L from A.P.
0.0 at F.P.
$f_{qwv-neg}$ = distribution factor for negative vertical wave shear force along the vessel length and is to be taken as:
0.0 at A.P.
0.92 for 0.2L to 0.3L from A.P.
0.7 for 0.4L to 0.6L from A.P.
$1.73 \frac{C_b}{(C_b+0.7)}$ for 0.7L to 0.85L from A.P.

0.0 at F.P.

Intermediate values of $f_{qwv-pos}$ and $f_{qwv-neg}$ are to be obtained by linear interpolation, see Figure 2.1.11 and Figure 2.1.12 respectively.

C_{wv} wave coefficient, as defined in 3.4.1.1
L rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1
B moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.1
C_b block coefficient, as defined in Chapter 1 Section 4/1.1.9.1

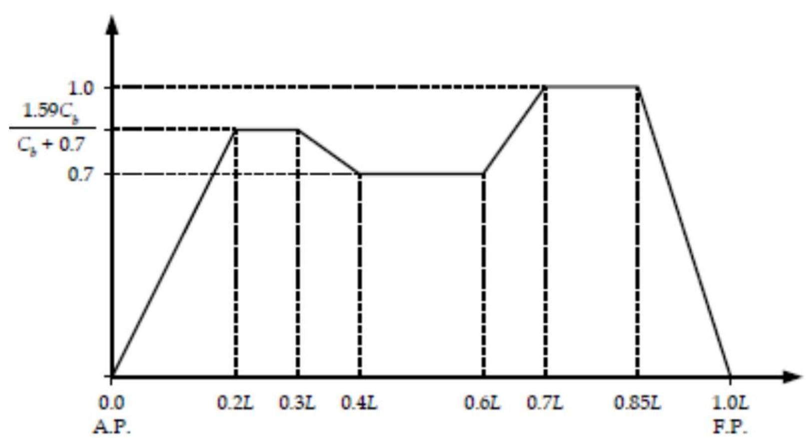


Figure 2.1.11: Positive Vertical Wave Shear Force Distribution

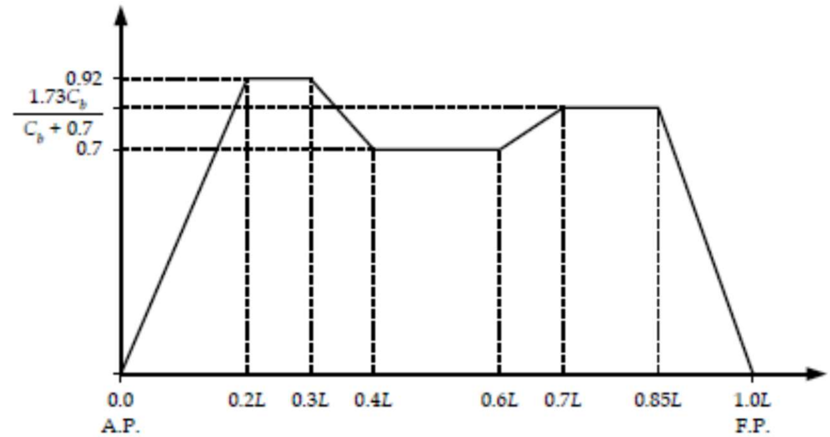


Figure 2.1.12: Negative Vertical Wave Shear Force Distribution

3.5. Dynamic Local Loads

3.5.1. General

3.5.1.1. This section provides the envelope values for dynamic wave pressure, dynamic tank pressure, green sea load and dynamic deck loads.

3.5.1.2. The envelope dynamic wave pressures are given in 3.5.2

3.5.1.3. The envelope green sea load given in 3.5.3 only applies to scantling requirements and strength assessment. The green sea load for fatigue strength is to be taken as 0.

3.5.1.4. The envelope dynamic tank pressure is a combination of the inertial components due to vertical, transverse and longitudinal acceleration. The envelope dynamic tank pressure components are given in 3.5.4.

3.5.1.5. The envelope dynamic deck loads are given in 3.5.5 and 3.5.6.

3.5.2. Dynamic wave pressure

3.5.2.1. The envelope dynamic wave pressure, $P_{ex\text{-}dyn}$, is to be taken as the greater of the following:

$$P_1 = 2f_{prob}f_{n1-P}\left[\left(P_{11} + \frac{135B_{local}}{4(B+75)} - 1.2(T_{LC} - Z)\right)f_1 + \frac{135B_{local}}{4(B+75)}f_2\right] \quad kN$$

$$P_2 = 26f_{prob}f_{n1-P2}\begin{bmatrix}\left(\frac{B_{local}}{8}\theta + f_T C_b \frac{0.25\quad local+0.8C_{wv}}{14}\left(0.7 + \frac{2z}{T_{LC}}\right)\right)f_1 \\ +\left(\frac{B_{local}}{8}\theta + f_T C_b \frac{0.25B_{local}}{14}\left(0.7 + \frac{2z}{T_{LC}}\right)\right)f_2\end{bmatrix} kN/m^2$$

where:
B_{local} = local breadth at the waterline, for considered draught, not to be taken less than 0.5B, in m
θ = roll angle, in rads, as defined in 3.2.2.2

$$P_{11} = (3f_s + 0.8)C_{wv}$$

C_{wv}= wave coefficient, as defined in 3.4.1.1
L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1
B = moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.1
T_{LC} = draught in the loading condition being considered, in m
T_{sc} = scantling draught, in m, as defined in Chapter 1 Section 4/1.1.5.5
C_b = block coefficient, as defined in Chapter 1 Section 4/1.1.9.1

$$f_1 = f_{lng} - \frac{f_{lng}}{f_v} f_2 + f_2$$

$$f_2 = 0.25 f_v \left(\frac{4|y|}{B_{local}} - 1 \right) \quad for\ |y| < 0.25 B_{local}$$

$$= f_v \left(\frac{4|y|}{B_{local}} - 1 \right) \quad for\ |y| \geq 0.25 B_{local}$$

$$f_T = \frac{T_{LC}}{T_{sc}}$$

$f_s = C_b + \frac{1.33}{\sqrt{C_b}}$ at, and aft of A.P.
= C_b between 0.2L and 0.7L from A.P.
$= C_b + \frac{1.33}{C_b}$at, and forward of F.P.
Intermediate values to be obtained by linear interpolation
= 1.0 at, and aft of A.P.
= 0.7 for 0.2L to 0.7L from A.P.
f_{lng}= 1.0 at, and forward of F.P.
Intermediate values to be obtained by linear interpolation
y = transverse coordinate, in m

z = vertical coordinate, in m

f_{nl-P1}, f_{nl-P2}, f_{prob}, and $f_V$are given in 3.5.2.2 for scantling requirements and strength assessment applicationand in 3.5.2.3 for fatigue strength.

3.5.2.2. For scantling requirements and strength assessment, the envelope maximum dynamic wave pressure, P_{ex-max}, see Figure 2.1.13, and minimum dynamic wave pressure, P_{ex-min}, see Figure 2.1.14, are to be taken as:

$P_{ex-max} = P_{ex-dyn}$ kN/m^2 below still waterline

$= P_{WL} - 10(z - T_{LC})$ kN/m^{2}for $T_{LC} < z \leq T_{LC} + P_{WL}/10$

$P_{ex-min} = - P_{ex-dyn}$ kN/m^2 below still waterline

= 0 kN/m^2 above still waterline

P_{ex-min} is not to be taken as less than $-\rho_{sw} g (T_{LC} - z)$

where:

P_{ex-dyn} = envelope dynamic wave pressure, in kN/m^2, as defined in 3.5.2.1 with:
f_{prob}= 1.0
f_{nl-P1} = 0.9
f_{nl-P2} = 0.65
f_V= 1.0
P_{WL}= pressure at waterline, to be taken as P_{ex-dyn} at still waterline, in kN/m^2

T_{LC}= draught in the loading condition being considered, in m
ρ_{sw}= density of sea water, 1.025 tonnes/m^3
z = vertical coordinate, in m

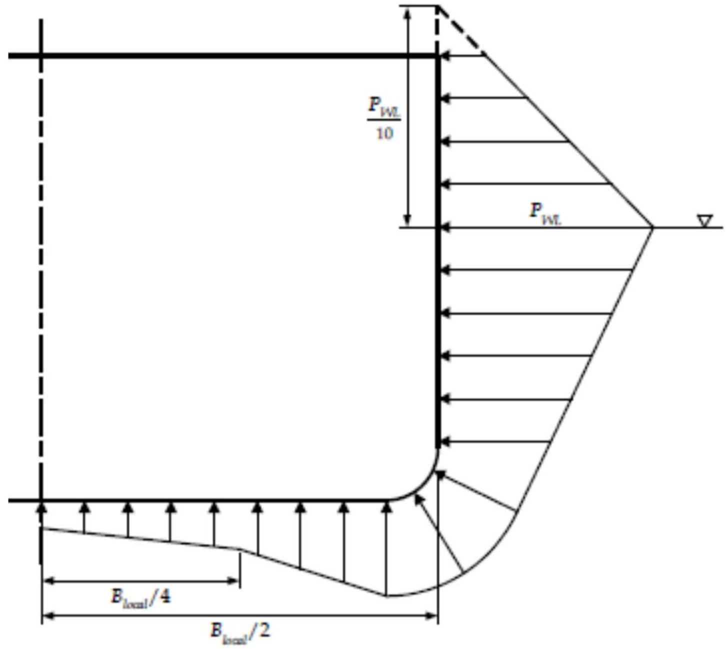


Figure 2.1.13: Transverse Distribution of Maximum Dynamic Wave Pressurefor Scantling Requirements and Strength Assessment

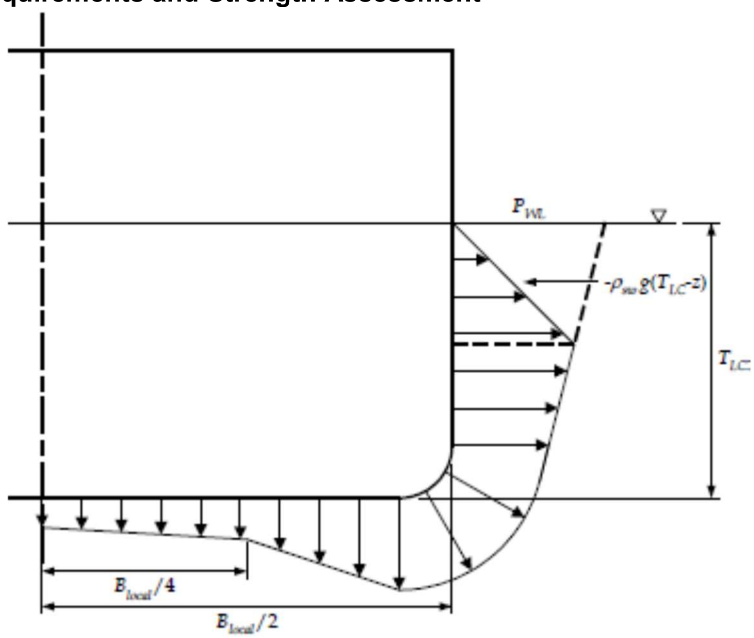


Figure 2.1.14: Transverse Distribution of Minimum Dynamic Wave Pressure for Scantling Requirements and Strength Assessment

3.5.2.3. The dynamic wave pressure pseudo-amplitude (half range), $P_{ex\text{-}amp}$, for fatigue strength, see Figure 2.1.15, is to be taken as:

$P_{ex\text{-}amp}$ = 0 kN/m^{2}for z ≥ T_{LC} + h_{WL}or D, whichever is the lesser
= 0.5 P_{WL} kN/m^2 at still waterline
= $P_{ex\text{-}dyn}$ kN/m^2 for z ≤ T_{LC} − h_{WL}or 0, whichever is the greater
Intermediate values between the still waterline and z = T_{LC} – $h_{WL}$to be obtained by linear interpolation

where:
h_{WL}= dynamic wave pressure head at the still waterline, is to be taken as:
= P_{WL} / 10 m
P_{WL} pressure at waterline, and is to be taken as P_{ex-max} at still waterline, in kN/m^2
P_{ex-max} envelope maximum dynamic wave pressure is to be taken as the greater of P_1 and P_2, in kN/m^2
T_{LC} draught in the loading condition being considered, in m
D moulded depth, in m, as defined in Chapter 1 Section 4/1.1.4.1
P_1 as defined in 3.5.2, in kN/m^2, with:
f_{prob} = 0.5
f_{nl-P1} = 1.0
f_v=1.5 at, and forward of F.P.
= 1.0 at, and aft of 0.7L
Intermediate values of f_V to be obtained by linear interpolation
P_2 as defined in 3.5.2.1, in kN/m^2, with:
f_{prob} = 0.5
f_{nl-P2} = 1.0
f_V = 1.0
z = vertical coordinate, in m

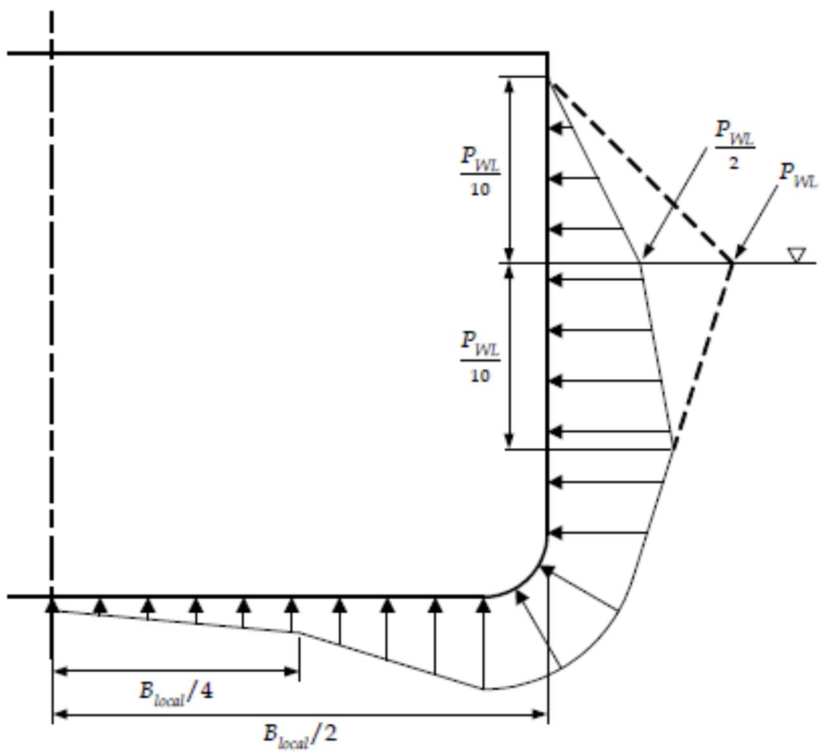


Figure 2.1.15: Transverse Distribution of Dynamic Wave Pressure Amplitude for Fatigue Strength

3.5.3. Green sea load

3.5.3.1. The envelope green sea load on the weather deck, P_{wdk}, is to be taken as the greater of the following:

$P_{wdk} = f_{1-dk}\left(f_{op}P_{1-WL} - 10z_{dk-T}\right)$ kN/m^2
$P_{wdk} = 0.8f_{2-dk}(P_{2-WL} - 10z_{dk-T})$ kN/m^2
P_{wdk} = 34.3 kN/m^2

where:

$$f_{1-dk} = 0.8 + \frac{L}{750}$$

$$f_{2-dk} = 0.5 + \frac{|y|}{B_{wdk}}$$

f_{op} = 1.0 at and forward of 0.2L from A.P.
= 0.8 at and aft of A.P.
Intermediate values to be obtained by linear interpolation
P_{1-WL} = P_1 pressure at still waterline for considered draught, in kN/m², see 3.5.2.1
P_{2-WL} = P_2 pressure at still waterline for considered draught, in kN/m², see 3.5.2.1
z_{dk-T} = distance from the deck to the still waterline at the applicable draught for the loading condition being considered, in m
B_{wdk}= local breadth at the weather deck, in m
L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1
y = transverse coordinate of load point, in m

3.5.4. Dynamic tank pressure

3.5.4.1. The envelope dynamic tank pressure, P_{in-v}, due to vertical tank acceleration is to be taken as:

$$P_{in-v} = \rho a_v (z_0 - z) \text{kN/m}^2$$

For strength assessment and scantling requirements

$$P_{in-v} = \rho a_v |z_0 - z| \text{ kN/m}^2$$

For fatigue strength
where:
$\boldsymbol{\rho}$ = density of liquid in the tank, in tonnes/m³, and is not to be taken as less than:
0.9 for cargo tanks for fatigue strength
1.025 otherwise,
See Chapter 1
a_v= envelope vertical acceleration, in m/s², as defined in 3.3.3.1, and is to be taken at tank centre of gravity
z = vertical coordinate of load point, in m
z_0= vertical coordinate of reference point, see 6.3.7 for scantling requirements and strength assessment, and 3.5.4.5 for fatigue strength, in m

3.5.4.2. The envelope dynamic tank pressure, P_{in-t}, due to transverse acceleration is to be taken as:

$$P_{in-t} = f_{ull-t} \rho a_t (y_0 - y) \text{kN/m}^2$$

For strength assessment and scantling requirements

$$P_{in-t} = \rho a_t |y_0 - y| \text{KN/m}^2$$

For fatigue strength
where:
$\boldsymbol{\rho}$= density of liquid in the tank, in tonnes/m³, and is not to be taken as less than:
0.9 for cargo tanks for fatigue strength
1.025 otherwise,
See Chapter 1 Section 2/3.1.8
f_{ull-t} = factor to account for ullage in cargo tanks, and is to be taken as:
0.67 for cargo tanks, including cargo tanks designed for filling with water ballast

1.0 for ballast and other tanks

a_t = envelope transverse acceleration, in m/s^2, as defined in 3.3.4.1, and is to be taken at tank centre of gravity

y = transverse coordinate of load point, in m

y_0= transverse coordinate of reference point, see 6.3.7 for scantling requirements and strength assessment, and 3.5.4.5 for fatigue strength, in m

3.5.4.3. Due to longitudinal acceleration the envelope dynamic tank pressure, P_{in-lng}, is to be taken as:

$P_{in-l} = f_{ull-lng} \rho a_{lng} (x_0 - x)$ kN/m^2
For strength assessment and scantling requirements
$P_{in-l} = \rho a_{lng} |x_0 - x|$kN/m^2
For fatigue strength
where:
ρ = density of tank liquid, in tonnes/m^3, and is not to be taken as less than:
0.9 for cargo tanks for fatigue strength
1.025 otherwise, see Chapter 1 Section 2/3.1.8
$f_{ull-lng}$ = factor to account for ullage in cargo tanks, and is to be taken as:
0.62 for cargo tanks, including cargo tanks designed for filling with water ballast
1.0 for ballast and other tanks
a_{lng} = envelope longitudinal acceleration, in m/s^2, as defined in 3.3.5.1, and is to be taken at tank centre of gravity
x = longitudinal coordinate of load point, in m
x_0= longitudinal coordinate of reference point, see 6.3.7 for scantling requirements and strength assessment, and 3.5.4.5 for fatigue strength, in m

3.5.4.4. The simultaneous acting dynamic tank pressure,P_{in-dyn}, is required to be taken as the summation of the components for the considered dynamic load case in case of scantling requirements and strength assessment, see 6.3.7.

3.5.4.5. For fatigue strength the dynamic tank pressure amplitude, P_{in-amp}, on a tank boundary with adjacenttank empty, is to be taken as:

$P_{in-am} = f_v P_{in-v} + f_{ull-t} f_t P_{in-t} + f_{ull-lng} f_{lng} P_{in-}$ kN/m^2
where:
P_{in-v} = envelope dynamic tank pressure due to vertical acceleration, in kN/m^2, as defined in 3.5.4.1
P_{in-t} = envelope dynamic tank pressure due to transverse acceleration, in kN/m^2, as defined in 3.5.4.2
P_{in-lng} = envelope dynamic tank pressure due to longitudinal acceleration, in kN/m^2, as defined in 3.5.4.3
f_{ull-t} = factor to account for ullage in cargo tanks, not to be taken less than 0.0 nor greater than 1.0
$= \frac{|z_0 - z| + h_{roll}}{2h_{roll}}$for cargo tanks
= 1.0 for ballast tanks
$f_{ull-lng}$ = factor to account for ullage in cargo tanks, not to be taken less than 0.0 nor greater than 1.0
$= \frac{|z_0 - z| + h_{pitc}}{2h_{pitch}}$for cargo tanks
= 1.0 for ballast tanks

roll height $h_{roll} = \frac{b_{fs} f_{prob} \theta}{2}$

pitch height $h_{pitch} = \frac{l_{fs} f_{prob} \varphi}{2}$

f_{prob} is to be taken as 0.5
θ = roll angle, in rads, as defined in 3.2.2.2
φ = pitch angle, in secs, as defined in 3.2.3.2
b_{fs} = tank breadth at the top of the tank, see Figure 2.1.16, in m
l_{fs}= tank length at the top of the tank, in m
x_0= longitudinal coordinate of reference point, and is to be taken as the middle of tank length at the top of the tank, in m

y_0= transverse coordinate of reference point, and is to be taken as the middle of tank breadth at the topof the tank, see Figure 2.1.16, in m
z_0 = vertical coordinate of reference point, and is to be taken as the highest point of the tank, excluding small hatchways, see Figure 2.1.16, in m
f_v= pressure combination factor, as given in Table 2.1.2
f_t =pressure combination factor, as given in Table 2.1.2
f_{lng} = pressure combination factor, as given in Table 2.1.2

3.5.4.6. For fatigue strength the dynamic tank pressure amplitude, Pin-amp, on a longitudinal tank boundary with adjacent tank full, is to be taken as:

$$P_{in-amp} = f_v |P_{in-v-tk1} - P_{in-v-tk2}| + f_t |f_{ull-t-tk1} P_{in-t-tk1}| + f_{ull-t-tk2} P_{in-t-tk2} + f_{lng} \left| f_{ull-lng-tk1} P_{in-lng-tk1} - f_{ull-lng-tk2} P_{in-lng-tk2} \right| \text{kN/m}^2$$

where:

$P_{in-v-tk1}$ = dynamic tank pressure due to vertical acceleration in tank 1, in kN/m²

$P_{in-v-tk2}$ = dynamic tank pressure due to vertical acceleration in tank 2, in kN/m²

$P_{in-t-tk1}$=dynamic tank pressure due to transverse acceleration in tank 1, in kN/m²
$P_{in-t-tk2}$ = dynamic tank pressure due to transverse acceleration in tank 2, in kN/m²
$P_{in-lng-tk1}$ = dynamic tank pressure due to longitudinal acceleration in tank 1, in kN/m²
$P_{in-lng-tk2}$ =dynamic tank pressure due to longitudinal acceleration in tank 2, in kN/m²
$f_{ull-t-tk1}$ =factor to account for ullage for tank 1, as defined in 3.5.4.5
$f_{ull-t-tk2}$ =factor to account for ullage for tank 2, as defined in 3.5.4.5
$f_{ull-lng-tk1}$ =factor to account for ullage for tank 1, as defined in 3.5.4.5
$f_{ull-lng-tk2}$ = factor to account for ullage for tank 2, as defined in 3.5.4.5
f_v = pressure combination factor, as given in Table 2.1.2
f_t = pressure combination factor, as given in Table 2.1.2
f_{lng} = pressure combination factor, as given in Table 2.1.2
Tank 1 and 2 are adjacent tanks with common longitudinal boundary

Table 2.1.2: Pressure Combination Factors for Fatigue Assessment

	Cargo tanks	Ballast tanks
f_v	0.9	0.9
f_t	0.9	0.6
f_{lng}	0.4	0.4

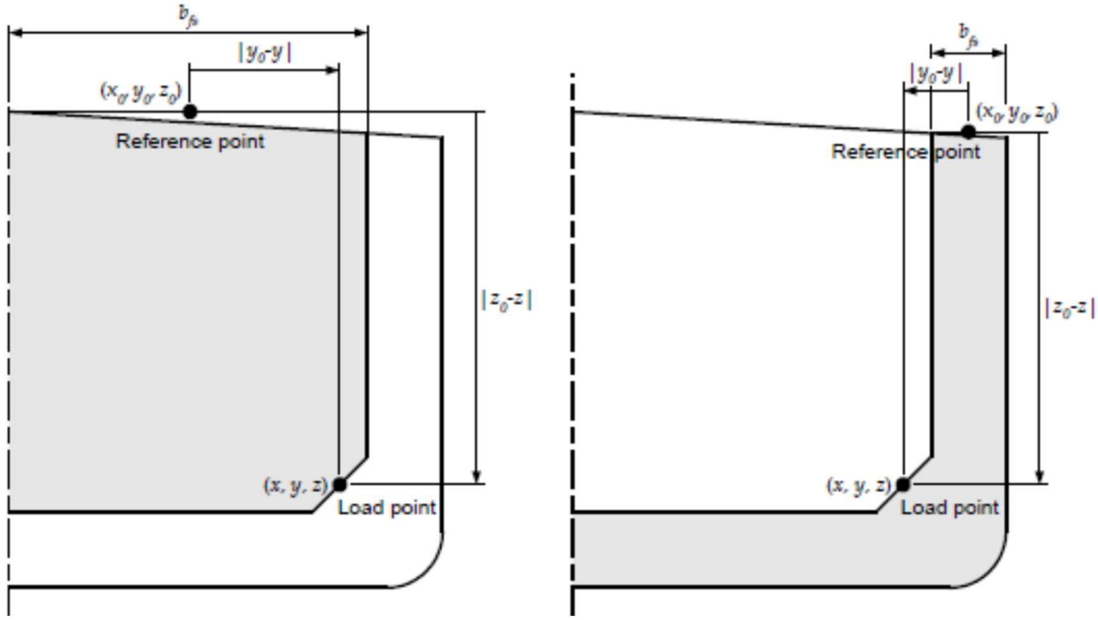


Figure 2.1.16: Dynamic Tank Pressure Load and Reference Points for Fatigue Strength

3.5.4.7. For fatigue strength by hot spot stress (FE) approach, the dynamic tank pressure amplitudes due to vertical, transverse and longitudinal accelerations, illustrated in Figure 2.1.17 are to be taken as:

$P_{in-v} = \rho a_v(z_0 - z)$ in kN/m^2

$P_{in-t} = f_{ull-t}\rho a_t(y_0 - y)$ in kN/m^2

$P_{in-l} = f_{ull-lng}\rho a_{lng}(x_0 - x)$

where:

ρ = density of liquid in the tank, in tonnes/m^3, and is not to be taken as less than:

0.9 for cargo tanks

1.025 otherwise,

See Chapter 1 Section 2/3.1.8

f_{ull-t} = factor to account for ullage in cargo tanks, as defined in 3.5.4.5

$f_{ull-lng}$ = factor to account for ullage in cargo tanks, as defined in 3.5.4.5

x = longitudinal coordinate of load point, in m

y = transverse coordinate of load point, in m

z = vertical coordinate of load point, in m

x_0 = longitudinal coordinate of reference point, and is to be taken as the middle of the tank length at the top of the tank, in m

y_0= transverse coordinate of reference point, and is to be taken as the middle of the tank breadth at the top of the tank, in m

z_0= vertical coordinate of reference point, and is to be taken as the highest point in the tank, in m

a_v= envelope vertical acceleration, in m/s^2, as defined in 3.3.3.1, at tank centre of gravity

a_t = envelope transverse acceleration, in m/s^2, as defined in 3.3.4.1, at tank centre of gravity

a_{lng}= envelope longitudinal acceleration, in m/s^2, as defined in 3.3.5.1, at tank centre of gravity

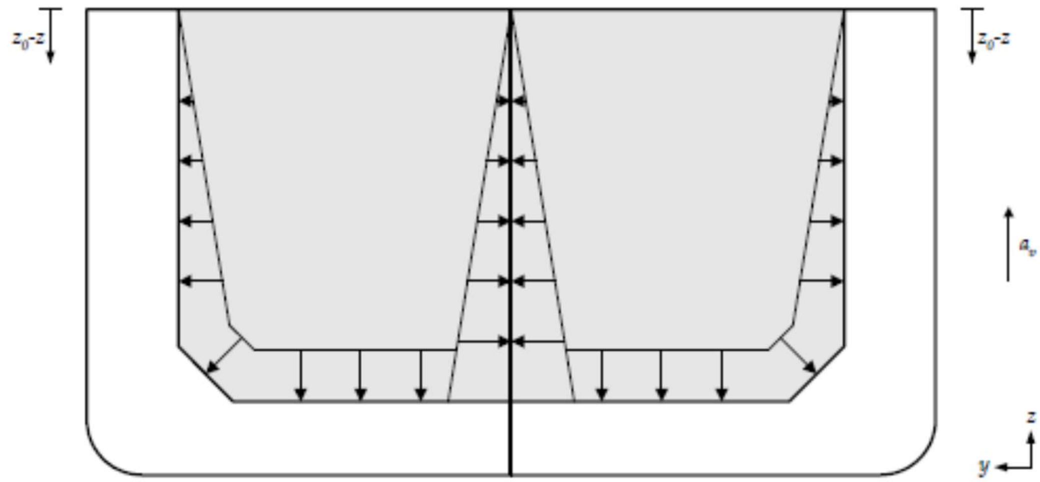


Figure 2.1.17(a): Dynamic Tank Pressure due to Vertical Acceleration for Fatigue Strength

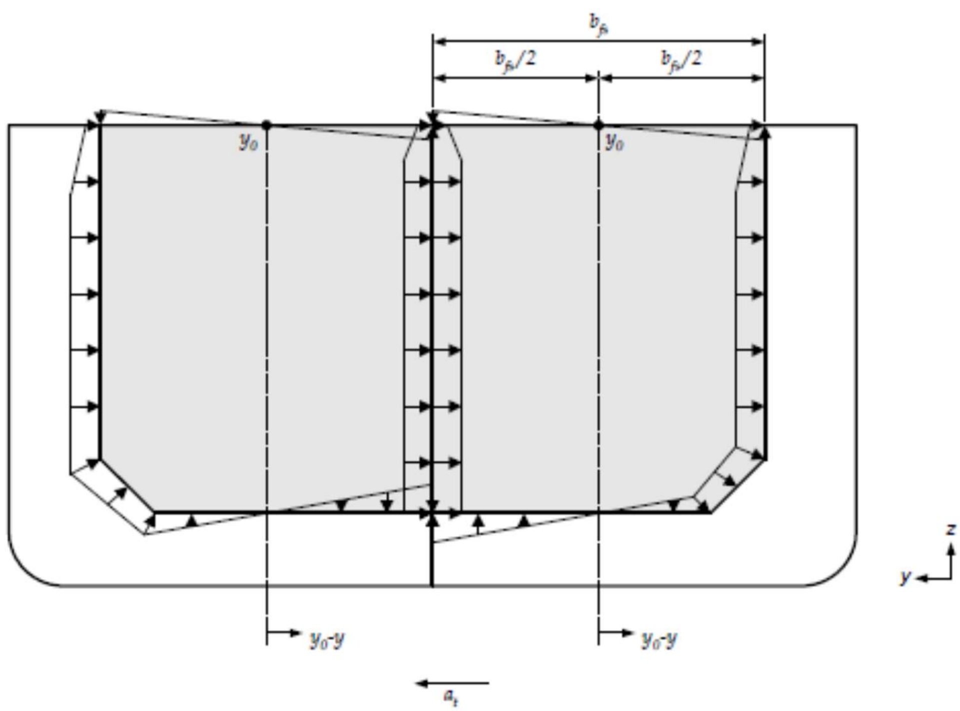


Figure 2.1.17(b): Dynamic Tank Pressure due to Transverse Acceleration for Fatigue Strength

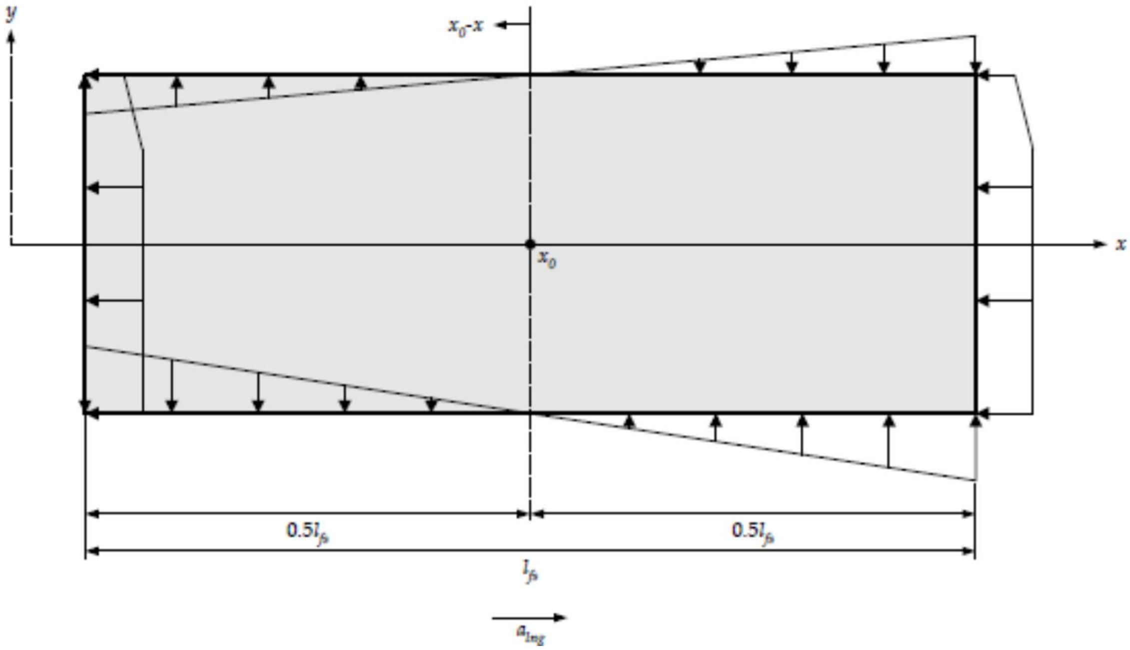


Figure 2.1.17(c): Dynamic Tank Pressure due to Longitudinal Acceleration for Fatigue Strength Illustrated for a Cargo Tank

3.5.5. Dynamic deck pressure from distributed loading

3.5.5.1. The envelope dynamic deck pressure, $P_{deck\text{-}dyn}$, on decks, inner bottom and hatch covers is to be taken as:

$$P_{deck-dyn} = P_{deck}\frac{a_v}{g} \text{kN/m}^2$$

where:

a_v= envelope vertical acceleration, in m/s^2, as defined in 3.3.3.1

P_{deck}= uniformly distributed pressure on lower decks and decks within superstructure, in kN/m^2, as defined in 2.2.4.1

g = acceleration due to gravity, 9.81 m/s^2

3.5.6. Dynamic loads from heavy units

3.5.6.1. The envelope dynamic deck loads, F_v, F_t, F_{lng} acting vertically, transversely and longitudinally on supporting structures and securing systems for heavy units of cargo, equipment or structural components are to be taken as:

$$F_v = m_{un}a_v \text{kN}$$
$$F_t = m_{un}a_t \text{kN}$$
$$F_{lng} = m_{un}a_{lng} \text{ kN}$$

where:

m_{un} = mass of unit, in tonnes

a_v= envelope vertical acceleration, in m/s^2, as defined in 3.3.3.1, at centre of gravity of considered unit

a_t= envelope transverse acceleration, in m/s^2, as defined in 3.3.4.1, at centre of gravity of considered unit

a_{lng} envelope longitudinal acceleration, in m/s^2, as defined in 3.3.5.1, at centre of gravity of considered unit

4. Sloshing and Impact Loads

4.1. General

4.1.1. Load Components

4.1.1.1. Sloshing pressures in tanks, and bow impact and bottom slamming pressures are given in this subsection.

4.2. Sloshing Pressure in Tanks

4.2.1. Application and limitations

4.2.1.1. The sloshing pressures given in 4.2.2 to 4.2.4 are pressures induced by free movement of the tank liquids as a result of ship motions.

4.2.1.2. The given pressures do not include the effect of impact pressures due to high velocity impacts with tank boundaries or internal structures. For tanks with a maximum effective sloshing breadth, b_{slh}, greater than 0.56B or a maximum effective sloshing length, l_{slh}, greater than 0.13L at any filling height from $0.05h_{max}$ to $0.95h_{max}$, an additional impact assessment is to be carried out in accordance with IRS procedures. The effective sloshing lengths and breadths, l_{slh} and b_{slh}, are calculated using the equations in 4.2.2.1 and 4.2.3.1 respectively.

4.2.2. Sloshing pressure due to longitudinal liquid motion

4.2.2.1. The sloshing pressure in way of transverse tight and wash bulkheads due to longitudinal liquid motion, $P_{slh\text{-}lng}$, for a particular filling height, is to be taken as:

$$P_{slh-l} \quad = \rho g \; _{slh} f_{sl} \; \left[0.4 - \left(0.39 - \frac{1.7 l_{sl}}{L}\right)\frac{L}{350}\right] \text{kN/m}^2$$

where:

$\boldsymbol{\rho}$ = density of liquid in the tank, in tonnes/m3, and is not to be taken as less than 1.025

l_{slh}= effective sloshing length, at considered filling height as given in 4.2.2.3 and 4.2.2.4 for transverse tight bulkheads and transverse wash bulkheads respectively, in m

$$f_{slh} = 1 - 2\left(0.7 - \frac{h_{fill}}{h_{max}}\right)^2$$

L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1

h_{fill}= filling height, measured from inner bottom, in m, see Figure 2.1.18

h_{max}= maximum tank height excluding small hatchways, measured from inner bottom, in m, see Figure 2.1.18

g = acceleration due to gravity, 9.81 m/s^2

4.2.2.2. The sloshing pressure due to longitudinal liquid motion, $P_{slh\text{-}lng}$, is to be taken as a constant value over the full tank depth and is to be taken as the greater of the sloshing pressures calculated for filling heights from $0.05h_{max}$ to $0.95h_{max}$, in $0.05h_{max}$ increments.

4.2.2.3. For calculation of sloshing pressures in way of transverse tight bulkheads, the effective sloshing length, l_{slh}, is to be taken as:

$$l_{sl} = \frac{(1+n_{wash-}\ \alpha_{wash-t})(1+f_{wf}\alpha_{wf})l_{tk-h}}{(1+n_{wash-}\ )(1+f_{wf})}\text{m}$$

where:

n_{wash-t} = number of transverse wash bulkheads in the tank

α_{wash-t} = transverse wash bulkhead coefficient,

$$\frac{A_{opn-wash-t}}{A_{tk-t-h}}$$

See Figure 2.1.18

α_{wf}= transverse web frame coefficient,

$$\frac{A_{opn-wf-h}}{A_{tk-t-}}$$

See Figure 2.1.19

For tanks with changing shape along the length and/or with web frames of different shape the transverse web frame coefficient,α_{wf}, may be taken as the weighted average of all web frame locations in the tank given as

$$= \frac{\sum_{i=1}^{n} \frac{A_{opn-wf-h-i}}{A_{tk-t-h-i}}}{n_{wf}}$$

$A_{opn-wash-t}$= total area of openings in the transverse section in way of the wash bulkhead below the considered filling height, in m^2

A_{tk-t-h} = total transversecross sectional area of the tank below the considered filling height, in m^2

$A_{opn-wf-h}$= the total area of openings in the transverse section in way of the web frame below the considered filling height, in m^2

f_{wf}= factor to account for number of transverse web frames and transverse wash bulkheads in the tank:

$$= n_{wf}/(1 + n_{wash-t})$$

n_{wf}= number of transverse web frames, excluding wash bulkheads, in the tank

l_{tk-h} = length of cargo tank, at considered filling height, in m

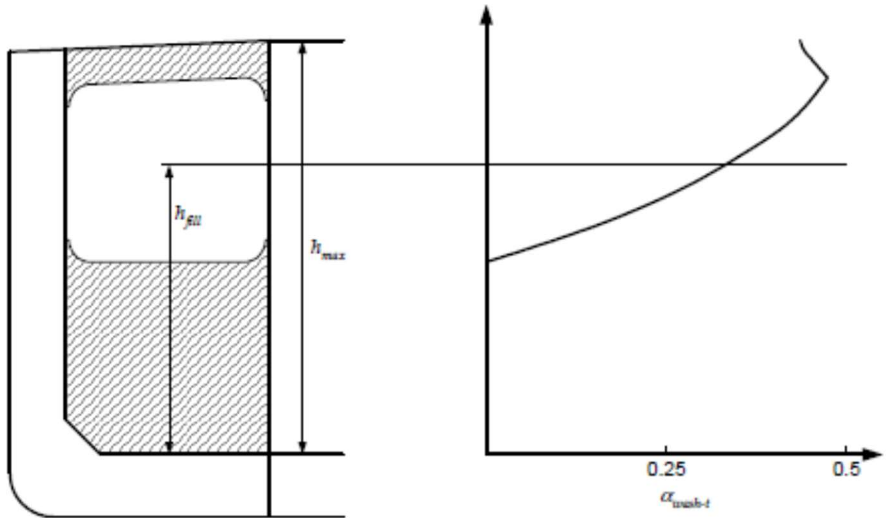


Figure 2.1.18: Transverse Wash Bulkhead Coefficient

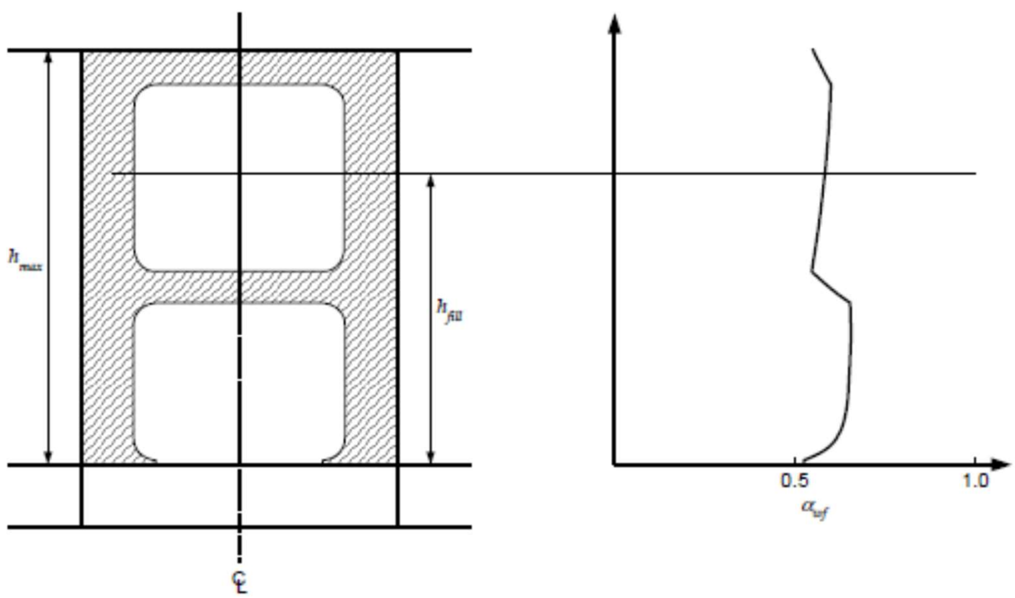


Figure 2.1.19: Transverse Web Frame Coefficient

4.2.2.4. For calculation of sloshing pressures in way of transverse wash bulkheads, the effective sloshing length, l_{slh}, is to be taken as:

$$l_{slh} = \frac{[1+(n_{wash-}\ -1)\alpha_{wash-}\ ](1+f_{wf}\alpha_{wf})l_{tk-h}}{(1+n_{wash-}\ )(1+f_{wf})}\ \mathrm{m}$$

where:

n_{wash-t} = number of transverse wash bulkheads in the tank

α_{wash-t} = transverse wash bulkhead coefficient,

$$= \frac{A_{opn-wash-t}}{A_{tk-t-}}$$

See Figure 2.1.18

α_{wf} = transverse web frame coefficient,

$$= \frac{A_{opn-wf-h}}{A_{tk-t-}}$$

See Figure 2.1.19

For tanks with changing shape along the length and/or with web frames of different shape the transverse web frame coefficient, α_{wf}, may be taken as the weighted average of all web frame locations in the tank given as

$$= \frac{\sum_{i=1}^{n} \frac{A_{opn-wf-h-i}}{A_{tk-t-h-i}}}{n_{wf}}$$

$A_{opn-wash-t}$ = the total area of openings in the transverse section in way of the wash bulkhead below theconsidered filling height, in m^2

A_{tk-t-h} = total transverse cross sectional area of the tank below the considered filling height, in m^2

$A_{opn-wf-h}$= the total area of openings in the transverse section in way of the web frame below the considered filling height, in m^2

f_{wf}= factor to account for number of transverse web frames and transverse wash bulkheads in the tank:

$$= n_{wf}/(1 + n_{wash-t})$$

n_{wf} = number of transverse web frames, excluding wash bulkheads, in the tank

l_{tk-h} = length of cargo tank, at considered filling height, in m

4.2.2.5. For tanks with internal web frames the sloshing pressure acting on a web frame adjacent to atransverse tight or wash bulkhead, P_{slh-wf}, provided it is located within 0.25 l_{slh} from the bulkhead, is to betaken as:

$$P_{slh-wf} = P_{slh-l} \quad \left(1 - \frac{s_{wf}}{l_{sl}}\right)^{\mathbf{2}} \text{kN/m}^2$$

where:

$P_{slh-lng}$ = sloshing pressure acting on bulkhead due to longitudinal liquid motion, as given in 4.2.2.1

s_{wf} = distance from bulkhead to web frame under consideration, in m

l_{slh}= effective sloshing length, at considered filling height as defined in 4.2.2.3 and 4.2.2.4 fortransverse tight and wash bulkheads respectively, in m

The distribution of pressure across the web frame is given in Figure 2.1.20.

4.2.2.6. For tanks with internal bulkhead stringers and/or web frames, the distribution of sloshing pressure,P_{slh}, across these members is shown in Figure 2.1.20.

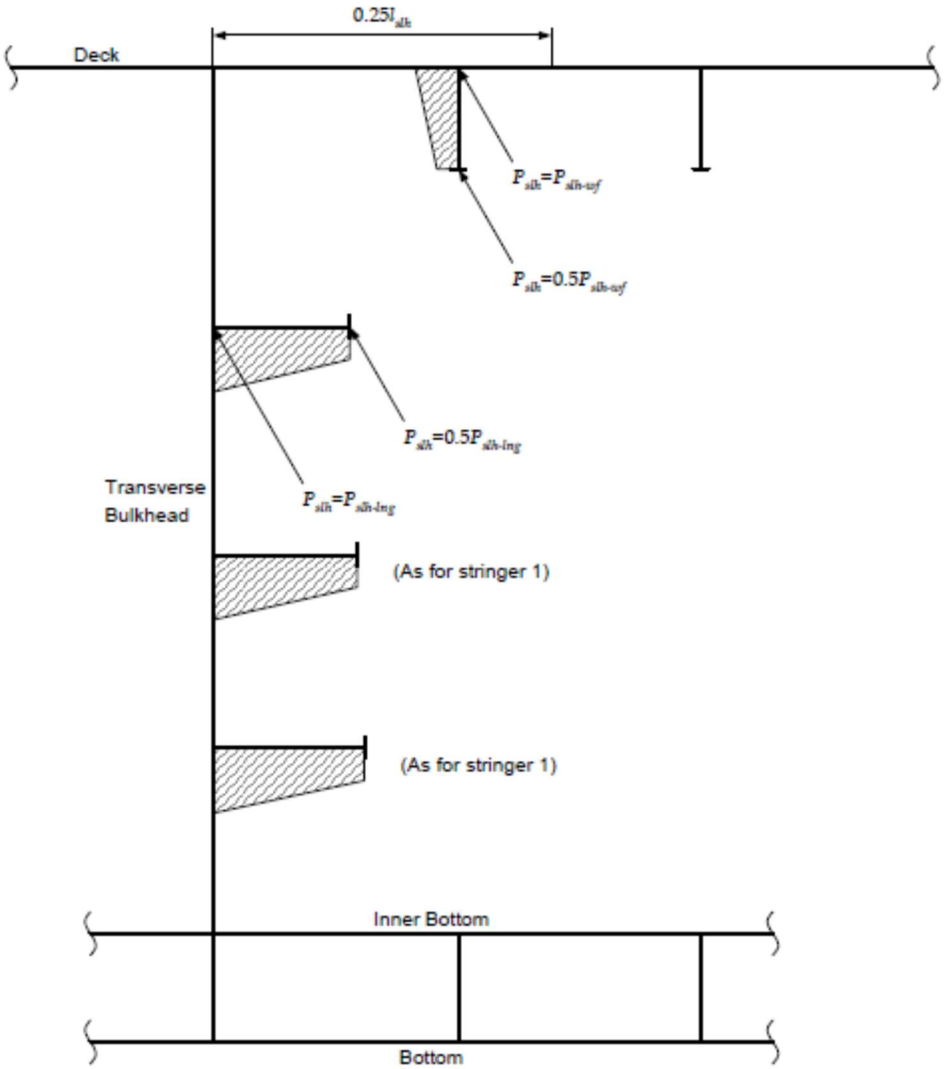


Figure 2.1.20: Sloshing Pressure Distribution on Stringers and Web Frames

4.2.3. Sloshing pressure due to transverse liquid motion

4.2.3.1. The sloshing pressure in way of longitudinal tight and wash bulkheads due to transverse liquid motion, P_{slh-t}, for a particular filling height, is to be taken as

$$P_{slh-t} = 7\rho g \ _{slh}\left(\frac{b_{slb}}{B} - 0.3\right) GM^{0.75} \text{kN/m}^2$$

where:

$\boldsymbol{\rho}$ = density of liquid in the tank, in tonnes/m^3, and is not to be taken as less than 1.025

b_{slh}= effective sloshing breadth, see 4.2.3.3 and 4.2.3.4 for longitudinal tight bulkheads and longitudinal wash bulkheads respectively, not to be taken less than 0.3B, in m.

GM = metacentric height, is to be taken as 0.33B for calculation of sloshing pressures in ballast tanks and0.24B for calculation of sloshing pressure in cargo tanks

$$f_{sl} = 1 - 2\left(0.7 - \frac{h_{fill}}{h_{max}}\right)^2$$

B moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.1

h_{fill} = filling height, measured from inner bottom, in m, see Figure 2.1.18

h_{max}= maximum tank height excluding small hatchways, measured from inner bottom, in m, see Figure 2.1.18

g = acceleration due to gravity, 9.81m/s^2

4.2.3.2. The sloshing pressure due to transverse liquid motion, P_{slh-t}, is to be taken as a constant value over thefull tank depth and is to be taken as the greater of the sloshing pressures calculated for filling heights from $0.05h_{max}$ to $0.95h_{max}$, in $0.05h_{max}$ increments.

4.2.3.3. For calculation of sloshing pressures in way of longitudinal tight bulkheads the effective sloshing breadth, bslh, is to be taken as:

$$b_{slh} = \frac{(1+n_{wash-lng}\alpha_{wash-lng})(1+f_{grd}\alpha_{grd})b_{tk-h}}{(1+n_{wash-lng})(1+f_{grd})} \text{m}$$

where:

$n_{wash-lng}$ = number of longitudinal wash bulkheads in the tank

$\alpha_{wash-lng}$ = longitudinal wash bulkhead coefficient

$$= \frac{A_{opn-wash-ln}}{A_{tk-lng-h}}$$

α_{grd}= girder coefficient

$$= \frac{A_{opn-grd-h}}{A_{tk-lng-h}}$$

$A_{opn-wash-lng}$ = total area of openings in the longitudinal section in way of the wash bulkhead below theconsidered filling height, in m^2

$A_{tk-lng-h}$= total longitudinal cross sectional area of the tank below the considered filling height, in m^2

$A_{opn-grd-h}$ = total area of openings in the longitudinal section below the considered filling height, in m^2

f_{grd}= factor to account for longitudinal girders and longitudinal wash bulkheads in the tank:

$$= n_{grd}/(1 + n_{wash-lng})$$

n_{grd}= number of longitudinal girders, excluding longitudinal wash bulkheads, in the tank

b_{tk-h}= tank breadth at considered filling height, in m

4.2.3.4. For calculation of sloshing pressures in way of longitudinal wash bulkheads the effective sloshingbreadth, b_{slh}, is to be taken as:

$$b_{slh} = \frac{\left(1 + \left(n_{wash-lng} - 1\right)\alpha_{wash-lng}\right)\left(1 + f_{grd}\alpha_{grd}\right)b_{tk-}}{\left(1 + n_{wash-lng}\right)\left(1 + f_{grd}\right)} \quad m$$

where:

$n_{wash-lng}$ = number of longitudinal wash bulkheads in the tank

$\alpha_{wash-lng}$ = longitudinal wash bulkhead coefficient

$$= \frac{A_{opn-grd-ln}}{A_{tk-lng-h}}$$

α_{grd} = girder coefficient

$$= \frac{A_{opn-grd-h}}{A_{tk-lng-h}}$$

$A_{opn-wash-lng}$ = total area of openings in the longitudinal section in way of the wash bulkhead below the considered filling height, in m^2

$A_{tk-lng-h}$ = total longitudinal cross sectional area of the tank below the considered filling height, in m^2

$A_{opn-grd-h}$ = total area of openings in the longitudinal section below the considered filling height, in m^2

f_{grd}= factor to account for longitudinal girders and longitudinal wash bulkheads in the tank:

$$= n_{grd}/\left(1 + n_{wash-lng}\right)$$

n_{grd}= number of longitudinal girders, excluding longitudinal wash bulkheads, in the tank

b_{tk-h} = tank breadth at considered filling height, in m

4.2.3.5. For tanks with internal longitudinal girders or webframes, the sloshing pressure on the girder/ web frame adjacent to a longitudinal wash bulkhead, $P_{slh-grd}$, provided it is located within 0.25b_{slh} from the bulkhead, is to be taken as:

$P_{slh-g} \quad = P_{slh-t}\left(1 - \frac{s_{grd}}{b_{slh}}\right)^2$ kN/m^2

where:

P_{slh-t} = sloshing pressure acting on bulkhead due to transverse liquid motion, in kN/m^2, see 4.2.3.1

s_{grd}= distance from longitudinal bulkhead to longitudinal girder being considered, in m

b_{slh}= effective sloshing breadth, see 4.2.3.3 and 4.2.3.4 for longitudinal tight bulkheads and longitudinal wash bulkheads respectively, in m

4.2.3.6. For tanks with internal longitudinal stringers and or girders/webframes, the distribution of sloshingpressure across these members is shown in Figure 2.1.21.

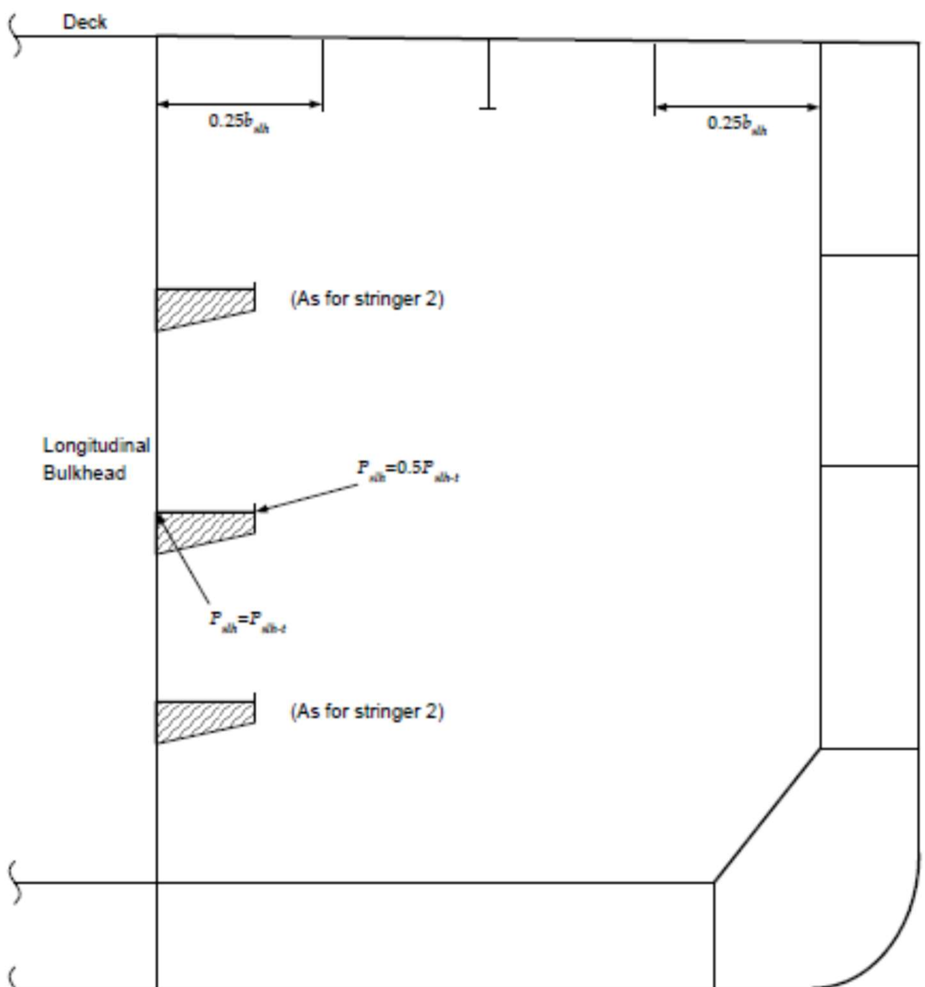


Figure 2.1.21: Pressure Distribution on Stringers and Longitudinal Girders

4.2.4. Minimum sloshing pressure

4.2.4.1. The minimum sloshing pressure, $P_{slh-min}$, in cargo and ballast tanks except tanks of cellular construction is to be taken as 20kN/m^2.

4.2.4.2. The minimum sloshing pressure, $P_{slh-min}$, in cellular construction ballast tanks is to be taken as 12kN/m^2.

4.3. Bottom Slamming Loads

4.3.1. Application and limitations

4.3.1.1. The slamming loads in this section apply to ships with Cb ≥0.7 and bottom slamming draught ≥0.01L and ≤0.045L.

4.3.2. Slamming pressure

4.3.2.1. The bottom slamming pressure, P_{slm}, is to be taken as the greater of:

$$P_{slm-m} = f_{slm} 130 g c_{slm-mt} e^{c1}$$

For empty ballast tanks

$$P_{slm-full} = f_{slm}\, 130 g c_{slm-full} e^{c1} - c_{av} \rho g z_{ball}$$

For full ballast tanks

where:

g = acceleration due to gravity, 9.81 m/s^2

f_{slm}= longitudinal slamming distribution factor, see Figure degrees 2, is to be taken as:

0 at 0.5L

1 at$[0.175 \ - 0.5(C_{bl} - 0.7)]$ L from F.P

1 at $[0.1 \ - 0.5(C_{bl} - 0.7)]$ L from F.P

0.5 at, and forward of F.P.

Intermediate values to be obtained by linear interpolation

C_{bl}= block coefficient, C_b, as defined in Chapter 1 Section 4/1.1.9.1, but not to be taken less than 0.7 or greater than 0.8

c_{slm-mt} = slamming coefficient for empty ballast tanks

$$= 5.95 - 10.5\left(\frac{T_{Fp-m}}{L}\right)^{0.2}$$

$c_{slm-full}$ = slamming coefficient for full ballast tanks

$$= 5.95 - 10.5\left(\frac{T_{Fp-full}}{L}\right)^{0.2}$$

c_1 is to be taken as:

0 for L ≤ 180m

$= -0.0125(L \ - \ 180)^{0.705}$for L > 180m

T_{FP-mt} =design slamming ballast draught at F.P. with ballast tanks within the bottom slamming regionempty as defined in 4.3.2.3, in m

$T_{FP-full}$ = design slamming ballast draught at F.P. with ballast tanks within the bottom slamming region fullas defined in 4.3.2.4, in m

c_{av}= dynamic load coefficient, to be taken as 1.25

L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1

z_{ball}= vertical distance from tank top to load point, in m

4.3.2.2. The design slamming draughts T_{FP-mt} and $T_{FP-full}$ is to be provided by the designer.

4.3.2.3. Wherein the ballast tanks within the bottom slamming region are empty,the design slamming draught at the F.P., T_{FP-mt}, is not to be greater than the minimum draught at theF.P. indicated in the loading manual for all seagoing conditions. This includes any loading conditions with tanks inside the bottom slamming region that use the “sequential” ballast water exchange method.

4.3.2.4. Wherein the ballast tanks within the bottom slamming region are full, the design slamming draught at the F.P., $T_{FP-full}$, is not to be greater than the minimum draught at theF.P. indicated in the loading manual for any seagoing conditions. Any loading condition with tanks inside the bottom slamming region that use the “flow-through” ballast water exchange method is included in it.

4.3.2.5. The loading guidance information is for the clear indication of the design slamming draughts and the ballastwater exchange method used for each ballast tank see Chapter 2 Section 2/1.1.

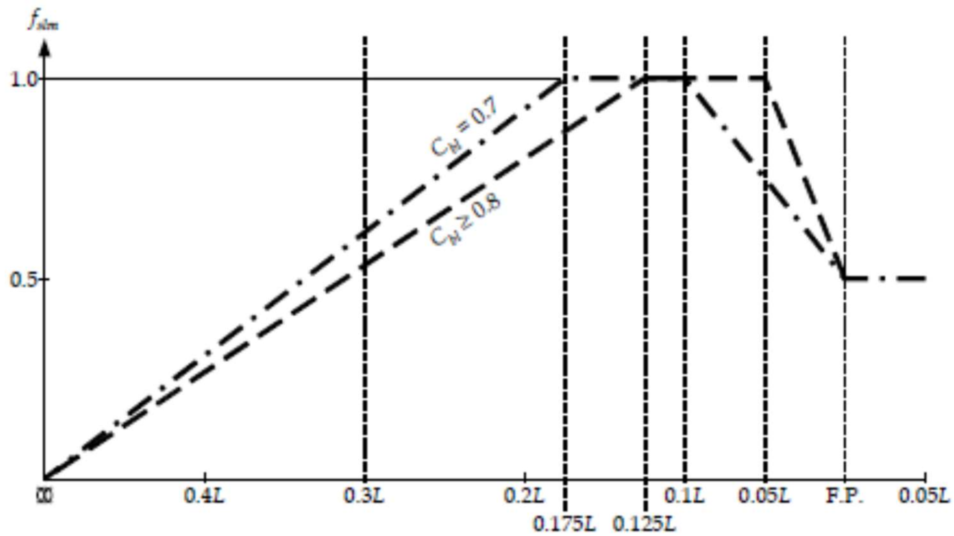


Figure 2.1.22: Longitudinal Distribution of Slamming Pressure

4.4. Bow Impact Loads

4.4.1. Application and limitations

4.4.1.1. The bow impact pressure applies to the side structure in the area forward of 0.1L aft of F.P. and between the waterline at draught T_{bal} and the highest deck at side.

4.4.2. Bow impact pressure

4.4.2.1. The bow impact pressure, P_{im}, is to be taken as:

$$P_{im} = 1.025\, f_{im} c_{im} V_{im}^{\ 2} \sin \gamma_{wl} \text{ kN/m}^2$$

where:

f_{im}= 0.55 at 0.1L aft of F.P.

= 0.9 at 0.0125L aft of F.P.

= 1.0 at and forward of F.P.

Intermediate values to be obtained by linear interpolation

V_{im} impact speed, in m/s

$$= 0.514 V_{fwd} \sin \alpha_{wl} + \sqrt{L}$$

V_{fwd}= forward speed, in knots

= 0.75V but is not to be taken as less than 10

V service speed, in knots, as defined in Chapter 1 Section 4/1.1.8.1

α_{wl}= local waterline angle at the position considered, but is not to be taken as less than 35^0, see Figure 2.1.23.

γ_{wl} = local bow impact angle measured normal to the shell from the horizontal to the tangent line at the position considered but is not to be less than 50^0, see Figure 2.1.23.

c_{im} = 1.0 for positions between draughts T_{bal} and T_{sc}

$$= \sqrt{1 + \cos^2 \left[90 \frac{(h_{fb} - 2h_0)}{h_{fb}} \right]}$$

For positions above draught T_{sc}

h_{fb}= vertical distance from the waterline at draught T_{sc} to the highest deck at side, see Figure 2.1.23, in m

h_o= vertical distance from the waterline at draught T_{sc}, to the position considered, see Figure 2.1.23 in m

L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1

T_{sc} = scantling draught, in m, as defined in Chapter 1 Section 4/1.1.5.5

T_{bal}= minimum design ballast draught, in m, for the normal ballast condition as defined in Chapter 1 Section 4/1.1.5.2

WL_j = waterline at the position considered, see Figure 2.1.23

note:

Where local bow impact angle measured normal to the shell, γ_{wl}, is not available, this angle may be taken as:

$$\gamma_{wl} = \tan^{-1} \left(\frac{\tan \beta_{pl}}{\cos \alpha_{wl}} \right)$$

where

β_{pl}= local body plan angle at the position considered from the horizontal to the tangent line, but is not to be less than 35°

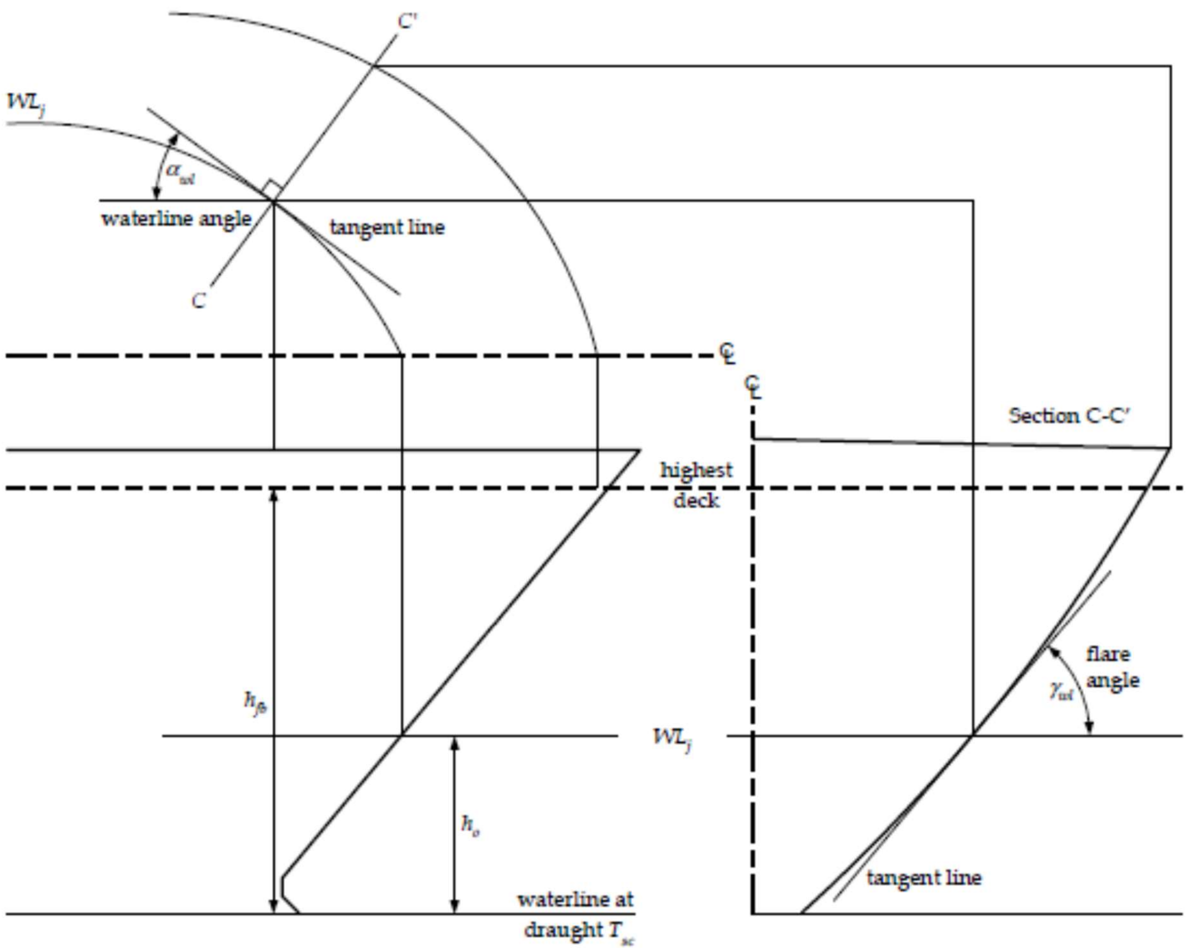


Figure 2.1.23: Definition of Bow Geometry

5. Accidental Loads

5.1. Flooded Condition

5.1.1. Local Pressure

5.1.1.1. The pressure in compartments and tanks in flooded condition or damaged condition is to be taken as $P_{in\text{-}flood}$, see 2.2.3.4.

6. Combination of Loads

6.1. General

6.1.1. Application

6.1.1.1. The design load combinations S, S + D, and A are to be used for scantling calculations for the scantling requirements and strength assessment (by FEM). Design load combinations are defined in Chapter 1 Section 2/4.2.2 and the relevant loads and load combination are to be taken as given in 6.2.

6.1.1.2. The dynamic loads, D, consist of several dynamic load cases. For each dynamic load case, theenvelope load values as given in Sub-Section 3 are multiplied with dynamic load combination factors to givesimultaneously acting dynamic loads. The procedures for calculating the simultaneously acting dynamic loadsare given in 6.3. The dynamic load combination factors are given in 6.4 for strength assessment (by FEM) andin 6.5 for scantling requirements.

6.2. Design Load Combination

6.2.1. General

6.2.1.1. The design load combinations are given in Table 2.1.3.

Table 2.1.3: Design Load Combinations

Design Load Combination / Load components		S	S + D	A
$M_{v\text{-}total}$		$M_{sw\text{-}harb}$	$M_{sw\text{-}sea} + M_{wv}$	-
$M_{h\text{-}total}$		-	M_h	-
Q		$Q_{sw\text{-}harb}$	$Q_{sw\text{-}sea} + Q_{wv}$	-
P_{ex}	Weather Deck	-	$P_{wdk\text{-}dyn}$	-
	Hull envelope	P_{hys}	$P_{hys} + P_{wv\text{-}dyn}$	-
P_{in}	Ballast tanks (BWE with sequential filling method)	the greater of a) $P_{in\text{-}test}$ b) $P_{in\text{-}air} + P_{drop}$	$P_{in\text{-}tk} + P_{in\text{-}dyn}$	$P_{in\text{-}flood}$
	Ballast tanks (BWE with flow-through method)	the greater of a) $P_{in\text{-}test}$ b) $P_{in\text{-}air} + P_{drop}$	$P_{in\text{-}air} + P_{drop} + P_{in\text{-}dyn}$	$P_{in\text{-}flood}$
	Cargo tanks including cargo tanks designed for filling with water ballast	the greater of a) $P_{in\text{-}test}$ b) $P_{in\text{-}tk} + P_{valve}$	$P_{in\text{-}tk} + P_{in\text{-}dyn}$	
	Other tanks with liquid filling	the greater of a) $P_{in\text{-}test}$ b) $P_{in\text{-}air}$	$P_{in\text{-}tk} + P_{in\text{-}dyn}$	$P_{in\text{-}flood}$
	Watertight boundaries		-	$P_{in\text{-}flood}$
P_{dk}	Internal decks for dry spaces	P_{stat}	$P_{stat} + P_{dk\text{-}dyn}$	-
	Decks for heavy units	F_{stat}	$F_{stat} + F_{dk\text{-}dyn}$	-

Note:
1. Separate load requirements may be specified in strength assessment (FEM) and scantling requirements

where:

$M_{v\text{-}total}$ design vertical bending moment, in kNm

$M_{sw\text{-}perm\text{-}harb}$ permissible hull girder hogging and sagging still water bending moment envelopes for harbour/sheltered water operation, in kNm see 2.1.1

$M_{sw\text{-}perm\text{-}sea}$ permissible hull girder hogging and sagging still water bending moment envelopes for seagoing operation, in kNm see 2.1.1

M_{wv} vertical wave bending moment for a considered dynamic load case, in kNm see 6.3.2.1

$M_{h\text{-}total}$ design horizontal bending moment, in kNm

M_h horizontal wave bending moment for a considered dynamic load case, in kNm see 6.3.3.1

Q design vertical shear force, in kN

$Q_{sw\text{-}perm\text{-}harb}$ permissible hull girder positive and negative still water shear force limits for harbour/ sheltered water operation, in KNsee 2.1.3

$Q_{sw\text{-}perm\text{-}sea}$ permissible hull girder positive and negative still water shear force limits for seagoing operation, in kN see 2.1.3

Q_{wv} vertical wave shear force for a considered dynamic load case, in kN see 6.3.4.1

P_{ex} design sea pressure, in kN/m^2

P_{hys} static sea pressure at considered draught, in kN/m^2 see 2.2.2.1

$P_{wv\text{-}dyn}$ dynamic wave pressure for a considered dynamic load case, in kN/m^2 see 6.3.5

$P_{wdk-dyn}$ green sea load for a considered dynamic load case, in kN/m^2 see 6.3.6
P_{in} design tank pressure, in kN/m^2
$P_{in-test}$ tank testing pressure, in kN/m^{2}see 2.2.3.5
P_{in-air} static tank pressure in the case of overfilling or filling during flow through ballast water exchange, in kN/m^2 see 2.2.3.2
P_{drop}added overpressure due to liquid flow through air pipe or overflow pipe, in kN/m^2 see 2.2.3.3
P_{valve} setting of pressure relief valve, in kN/m^{2}see 2.2.3.5
P_{in-tk} static tank pressure, in kN/m^{2}see 2.2.3.1
P_{in-dyn} dynamic tank pressure for a considered dynamic load case, in kN/m^{2}see 6.3.7
$P_{in-flood}$ pressure in compartments and tanks in flooded or damaged condition, in kN/m^{2}see 2.2.3.4
P_{stat}static pressure on decks and inner bottom, in kN/m^{2}see 2.2.4.1
P_{dk} design deck pressure, in kN/m^2
P_{dk-dyn} dynamic deck pressure on decks, inner bottom and hatch covers for a considered dynamicsee 6.3.8.1
load case, in kN/m^2
F_{stat} load acting on supporting structures and securing systems for heavy units of cargo, equipment or structural components, in kN see 2.2.5.1
F_{dk-dyn} dynamic load acting on supporting structures and securing systems for heavy units of cargo,
equipment or structural components, in kN see 6.3.8.2

6.3. Application of Dynamic Loads

6.3.1. Heading correction factor and dynamic load combination factors

6.3.1.1. The heading correction factor, f_β, is to be taken as:

f_β = 0.8 for beam sea dynamic load cases

= 1.0 for all other dynamic load cases

6.3.1.2. The dynamic load combination factors used for the calculations of the simultaneously acting dynamic loads are to be taken as given in Table 2.1.4 for strength assessment by FEM, see 6.4. For scantling assessment,dynamic load factorsare to be taken as given in Table 2.1.6 to Table 2.1.11, see 6.5.

6.3.2. Vertical wave bending moment for a considered dynamic load case

6.3.2.1. The simultaneously acting vertical wave bending moment, M_{wv}, is to be taken as:

$M_{wv} = f_\beta f_{mv} M_{wv-ho}$ kN/m^2 for $f_{mv} \geq 0$

$M_{wv} = -f_\beta f_{mv} M_{wv-sag}$kN/m^2 *for* $f_{mv} < 0$

where:

M_{wv-hog} = hogging vertical wave bending moment, in kNm, as defined in 3.4.1.1

M_{wv-sag} = sagging vertical wave bending moment, in kNm, as defined in

f_{mv}= dynamic load combination factor for vertical wave bending moment for considered dynamic load case, see 6.3.1.2

f_β = heading correction factor, as defined in 6.3.1.1

6.3.3. Horizontal wave bending moment for a considered dynamic load case

6.3.3.1. The simultaneously acting horizontal wave bending moment, M_h, is to be taken as:

$M_h = f_\beta f_{mh} M_{wv-h}$kN

where:

M_{wv-h} = horizontal wave bending moment, in kNm, as defined in 3.4.2

f_{mh}= dynamic load combination factor for horizontal wave bending moment for considered dynamic load case, see 6.3.1.2

f_β = heading correction factor, as defined in 6.3.1.1

6.3.4. Vertical wave shear force for a considered dynamic load case

6.3.4.1. The simultaneously acting vertical wave shear force, Q_{wv}, is to be taken as:

$Q_{\ wv} = f_\beta f_{qv} Q_{wv-pos}$kN for $f_{qv} \geq 0$
$Q_{\ wv} = -f_\beta f_{qv} Q_{wv-n}$ kN for $f_{qv} < 0$

where:
Q_{wv-pos} = envelope positive vertical wave shear force, in kN, as defined in 3.4.3
Q_{wv-neg} =envelope negative vertical wave shear force, in kN, as defined in 3.4.3
f_{qv}= dynamic load combination factor for vertical wave shear force for considered dynamic load case, see 6.3.1.2
f_β = heading correction factor, as defined in 6.3.1.1

6.3.5. Dynamic wave pressure distribution for a considered dynamic load case

6.3.5.1. The simultaneously acting dynamic wave pressure, P_{wv-dyn}, for the port and starboard side within the cargo tank region for a considered dynamic load case is to be taken as follows, but not to be less than $-\boldsymbol{\rho}_{swg}(T_{LC}-z)$ below still waterline or less than 0 above still waterline:

$P_{wv-dy} \ = P_{ctr} + \frac{|y|}{0.5B_{local}}\left(P_{bilge} - P_{ctr}\right)$between centreline and start of bilge

$P_{wv-d} \quad = P_{bilge} + \frac{z}{T_{LC}}\left(P_{WL} - P_{bilge}\right)$between end of bilge and still waterline

$P_{wv-dyn} = P_{WL} - 10(z - T_{LC})$for side-shell above still waterline

Intermediate values of P_{wv-dyn} around the bilge are to be obtained by linear interpolation along the vertical distance

where:

P_{ctr} = dynamic wave pressure at bottom centreline, to be taken as:

$= \mathrm{f_{ctr}P_{ex-max}}$ kN/m^2

P_{bilge}= dynamic wave pressure at z = 0 and y = $B_{local}/2$, to be taken as:

$= \mathrm{f}_{bilge}\mathrm{P_{ex-max}}$ kN/m^2

P_{WL} dynamic wave pressure at waterline, to be taken as:

$= \mathrm{f}_{WL}\mathrm{P_{ex-max}}$ kN/m^2

P_{ex-max} envelope maximum dynamic wave pressure, in kN/m^2, as defined in 3.5.2.2

f_{WL}= dynamic load combination factor for dynamic wave pressure at still waterline for considered dynamic load case, see 6.3.1.2

f_{bilge}= dynamic load combination factor for dynamic wave pressure at bilge for considered dynamic load case, see 6.3.1.2

f_{ctr}= dynamic load combination factor for dynamic wave pressure at centreline for considered dynamic load case, see 6.3.1.2

B_{local}= local breadth at waterline for considered draught, in m

T_{LC}= draught in the loading condition being considered, in m

y = transverse coordinate, in m

z = vertical coordinate, in m

ρ_{sw}= density of sea water, 1.025 tonnes/m^3

g = acceleration due to gravity, 9.81m/s^2

6.3.5.2. The simultaneously acting dynamic wave pressure for the port and starboard side outside the cargo region, P_{wv-dyn}, for a considered dynamic load case is to be obtained by linear interpolation between P_{ctr} and P_{WL}, but not to be taken less than $-\rho_{sw}g(T_{LC} - z)$ below still waterline or less than 0 above still waterline

$P_{wv-dy} \quad = P_{ctr} + \frac{z}{T_{LC}}(P_{WL} - P_{ctr})$ between bottom centreline and stillwaterline

$P_{wv-d} \quad = P_{WL} - 10(z - T_{LC})$ above still waterline

where:

P_{ctr}= dynamic wave pressure at bottom centreline, and is to be taken as:

$f_{ctr}P_{ex-m}$ kN/m^2

P_{WL} = dynamic wave pressure at still waterline, and is to be taken as:

$f_{WL}P_{ex-max}$kN/m^2

P_{ex-max} = envelope maximum dynamic wave pressure, in kN/m^2, as defined in 3.5.2.2

f_{WL} = dynamic load combination factor for dynamic wave pressure at still waterline for considered dynamic load case, see 6.3.1.2

f_{ctr}= dynamic load combination factor for dynamic wave pressure at centreline for considered dynamic load case, see 6.3.1.2

T_{LC}=draught in the loading condition being considered, in m

z = vertical coordinate, in m

ρ_{sw}= density of sea water, 1.025 tonnes/m^3

g acceleration due to gravity, 9.81m/s^2

6.3.5.3. Figure 2.1.24 to Figure 2.1.26 illustrates simultaneously acting dynamic wave pressures.

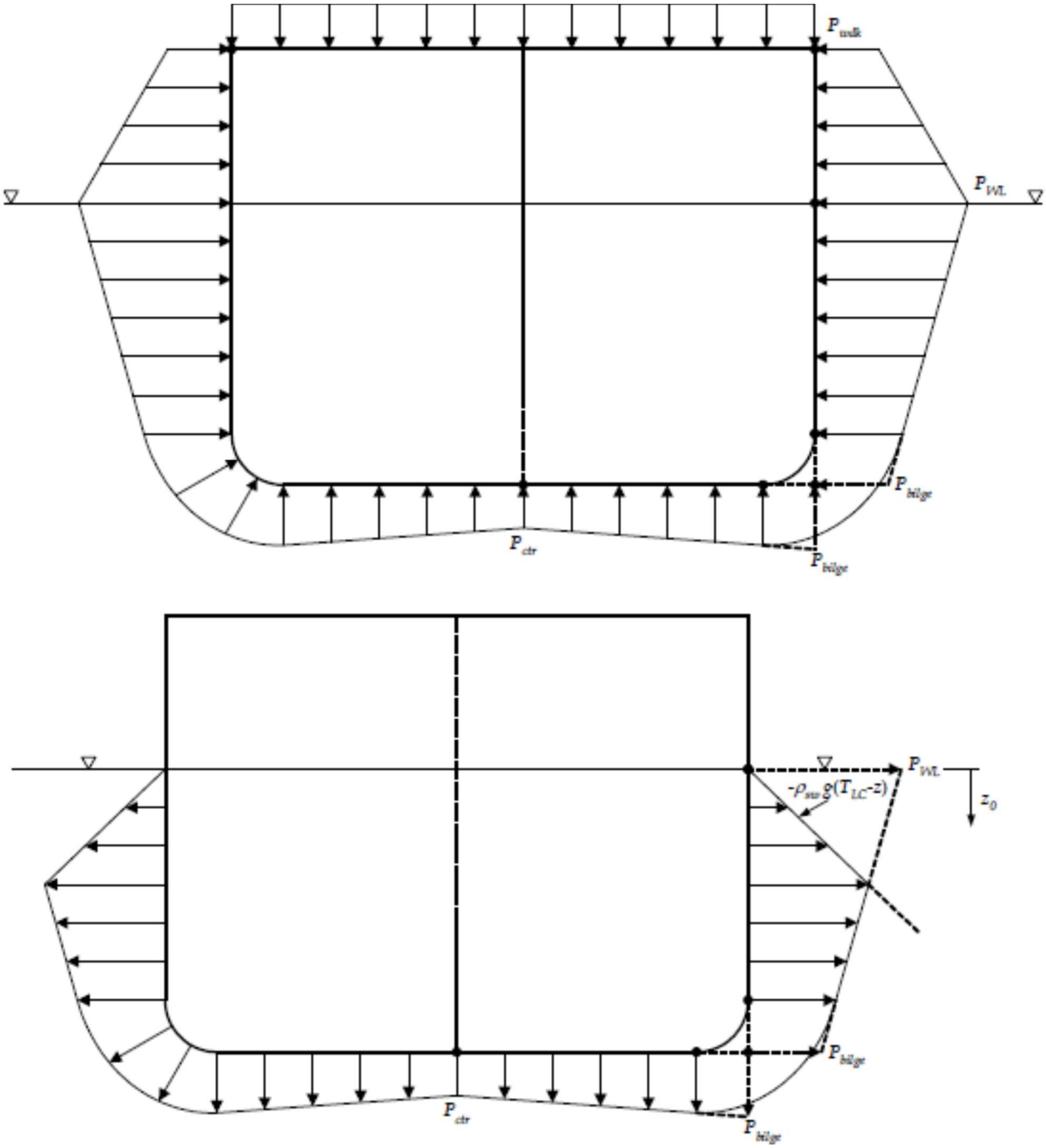


Figure 2.1.24: Dynamic Wave Pressure for Head Sea Dynamic Load Cases

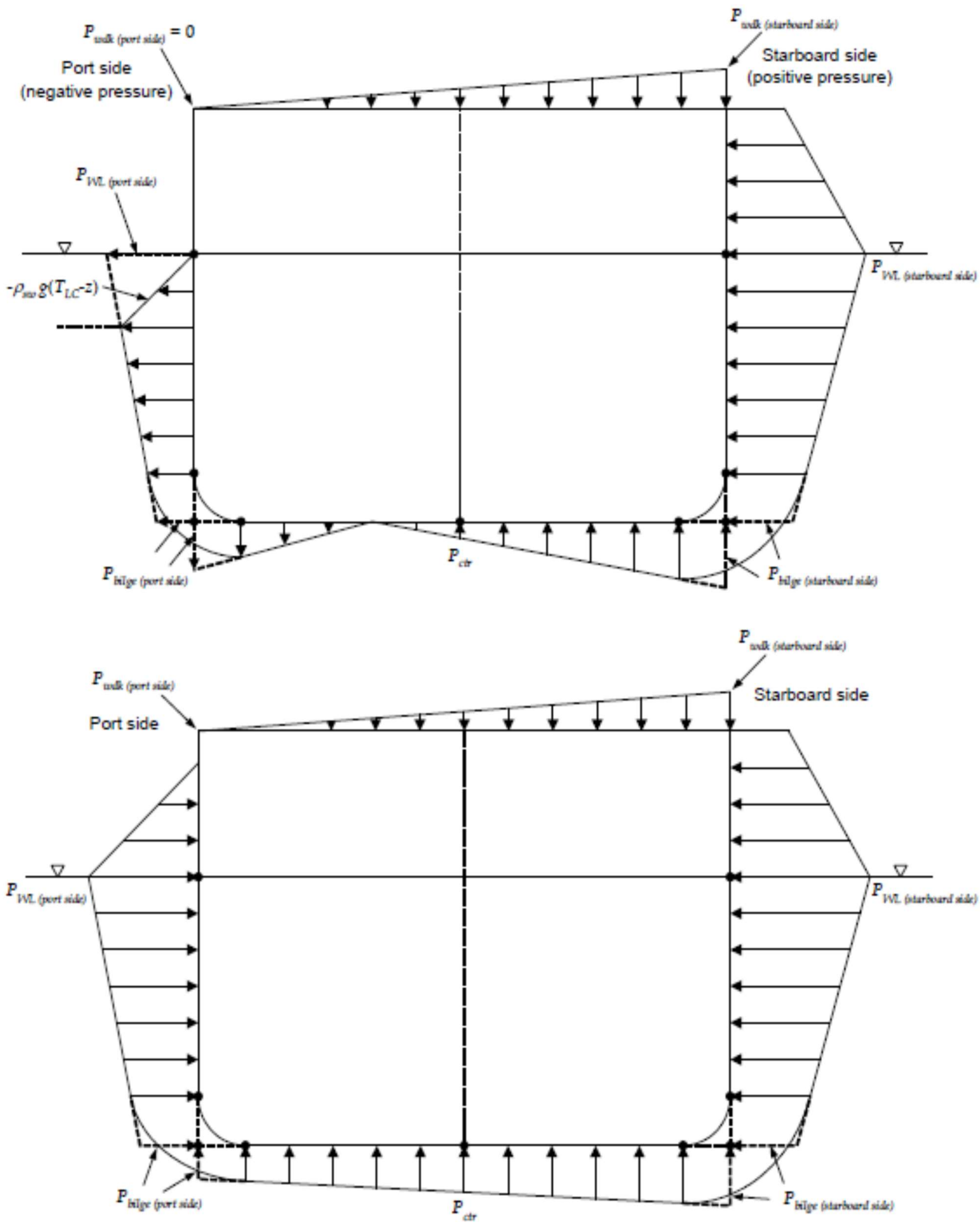


Figure 2.1.25: Dynamic Wave Pressure for Beam and Oblique Sea Dynamic Load Cases

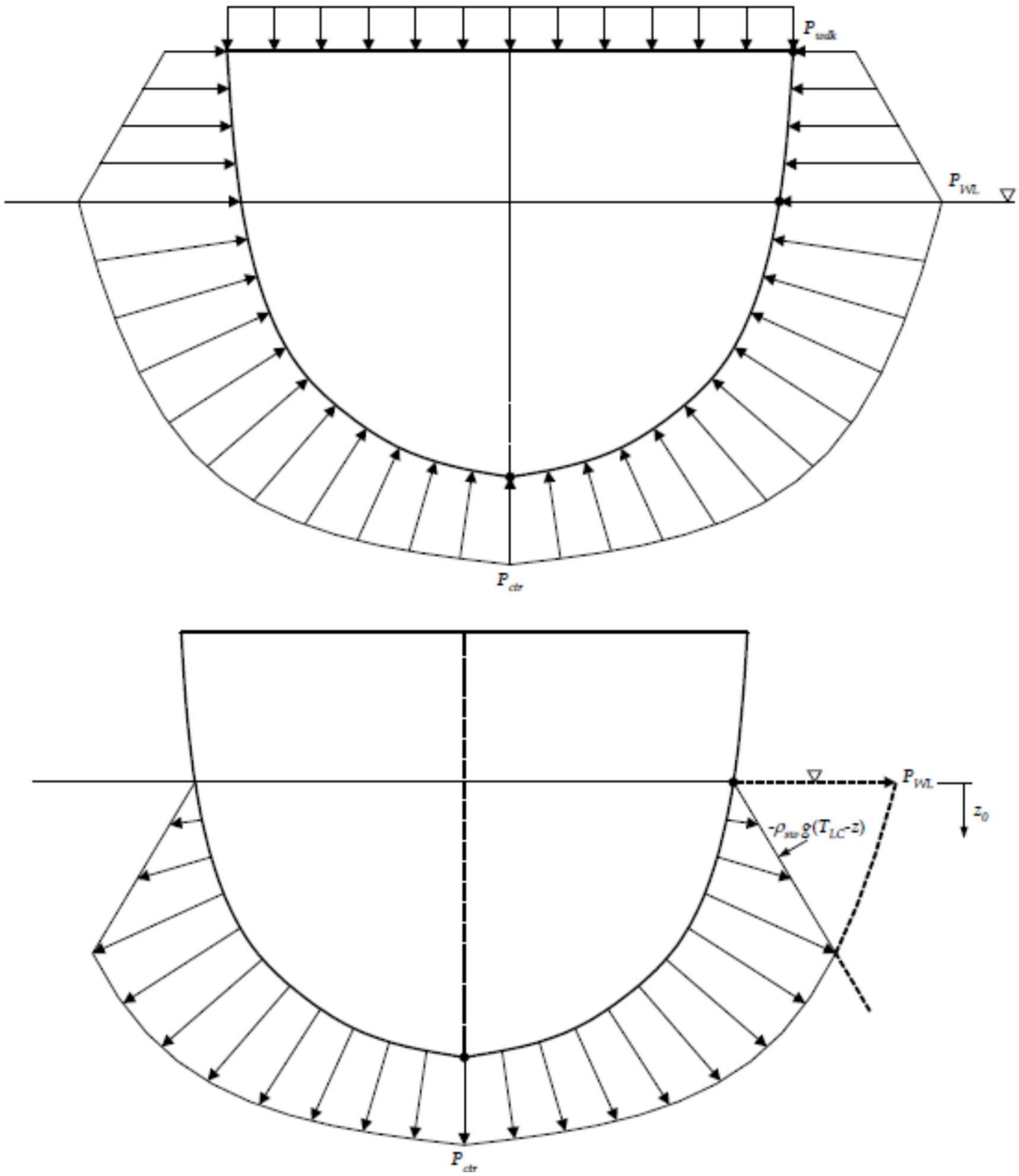


Figure 2.1.26: Pressure Distribution for Wave Crest and Wave Trough for Forward and Aft

6.3.6. Green sea load for a considered dynamic load case

6.3.6.1. The simultaneously acting green sea load on the weather deck, $P_{wdk-dyn}$, for strength assessment is obtained by linear interpolation between P_{wdk-pt} and $P_{wdk-stb}$:

The green sea load at the port side, P_{wdk-pt}, is to be taken as the greater of:

$$P_{wdk-pt} = f_{1-dk}(f_{WL} f_{op} P_{1-WL} - 10 z_{dk-T}) \text{kN/m}^2$$

$$P_{wdk-p} = 0.8\,(f_{WL} P_{2-WL} - 10 z_{dk-T}) \text{kN/m}^2$$

P_{wdk-pt} is not to be taken as less than 34.3 kN/m^2

When f_{WL} = 1.0 and the ship's draught used in the design load case is greater or equal to $0.9T_{sc}$

The green sea load at the starboard side, $P_{wdk-stb}$, is to be taken as the greater of:

$$P_{wdk-s} = f_{1-dk}\,(f_{WL}\,f_{op}P_{1-WL} - 10z_{dk-T}) \text{ kN/m}^2$$

$$P_{wd} = 0.8\left(f_{_{WL}}P_{2-WL} - 10z_{dk-T}\right) \text{ kN/m}^2$$

$P_{wdk-stb}$ is not to be taken as less than 34.3 kN/m²

When f_{WL} = 1.0 and the ship's draught used in the design load case is greater or equal to $0.9T_{sc}$

P_{wdk-pt} and $P_{wdk-stb}$ are not to be taken as less than 0.

where:

$$f_{1-dk} = 0.8 + \frac{L}{750}$$

f_{op} = 1.0 at and forward of 0.2L from A.P.

= 0.8 at and aft of A.P.

Intermediate values to be obtained by linear interpolation

P_{1-WL}= P_1 pressure at still waterline for considered draught, in kN/m², see 3.5.2.1

P_{2-WL}= P_2 pressure at still waterline for considered draught, in kN/m², see 3.5.2.1

f_{WL}= dynamic load combination factor for dynamic wave pressure at still waterline for considered dynamic load case, see 6.3.1.2

z_{dk-T} = distance from the deck to the still waterline at the applicable draught for the loading condition being considered, in m

L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1

6.3.6.2. The simultaneously acting green sea load on the weather deck, $P_{wdk-dyn}$, for scantling requirements is to be taken as the greater of:

$$P_{wdk-dyn} = f_{1-dk}(f_{WL}f_{op}P_{1-WL} - 10z_{dk-T}) \text{ kN/m}^2$$

But is not to be taken as less than 34.3kN/m² when f_{WL} = 1.0 and the ship's draught used in the design load case is greater or equal to $0.9T_{sc}$

$$P_{wdk-dyn} = 0.8\left(f_{_{WL}}P_{2-WL} - 10z_{dk-T}\right)$$

But is not to be taken as less than 34.3kN/m² when f_{WL} = 1.0 and f_{2-dk} =1.0 and the ship's draught used in the design load case is greater or equal to $0.9T_{sc}$

$P_{wdk-dyn}$ = 0

where:

$$f_{1-dk} = 0.8 + \frac{L}{750}$$

$$f_{2-dk} = 0.5 + \frac{|y|}{B_{wdk}}$$

f_{op} = 1.0 at and forward of 0.2L from A.P.
= 0.8 at and aft of A.P.
Intermediate values to be obtained by linear interpolation
$P_{1\text{-}WL}$ = P_1 pressure at still waterline for considered draught, in kN/m^2
$P_{2\text{-}WL}$ = P_2 pressure at still waterline for considered draught, in kN/m^2
f_{WL} = dynamic load combination factor for dynamic wave pressure at still waterline for considered dynamic load case, see 6.3.1.2
y = transverse coordinate, in m
$z_{dk\text{-}T}$ = distance from the deck at side to the still waterline at the applicable draught for the loading condition being considered, in m
B_{wdk}= local breadth at the weather deck, in m
L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1

6.3.7. Dynamic tank pressure for a considered dynamic load case

6.3.7.1. The simultaneously acting dynamic tank pressure, $P_{in\text{-}dyn}$, for tanks in the cargo region, is to be taken as:

$$P_{in-dy} \;\; = f_{\beta}\big(f_v P_{in-v} \; + f_t P_{in-} \;\; + f_{lng} P_{in-l} \quad \big) \text{kN/m}^2$$

where:

$P_{in\text{-}v}$ = envelope dynamic tank pressure due to vertical acceleration as defined in 3.5.4.1 with reference point z_0 taken as:

a. Top of tank

b. Top of air pipe/overflow for ballast tanks designed for BWE by flow-through methodsee Figure 2.1.27, in kN/m^2

$P_{in\text{-}t}$=envelope dynamic tank pressure due to transverse acceleration as defined in 3.5.4.2 with reference point y_0 taken as:

a. Tank top towards port side for ft > 0

b. Tank top towards starboard side for ft < 0see Figure 2.1.28, in kN/m^2

$P_{in\text{-}lng}$ = envelope dynamic tank pressure due to longitudinal acceleration as defined in 3.5.4.3 with reference point x_0 taken as:

(a) Forward bulkhead for f_{lng}> 0

(b) Aft bulkhead of the tank for f_{lng}< 0see Figure 2.1.29, in kN/m^2

f_v= dynamic load combination factor for vertical acceleration for considered dynamic load case. f_v is to betaken as appropriate to the tank location, see 6.3.1.2

f_t= dynamic load combination factor for transverse acceleration for considered dynamic load case, see 6.3.1.2

f_{lng} = dynamic load combination factor for longitudinal acceleration for considered dynamic load case. f_{lng} is to be taken as most appropriate dependent on tank location, see 6.3.1.2

f_b= heading correction factor, as defined in 6.3.1.1

x_0= longitudinal coordinate of reference point, in m

y_0= transverse coordinate of reference point, in m

z_0= vertical coordinate of reference point, in m

Note:

For a non-parallel tank, y_0 should be selected from either forward or aft bulkhead corresponding to the reference point x_0. If the longitudinal load combination factor f_{lng} = 0, y_0 should be selected from the bulkhead with the greater breadth.

The vertical, transverse and longitudinal acceleration is to be taken at the centre of gravity of the tank under consideration.

6.3.7.2. The simultaneously acting dynamic tank pressure for tanks outside the cargo region, P_{in-dyn}, is to betaken as:

$$P_{in-dyn} = f_\beta \left(f_{v-mid} P_{in-v} + f_t P_{in-t} + f_{lng} P_{in-l}\right) \text{kN/m}^2$$

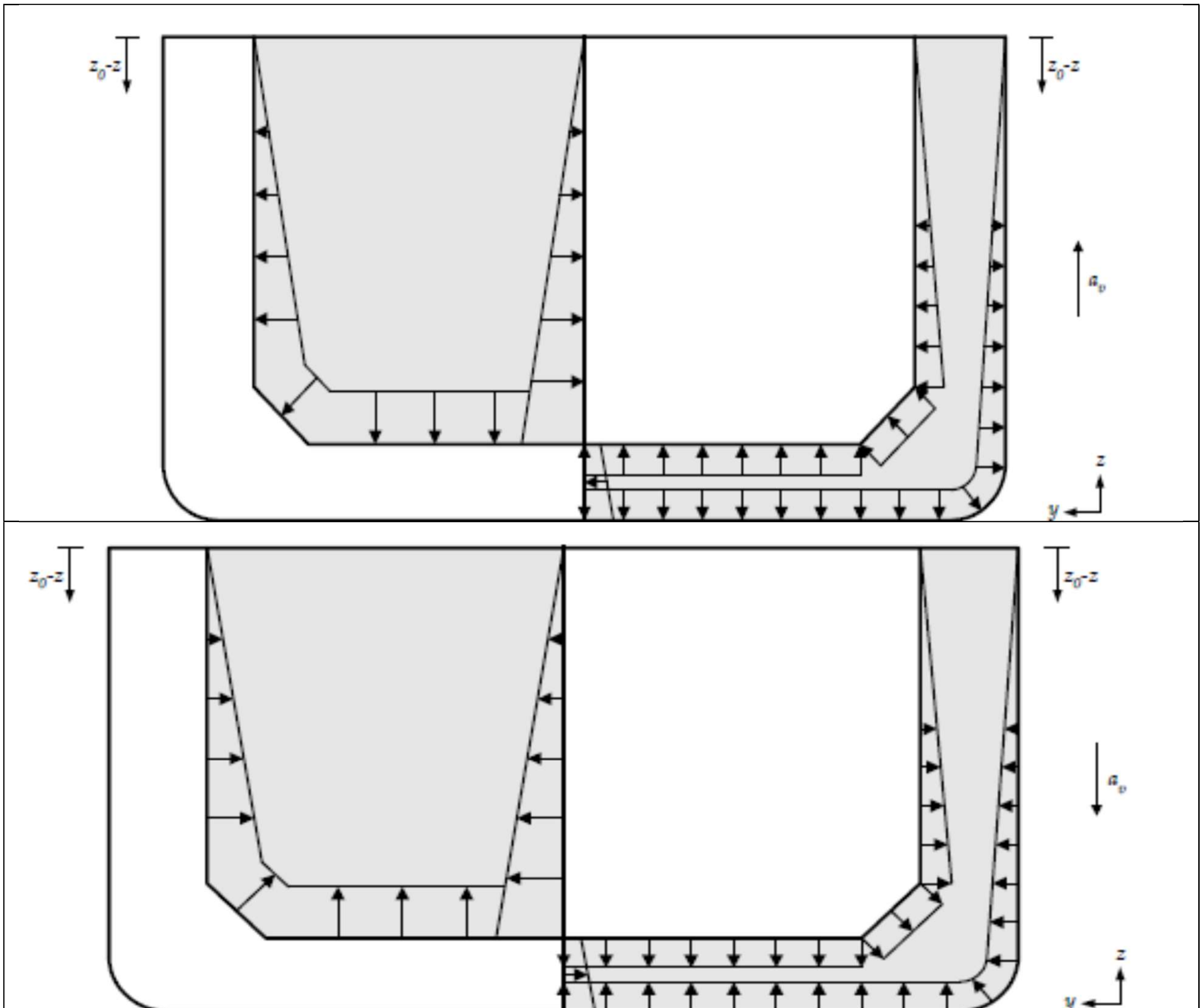
where:

P_{in-v} = envelope dynamic wave pressure due to vertical acceleration as given in 3.5.4.1 with reference point z_0 taken as:

a. top of tank

b. top of air pipe for ballast tanks design for BWE by flow through see Figure 2.1.28, in kN/m^2

P_{in-t} = envelope dynamic tank pressure due to transverse acceleration as given in 3.5.4.2 using (y_0 – y) as extreme breadth of tank, in kN/m^2
P_{in-lng} = envelope dynamic tank pressure due to longitudinal acceleration as given in 3.5.4.3 using (x_0 – x) as extreme length of tank, in kN/m^2
f_{v-mid} = dynamic load combination factor for vertical acceleration for considered dynamic load case, see 6.3.1.2
f_t= dynamic load combination factor for transverse acceleration for considered dynamic load case, see 6.3.1.2
f_{lng} dynamic load combination factor for longitudinal acceleration for considered dynamic load case, see 6.3.1.2
f_b= heading correction factor, as defined in 6.3.1.1
x_0= longitudinal coordinate of reference point, in m
y_0= transverse coordinate of reference point, in m
z_0= vertical coordinate of reference point, in m



Note

For ballast tank which is designed for ballast water exchange by flow-through method, reference point z_0 is to be taken as top of air pipe/overflow of the tank

Figure 2.1.27: Dynamic Tank Pressure in Cargo Tank (Left) and Ballast Tank (Right) due to Positive and Negative Vertical Tank Acceleration

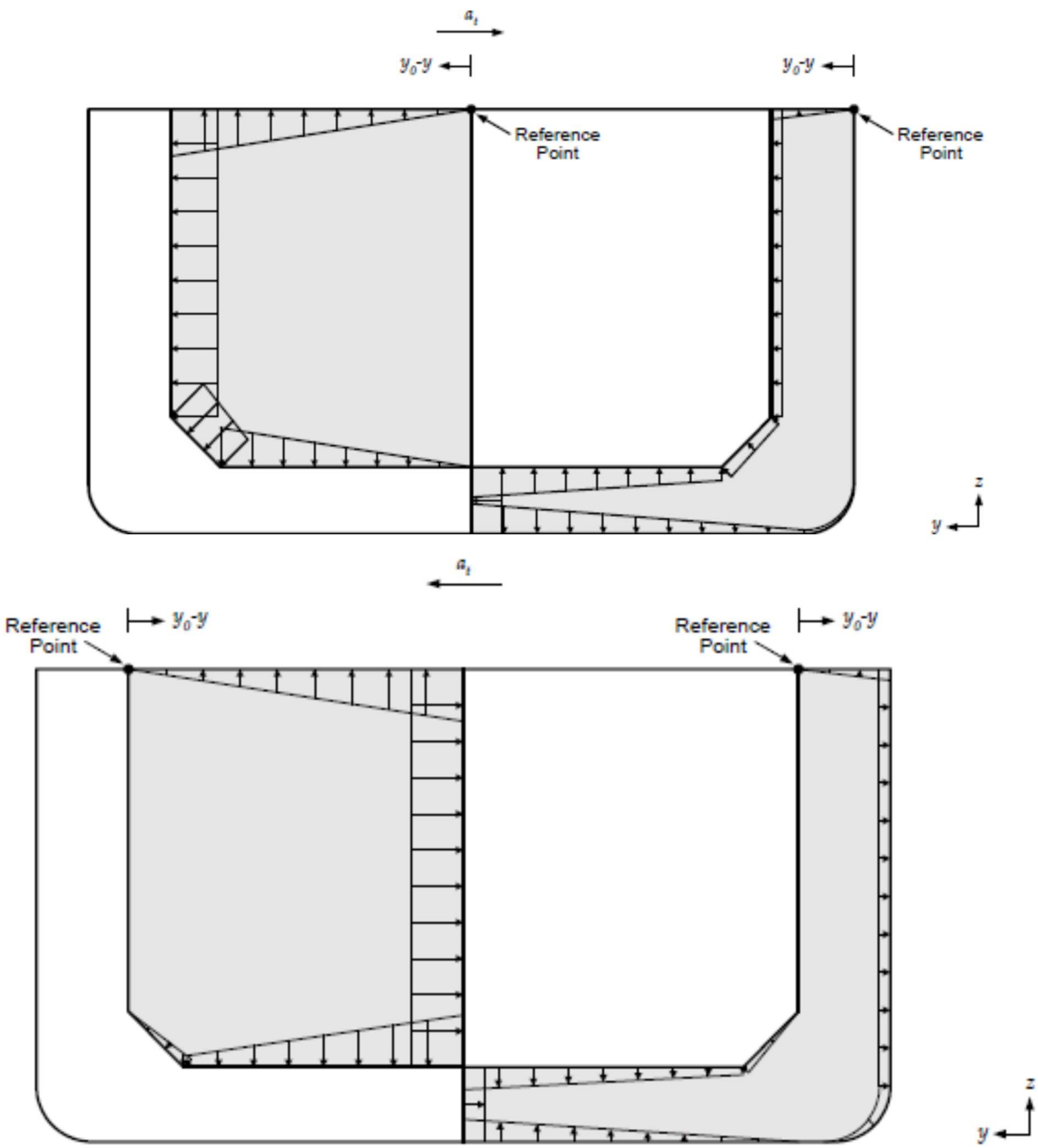


Figure 2.1.28: Dynamic Tank Pressure in Cargo Tank (Left) and Ballast Tank (Right) due to Negative and Positive Transverse Tank Acceleration

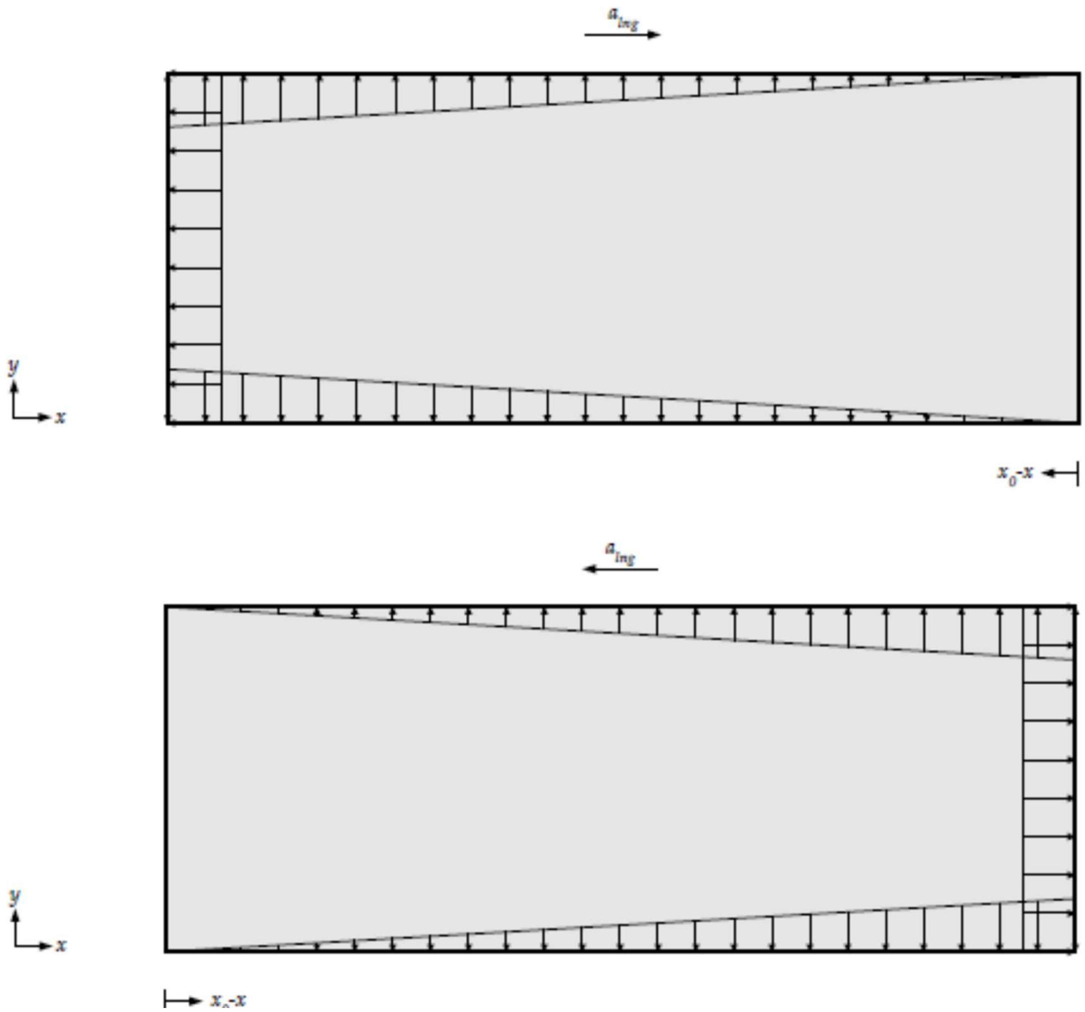


Figure 2.1.29: Dynamic Tank Pressure in Tanks due to Positive and Negative Longitudinal Acceleration

6.3.8. Dynamic deck loads for a considered dynamic load case

6.3.8.1. The simultaneously acting dynamic deck load for uniformly distributed load, $P_{dk\text{-}dyn}$, on the enclosed upper deck, where a forecastle or poop is fitted, and also on all lower decks, is to be taken as:

$$P_{dk-dy} = f_{\beta} f_{v-mid} P_{deck-dyn} \text{ kN/m}^2$$

where:

$P_{deck\text{-}dyn}$ = envelope dynamic deck pressure on decks, inner bottom and hatch covers, in kN/m^2, as defined in 3.5.5.1

$f_{v\text{-}mid}$ = dynamic load combination factor for vertical acceleration for considered dynamic load case, see 6.3.1.2

f_b= heading correction factor, as defined in 6.3.1.1

6.3.8.2. The simultaneously acting dynamic vertical force for heavy units, $F_{dk\text{-}dyn}$, acting on supportingstructures and securing systems for heavy units of cargo, equipment or structural components, is to be taken as:

$$F_{dk-d} = f_{\beta} f_{v-mid} F_v \text{kN}$$

where:

F_v= envelope vertical dynamic load from heavy units, in kN, as defined in 3.5.6

$f_{v\text{-}mid}$ = dynamic load combination factor for vertical acceleration for the considered dynamic load case, see Table 2.1.4 and Table 2.1.6 to 2.1.11

f_b=heading correction factor, as defined in 6.3.1.1

6.4. Dynamic Load Cases and Dynamic Load Combination Factors for Strength Assessment

6.4.1. General

6.4.1.1. For strength assessment (FEM) the dynamic load cases given in Table 2.1.4 are to be applied in accordance with the requirements of Ch 4 Sec 2 B for Design Load Combination S + D. The simultaneously acting dynamic load cases are to be derived using the dynamic load combination factors given in Table 2.1.4.

Table 2.1.4: Dynamic Load Cases for Strength Assessment (by FEM)

Wave direction			**Head sea**				**Beam sea**		**Oblique sea**	
Max response			**M_{wv} (Sagging)**	**M_{wv} (Hogging)**	**Q_{wv} (Sagging)**	**Q_{wv} (Hogging)**	**a_v**		**$M_{wv\text{-}h}$ (Hogging)**	
Dynamic Load Case			**1**	**2**	**3**	**4**	**5a**	**5b**	**6a**	**6b**
Global loads	M_{wv}	f_{mv}	-1.0	1.0	-1.0	1.0	0.0	0.0	0.0	0.0
	Q_{wv}	f_{qv}	1.0	-1.0	1.0	-1.0	0.0	0.0	0.0	0.0
	$M_{wv\text{-}h}$	f_{mh}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Accelerations	a_v	f_v	0.5	-0.5	0.3	-0.3	1.0	1.0	-0.1	-0.1
	a_t	f_t	0.0	0.0	0.0	0.0	-0.6	0.6	0.0	0.0
	a_{lng}	f_{lng}	-0.6	0.6	-0.6	0.6	-0.5	-0.5	0.5	0.5
Dynamic Wave pressure for port side	P_{WL}	f_{WL}	-0.3	0.3	0.1	-0.1	1.0	0.4	0.6	0.0
	P_{bilge}	f_{bilge}	-0.3	0.3	0.1	-0.1	1.0	0.4	0.4	0.0
	P_{ctr}	f_{ctr}	-0.7	0.7	0.3	-0.3	0.9	0.9	0.5	0.5
Dynamic wave pressure for starboard side	P_{WL}	f_{WL}	-0.3	0.3	0.1	-0.1	0.4	1.0	0.0	0.6
	P_{bilge}	f_{bilge}	-0.3	0.3	0.1	-0.1	0.4	1.0	0.0	0.4
	Pc_{tr}	f_{ctr}	-0.7	0.7	0.3	-0.3	0.9	0.9	0.5	0.5

Where:
Symbols are as defined in 3.3, 6.3.5.1, Table 2.1.3 and below:
$f_{v\text{-}mid}$ dynamic load combination factor associated with the vertical acceleration of a centre cargo and ballast tank
$f_{v\text{-}pt}$ dynamic load combination factor associated with the vertical acceleration of a port cargo and side ballast tank
$f_{v\text{-}stb}$ dynamic load combination factor associated with the vertical acceleration of a starboard cargo and side ballast tank
Note:
1) Load parameters and locations to be used for the calculations are to be taken as specified in Chapter 4 Section 2/2.4.1

6.5. Dynamic Load Cases and Dynamic Load Combination for Scantling Requirements

6.5.1. General

6.5.1.1. For the scantling requirements the dynamic load cases are to be applied in accordance with the design load sets given in Table 2.2.13 through Table 2.2.15 for the design load combination S + D. The simultaneously acting dynamic load cases are to be derived using the dynamic load combination factors given in Table 2.1.6 to Table 2.1.11.

6.5.1.2. The Dynamic Load Combination Factor (DLCF) table to be used depends on the longitudinal position being considered and is specified in Figure 2.1.30 and Table 2.1.5.

6.5.1.3. Each dynamic load case in the DLCF tables maximizes one or more dynamic load components. Theminimized dynamic load components are to be calculated by multiplying all the dynamic load combinationfactors for a dynamic load case by −1.0. The scantling requirements are to be evaluated for all maximized andminimized dynamic load cases.

6.5.1.4. Load parameters to be used for the calculations are to be taken as specified in Table 2.2.14 and Table 2.2.15.

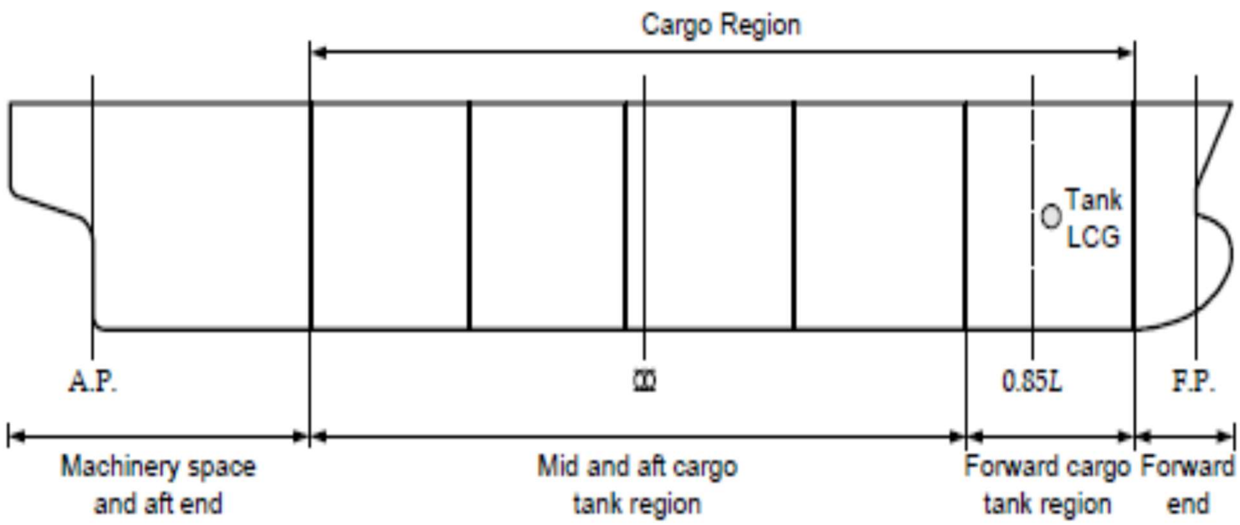


Figure 2.1.30: Illustration of Structural Regions

Table 2.1.5: Dynamic Load Combination Factor Tables used for Structural Region and Loading Condition				
Structural region	**Machinery Space and AftEnd**	**Mid and aft cargo tank region**	**Forward cargo tank region**	**Forward end**
Applicable for tanks and spaces	aft of aftmost cargo tank	where the tankLCG is aft of 0.85L	where the tank LCG is at or forward of 0.85L	forward of foremost bulkhead
Loaded DLCF	Table 2.1.10	Table 2.1.6	Table 2.1.8	Table 2.1.10
Ballast DLCF	Table 2.1.11	Table 2.1.7	Table 2.1.9	Table 2.1.11

Table 2.1.6: Dynamic Load Cases for Mid and Aft Cargo Tank Region for Loaded Condition

Wave direction			Head Sea			Oblique Sea		Beam Sea					
Max response			**M_{wv}**	**a_v**	**a_{lng}**	**M_{wv-h}**		**a_t**		**P_{ctr}**		**P_{WL}**	
Dynamic Load Case			**1**	**2**	**3**	**4a**	**4b**	**5a**	**5b**	**6a**	**6b**	**7a**	**7b**
Global loads	M_{wv}	f_{mv}	1.0	-1.0	0.5	-0.2	-0.2	-0.1	-0.1	-0.2	-0.2	-0.3	-0.3
	M_{wv-h}	f_{mh}	0.0	0.0	0.0	1.0	-1.0	-0.1	0.1	0.0	0.0	0.0	0.0
Accelerations	a_{v-mid}	f_{v-mid}	-0.2	0.5	-0.4	-0.1	-0.1	0.5	0.5	1.0	1.0	1.0	1.0
	av-pt	f_{v-pt}	-0.2	0.5	-0.4	-0.1	-0.1	0.2	0.6	0.8	1.0	0.8	1.0
	a_{v-stb}	f_{v-stb}	-0.2	0.5	-0.4	-0.1	-0.1	0.6	0.2	1.0	0.8	1.0	0.8
	a_t	f_t	0.0	0.0	0.0	0.0	0.0	1.0	-1.0	0.5	-0.5	0.6	-0.6
	$a_{lng-mid}$	$f_{lng-mid}$	0.3	-0.6	1.0	-0.3	-0.3	-0.1	-0.1	-0.5	-0.5	-0.6	-0.6
	a_{lng-pt}	f_{lng-pt}	0.3	-0.6	1.0	-0.4	-0.2	-0.1	-0.1	-0.5	-0.5	-0.6	-0.6
	$a_{lng-stb}$	$f_{lng-stb}$	0.3	-0.6	1.0	-0.2	-0.4	-0.1	-0.1	-0.5	-0.5	-0.6	-0.6
	$a_{lng-ctr}$	$f_{lng-ctr}$	0.3	-0.6	1.0	-0.3	-0.3	-0.1	-0.1	-0.5	-0.5	-0.6	-0.6
Dynamic wave pressure for starboard side	P_{ctr}	f_{ctr}	0.7	-0.6	0.2	-0.3	-0.3	0.5	0.5	1.0	1.0	0.9	0.9
	P_{bilge}	f_{bilge}	0.3	-0.2	0.1	-0.4	-0.1	0.8	-0.3	0.9	0.4	1.0	0.4
	P_{WL}	f_{WL}	0.3	-0.3	0.1	-0.6	-0.1	0.5	-0.2	0.8	0.4	1.0	0.4
Dynamic wave pressure for port side	P_{ctr}	f_{ctr}	0.7	-0.6	0.2	-0.3	-0.3	0.5	0.5	1.0	1.0	0.9	0.9
	P_{bilge}	f_{bilge}	0.3	-0.2	0.1	-0.1	-0.4	-0.3	0.8	0.4	0.9	0.4	1.0
	P_{WL}	f_{WL}	0.3	-0.3	0.1	-0.1	-0.6	-0.2	0.5	0.4	0.8	0.4	1.0

Where: Symbols are as defined in 3.3, 3.4.2, 6.3.5.1 and Table 2.1.3 and Table 2.1.4 and below:

a_{v-pt} vertical acceleration for port tank, in m/s^2

a_{v-stb} vertical acceleration for starboard tank, in m/s^2

$a_{lng-mid}$ longitudinal acceleration for centre tank, in m/s^2

a_{lng-pt} longitudinal acceleration for port tank, in m/s^2

$a_{lng-stb}$ longitudinal acceleration for starboard tank, in m/s^2

$a_{lng-ctr}$ longitudinal acceleration for centre double bottom ballast tank, in m/s^2

f_{lng-pt} dynamic load combination factor associated with the longitudinal acceleration of a port side cargo or ballast tank

$f_{lng-stb}$ dynamic load combination factor associated with the longitudinal acceleration of a starboard side cargo or ballast tank

$f_{lng-ctr}$ dynamic load combination factor associated with the longitudinal acceleration of a centre double bottom ballast tank

$f_{lng-mid}$ dynamic load combination factor associated with the longitudinal acceleration of a centre tank

Table 2.1.7 : Dynamic Load Cases for Mid and Aft Cargo Tank Region for Ballast Condition

Wave direction			Head Sea			Oblique Sea		Beam Sea					
Max response			M_{wv}	a_v	a_{lng}	M_{wv-h}		at		Pctr		PWL	
Dynamic Load Case			1	2	3	4a	4b	5a	5b	6a	6b	7a	7b
Global loads	M_{wv}	f_{mv}	1.0	-1.0	0.4	-0.4	-0.4	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2
	M_{wv-h}	f_{mh}	0.0	0.0	0.0	1.0	-1.0	0.1	-0.1	-0.1	0.1	-0.2	0.2
Accelerations	a_{v-mid}	f_{v-mid}	-0.1	0.4	-0.2	0.1	0.1	0.5	0.5	1.0	1.0	1.0	1.0
	a_{v-pt}	f_{v-pt}	-0.1	0.4	-0.2	0.1	0.1	0.1	0.8	0.7	1.0	0.6	1.0
	a_{v-stb}	f_{v-stb}	-0.1	0.4	-0.2	0.1	0.1	0.8	0.1	1.0	0.7	1.0	0.6
	a_t	f_t	0.0	0.0	0.0	0.0	0.0	1.0	-1.0	0.8	-0.8	0.6	-0.6
	$a_{lng-mid}$	$f_{lng-mid}$	0.2	-0.1	1.0	-0.6	-0.6	0.0	0.0	-0.2	-0.2	-0.1	-0.1
	a_{lng-pt}	f_{lng-pt}	0.2	-0.1	1.0	-0.6	-0.4	0.0	0.0	-0.2	-0.2	-0.1	-0.1
	$a_{lng-stb}$	f_{lngstb}	0.2	-0.1	1.0	-0.4	-0.6	0.0	0.0	-0.2	-0.2	-0.1	-0.1
	$a_{lng-ctr}$	$f_{lng-ctr}$	0.2	-0.1	1.0	-0.4	-0.4	0.0	0.0	-0.2	-0.2	-0.1	-0.1
Dynamic wave pressure for starboard side	P_{ctr}	f_{ctr}	1.0	-0.8	0.3	-0.5	-0.5	0.3	0.3	0.8	0.8	0.4	0.4
	P_{bilge}	f_{bilge}	0.3	-0.2	0.1	-0.4	0.0	0.9	-0.4	0.9	0.3	0.9	0.2
	P_{WL}	f_{WL}	0.3	-0.2	0.1	-0.6	0.0	0.7	-0.4	0.9	0.2	1.0	0.2
Dynamic wave pressure for ort side	P_{ctr}	f_{ctr}	1.0	-0.8	0.3	-0.5	-0.5	0.3	0.3	0.8	0.8	0.4	0.4
	P_{bilge}	f_{bilge}	0.3	-0.2	0.1	0.0	-0.4	-0.4	0.9	0.3	0.9	0.2	0.9
	P_{WL}	f_{WL}	0.3	-0.2	0.1	0.0	-0.6	-0.4	0.7	0.2	0.9	0.2	1.0

Where:
Symbols are as defined in 3.3, 3.4.2, 6.3.5.1 and Table 2.1.3, Table 2.1.4 and Table 2.1.6

Table 2.1.8: Dynamic Load Cases for Forward Cargo Tank Region for Loaded Condition

Wave direction			Head Sea		Oblique Sea								Beam			
Max response			a_v	a_{lng}	a_{lng}		P_{ctr}		P_{bilge}		P_{WL}		a_v		a_t	
Dynamic Load Case			1	2	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b	8a	8b
Global loads	M_{wv}	f_{mv}	-0.7	0.9	0.3	0.3	-0.6	-0.6	-0.3	-0.3	-0.4	-0.4	-0.4	-0.4	-0.1	-0.1
	M_{wv-h}	f_{mh}	0.0	0.0	-0.2	0.2	0.2	-0.2	-0.1	0.1	0.2	-0.2	-0.1	0.1	-0.5	0.5
Accelerations	a_{v-mid}	f_{v-mid}	0.7	-0.6	-0.6	-0.6	0.7	0.7	0.9	0.9	0.7	0.7	1.0	1.0	0.4	0.4
	a_{v-pt}	f_{v-pt}	0.7	-0.6	-0.6	-0.6	0.7	0.7	0.9	1.0	0.7	0.7	0.9	1.0	0.3	0.6
	a_{v-stb}	f_{v-stb}	0.7	-0.6	-0.6	-0.6	0.7	0.7	1.0	0.9	0.7	0.7	1.0	0.9	0.6	0.3
	a_t	f_t	0.0	0.0	-0.4	0.4	0.1	-0.1	0.7	-0.7	0.5	-0.5	0.6	-0.6	1.0	-1.0
	$a_{lng-mid}$	$f_{lng-mid}$	-0.8	1.0	0.8	0.8	-1.0	-1.0	-0.5	-0.5	-1.0	-1.0	-0.5	-0.5	-0.1	-0.1
	a_{lng-pt}	f_{lng-pt}	-0.8	1.0	1.0	0.6	-1.0	-0.9	-0.5	-0.5	-1.0	-0.7	-0.5	-0.5	-0.1	-0.1
	$a_{lng-stb}$	$f_{lng-stb}$	-0.8	1.0	0.6	1.0	-0.9	-1.0	-0.5	-0.5	-0.7	-1.0	-0.5	-0.5	-0.1	-0.1
	$a_{lng-ctr}$	$f_{lng-ctr}$	-0.8	1.0	0.8	0.8	-1.0	-1.0	-0.5	-0.5	-1.0	-1.0	-0.5	-0.5	-0.1	-0.1
Dynamic wave pressure on starboard side	P_{ctr}	f_{ctr}	1.0	-0.9	-0.4	-0.4	1.0	1.0	0.8	0.8	0.5	0.5	0.8	0.8	0.4	0.4
	P_{bilge}	f_{bilge}	0.6	-0.7	-0.6	-0.2	0.9	0.6	1.0	0.5	0.7	0.3	1.0	0.5	0.8	-0.1
	P_{WL}	f_{WL}	0.3	-0.5	-0.9	-0.2	0.8	0.4	0.9	0.4	1.0	0.2	0.9	0.4	0.6	-0.2
Dynamic wave pressure on port side	P_{ctr}	f_{ctr}	1.0	-0.9	-0.4	-0.4	1.0	1.0	0.8	0.8	0.5	0.5	0.8	0.8	0.4	0.4
	P_{bilge}	f_{bilge}	0.6	-0.7	-0.2	-0.6	0.6	0.9	0.5	1.0	0.3	0.7	0.5	1.0	-0.1	0.8
	P_{WL}	f_{WL}	0.3	-0.5	-0.2	-0.9	0.4	0.8	0.4	0.9	0.2	1.0	0.4	0.9	-0.2	0.6

Where:
Symbols are as defined in 3.3, 3.4.2, 6.3.5.1 and Table 2.1.3, Table 2.1.4 and Table 2.1.6

Table 2.1.9: Dynamic Load Cases for Forward Cargo Tank Region for Ballast Condition

Wave direction			Head Sea		Oblique Sea								Beam Sea			
Max response			a_v	a_{lng}	a_{lng}		P_{ctr}		P_{bilge}		P_{WL}		a_v		a_t	
Dynamic Load Case			1	2	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b	8a	8b
Global loads	M_{wv}	f_{mv}	-0.8	0.9	0.7	0.7	-1.0	-1.0	-0.2	-0.2	-0.3	-0.3	-0.1	-0.1	-0.1	-0.1
	M_{wv-h}	f_{mh}	0.0	0.0	-0.4	0.4	0.0	0.0	-0.5	0.5	0.3	-0.3	-0.4	0.4	-0.4	0.4
Accelerations	a_{v-mid}	f_{v-mid}	0.7	-0.6	-0.7	-0.7	0.4	0.4	0.6	0.6	0.9	0.9	1.0	1.0	0.4	0.4
	a_{v-pt}	f_{v-pt}	0.7	-0.6	-0.7	-0.7	0.4	0.4	0.3	0.8	0.7	0.7	0.5	1.0	0.0	0.7
	a_{v-stb}	f_{v-stb}	0.7	-0.6	-0.7	-0.7	0.4	0.4	0.8	0.3	0.7	0.7	1.0	0.5	0.7	0.0
	a_t	f_t	0.0	0.0	0.0	0.0	0.0	0.0	0.9	-0.9	0.2	-0.2	0.7	-0.7	1.0	-1.0
	$a_{lng-mid}$	$f_{lng-mid}$	-0.9	1.0	1.0	1.0	-0.6	-0.6	-0.3	-0.3	-0.9	-0.9	0.0	0.0	0.0	0.0
	a_{lng-pt}	f_{lng-pt}	-0.9	1.0	1.0	1.0	-0.6	-0.6	-0.5	0.2	-0.9	-0.6	0.0	0.0	0.0	0.0
	$a_{lng-stb}$	$f_{lng-stb}$	-0.9	1.0	1.0	1.0	-0.6	-0.6	0.2	-0.5	-0.6	-0.9	0.0	0.0	0.0	0.0
	$a_{lng-ctr}$	$f_{lng-ctr}$	-0.9	1.0	1.0	1.0	-0.6	-0.6	-0.3	-0.3	-0.9	-0.9	0.0	0.0	0.0	0.0
Dynamic wave pressure on starboard side	P_{ctr}	f_{ctr}	1.0	-0.7	-0.9	-0.9	1.0	1.0	0.6	0.6	0.6	0.6	0.4	0.4	0.2	0.2
	P_{bilge}	f_{bilge}	0.5	-0.4	-0.7	-0.3	0.6	0.6	1.0	-0.3	0.9	0.2	0.8	0.2	0.7	-0.3
	P_{WL}	f_{WL}	0.3	-0.2	-0.6	-0.1	0.4	0.4	0.9	-0.3	1.0	0.1	0.8	0.2	0.7	-0.4
Dynamic wave pressure on port side	P_{ctr}	f_{ctr}	1.0	-0.7	-0.9	-0.9	1.0	1.0	0.6	0.6	0.6	0.6	0.4	0.4	0.2	0.2
	P_{bilge}	f_{bilge}	0.5	-0.4	-0.3	-0.7	0.6	0.6	-0.3	1.0	0.2	0.9	0.2	0.8	-0.3	0.7
	P_{WL}	f_{WL}	0.3	-0.2	-0.1	-0.6	0.4	0.4	-0.3	0.9	0.1	1.0	0.2	0.8	-0.4	0.7
Where: Symbols are as defined in 3.3, 3.4.2, 6.3.5.1 and Table 2.1.3, Table 2.1.4 and Table 2.1.6																

Table 2.1.10: Dynamic Load Cases for Spaces outside the Cargo Tank Region for Loaded Condition

Ship location			Machinery Space and Aft End							Forward End			
Wave direction			Following Sea	Oblique Sea		Beam Sea				Beam Sea			
Max response			P_{ctr}	P_{WL}		a_v		a_t		a_v		a_t	
Dynamic Load Case			1	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b
Global Load	M_{wv}	f_{mv}	-1.0	-0.7	-0.7	-0.4	-0.4	-0.1	-0.1	-	-	-	-
Accelerations	a_{v-mid}	f_{v-mid}	0.6	0.9	0.9	1.0	1.0	0.3	0.3	1.0	1.0	0.3	0.3
	a_{v--pt}	f_{v-pt}	0.6	-	0.9	-	1.0	-	0.4	-	1.0	-	0.3
	a_{v-stb}	f_{v-stb}	0.6	0.9	-	1.0	-	0.4	-	1.0	-	0.3	-
	a_t	f_t	0.0	0.2	-0.2	0.5	-0.5	1.0	-1.0	0.7	-0.7	1.0	-1.0
	a_{lng}	f_{lng}	0.8	0.7	0.7	0.6	0.6	-0.1	-0.1	-0.7	-0.7	-0.1	-0.1
Dynamic wave pressure on starboard side	P_{ctr}	f_{ctr}	1.0	0.8	0.7	0.7	0.7	0.2	0.2	1.0	1.0	0.2	0.2
	P_{WL}	f_{WL}	0.5	1.0	0.3	0.8	0.3	0.5	-0.3	1.0	0.8	0.2	0.0
Dynamic wave pressure on port side	P_{ctr}	f_{ctr}	1.0	0.8	0.7	0.7	0.7	0.2	0.2	1.0	1.0	0.2	0.2
	P_{WL}	f_{WL}	0.5	0.2	1.0	0.3	0.8	-0.3	0.5	0.8	1.0	0.0	0.2
Where: Symbols are as defined in 3.3, 6.3.5.1 and Table 2.1.3, Table 2.1.4 and Table 2.1.6													

Table 2.1.11: Dynamic Load Cases for Spaces outside the Cargo Tank Region for Ballast Condition

Ship location			**Machinery Space and Aft End**							**Forward End**			
Wave direction			**Following Sea**	**Oblique Sea**		**Beam Sea**				**Beam Sea**			
Max response			P_{ctr}	P_{WL}		a_v		a_t		a_v		a_t	
Dynamic Load Case			**1**	**2a**	**2b**	**3a**	**3b**	**4a**	**4b**	**5a**	**5b**	**6a**	**6b**
Global Load	M_{wv}	f_{mv}	-1.0	-0.3	-0.3	0.2	0.2	0.1	0.1	-	-	-	-
Accelerations	$a_{v\text{-}mid}$	$f_{v\text{-}mid}$	0.6	0.9	0.9	1.0	1.0	0.3	0.3	1.0	1.0	0.3	0.3
	$a_{v\text{--}pt}$	$f_{v\text{-}pt}$	0.6	-	0.9	-	1.0	-	0.5	-	1.0	-	0.5
	$a_{v\text{-}stb}$	$f_{v\text{-}stb}$	0.6	0.9	-	1.0	-	0.5	-	1.0	-	0.5	-
	a_t	f_t	0.0	0.1	-0.1	0.6	-0.6	1.0	-1.0	0.7	-0.7	1.0	-1.0
	a_{lng}	f_{lng}	0.7	0.8	0.8	0.2	0.2	0.0	0.0	-0.3	-0.3	0.0	0.0
Dynamic wave pressure on starboard side	P_{ctr}	f_{ctr}	1.0	0.7	0.7	0.5	0.5	0.1	0.1	0.6	0.6	0.1	0.1
	P_{WL}	f_{WL}	0.8	1.0	0.3	0.6	0.1	0.4	-0.3	0.7	0.3	0.3	-0.1
Dynamic wave pressure on port side	P_{ctr}	f_{ctr}	1.0	0.7	0.7	0.5	0.5	0.1	0.1	0.6	0.6	0.1	0.1
	P_{WL}	f_{WL}	0.8	0.3	1.0	0.1	0.6	-0.3	0.4	0.3	0.7	-0.1	0.3
where: Symbols are as defined in 3.3, 6.3.5.1 and Table 2.1.3, Table 2.1.4 and Table 2.1.6													

SECTION 2 SCANTLING REQUIREMENTS

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1. Longitudinal Strength

1.1. Loading Guidance

1.1.1. General

1.1.1.1. Loading guidance information containing sufficient information to enable the master of the ship in order to maintain the ship within the stipulated operational limitations is required to be provided in all the ships. An approved Loading Manual and Loading Computer System complying with the requirements given in 1.1.2 and 1.1.3 respectively are to be included in the loading guidance information.

1.1.1.2. On the basis of the final data of the ship,the loading guidance information is to be prepared.

1.1.1.3. It is essential for the Loading Manual to be updated and re-approved, and subsequently the Loading Computer System to be updated and re-approved in case there are modifications which results in changes to the main data of the ship (lightship weight, buoyancy distribution, tank volumes or usage, etc.).Provided that the resulting draughts, still water bending moments and shear forces do not differ from the originally approved data by more than 2%, re-submission of the new loading guidance are not required.

1.1.1.4. The loading guidance is to be prepared in a language understood by the users. A translation into English shall be included, when this language is not English. Where applicable a document translating the language of the input and output data for the Loading Computer System into English is to be provided.

1.1.1.5. In order to ensure the crew are aware of the operational limitations for minimum draught forward, the loading guidance information is to include the following statement:

The scantlings are approved for a minimum draught forward, at F.P. In sea conditions where slamming is likely to occur, the forward draught is not to be less than the following:

a. …m with double bottom ballast tanks No(s)... filled, or
b. …m with double bottom ballast tanks No(s)… empty

1.1.2. Loading Manual

1.1.2.1. The Loading Manual is a document that:

a. Describes the loading conditions on which the design and approval of the ship has been based for seagoing and harbour/sheltered water operation

b. Describes the results of the calculations of still water bending moments, shear forces and where applicable,limitations due to torsional and lateral loads

c. Describes relevant operational limitations as given in 1.1.2.7.

1.1.2.2. The Loading Manual shall include the following loading conditions and design loading and ballast conditions upon which the approval of the hull scantlings is based:

a) Seagoing conditions including both departure and arrival conditions

- Homogeneous loading conditions including a condition at the scantling draft (homogeneous loadingconditions shall not include filling of dry and clean ballast tanks)

- Anormal ballast condition where:
  — The ballast tanks may be full, partially full or empty. Where partially full options are exercised, the conditions in 1.1.2.5 are to be complied with
  — All cargo tanks are to be empty including cargo tanks suitable for the carriage of water ballast at sea
  — Full immersion of the propeller is to be considered, and
  — The trim is to be by the stern and is not to exceed 0.015L, where L is as defined in Chapter 1 Section 4/1.1.1

- A heavy ballast condition where:
  — The draught at the forward perpendicular is not to be less than that for the normal ballast condition
  — Ballast tanks in the cargo tank region or aft of the cargo tank region may be full, partially full or empty. The conditions in 1.1.2.5 are to be compliedwith where the partially full options are exercised.
  — The fore peak water ballast tank is to be full. The lower is required to be fullif upper and lower fore peak water ballast tanks are fitted. The upper fore peak tank may be full, partially full or empty.If upper and lower fore peak tanks are fitted and only one of them is designated as water ballast tank,the other may be empty.
  — All cargo tanks are to be empty including cargo tanks suitable for the carriage of water ballast at sea
  — Full immersion ofthe propeller is to be considered.
  — The trim is to be by the stern and is not to exceed 0.015L, where L is as defined in Chapter 1 Section 4/1.1.1

- any specified non-uniform distribution of loading

- conditions with high density cargo including the maximum design cargo density, when applicable

- mid-voyage conditions relating to tank cleaning or other operations where these differ significantlyfrom the ballast conditions

- conditions covering ballast water exchange procedures with the calculations of the intermediatecondition just before and just after ballasting and/or deballasting any ballast tank

b) Harbour/sheltered water conditions

- conditions representing typical complete loading and unloading operations

- docking condition afloat

- propeller inspection afloat condition, in which the propeller shaft centre line is at least $D_{prop}/4$ above

- The waterline in way of the propeller, where D_{prop} is the propeller diameter

c) Additional design conditions
   - a design ballast condition in which all segregated ballast tanks in the cargo tank region are full and allother tanks are empty including fuel oil and fresh water tanks.

Note:

The design condition specified in (c) is for assessment of hull strength and is not intended for ship operation. Provided that the corresponding condition in the Loading Manual only includes ballast in segregated ballast tanks in the cargo tank region, this condition will also be covered by the IMO 73/78 SBT condition.

1.1.2.3. The calculation for the departure conditions are to be based on full tanks according to the applicable stability regulations for filling of tanks; note bunker tanks are not to be taken less than 95% full and other consumables are to be taken at 100% capacity. On the basis of 10% of the maximum capacity of bunker, fresh water and stores, arrival conditions are to be provided.

1.1.2.4. In case of approval, submission of calculations for such intermediate conditions are also to be considered when the amount and disposition consumables at any intermediate stage of the voyage are considered more severe than of those described in 1.1.2.3.

1.1.2.5. Permission of the Ballast loading conditions involving partially filled peak and/or other ballast tanks in any departure, arrival or intermediate condition are not to be given so as to be used as design loading conditionsunless, for all filling levels between empty and full, the resulting stress levels within the stress and buckling acceptance criteria. If the stress levels are within the stress and buckling acceptance criteria for loading conditions with the appropriate tanks full, empty and partially filled at intended level in any departure, arrival or intermediate condition, then for design purpose, satisfaction of this criterion is to be declared.. The corresponding full, empty and partially filled tank conditions are to be considered as design conditions for calculation of the still water bending moment and shear force, but these do not need to comply with propeller immersion and trim requirements as specified in 1.1.2.2(a). Where multiple ballast tanks are intended to be partially filled, investigation of all combinations of full, empty or partially filled at intended levels for those tanks are required to be considered. By using sequential method, applications of these requirements are not to be given for ballast water exchange.

1.1.2.6. In cargo loading conditions, as specified in 1.1.2.5, application ofthe requirements for partially filled ballast tanks are to be considered f the peak ballast tanks only.

1.1.2.7. On the basis of which the approval of the hull scantlings are done, the Loading Manual is required to include the design basis and operational limitations. The Loading Manual is required to include the information listed in Table 2.2.1.

1.1.2.8. The approval of the hull scantlings is to be based on the rule that define loading patterns and the loading conditions as given in the Loading Manual.

Table 2.2.1: Design Parameters

Parameter
Permissible limits of still water bending moments (seagoing operation and harbour/sheltered water operation)
Permissible limits of still water shear forces (seagoing operation and harbour/sheltered water operation)
Scantling draught, T_{sc}
Design minimum ballast draught at midships, T_{bal}
Design slamming draught forward with forward double bottom ballast tanks filled, $T_{FP-full}$
Design slamming draught forward with forward double bottom ballast tanks empty, T_{FP-mt}
Maximum allowable cargo density
Maximum cargo density in any loading condition in Loading Manual
Description of the ballast exchange operations including any limitations
Design speed

1.1.2.9. If the ship is specifically approved and intended to be operated in the below mentioned conditions,then the following additional loading conditions are to be included in the Loading Manual:

a. As allowed by MARPOL Regulation 13. (Ship approved for loading pattern A8 of Table B.2.3 or B7 of Table B.2.4), sea-going ballast conditions includes water ballast carried in one or more cargo tanks which are intended for use in emergency situations.

b. Seagoing loading conditions where the net static upward load on the double bottom exceeds the limits is given with the combination of an empty cargo tank and a mean ship's draught of $0.9T_{sc}$

c. Seagoing loading conditions with cargo tanks less than 25% full with the combination of mean ship's draught greater than $0.9T_{sc}$

d. Seagoing loading conditions where the net static downward load on the double bottom exceeds that given with the combination of a full cargo tank at a cargo density of 1.025 tonnes/m^3 and a mean ship's draught of $0.6T_{sc}$

e. For ships arranged with cross ties in the centre cargo tank , seagoing loading conditions showing a non-symmetricloading pattern where the difference in filling level between corresponding port and starboard wing cargo tanks exceeds 25% of the filling height in the wing cargo tank (Ship approved for loading pattern A7 of Table 4.2.4)

1.1.2.10. This sub-section is intended neither to prevent any other loading conditions that is to be included in the Loading Manual, nor is it intended to replace in any way the required Loading Manual/Instrument.

1.1.2.11. A tanker may in actual operation be loaded differently from the design loading conditions specified in the Loading Manual, provided limitations for longitudinal and local strength as defined in the Loading Manual and Loading Instrument onboard and applicable stability requirements are not exceeded.

1.1.3. Loading computer system

1.1.3.1. The loading computer system, is to be a system, which unless stated otherwise is digital and that can easily and quickly ascertain whether operational limitations are exceeded for any loading condition.

1.1.3.2. On the basis of IRS, approval of the loading computer system is required to be done.

1.1.3.3. The loading computer system is to be capable of producing any specific loading condition and verify that these comply with all the operational limitations given in 1.1.2.2, and provide plots including input and output.

1.1.3.4. The user is required to be properly informed when using the system, and by the plots provided, in case if any of the operational limitations are not checked, so that verification of each such item is conducted by other means. The loading computer system is as a minimum to verify that the following are satisfied:

a. Draught limitations
b. Still water bending moments and shear forces are reported at the specified locations/read-out points.

1.1.3.5. On the basis of the conditions given in the final Loading Manual, the final test conditions for the loading computer are to be prepared. The test conditions are subject to approval and the calculation of the shear forces and bending moments by the loading computer system are to be done, at each read out point, and are required to be within $0.02Q_{sw\text{-}perm}$ or $0.02M_{sw\text{-}perm}$ of the results given in the loading manual, where $Q_{sw\text{-}perm}$ and $M_{sw\text{-}perm}$ are the assigned permissible shear force and bending moment at each read out point respectively.

1.1.3.6. Before the acceptance of a loading computer system is given, all relevant aspects of the computer, including but not limited to the following, are to be demonstrated to the Surveyor:

a. Verification that the final data of the ship has been used
b. Verification that the relevant limits for all read-out points are correct
c. That the operation of the system after installation onboard, is in accordance with the approved test conditions
d. That the approved test conditions are available onboard
e. That an operational manual is available onboard

1.2. Hull Girder Bending Strength

1.2.1. General

1.2.1.1. As given by 1.2.2.2 and 1.2.3.2, the net vertical hull girder section modulus, $Z_{v\text{-}net50}$, is required to be equal to or greater than those requirements. The net vertical hull girder moment of inertia, $I_{v\text{-}net50}$, as defined in Chapter 1 Section 4/2.6.1.1 is required to be equal to or greater than the requirement given by 1.2.2.1.

1.2.1.2. Scantlings of all continuous longitudinal members of the hull girder based on moment of inertia and section modulus requirement in 1.2.2.1 and 1.2.2.2 are to be maintained within 0.4L midships.

1.2.1.3. The hull girder section modulus requirements in 1.2.3 apply along the full length of the hull girder, from A.P. to F.P.

1.2.1.4. Structural members included in the hull girder section modulus are to satisfy the buckling criteria given in 1.4.

1.2.2. Minimum requirements

1.2.2.1. At the midship cross section the net vertical hull girder moment of inertia about the horizontal neutral axis, $I_{v-net50}$, is not to be less than the rule minimum vertical hull girder moment of inertia, I_{v-min}, defined as:

$$I_{v-mi} = 2.7 C_{wv} L^3 B (C_b + 0.7).10^{-8} \text{ m}^4$$

where:
C_{wv} = wave coefficient as defined in Table 2.2.2
L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1
B = moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.1
C_b = block coefficient, as defined in Chapter 1 Section 4/1.1.9.1 but is not to be taken as less than 0.70

Table 2.2.2: Wave Coefficient C_{wv}	
Rule length	**C_{wv}**
150 ≤ L ≤ 300	10.75 – $[(300 – L) / 100]^{3/2}$
300 < L < 350	10.75
350 ≤ L ≤ 500	10.75 – $[(L – 350) / 150]^{3/2}$
See Part 3 Table 4.2.1	

1.2.2.2. At the midship cross section the net vertical hull girder section modulus, Z_{v-min}, at the deck and keel is not to be less than the rule minimum hull girder section modulus, Z_{v-min}, defined as:

$$Z_{v-min} = 0.9 k C_{wv} L^2 B (C_b + 0.7).10^{-6} \text{m}^3$$

where:
k = higher strength steel factor, as defined in Chapter 1 Section 6/1.1.4
C_{wv}= wave coefficient as defined in Table 2.2.2
L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1
B =moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.1
C_b = block coefficient, as defined in Chapter 1 Section 4/1.1.11.1 but is not to be taken as less than 0.70

1.2.2.3. In accordance with Chapter 1 Section 4/2.6.1.2 and taking z at the keel,the net hull girder section modulus at keel, $Z_{v-net50-kl}$, is required to be calculated.

1.2.2.4. In accordance with Chapter 1 Section 4/2.6.1.2 and taking z at the effective deck height, the net hull girder section modulus at deck, $Z_{v-net50-dk}$, is to be calculated, see 1.2.2.5.

1.2.2.5. The effective deck height from the horizontal neutral axis for the hull girder section modulus, z_{dk-eff}, is to be taken as:

$$z_{dk-e} = z_{dk-side} - z_{NA-net50} \text{m}$$

When no effective longitudinal strength members are positioned above a line extending from moulded deck line at side to a position
$(z_{dk-side} - z_{NA-net50})/0.9$ from the neutral axis at the centreline

$$z_{dk-e} = \left(z_y - z_{NA-net50}\right)\left(0.9 + 0.2\frac{y_d}{B}\right) \text{m}$$

When any effective longitudinal strength members are positioned above a line extending from moulded deck line at side to a position
$(z_{dk-side} - z_{NA-net50})/0.9$ from the neutral axis at the centreline

where:

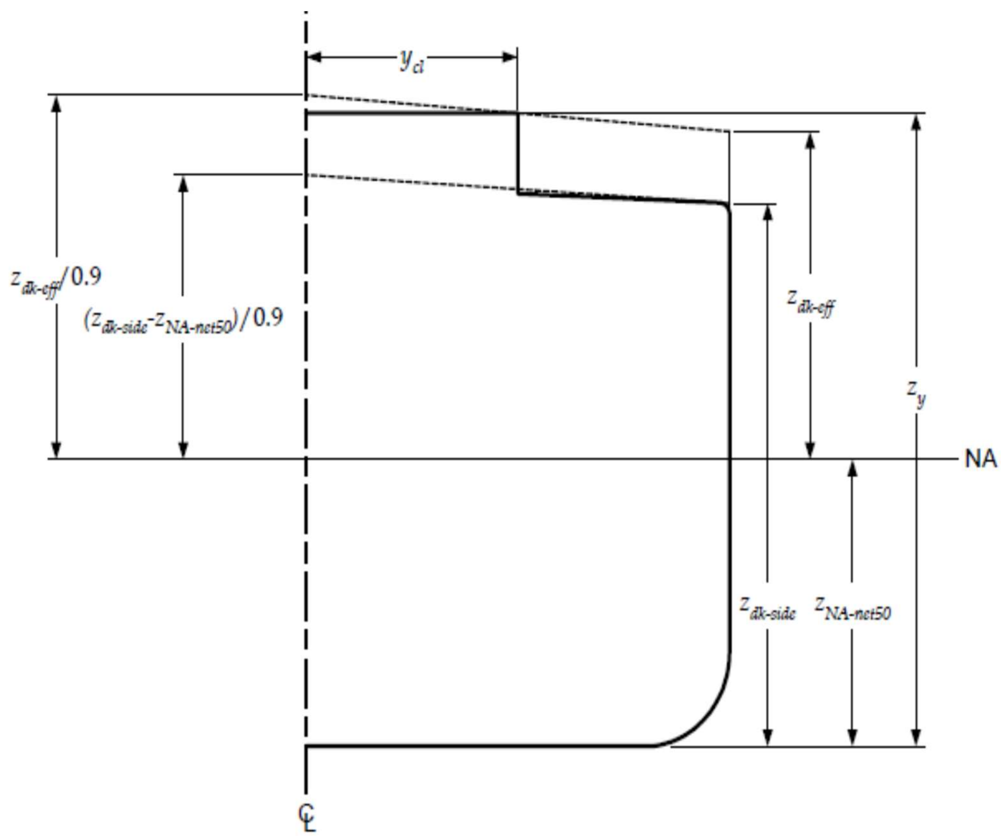
z_y= distance from the baseline to top of the continuous strength member at a distance y from the centreline, in m, giving the largest value of $z_{dk\text{-}eff}$, see Figure 2.2.1

$z_{NA\text{-}net50}$ = distance from baseline to horizontal neutral axis, in m, see Figure 2.2.1

y_{cl} = distance from the top of the continuous strength member to the centreline of the ship, in m, givingthe largest value of $z_{dk\text{-}eff,}$ see Figure 2.2.1

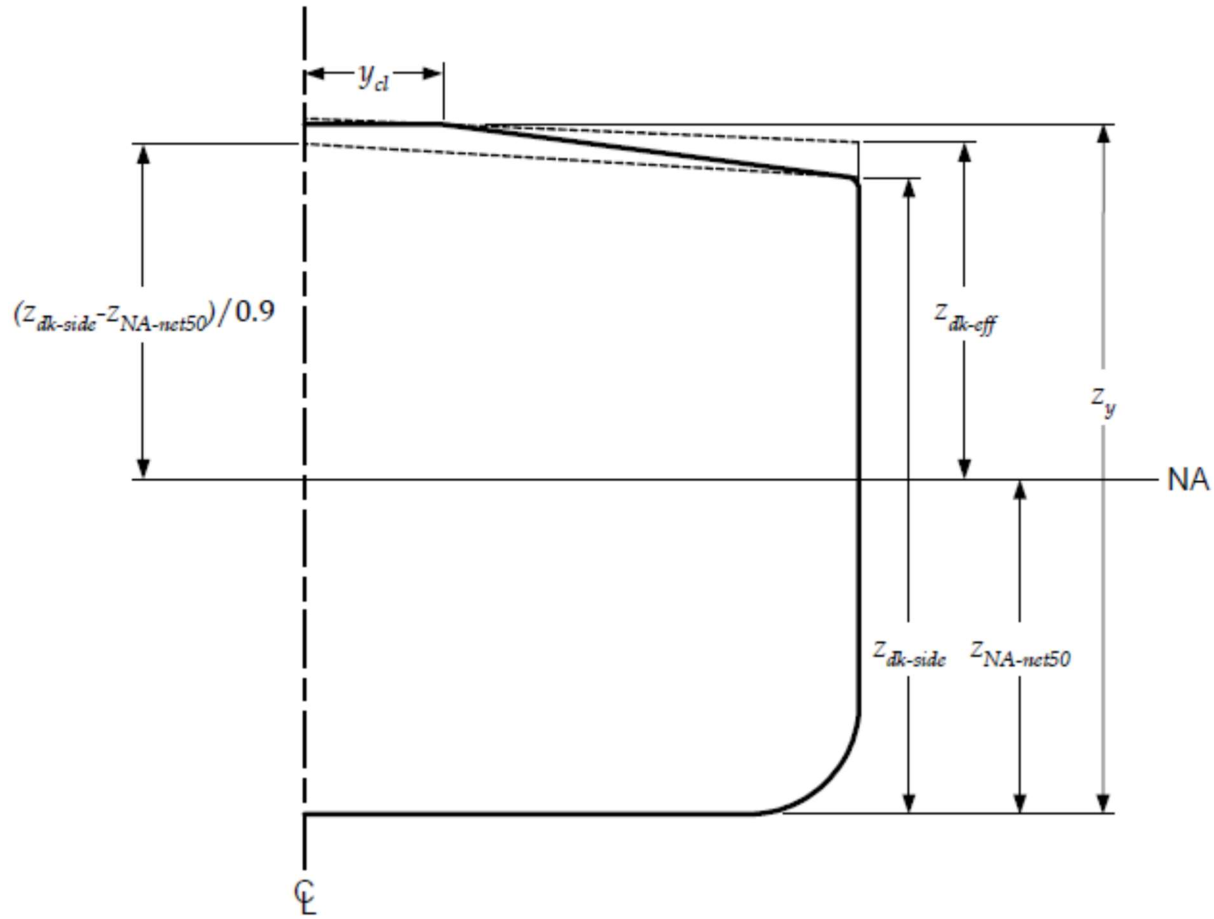
B = moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.1

$z_{dk\text{-}side}$ = distance from the baseline to the moulded deck line at side, in m, see Figure 2.2.1



a. Trunk deck or continuous hatch coaming

Figure 2.2.1: Position for Calculation of Section Modulus Deck



b. Ship with large camber

Figure 2.2.1: Position for Calculation of Section Modulus Deck (Continued)

1.2.3. Hull girder requirement on total design bending moment

1.2.3.1. Assessment of the net vertical hull girder section modulus requirement as defined in 1.2.3.2 is to be done for both hogging and sagging conditions.

1.2.3.2. On the basis of the permissible still-water bending moment and design wave bending moment as defined below,the net hull girder section modulus about the horizontal neutral axis, $Z_{v\text{-}net50}$, shall not to be less than the rule required hull girder section modulus, $Z_{v\text{-}req}$,:

$$Z_{v-re} \;= \frac{|M_{sw-perm}+M_{wv-v}|}{\sigma_{perm}} 10^{-3}\text{m}^3$$

where:

$M_{sw\text{-}perm}$ = permissible hull girder hogging or sagging still water bending moment as given in Table 2.2.3, in kNm

$M_{wv\text{-}v}$ = hogging or sagging vertical wave bending moment, in kNm as given in Table 2.2.3

σ_{perm} = permissible hull girder bending stress as given in Table 2.2.3, in N/mm^2

Table 2.2.3: Loads and Corresponding Acceptance Criteria for Hull Girder Bending Assessment

Design load combination	Still water bending moment, $M_{sw-perm}$	Wave bending moment, M_{wv-v}	Permissible hull girder bending stress, σ_{perm} (1)	
(S)	$M_{sw-perm-harb}$	0	143/k	within 0.4L amidships
			105/k	at and forward of 0.9L from A.P. andat and aft of 0.1L from A.P.
(S + D)	$M_{sw-perm-sea}$	M_{wv-v}	190/k	within 0.4L amidships
			140/k	at and forward of 0.9L from A.P. andat and aft of 0.1L from A.P

where:

$M_{sw-perm-harb}$ permissible hull girder hogging and sagging still water bending moment for harbour/sheltered water operation, in kNm, as defined in Section 7/2.1.1

$M_{sw-perm-sea}$ permissible hull girder hogging and sagging still water bending moment for seagoing operation, in kNm, as defined in Section 7/2.1.1

M_{wv-v} hogging and sagging vertical wave bending moments, in kNm, as defined in Section 7/3.4.1

M_{wv-v} is to be taken as:

M_{wv-hog} for assessment with respect to hogging vertical wave bending moment

M_{wv-sag} for assessment with respect to sagging vertical wave bending moment

k higher strength steel factor, as defined in Section 6/1.1.4

Note

1) σ_{perm} is to be linearly interpolated between values given.

1.3. Hull Girder Shear Strength

1.3.1. General

1.3.1.1. Applications of the hull girder shear strength requirements are considered along the full length of the hull girder, from A.P to F.P.

1.3.2. Assessment of hull girder shear strength

1.3.2.1. As defined in 1.3.2.2,the net hull girder shear strength capacity, $Q_{v-net50}$, is not to be less than the required vertical shear force, Q_{v-req}, as indicated in the following:

$$Q_{v-req} = Q_{sw-perm} + Q_{wv} \text{ KN}$$

where:

$Q_{sw-perm}$= permissible hull girder positive or negative still water shear force as given in Section 1/2.1.3, in kN

Q_{wv} = vertical wave positive or negative shear force as defined in Section 1/3.4.3, in kN

1.3.2.2. Satisfaction of the permissible positive and negative still water shear forces for seagoing and harbour/sheltered water operations, $Q_{sw-perm-sea}$ and $Q_{sw-perm-harb}$ are to be done:

$$Q_{sw-pe} \quad \leq Q_{v-net} \quad - Q_{wv-pos} \text{kN}$$

For maximum permissible positive shear force

$Q_{sw-pe} \quad \geq -Q_{v-net} \quad - Q_{wv-n}$ kN

For minimum permissible negative shear force

where:

$Q_{sw-perm}$= permissible hull girder still water shear force as given in Table 2.2.4, in kN

$Q_{v-net50}$ = net hull girder vertical shear strength to be taken as the minimum for all plate elements that contribute to the hull girder shear capacity

$$= \frac{\tau_{ij-perm} t_{ij-net50}}{1000 \quad v} \text{kN}$$

$\tau_{ij-perm}$= permissible hull girder shear stress, τ_{perm}, as given in Table 2.2.4, in N/mm^2 , for plate ij

Q_{wv-pos} = positive vertical wave shear force, in kN, as defined in Table 2.2.4

Q_{wv-neg} = negative vertical wave shear force, in kN, as defined in Table 2.2.4

$t_{ij-net50}$ = equivalent net thickness, t_{net50}, for plate ij, in mm. For longitudinal bulkheads between cargo tanks, t_{net50} is to be taken as $t_{sfc-net50}$ and t_{str-k} as appropriate, see 1.3.3.1 and 1.3.4.1

t_{net50}= net thickness of plate, in mm

$= t_{grs} - 0.5 t_{corr}$

t_{grs}= gross plate thickness, in mm. The gross plate thickness for corrugated bulkheads is to be taken as the minimum of t_{w-grs} and t_{f-grs}, in mm

t_{w-grs} = gross thickness of the corrugation web, in mm

t_{f-grs} = gross thickness of the corrugation flange, in mm

t_{corr} = corrosion addition, in mm, as defined in Chapter 1 Section 6/3.2

q_v= unit shear flow per mm for the plate being considered and based on the net scantlings. Where direct calculation of the unit shear flow is not available, the unit shear flow may be taken equal to:

$= f_i \left(\frac{q_{1-net50}}{I_{v-net50}}\right) . 10^{-9}$mm^{-1}

f_i= shear force distribution factor for the main longitudinal hull girder shear carrying members being considered. For standard structural configurations fi is as defined in Figure 2.2.2

$q_{1-net50}$ = first moment of area, in cm^2, about the horizontal neutral axis of the effective longitudinal members between the vertical level at which the shear stress is being determined and the vertical extremity, taken at the section being considered. The first moment of area is to be based on the net thickness, t_{net50}

$I_{v-net50}$ = net vertical hull girder section moment of inertia, in m^4, as defined in Chapter 1 Section 4/2.6.1.1

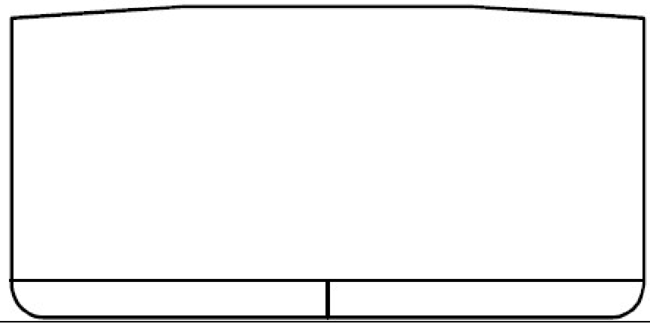
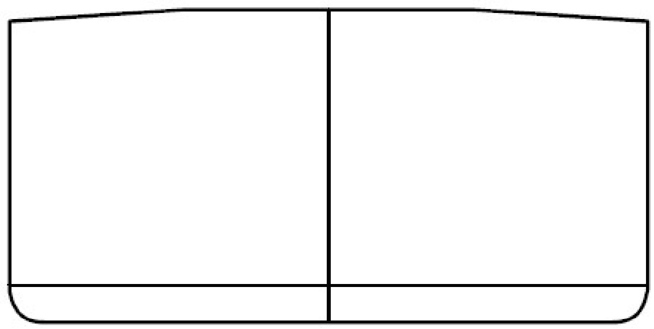
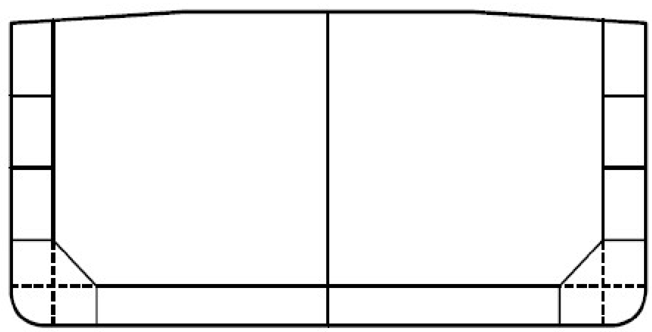
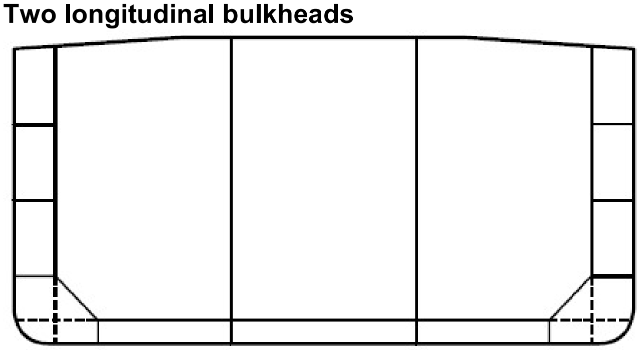
Table 2.2.4: Loads and Corresponding Acceptance Criteria for Hull Girder Shear Assessment

Design load combination	Still water shear force, $Q_{sw-perm}$	Vertical wave shear force, Q_{wv}	Permissible shear stress, τ_{perm}
Harbour/sheltered water operations (S)	$Q_{sw-perm-harb}$	0	105/k for plate ij
Seagoing operations (S + D)	$Q_{sw-perm-sea}$	Q_{wv}	120/k for plate ij

where:

$Q_{sw-perm-harb}$	permissible positive or negative hull girder still water shear force for harbour operation, in kN, as defined in Section 1/2.1.3
$Q_{sw-perm-sea}$	permissible positive or negative hull girder still water shear force for seagoing operation, in kN, as defined in Section 1/2.1.3
Q_{wv}	Positive or negative vertical wave shear, in kN, as defined in Section 1/3.4.3. $Q_{vw}$is to be taken as: Q_{wv-pos} for assessment with respect to maximum positive permissible still water shear force Q_{wv-neg} for assessment with respect to minimum negative permissible still water shear force
plate ij	for each plate j, index i denotes the structural member of which the plate forms a component
k	higher strength steel factor, as defined in Chapter 1 Section 6/1.1.4

Figure 2.2.2: Shear Force Distribution Factors

f_i factors	**Hull configuration**
Side shell $f_1 = 0.5$	**Outside cargo region (no longitudinal bulkhead)** 
Side shell $f_1 = 0.231 + 0.076 \frac{A_{1-net50}}{A_{3-net50}}$ Longitudinal bulkhead $f_3 = 0.538 - 0.152 \frac{A_{1-net}}{A_{3-net50}}$	**Outside cargo region (centreline bulkhead)** 
Side shell $f_1 = 0.055 + 0.097 \frac{A_{1-net50}}{A_{2-net}} + 0.020 \frac{A_{2-net50}}{A_{3-net}}$ Inner hull $f_2 = 0.193 - 0.059 \frac{A_{1-net50}}{A_{2-net}} + 0.058 \frac{A_{2-net}}{A_{3-net50}}$ Longitudinal bulkhead $f_3 = 0.504 - 0.076 \frac{A_{1-net}}{A_{2-net}} - 0.156 \frac{A_{2-net}}{A_{3-n}}$	**One centreline bulkhead** 
Side shell $f_1 = 0.028 + 0.087 \frac{A_{1-net50}}{A_{2-net50}} + 0.023 \frac{A_{2-net50}}{A_{3-net50}}$ Inner hull $f_2 = 0.119 - 0.038 \frac{A_{1-net50}}{A_{2-net}} + 0.072 \frac{A_{2-net50}}{A_{3-net}}$ Longitudinal bulkhead $f_3 = 0.353 - 0.049 \frac{A_{1-net50}}{A_{2-net}} - 0.095 \frac{A_{2-net50}}{A_{3-net}}$	**Two longitudinal bulkheads** 

where:

i = index for the structural member under consideration:

- 1, for the side shell
- 2, for the inner hull
- 3, for the longitudinal bulkhead

$A_{i-net50}$ net area as defined in Chapter 1 Section 4/2.6.4 and based on deduction of $0.5t_{corr}$, of the structural member, i, at one side of the section under consideration. The area $A_{3-net50}$ for the centreline bulkhead is not to be reduced for symmetry around the centreline.

1.3.3. Shear force correction for longitudinal bulkheads between cargo tanks

1.3.3.1. For longitudinal bulkheads between cargo tanks the effective net plating thickness of the plating above the inner bottom, $t_{sfc-net50}$ for plate ij, used for calculation of hull girder shear strength, $Q_{v-.net50}$, is to be corrected for local shear distribution and is given by:

$$t_{sfc-net50} = t_{grs} - 0.5t_{corr} - t_{\Delta} \text{ mm}$$

where:

t_{grs}= gross plate thickness, in mm

t_{corr}= corrosion addition, in mm, as defined in Chapter 1 Section 6/3.2

t_{Δ} = thickness deduction for plate ij, in mm, as defined in 1.3.3.2

1.3.3.2. The vertical distribution of thickness reduction for shear force correction is assumed to be triangular as indicated in Figure 2.2.3. The thickness deduction, t_D, to account for shear force correction is to be taken as:

$$t_{\Delta} = \frac{\delta Q_3}{h_{blk}T_{ij-perm}}\left(1 - \frac{x_{blk}}{0.5l_{tk}}\right)\left(2 - \frac{2(z_p - h_{db})}{h_{blk}}\right) \text{ m}$$

where:

δQ_3= shear force correction for longitudinal bulkhead as defined in 1.3.3.3 and 1.3.3.5 for ships with one ortwo longitudinal bulkheads respectively, in kN.

l_{tk} = length of cargo tank, in m

h_{blk} = height of longitudinal bulkhead, in m, defined as the distance from inner bottom to the deck at the top of the bulkhead, as shown in Figure 2.2.3

x_{blk}= the minimum longitudinal distance from section considered to the nearest cargo tank transverse bulkhead, in m. To be taken positive and not greater than $0.5l_{tk}$

z_p= the vertical distance from the lower edge of plate ij to the base line, in m. Not to be taken as less than h_{db}

h_{db}= height of double bottom, in m, as shown in Figure 2.2.3

$\tau_{ij-perm}$= permissible hull girder shear stress, τ_{perm}, in N/mm^2 for plate ij = $120/k_{ij}$

k_{ij} = higher strength steel factor, k, for plate ij as defined in Chapter 1 Section 6/1.1.4

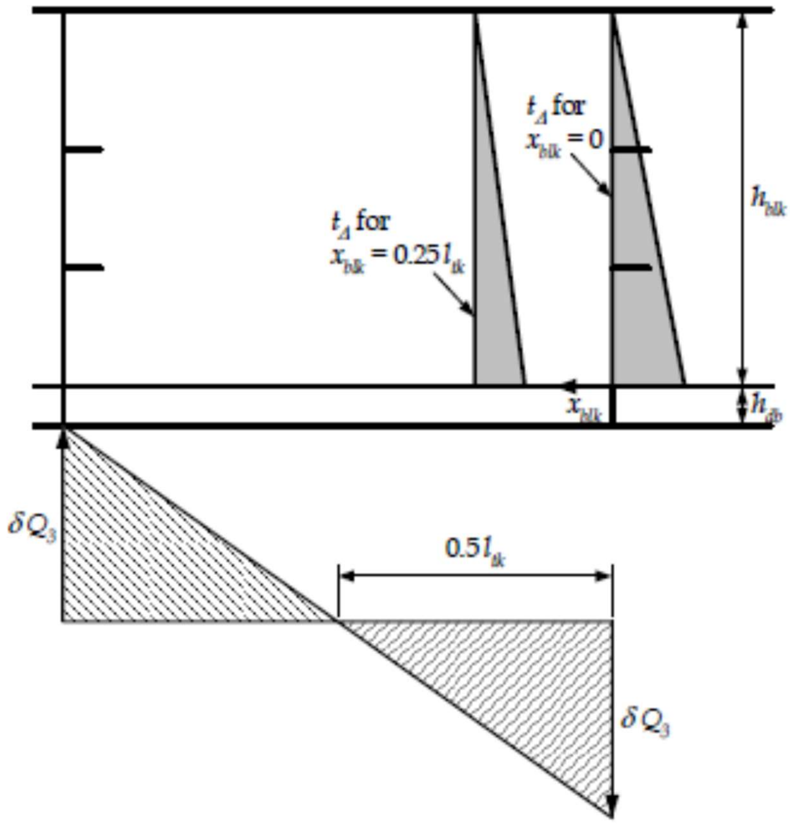


Figure 2.2.3: Shear Force Correction for Longitudinal Bulkheads

1.3.3.3. For ships with a centreline bulkhead between the cargo tanks, the shear force correction in way of transverse bulkhead, δQ_3, is to be taken as:

$$\delta Q_3 = 0.5K_3F_{db}\text{kN}$$

where:

K_3= correction factor, as defined in 1.3.3.4

F_{db}= maximum resulting force on the double bottom in a tank, in kN, as defined in 1.3.3.7

1.3.3.4. For ships with a centreline bulkhead between the cargo tanks, the correction factor, K_3, in way of transverse bulkheads is to be taken as:

$$K_3 = \left[0.40\left(1 - \frac{1}{1+n}\right) - f_3\right]$$

here:

n = number of floors between transverse bulkheads

f_3= shear force distribution factor, see Figure 2.2.2

1.3.3.5. For ships with two longitudinal bulkheads between the cargo tanks, the shear force correction, δQ_3,is to be taken as:

$$\delta Q_3 = 0.5K_3F_{db}\text{ kN}$$

where:

K_3= correction factor, as defined in 1.3.3.6

F_{db}= maximum resulting force on the double bottom in a tank, in kN, as defined in 1.3.3.7

1.3.3.6. For ships with two longitudinal bulkheads between the cargo tanks, the correction factor, K_3, in way of transverse bulkhead is to be taken as:

$$K_3 = \left[0.5\left(1 - \frac{1}{1+n}\right)\left(\frac{1}{r+1}\right) - f_3\right]$$

where:

n = number of floors between transverse bulkheads

r = ratio of the part load carried by the wash bulkheads and floors from longitudinal bulkhead to the double side and is given by:

$$r = \frac{1}{\left[\frac{A_{3-net50}}{A_{1-net} \quad +A_{2-net50}} + \frac{2\times10^4 b_{80}(n_s+1)A_{3-net}}{l_{tk}(n_s A_{T-net} \quad +R)}\right]}$$

Note: for preliminary calculations, r may be taken as 0.5

l_{tk} = length of cargo tank, between transverse bulkheads in the side cargo tank, in m

b_{80}= 80% of the distance from longitudinal bulkhead to the inner hull longitudinal bulkhead, in m, at tank mid length

$A_{T-net50}$= net shear area of the transverse wash bulkhead, including the double bottom floor directlybelow, in the side cargo tank, in cm^2, taken as the smallest area in a vertical section. $A_{T-net50}$is to be calculated with net thickness given by t_{grs} - 0.5t_{corr}

$A_{1-net50}$ = net area, as shown in Figure 2.2.2, in m^2

$A_{2-net50}$ = net area, as shown in Figure 2.2.2, in m^2

$A_{3-net50}$ = net area, as shown in Figure 2.2.2, in m^2

f_3 = shear force distribution factor, as shown in Figure 2.2.2

n_S= number of wash bulkheads in the side cargo tank

R = total efficiency of the transverse primary support members in the side tank

$$R = \left(\frac{n-n_s}{2} - 1\right)\frac{A_{Q-net50}}{\gamma}\text{cm}^2$$

$$\gamma = 1 + \frac{300 b_{80}^2 A_{Q-net}}{I_{psm-net5}}$$

$A_{Q-net50}$ = net shear area, in cm^2, of a transverse primary support member in the wing cargo tank, taken as the sum of the net shear areas of floor, cross ties and deck transverse webs. $A_{Q-net50}$ is to be calculated using the net thickness given by t_{grs} - 0.5t_{corr}. The net shear area is to be calculated at the mid span of the members.

$I_{psm-net50}$ = net moment of inertia for primary support members, in cm4, of a transverse primary supportmember in the wing cargo tank, taken as the sum of the moments of inertia of transverses and cross ties. It is to be calculated using the net thickness given by t_{grs} - 0.5t_{corr}. The net moment of inertia is to be calculated at the mid span of the member including an attached plate width equal to the primary support member spacing

t_{grs} = gross plate thickness, in mm

t_{corr} = corrosion addition, in mm, as defined in Chapter 1 Section 6/3.2

1.3.3.7. The maximum resulting force on the double bottom in a tank, F_{db}, is to be taken as:

$$F_{db} = g|W_{CT} + W_{CWBT} - \rho_{sw} b_2 l_{tk} T_{mean}|\text{kN}$$

where:

W_{CT} = weight of cargo, in tonnes, as defined in Table 2.2.5

W_{CWBT} = weight of ballast, in tonnes, as defined in Table 2.2.5

b_2 breadth, in m, as defined in Table 2.2.5

l_{tk} =length of cargo tank, between watertight transverse bulkheads in the wing cargo tank, in m

T_{mean}= draught at the mid length of the tank for the loading condition considered, in m.

g = acceleration due to gravity, 9.81 m/s^2

ρ_{sw}= density of sea water, 1.025 tonnes/m^3

Table 2.2.5: Design Conditions for Double Bottoms

Structural Configuration	W_{CT}	W_{CWBT}	b_2
Ships with one longitudinalbulkhead	weight of cargo in cargo tanks, in tonnes, using a minimum specific gravityof 1.025 tonnes/m^3	weight of ballast between port and starboard inner sides, in tonnes	maximum breadth betweenport and starboard inner sides at mid length of tank, in m, asshown in Figure 2.2.4
Ships with two longitudinalbulkheads	weight of cargo in the centre tank, in tonnes, using a minimum specificgravity of 1.025 tonnes/m^3	weight of ballast below thecentre cargo tank, in tonnes	maximum breadth of the centre cargo tank at mid length of tank, in m, as shown in Figure 2.2.4

1.3.3.8. The maximum resulting force on the double bottom in a tank, F_{db}, is in no case to be less than thatgiven by the rule minimum conditions given in Table 2.2.6.

Table 2.2.6: Rule Minimum Conditions for Double Bottoms

Structural Configuration	Positive/negative force, F_{db}	Minimum condition
Ships with one longitudinal bulkhead	Max positive net vertical force, F_{db}+	0.9T_{sc} and empty cargo and ballasttanks
	Max negative net vertical force, F_{db}-	0.6T_{sc} and full cargo tanks and emptyballast tanks
Ships with two longitudinal bulkheads	Max positive net vertical force, F_{db}+	0.9T_{sc} and empty cargo and ballasttanks
	Max negative net vertical force, F_{db}-	0.6T_{sc} and full centre cargo tank andempty ballast tanks

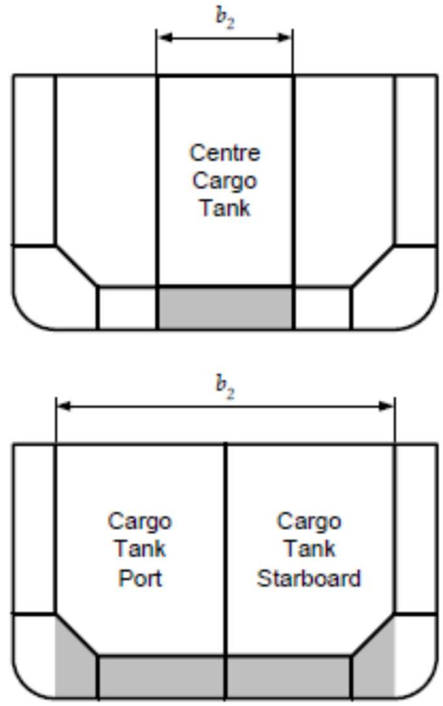


Figure 2.2.4: Tank Breadth to be Included for Different Tanker Types

1.3.4. Shear force correction due to loads from transverse bulkhead stringers

1.3.4.1. In way of transverse bulkhead stringer connections, within areas as specified in Figure 2.2.6, the equivalent net thickness of plate used for calculation of the hull girder shear strength, t_{str-k}, where the index k refers to the identification number of the stringer, is not to be taken greater than:

$$t_{str-k} = t_{sfc-net5} \left(1 - \frac{T_{str}}{T_{ij-perm}}\right)$$

where:

$t_{sfc-net50}$ = effective net plating thickness, in mm, as defined in 1.3.3.1 and calculated at the transverse bulkhead for the height corresponding to the level of the stringer

$\tau_{ij-perm}$ = permissible hull girder shear stress, τ_{perm}, for plate ij

= $120/k_{ij}$ N/mm^2

k_{ij}= higher strength steel factor, k, for plate ij as defined in Chapter 1 Section 6/1.1.4

$= 0.8F_{str-k}\left(1 - \frac{z_{str}-h_{db}}{h_{bhd}}\right)$kN

l_{str} = connection length of stringer, in m, see Figure 2.2.5

Q_{str-k}= shear force on the longitudinal bulkhead from the stringer in loaded condition with tanks abreast full

$$= 0.8F_{str-k}\left(1 - \frac{z_{str} - h_{db}}{h_{bhd}}\right)$$

F_{str-k} = total stringer supporting force, in kN, as defined in 1.3.4.2

h_{db}= the double bottom height, in m, as shown in Figure 2.2.6

h_{blk} = height of bulkhead, in m, defined as the distance from inner bottom to the deck at the top of the bulkhead, as shown in Figure 2.2.6

z_{str}= the vertical distance from baseline to the considered stringer, in m.

1.3.4.2. The total stringer supporting force, F_{str-k}, in way of a longitudinal bulkhead is to be taken as:

$$F_{str-k} = \frac{P_{str} b_{str} (h_k + h_{k-1})}{2} \ kN$$

where:

P_{str} = pressure on stringer, in kN/m^2, to be taken as: $10h_{tt}$

h_{tt} = the height from the top of the tank to the midpoint of the load area between $h_k/2$ below the stringer and $h_{k-1}/2$ above the stringer, in m

h_k= the vertical distance from the considered stringer to the stringer below. For the lowermost stringer, it is to be taken as 80 % of the average vertical distance to the inner bottom, in m

h_{k-1}= the vertical distance from the considered stringer to the stringer above. For the uppermost stringer, it is to be taken as 80 % of the average vertical distance to the upper deck, in m

b_{str}= load breadth acting on the stringer, in m, see Figure 2.2.7 and 2.2.8

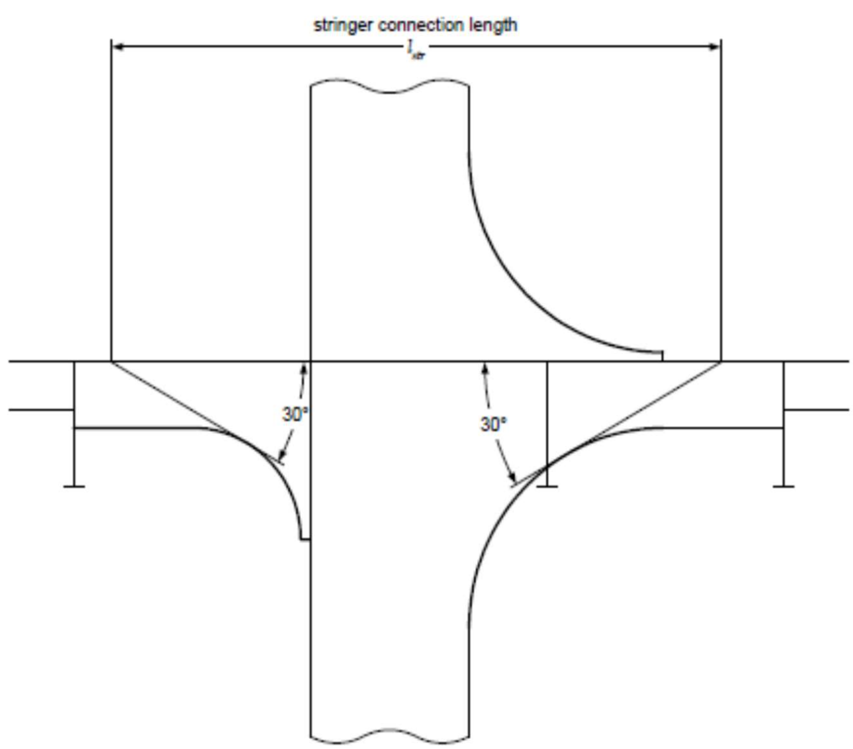


Figure 2.2.5: Effective Connection Length of Stringer

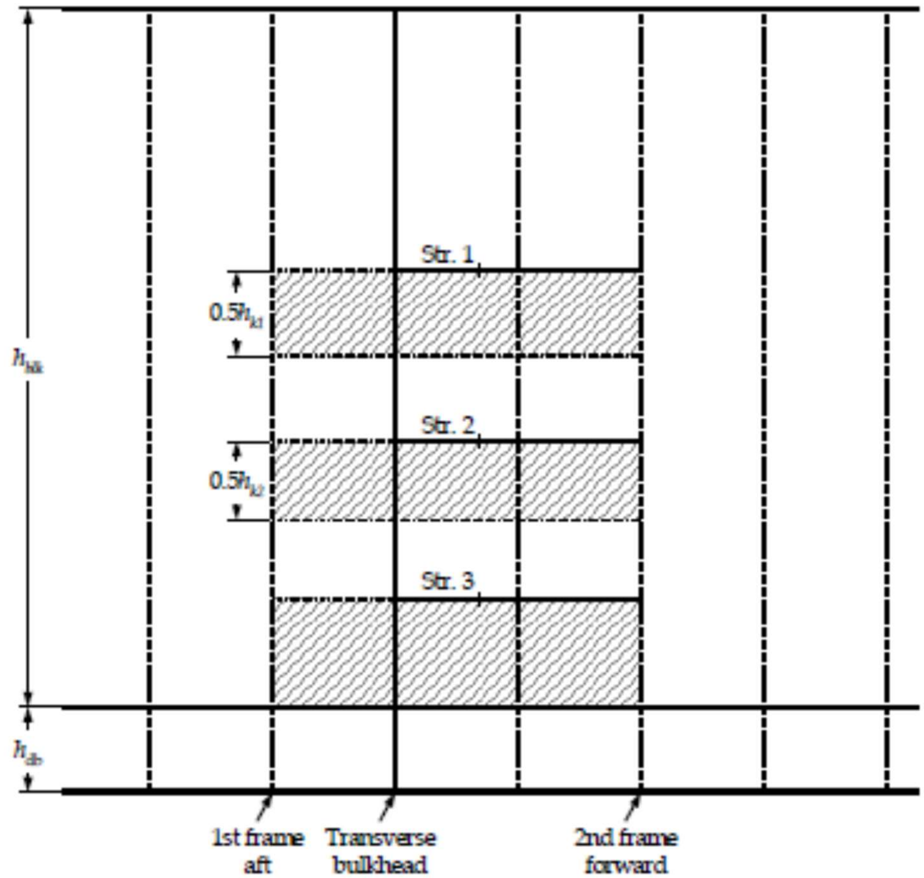


Figure 2.2.6: Region for Stringer Correction, t_{ij}, for a Tanker with Three Stringers

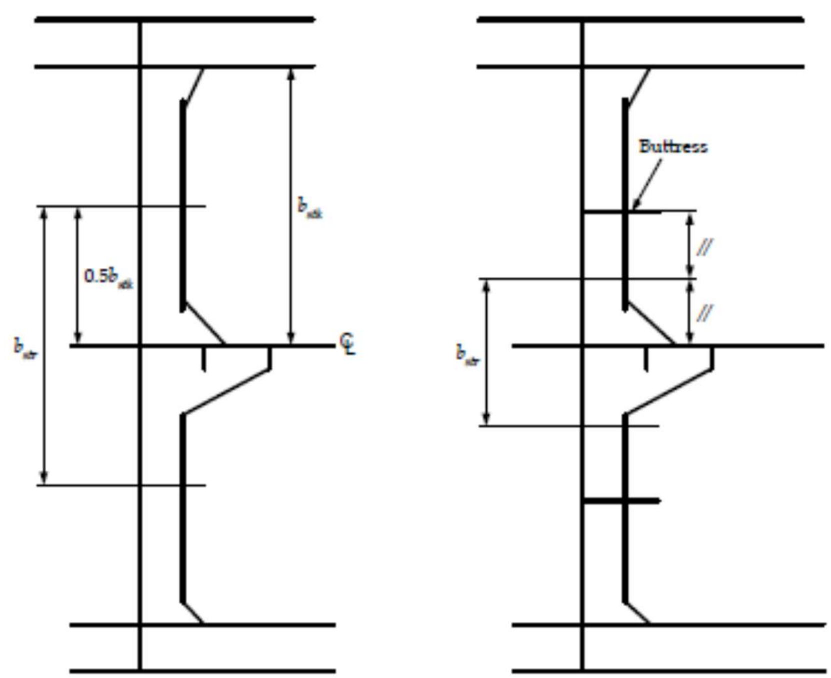
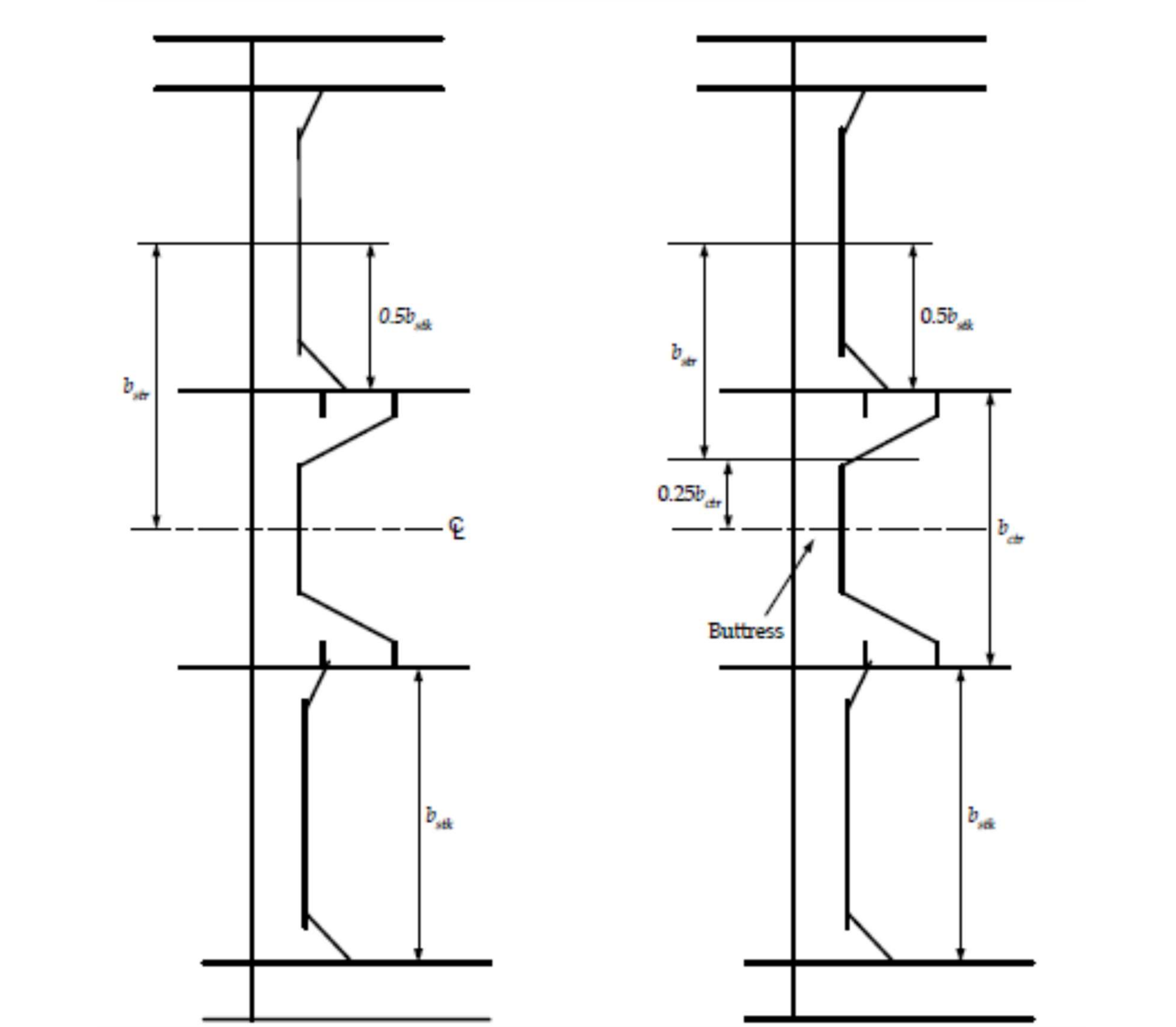


Figure 2.2.7: Load Breadth of Stringers for Ships with a Centreline Bulkhead

1.3.4.3. The reinforced area based on t_{str-k} is to extend longitudinally for the full length of the stringer connection and a minimum of one frame spacing forward and aft of the bulkheadwhere, reinforcement is provided to meet the above requirement. The reinforced area shall extend vertically from above the stringer level and down to $0.5h_k$ below the stringer, where h_k, the vertical distance from the considered stringer to the stringer below is as defined in 1.3.4.2. For the lowermost stringer the plate thickness requirement t_{str-k} is to be extended downto the inner bottom, , see Figure 2.2.6



Notes

1) b_{stk} is the breadth of wing cargo tank, in m.
2) b_{ctr} is the breadth of centre cargo tank, in m.

Figure 2.2.8: Load Breadth of Stringers for Ships with Two Inner Longitudinal Bulkheads

1.4. Hull Girder Buckling Strength

1.4.1. General

1.4.1.1. Application of these requirements is done to plate panels and longitudinals subject to hull girder compression and shear stresses. These stresses are to be based on the permissible values for still water bending and shear forces given in Section 1/2.1, and wave bending moments and shear forces given in Section 1/3.4.

1.4.1.2. Application of the hull girder buckling strength requirements are considered along the full length of the ship, from A.P to F.P.

1.4.1.3. In order to assess the hull girder buckling strength in this sub-section, the following are to be considered separately:

a. Axial hull girder compressive stress to satisfy requirements in 1.4.2.6 and 1.4.2.8

b. Hull girder shear stress to satisfy requirements in 1.4.2.7.

1.4.2. Buckling assessment

1.4.2.1. According to Section 4/3.1, determination of the buckling assessment of plate panels and longitudinals is to be done with hull girder stresses calculated on net hull girder sectional properties.

1.4.2.2. The buckling strength for the buckling assessment is to be derived using local net scantlings, t_{net}, as follows:

$$t_{net} = t_{grs} - 1.0 t_{corr} \text{mm}$$

where:

t_{grs}= gross plate thickness, in mm

t_{corr} = corrosion addition, in mm, as defined in Chapter 1 Section 6/3.2

1.4.2.3. Calculation of the hull girder compressive stress due to bending, $\sigma_{hg\text{-}net50}$, for the buckling assessment is to be done using net hull girder sectional properties and is to be taken as the greater of the following:

$$\sigma_{hg-net50} = \left|\frac{(z - z_{NA-net50})(M_{sw-perm-sea} + M_{wv-v})}{I_{v-net50}}\right| 10^{-3} \text{ N/mm}^2$$

$$\sigma_{hg-net50} = \frac{30}{k} \text{N/mm}^2$$

where:

$M_{sw\text{-}perm\text{-}sea}$ =permissible still water bending moment for seagoing operation, in kNm, as defined in Section 1/2.1.1, with signs as given in 1.4.2.4

$M_{wv\text{-}v}$ = hogging and sagging vertical wave bending moments, in kNm, as defined in Section 1/3.4.1, with signs as given in 1.4.2.4

$M_{wv\text{-}v}$ is to be taken as:

$M_{wv\text{-}hog}$ = for assessment with the hogging still water bending moment

$M_{wv\text{-}sag}$ = for assessment with the sagging still water bending moment

z = distance from the structural member under consideration to the baseline, in m

$z_{NA\text{-}net50}$ = distance from the baseline to the horizontal neutral, in m, see Figure 2.2.1

$I_{v\text{-}net50}$ = net vertical hull girder section moment of inertia, in m^4, as defined in Chapter 1 Section 4/2.6.1.1

k = higher strength steel factor, as defined in Chapter 1 Section 6/1.1.4.1

1.4.2.4. For members above the neutral axis,the sagging bending moment values of $M_{sw-perm-sea}$ and M_{wv-v} are to be taken. For members below the neutral axis,the hogging bending moment values are to be taken.

1.4.2.5. Calculation of the design hull girder shear stress for the buckling assessment,$\tau_{hg-net50}$, is to be based on net hull girder sectional properties and is to be taken as:

$$\tau_{hg-net50} = \left|\left(Q_{sw-perm-sea} + Q_{wv}\right)\left(\frac{1000\ \ v}{t_{ij-net50}}\right)\right| \text{N/mm}^2$$

where:
$Q_{sw-perm-sea}$= positive and negative still water permissible shear force for seagoing operation, in kN, as defined in Section 1/2.1.3
Q_{wv}= positive or negative vertical wave shear, in kN, as defined in Section 1/3.4.3.
Q_{vw} is to be taken as:
Q_{wv-pos} for assessment with the positive permissible still water shear force
Q_{wv-neg} for assessment with the negative permissible still water shear force
$t_{ij-net50}$ net thickness for the plate ij, in mm
= t_{ij-grs} $0.5t_{corr}$
t_{ij-grs} gross plate thickness of plate ij, in mm. The gross plate thickness for corrugated bulkheads is to be taken as the minimum of t_{w-grs} and t_{f-grs}, in mm
t_{w-grs} = gross thickness of the corrugation web, in mm
t_{f-grs} = gross thickness of the corrugation flange, in mm
t_{corr}= corrosion addition, in mm, as defined in Chapter 1 Section 6/3.2
q_v= unit shear per mm for the plate being considered as defined in 1.3.2.2
Note

1. Maximum of the positive shear (still water + wave) and negative shear (still water + wave) is to be used as the basis for calculation of design shear stress

2. All plate elements ij that contribute to the hull girder shear capacity are to be assessed. See also Table 2.2.4 and Figure 2.2.2

3. The gross rule required thicknesses is to be calculated considering shear force correction.

4. For longitudinal bulkheads between cargo tanks, $t_{ij-net50}$ is to be taken as $t_{sfc-net50}$ and t_{str-k} as appropriate.

1.4.2.6. The compressive buckling strength, of plate panels, is to satisfy the following criteria

$\eta \leq \eta_{allow}$

where:

H = buckling utilisation factor

$$\frac{\sigma_{hg-net50}}{\sigma_{cr}}$$

$\sigma_{hg-net50}$=hull girder compressive stress based on net hull girder sectional properties, in N/mm^{2}as defined in 1.4.2.3

σ_{cr}= critical compressive buckling stress, σ_{xcr} or σ_{ycr} as appropriate, in N/mm^2, as specified in Section 4/3.2.1.3. Calculation of the critical compressive buckling stress is to be done for the effects of hull girder compressive stress only. The effects of other membrane stresses and lateral pressure are to be ignored. The net thickness given as $t_{grs} - t_{corr}$ as described in Chapter 1 Section 6/3.3.2.2 is to be used for calculation of σ_{cr}

η_{allow}= allowable buckling utilisation factor:

= 1.0 for plate panels at or above 0.5D

= 0.90 for plate panels below 0.5D

t_{grs} = gross plate thickness, in mm

t_{corr}= corrosion addition, in mm, as defined in Chapter 1 Section 6/3.2

1.4.2.7. The shear buckling strength, of plate panels, is to satisfy the following criteria:

$\eta \leq \eta_{allow}$

where:

η = buckling utilisation factor

$$\frac{\sigma_{hg-net50}}{\sigma_{cr}}$$

$\sigma_{hg-net50}$ = design hull girder shear stress, in N/mm^2, as defined in 1.4.2.5

σ_{cr}= critical shear buckling stress, in N/mm^2, as specified in Section 4/3.2.1.3.. The critical shear buckling stress is to be calculated for the effects of hull girder shear stress only. The effects of other membrane stresses and lateral pressure are to be ignored. The net thickness given as $t_{grs} - t_{corr}$ as described in Chapter 1 Section 6/3.3.2.2 is to be used for the calculation of σ_{cr}

η_{allow}= allowable buckling utilisation factor

= 0.95

t_{grs}= gross plate thickness, in mm

t_{corr}= corrosion addition, in mm, as defined in Chapter 1 Section 6/3.2

1.4.2.8. The compressive buckling strength of longitudinal stiffeners is to satisfy the following criteria:

$\eta \leq \eta_{allow}$

where:

η = greater of the buckling utilisation factors given in Section 4/3.3.2.1 and Section 4/3.3.3.1. Calculation of the buckling utilisation factor is to be done for the effects of hull girder compressive stress only. The effects of other membrane stresses and lateral pressure are to be ignored.

η_{allow}= allowable buckling utilisation factor:

= 1.0 for stiffeners at or above 0.5D

= 0.90 for stiffeners below 0.5D

1.5. Hull Girder Fatigue Strength

1.5.1. General

1.5.1.1. The following provides a simplified fatigue control measure against the dynamic hull girder stresses in the longitudinal deck structure.

1.5.1.2. The requirements in 1.5.1.3 are not mandatory, but recommendations are made for the application in the early design phase in order to give an indication of the required hull girder section modulus for compliance with the mandatory fatigue requirements specified in Section 3/3 and Chapter 4 Section 3.

1.5.1.3. The fatigue life for the deck structure as required by Section 3/3 and Ch 4 Sec 3 is normally satisfied providing the net vertical hull girder section modulus at the moulded deck line at side, $Z_{v-net50}$, as defined in Chapter 1 Section 4/2.6.1.1, is not less than the required hull girder section modulus, Z_{v-fat}, defined as:

$$Z_{v-fat} = \frac{M_{wv-hog} - M_{wv-sag}}{100 \quad {}_{al}} \mathrm{m}^3$$

where:

M_{wv-hog} = hogging vertical wave bending moment for fatigue, in kNm, as defined in Section 1/3.4.1

M_{wv-sag} = sagging vertical wave bending moment for fatigue, in kNm, as defined in Section 1/3.4.1

R_{al}= allowable stress range, in N/mm^2

= 0.17L + 86 for class F-details

= 0.15L + 76 for class F2-details

L = rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1

1.6. Tapering and Structural Continuity of Longitudinal Hull Girder Elements

1.6.1. Tapering based on minimum hull girder section property requirements

1.6.1.1. Scantlings of all continuous longitudinal members of the hull girder based on the moment of inertia and section modulus requirements given in 1.2.2 are to be maintained within 0.4L of amidships.

1.6.1.2. Scantlings outside of 0.4L amidships as required by the rule minimum moment of inertia and section modulus as given in 1.2.2 may be gradually reduced to the local requirements at the ends provided the hull girder bending and buckling requirements, along the full length of the ship, as given in 1.2.3 and 1.4 are complied with. For tapering of higher strength steel, see 1.6.2 and 1.6.3.

1.6.2. Longitudinal extent of higher strength steel

1.6.2.1. Where used, the application of higher strength steel is to be continuous over the length of the ship up to locations where the longitudinal stress levels are within the allowable range for mild steel structure, see Figure 2.2.9.

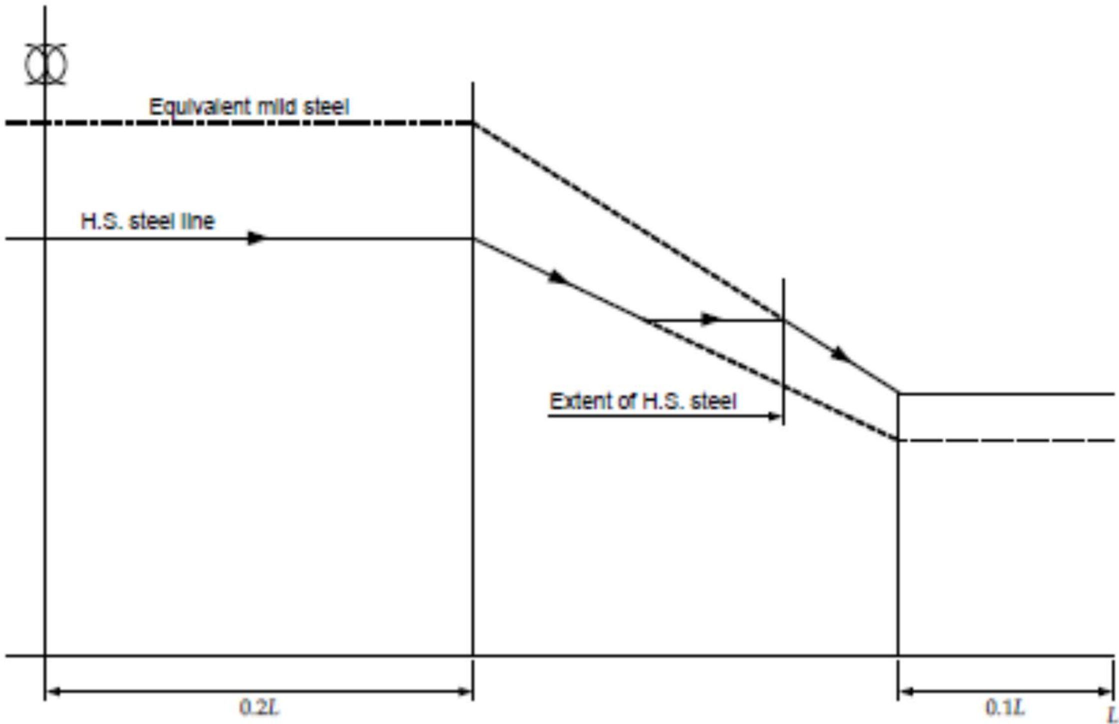


Figure 2.2.9: Longitudinal Extent of Higher Strength Steel

1.6.3. Vertical extent of higher strength steel

1.6.3.1. The vertical extent of higher strength steel, z_{hts}, used in the deck or bottom and measured from the moulded deck line at side or keel is not to be taken less than the following, see also Figure 2.2.10.

$$Z_{hts} = Z_1\left(1 - \frac{190}{\sigma_1 k_i}\right)\text{m}$$

where:

1.6.3.2. z_1= distance from horizontal neutral axis to moulded deck line or keel respectively, in m

σ_1 to be taken as σ_{dk} orσ_{kl} for the hull girder deck and keel respectively, in N/mm²

σ_{dk} hull girder bending stress at moulded deck line given by:

$$= \frac{|M_{sw-perm-se} \ +M_{wv-v}|}{I_{v-net}}(z_{dk-side} - z_{NA-net50}).\,10^{-3}\text{N/mm}^2$$

σ_{kl}= hull girder bending stress at keel given by :

$$= \frac{|M_{sw-perm-sea}+M_{wv-v}|}{I_{v-net}}(z_{NA-net50} - z_{kl}).\,10^{-3}\text{N/mm}^2$$

$M_{sw\text{-}perm\text{-}sea}$ = permissible hull girder still water bending moment for seagoing operation, in kNm, as defined in Section 1/2.1.1

$M_{wv\text{-}v}$ = hogging and sagging vertical wave bending moments, in kNm, as defined in Section 1/3.4.1

$M_{wv\text{-}v}$ is to be taken as:

$M_{wv\text{-}hog}$= for assessment with respect to hogging vertical wave bending moment

$M_{wv\text{-}sag}$ = for assessment with respect to sagging vertical wave bending moment

$I_{v\text{-}net50}$ = net vertical hull girder moment of inertia, in m4, as defined in Chapter 1 Section 4/2.6.1.1

$z_{dk\text{-}side}$ = distance from baseline to moulded deck line at side, in m

z_{kl}= vertical distance from the baseline to the keel, in m

$z_{NA\text{-}net50}$ = distance from baseline to horizontal neutral axis, in m

k_i= higher strength steel factor for the area i defined in Figure 8.1.10. The factor, k, is defined in Chapter 1 Section 6/1.1.4

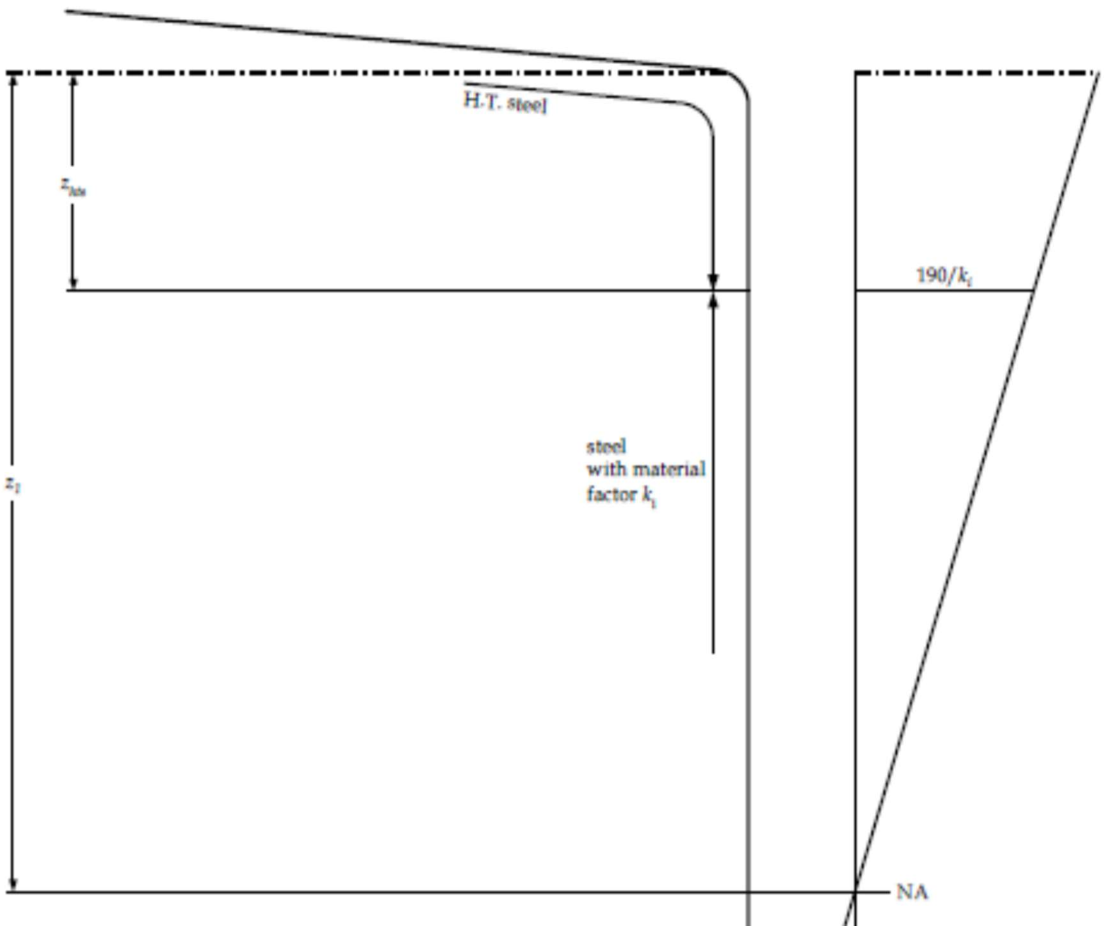


Figure 2.2.10: Vertical Extent of Higher Strength Steel

1.6.4. Tapering of plate thickness due to hull girder shear requirement

1.6.4.1. Provided that for any longitudinal position the requirements given in 1.3.2 are complied with, longitudinal tapering of shear reinforcement is to be permitted. With the help of linear interpolation of permissible shear limits at the bulkhead and in the middle of the tank,control of the shear strength at intermediate positions is required to be carried out.

1.6.5. Structural continuity of longitudinal bulkheads

1.6.5.1. In order to ensure continuity of strength and the avoidance of abrupt structural changes,suitable scarphing arrangements are required to be made. In particular, termination of the longitudinal bulkheads is to be done at an effective transverse bulkhead and fitting of large transition brackets shall be provided in line with the longitudinal bulkhead.

1.6.6. Structural continuity of longitudinal stiffeners

1.6.6.1. In order to avoid an abrupt changeover, adequate arrangements are to be made where longitudinal stiffeners terminate, and are replaced by a transverse system.

1.6.6.2. Where a deck longitudinal stiffener is cut, in way of an opening, arrangement of the compensation is to be provided in order to ensure structural continuity of the area. The compensation area is to extend well beyond the forward and aft end of the opening and not be less than the area of the longitudinal that is cut. Consideration of the stress concentration in way of the stiffener termination and the associated buckling strength of the plate and panel are to be considered.

2. Cargo Tank Region

2.1. General

2.1.1. Application

2.1.1.1. Application of the requirements of this Sub-Section are considered for to the hull structure within the cargo tank region of the ship, for the shell, deck, inner bottom and bulkhead plating, stiffeners and primary support members.

2.1.2. Basis of scantlings

2.1.2.1. The net scantlings described in this Sub-Section are related to gross scantlings as follows:

a. For application of the minimum thickness requirements specified in 2.1.5 and 2.1.6, the gross thickness is obtained from the applicable requirements by adding the full corrosion additions specified in Chapter 1 Section 6/3

b. For plating and local support members, the gross thickness and gross cross sectional properties are obtained from the applicable requirements by adding the full corrosion additions specified in Chapter 1 Section 6/3.

c. As specified in Chapter 1 Section 6/3, for primary support members, the gross shear area, gross section modulus, and other gross cross sectional properties are obtained from the applicable requirements by adding one half of the relevant full corrosion addition.

d. For application of the buckling requirements of Section 4/3, the gross thickness and gross cross-sectional properties are obtained from the applicable requirements by adding the full corrosion additions specified in Chapter 1 Section 6/3.

2.1.3. Evaluation of scantlings

2.1.3.1. The following scantling requirements are based on the assumption that all structural joints and welded details are designed and fabricated, such that they are to be compatible with the anticipated working stress levels at the locations considered. Consideration of the loading patterns, stress concentrations and potential failure modes of structural joints and details during the design of highly stressed regions are to be considered. Structural design details are to comply with the requirements given in Chapter 1 Section 4/3.

2.1.3.2. Wherever applicable, assessment of the scantlings is to be considered in order to ensure that the strength criteria are satisfied at all longitudinal positions.

2.1.3.3. Application of local scantling increases are to be considered where applicable to cover local variations, such as increased spacing, increased stiffener spans and green sea pressure loads. Local scantling increases may also be required to cover fore end strengthening requirements, see Chapter 1 Section 8/3.

2.1.4. General scantling requirements

2.1.4.1. The hull structure is to comply with the applicable requirements of:

a. Hull girder longitudinal strength, see Section 2/1
b. Strength against sloshing and impact loads, see Section 2/6
c. Hull girder ultimate strength, see Section 3
d. Strength assessment (FEM), see Section 3
e. Fatigue strength, see Section 3/3
f. Buckling and ultimate strength, see Section 4.

2.1.4.2. In accordance with Chapter 1 Section 4/2, determination of the net section modulus, shear areas and other sectional properties of the local and primary support members are to be considered.

2.1.4.3. Application of the section modulus, shear areas and other sectional properties of the local and primary support members are to be considered for the areas clear of the end brackets.

2.1.4.4. The spans of the local and primary support members are defined in Chapter 1 Section 4/2.1.

2.1.4.5. Determination of the moments of inertia for the primary support members are to be done in association with the effective attached plating at the mid span as specified in Chapter 1 Section 4/2.3.2.3.

2.1.4.6. Limber, drain and air holes are to be cut in all parts of the structure, as required, to ensure the free flow to the suction pipes and escape of air to the vents. See also Chapter 1 Section 4/3.

2.1.4.7. In general, all shell frames and tank boundary stiffeners are to be continuous, or are to be bracketed at their ends, except as permitted in Chapter 1 Sections 4/3.2.4 and 4/3.2.5.

2.1.4.8. Enlarged stiffeners (with or without web stiffening) used for Permanent Means of Access (PMA) are to comply with the following requirements:

a. Buckling strength including proportion (slenderness ratio) requirements for primary support members as follows:
   - for stiffener web, see Sections 4/2.3.1.1(a), 4/3.2
   - for stiffener flange, see Sections 4/2.3.1.1(b), 4/2.3.3.1
   - for web stiffeners, see Sections 4/2.3.2.1, 4/2.3.2.2, 4/3.3.
     Note 1 of table 2.4.1 is not applicable.

b. Buckling strength of longitudinal PMA platforms without web stiffeners may also be ensured using the criteria for local support members in Section 4/2.2 and Section 4/3.3, including Note 1 of

Table 2.4.1, provided shear buckling strength of web is verified in line with Section 4/3.2.

c. All other requirements for local support members as follows:
- Corrosion additions: requirements for local support members
- Minimum thickness: requirements for local support members
- Fatigue: requirements for local support members.

Note: For primary support members (or part of this) used as a PMA platform, application of the requirements for primary support members are to be considered.

2.1.5. Minimum thickness for plating and local support members

2.1.5.1. The thickness of plating and stiffeners in the cargo tank region is to comply with the appropriate minimum thickness requirements given in Table 2.2.7.

Table 2.2.7: Minimum Net Thickness for Plating and Local Support Members in the Cargo Tank Region

Scantling Location			Net Thickness (mm)
Plating	Shell	Keel plating	$6.5+0.03L_2$
		Bottom shell/bilge/side shell	$4.5+0.03L_2$
	Upper Deck		$4.5+0.02L_2$
	Other structure	Hull internal tank boundaries	$4.5+0.02L_2$
		Non-tight bulkheads, bulkheads between dry spaces and other plates in general	$4.5+0.01L_2$
Local support members	Local support members on tight boundaries		$3.5+0.015L_2$
	Local support members on other structure		$2.5+0.015L_2$
Tripping brackets			$5.0+0.015L_2$

where:
L_2 rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but need not be taken greater than 300m

2.1.6. Minimum thickness for primary support members

2.1.6.1. The thickness of web plating and face plating of primary support members in the cargo tank region is to comply with the appropriate minimum thickness requirements given in Table 2.2.8.

Table 2.2.8: Minimum Net Thickness for Primary Support Members in Cargo Tank Region

Scantling Location	Net Thickness (mm)
Double bottom centreline girder	$5.5 + 0.025L_2$
Other double bottom girders	$5.5 + 0.02L_2$
Double bottom floors, web plates of side transverses and stringers in double hull	$5.0 + 0.015L_2$
Web and flanges of vertical web frames on longitudinal bulkheads, horizontal stringers on transverse bulkhead, deck transverses (above and below upper deck) and cross ties.	$5.5 + 0.015L_2$

Where:
L_2 rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but need not be taken greater than 300m

2.2. Hull Envelope Plating

2.2.1. Keel plating

2.2.1.1. Keel plating is to extend over the flat of bottom for the complete length of the ship. The breadth, b_{kl}, is not to be less than:

$$b_{kl} = 800 + 5L_2 \text{mm}$$

where:

L_2 = rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but not to be taken greater than 300m

2.2.1.2. The thickness of the keel plating is to comply with the requirements given in 2.2.2.

2.2.2. Bottom shell plating

2.2.2.1. As given in Table 2.2.10, the thickness of the bottom shell plating is required to comply with the requirements.

2.2.3. Bilge plating

2.2.3.1. The thickness of bilge plating is not to be less than that required for the adjacent bottom shell, see 2.2.2.1 or adjacent side shell plating, see 2.2.4.1, whichever is the greater.

2.2.3.2. The net thickness of bilge plating, t_{net}, without longitudinal stiffening is not to be less than:

$$t_{net} = \frac{\sqrt[3]{r^2 S_t P_{ex}}}{100} \text{mm}$$

where:

P_{ex} = design sea pressure for the design load set 1 calculated at the lower turn of bilge, in kN/m^2

r = effective bilge radius

$= r_0 + 0.5(a + b)$ mm

r_0 = radius of curvature, in mm. See Figure 2.2.11

S_t = distance between transverse stiffeners, webs or bilge brackets, in m a distance between the lower turn of bilge and the outermost bottom longitudinal, in mm, see Figure 2.2.11 and 2.3.1.2. This distance is to be taken as zero where the outermost bottom longitudinal is within the curvature.

b = distance between the upper turn of bilge and the lowest side longitudinal, in mm, see Figure 2.2.11 and 2.3.1.2.. This distance is to be taken as zero where the lowest side longitudinal is within the curvature.

Any increased thickness required for the bilge plating does not have to extend to the adjacent plate above the bilge where plate seam is located in the straight plate just below the lowest stiffener on the side shell, provided that the plate seam is not more than s_b/4 below the lowest side longitudinal. Similarly for flat part of adjacent bottom plating, any increased thickness for the bilge plating not r to be provided where the plate seam is not more than s_a/4 beyond the outboard bottom longitudinal. Regularly longitudinally stiffened bilge plating is to be assessed as a stiffened plate. The bilge keel is not considered as “longitudinal stiffening” for the application of this requirement.

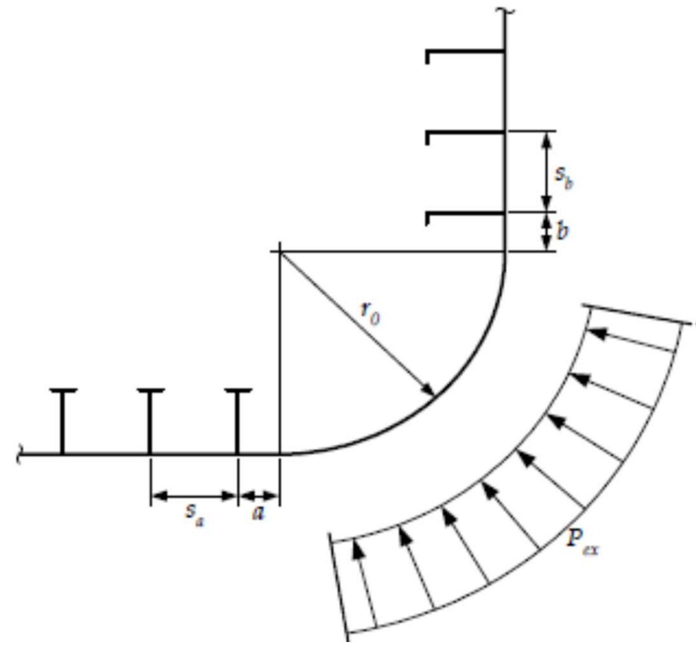


Figure 2.2.11: Unstiffened Bilge Plating

2.2.3.3. Where bilge longitudinals are omitted, the bilge plate thickness outside 0.4L amidships will be considered in relation to the support derived from the hull form and internal stiffening arrangements. In general, outside of 0.4L amidships the bilge plate scantlings and arrangement are to comply with the requirements of ordinary side or bottom shell plating in the same region. Consideration is to be given where there is increased loading in the forward region.

2.2.4. Side shell plating

2.2.4.1. The thickness of the side shell plating is to comply with the requirements in Table 2.2.10.

2.2.4.2. The net thickness, t_{net}, of the side plating within the range as specified in 2.2.4.3 is not to be less than:

$$t_{net} = 26\left(\frac{s}{1000} + 0.7\right)\left(\frac{BT_{sc}}{\sigma_{yd}}\right)^{0.25} \text{ mm}$$

where:
s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2
B = moulded breadth, in mm as defined in Chapter 1 Section 4/1.1.3.1
T_{sc} = scantling draught, in m, as defined in Chapter 1 Section 4/1.1.5.5
σ_{yd} = specified minimum yield stress of the material, in N/mm^2

2.2.4.3. Application of the thickness in 2.2.4.2 is to be done to the following extent of the side shell plating, see Figure 2.2.12:

a. Longitudinal extent:
- between a section aft of amidships where the breadth at the waterline exceeds 0.9B, and a sectionforward of amidships where the breadth at the waterline exceeds 0.6B

b. Vertical extent:
- Between 300mm below the minimum design ballast waterline, T_{bal}, amidships to $0.25T_{sc}$or 2.2m, whichever is greater, above the draught T_{sc}.

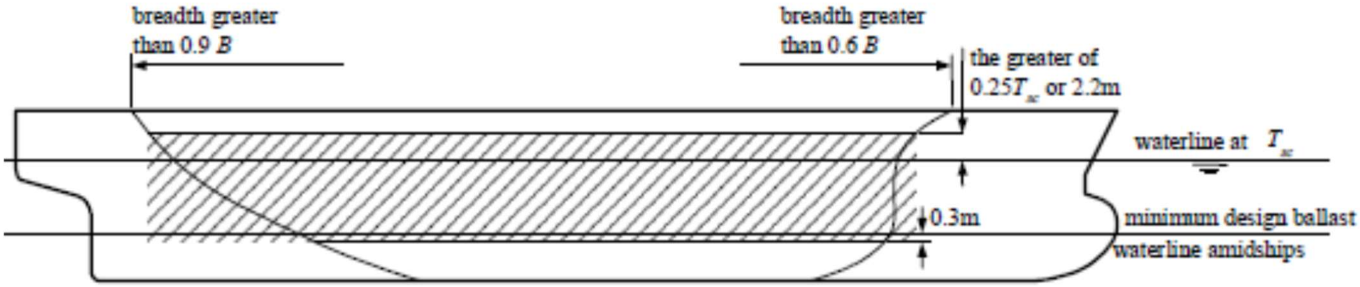


Figure 2.2.12: Extent of Side Shell Plating

2.2.5. Sheer strake

2.2.5.1. The sheer strake is to comply with the requirements in 2.2.4.

2.2.5.2. The welding of deck fittings to rounded sheer strakes is to be avoided within 0.6L of amidships.

2.2.5.3. The top edge of the sheer strake is to be kept free from notches and isolated welded fittings, and is to be smooth with rounded edges where the sheer strake extends above the deck stringer plate.If the cutting surface is not smooth,grinding may be required. Permission of the drainage openings with a smooth transition in the longitudinal direction may be given.

2.2.6. Deck plating

2.2.6.1. The thickness of the deck plating is to comply with the requirements given in Table 2.2.10.

2.3. Hull Envelope Framing

2.3.1. General

2.3.1.1. In the cargo tank region, the bottom shell, inner bottom and deck are to be longitudinally framed. Generally the side shell, inner hull bulkheads and longitudinal bulkheads are to be longitudinally framed.The inner hull bulkheads are to be similarly constructed where the side shell is longitudinally framed. Special consideration will be given for suitable alternatives which take account of resistance to buckling.

2.3.1.2. Where longitudinals are omitted in way of the bilge, a longitudinal is to be fitted at the bottom and at the side close to the position where the curvature of the bilge plate starts.Generally the distance between the lower turn of bilge and the outermost bottom longitudinal, a, is not to be greater than one-third of the spacing between the two outermost bottom longitudinals, s_a. Similarly, the distance between the upper turn of the bilge and the lowest side longitudinal, b, is generally not to be greater than one-third of the spacing between the two lowest side longitudinals, s_b. Figure 2.2.11.

2.3.1.3. The longitudinals are to comply with the requirements of continuity given in Chapter 1 Section 4/3.2.

2.3.2. Scantling criteria

2.3.2.1. The section modulus, and thickness, of the hull envelope framing is to comply with the requirements given in Tables 2.2.11 and 2.2.12.

2.3.2.2. The span is to be taken in accordance with Chapter 1 Section 4/2.1.3where the side shell longitudinal or the vertical stiffener is inclined to the longitudinal or vertical axis, respectively.

2.3.2.3. The span is to be taken in accordance with Chapter 1 Section 4/2.1.3for curved stiffeners.

2.4. Inner Bottom

2.4.1. Inner bottom plating

2.4.1.1. The thickness of the inner bottom plating is to comply with the requirements given in Table 2.2.10.

2.4.1.2. In way of a welded hopper knuckle, the inner bottom is to be scarfed to ensure adequate load transmission to surrounding structure and reduce stress concentrations.

2.4.1.3. In way of corrugated bulkhead stools, where fitted, particular attention is to be given to the through thickness properties, and arrangements for continuity of strength, at the connection of the bulkhead stool to the inner bottom. For requirements for plates with specified through-thickness properties, see Chapter 1 Section 6/1.1.5.

2.4.2. Inner bottom longitudinals

2.4.2.1. The section modulus and web plate thickness of the inner bottom longitudinals are to comply with the requirements given in Tables 2.2.11 and 2.2.12

2.5. Bulkheads

2.5.1. General

2.5.1.1. Generally the inner hull and longitudinal bulkheads are to be longitudinally framed, and plane. Corrugated bulkheads are to comply with the requirements given in 2.5.6.

2.5.1.2. The structural arrangements in way are to be adequate for the loads imparted to the bulkheads by the hydraulic forces in the pipes where bulkheads are penetrated by cargo or ballast piping.

2.5.2. Longitudinal tank boundary bulkhead plating

2.5.2.1. The thickness of the longitudinal tank boundary bulkhead plating is to comply with the requirements given in Table 2.2.10

2.5.2.2. As far forward and aft as practicable,inner hull and longitudinal bulkheads are required to be extended and are to be effectively scarfed into the adjoining structure.

2.5.3. Hopper side structure

2.5.3.1. Knuckles in the hopper tank plating are to be supported by side girders and stringers, or by a deep longitudinal.

2.5.4. Transverse tank boundary bulkhead plating

2.5.4.1. The thickness of the transverse tank boundary bulkhead plating is to comply with the requirements given in Table 2.2.10.

2.5.5. Tank boundary bulkhead stiffeners

2.5.5.1. The section modulus and web thickness of stiffeners, on longitudinal or transverse tank boundary bulkheads, are to comply with the requirements given in Tables 2.2.11 and 2.2.12.

2.5.6. Corrugated bulkheads

2.5.6.1. The scantling requirements relating to corrugated bulkheads defined in 2.5.6 and 2.5.7 are net requirements. The gross scantling requirements are obtained from the applicable requirements by adding the full corrosion additions specified in Chapter 1 Section 6/3.

2.5.6.2. In general, corrugated bulkheads are to be designed with the corrugation angles, ϕbetween 55^0 and 90^0, see Figure 2.2.13.

2.5.6.3. The global strength of corrugated bulkheads, lower stools and upper stools, where fitted, and attachments to surrounding structures are to be verified with the cargo tank FEM model in the midship region, see Section 3/2. Consideration of the global strength of corrugated bulkheads outside of midship region are to be provided based on results from the cargo tank FEM model and using the appropriate pressure for the bulkhead being considered. If the bulkhead geometry, structural details and support arrangement details differ significantly from bulkheads within the mid cargo tank region then additional FEM analysis of cargo tank bulkheads forward and aft of the midship region may be necessary.

2.5.6.4. The net thicknesses, t_{net}, of the web and flange plates of corrugated bulkheads are to be taken as the greatest value calculated for all applicable design load sets, as given in Table 2.2.13, and given by:

$$t_{net} = 0.0158 b_p \sqrt{\frac{|P|}{C_a \sigma_{yd}}} \text{ mm}$$

P =design pressure for the design load set being considered, calculated at the load point defined in Chapter 1 Section3/5.1, in kN/m^2

b_p = breadth of plate:

= b_f for flange plating, in mm. See Figure 2.2.13

= b_w for web plating, in mm. See Figure 2.2.13

C_a= permissible bending stress coefficient:

= 0.75 for acceptance criteria set AC1

= 0.90 for acceptance criteria set AC2

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

2.5.6.5. The thicker net plating thickness, t_{m-net}, is to be taken as the greatest value calculated for all applicable design load sets, as given in Table 2.2.13,where the corrugated bulkhead is built with flange and web plate of different thicknesses,and given by:

$$t_{m-net} = \sqrt{\frac{0.0005 b_p^2 |P|}{C_a \sigma_{yd}} - t_{n-net}^2} \text{mm}$$

where:

t_{n-net} = net thickness of the thinner plating, either flange or web, in mm

b_p= breadth of thicker plate, either flange or web, in mm

P = design pressure for the design load set being considered, calculated at the load point defined in Chapter 1 Section 3/5.1, in kN/m^2
C_a= permissible bending stress coefficient:
= 0.75 for acceptance criteria set AC1
= 0.90 for acceptance criteria set AC2
σ_{yd} = specified minimum yield stress of the material, in N/mm^2

2.5.7. Vertically corrugated bulkheads

2.5.7.1. In addition to the requirements of 2.5.6, vertically corrugated bulkheads are also to comply with the requirements of 2.5.7.

2.5.7.2. The net plate thicknesses as required by 2.5.7.5 and 2.5.7.6 are to be maintained for two thirds of the corrugation length, l_{cg}, from the lower end, where l_{cg} is as defined in 2.5.7.3. Above that, the net plate thickness may be reduced by 20%.

2.5.7.3. The net web plating thickness of the lower 15% of the corrugation, tw-net, is to be taken as the greatest value calculated for all applicable design load sets, as given in Table 2.2.13, and given by the following. This requirement is not applicable to corrugated bulkheads without a lower stool, see 2.5.7.9.

$$t_{w-net} = \frac{1000|Q_{cg}|}{d_{cg}C_{t-cg}\tau_{yd}} \text{mm}$$

where:

Q_{cg} = design shear force imposed on the web plating at the lower end of the corrugation

$$= \frac{S_{cg}l_{cg}|3P_l+P_u|}{8000} \text{ kN}$$

P_l = design pressure for the design load set being considered, calculated at the lower end of the corrugation, in kN/m^2

P_u= design pressures for the design load set being considered, calculated at the upper end of the corrugation, in kN/m^2

s_{cg}= spacing of corrugation, in mm. See Figure 2.2.13

l_{cg} = length of corrugation, which is defined as the distance between the lower stool and the upper stool or the upper end where no upper stool is fitted, in m, see Figure 2.2.13

d_{cg} = depth of corrugation, in mm. See 2.5.7.4 and Figure 2.2.13

C_{t-cg}= permissible shear stress coefficient

= 0.75for acceptance criteria set AC1

= 0.90for acceptance criteria set AC2

$$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}} \text{ N/mm}^2$$

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

2.5.7.4. The depth of the corrugation, d_{cg}, is not to be less than:

$$d_{cg} = \frac{1000\ \ _{cg}}{15} \text{mm}$$

where:

l_{cg} = length of corrugation, which is defined as the distance between the lower stool or the inner bottom if no lower stool is fitted and the upper stool or the upper end where no upper stool is fitted, in m, see Figure 2.2.13

2.5.7.5. The net thicknesses of the flanges of corrugated bulkheads, t_{f-net}, for two thirds of the corrugation length from the lower end are to be taken as the greatest value calculated for all applicable design load sets, as given in Table 2.2.13, and given by the following. This requirement is not applicable to corrugated bulkheads without a lower stool, see 2.5.7.9.

$$t_{f-net} = \frac{0.00657 b_f \sqrt{\sigma_{bdg-m}}}{C_f} \text{mm}$$

where:

$\sigma_{bdg-max}$ = maximum value of the vertical bending stresses in the flange. The bending stress is to be calculated at the lower end and at the mid span of the corrugation length

$$= \frac{1000 M_{cg}}{Z_{cg-act-net}} \text{N/mm}^2$$

M_{cg} as defined in 2.5.7.6

$Z_{cg-act-net}$ = actual net section modulus at the lower end and at the mid length of the corrugation, in cm^3

b_f = breadth of flange plating, in mm. See Figure 2.2.13

b_w = breadth of web plating, in mm. See Figure 2.2.13

C_f= coefficient

$$= 7.65 - 0.26\left(\frac{b_w}{b_f}\right)^2$$

2.5.7.6. The net section modulus at the lower and upper ends and at the mid length of the corrugation ($l_{cg}/2$) of a unit corrugation, Z_{cg-net}, are to be taken as the greatest value calculated for all applicable design load sets, as given in Table 2.2.13, and given by the following.

$$Z_{cg-net} = \frac{1000\quad cg}{C_{s-cg}\sigma_{yd}} \text{cm}^3$$

where:

$$M_{cg} = \frac{C_i |P| s_{cg} l_0^2}{12000} \text{kN}$$

$$P = \frac{P_u + P_l}{2} \text{kNm}^2$$

P_l, P_u design pressure for the design load set being considered, calculated at the lower and upper ends of the corrugation, respectively, in kN/m^2:

a. For transverse corrugated bulkheads, the pressures are to be calculated at a section located at $b_{tk}/2$ from the longitudinal bulkheads of each tank

b. For longitudinal corrugated bulkheads, the pressures are to be calculated at the ends of the tank, i.e., the intersection of the forward and aft transverse bulkheads and the longitudinal bulkhead

b_{tk}= maximum breadth of tank under consideration measured at the bulkhead, in m

s_{cg}= spacing of corrugation, in mm. See Figure 2.2.13

l_o = effective bending span of the corrugation, measured from the mid depth of the lower stool to the middepth of the upper stool, or upper end where no upper stool is fitted, in m, see Figure 2.2.13

l_{cg} = length of corrugation, which is defined as the distance between the lower stool and the upper stool or the upper end where no upper stool is fitted, in m, see Figure 2.2.13

C_i = the relevant bending moment coefficients as given in Table 2.2.9

$C_{s\text{-}cg}$ = permissible bending stress co-efficient

At the mid length of the corrugation length, l_{cg}:

= c_e, but not to be taken as greater than 0.75 for acceptance criteria set AC1

= c_e, but not to be taken as greater than 0.90 for acceptance criteria set AC2

At the lower and upper ends of corrugation length, l_{cg}:

= 0.75 for acceptance criteria set AC1

= 0.90 for acceptance criteria set AC2

$c_e = \frac{2.25}{\beta} - \frac{2.25}{\beta^2}$ for $\beta \geq 1.25$

= 1.0 for $\beta < 1.25$

$$\beta = \frac{b_f}{t_{f-n}} \sqrt{\frac{\sigma_{yd}}{E}}$$

b_f = breadth of flange plating, in mm, see Figure 2.2.13
$t_{f\text{-net}}$ = net thickness of the corrugation flange, in mm
E = modulus of elasticity, in N/mm^2
σ_{yd}= specified minimum yield stress of the material, in N/mm^2

Table 2.2.9: Values of C_i

Bulkhead	At lower end of l_{cg}	At mid length of l_{cg}	At upper end of l_{cg}
Transverse Bulkhead	C_1	C_{m1}	$0.80C_{m1}$
Longitudinal Bulkhead	C_3	C_{m3}	$0.65C_{m3}$

where:

$A_1 = a_1 + b_1\sqrt{\frac{A_{dt}}{b_{dk}}}$ but is not to be taken as less than 0.60

$= a_1 - b_1\sqrt{\frac{A_{dt}}{b_{dk}}}$ for transverse bulkhead with no lower stool, but is not to be taken as less than 0.55

$a1 = 0.95 - \frac{0.41}{R_{bt}}$

= 0.6 for transverse bulkhead with no lower stool

$b_1 = -0.20 + \frac{0.078}{R_{bt}}$

= 0.13 for transverse bulkhead with no lower stool

$C_{m1} = a_{ml} + b_{ml}\sqrt{\frac{A_{dt}}{b_{dk}}}$ but is not to be taken as less than 0.55

$= a_{ml-}b_{ml}\sqrt{\frac{A_{dt}}{b_{dk}}}$for transverse bulkhead with no lower stool, but is not to be taken as less than 0.60

$a_{m1} = 0.63 + \frac{0.25}{R_{bt}}$

= 0.96 for transverse bulkhead with no lower stool

$b_{m1} = -0.25 - \frac{0.11}{R_{bt}}$

= 0.34 for transverse bulkhead with no lower stool

$c_3 = a_{3+}b_3\sqrt{\frac{A_{dl}}{l_{dk}}}$ but is not to be taken as less than 0.60

$= a_{3-}b_3\sqrt{\frac{A_{dl}}{l_{dk}}}$ for longitudinal bulkhead with no lower stool, but is not to be taken as less than 0.55

$a_3 = 0.86 - \frac{0.35}{R_{bl}}$

= 0.6 for longitudinal bulkhead with no lower stool

$b_3 = -0.17 + \frac{0.10}{R_{bl}}$

= 0.13 for longitudinal bulkhead with no lower stool

$C_{m3} = a_{m3+}b_{m3}\sqrt{\frac{A_{dl}}{l_{dk}}}$ but is not to be taken as less than 0.55

$= \mathrm{a_{m3}}\ \ \mathrm{b_{m3}}\sqrt{\frac{\mathrm{A_{dl}}}{\mathrm{l_{dk}}}}$ for longitudinal bulkhead with no lower stool, but is not to be taken as less than 0.60

$\mathrm{c_{m3}} = 0.32 + \frac{0.24}{\mathrm{R_{bl}}}$

= 0.9 for longitudinal bulkhead with no lower stool

$\mathrm{b_{m3}} = -0.12 - \frac{0.10}{\mathrm{R_{bl}}}$

= 0.19 for longitudinal bulkhead with no lower stool

$R_{bt} = \frac{A_{bt}}{b_{ib}}\left(1 + \frac{l_{ib}}{b_{ib}}\right)\left(1 + \frac{b_{av-t}}{h_{st}}\right)$for transverse bulkheads

$R_{bl} = \frac{A_{bl}}{l_{ib}}\left(1 + \frac{l_{ib}}{b_{ib}}\right)\left(1 + \frac{b_{av-l}}{h_{sl}}\right)$for longitudinal bulkheads

A_{dt} cross sectional area enclosed by the moulded lines of the transverse bulkhead upper stool, in m^2= 0 if no upper stool is fitted

A_{dl} cross sectional area enclosed by the moulded lines of the longitudinal bulkhead upper stool, in m^2 = 0 if no upper stool is fitted

A_{bt} cross sectional area enclosed by the moulded lines of the transverse bulkhead lower stool, in m^2

A_{bl} cross sectional area enclosed by the moulded lines of the longitudinal bulkhead lower stool, in m^2

b_{av-t} average width of transverse bulkhead lower stool, in m. See Figure 2.2.13

b_{av-l} average width of longitudinal bulkhead lower stool, in m. See Figure 2.2.13

where:

$C_1 = a_{1+}b_1\sqrt{\frac{A_{dt}}{b_{dk}}}$ but is not to be taken as less than 0.60

$= a_{1-}b_1\sqrt{\frac{A_{dt}}{b_{dk}}}$ for transverse bulkhead with no lower stool, but is not to be taken asless than 0.55

$a_1 = 0.95 - \frac{0.41}{R_{bt}}$

= 0.6 for transverse bulkhead with no lower stool

$b_1 = -0.20 + \frac{0.078}{R_{bt}}$

= 0.13 for transverse bulkhead with no lower stool

$C_{ml} = a_{ml+}b_{ml}\sqrt{\frac{A_{dt}}{b_{dk}}}$ but is not to be taken as less than 0.55

$= a_{ml-}b_{ml}\sqrt{\frac{A_{dt}}{b_{dk}}}$ for transverse bulkhead with no lower stool, but is not to be taken asless than 0.60

a_{m1}

$a_{ml} = 0.63 + \frac{0.25}{R_{bt}}$

= 0.96 for transverse bulkhead with no lower stool

$b_{ml} = -0.25 - \frac{0.11}{R_{bt}}$

= 0.34 for transverse bulkhead with no lower stool

$C_3 = a_{3+}b_3\sqrt{\frac{A_{dl}}{l_{dk}}}$ but is not to be taken as less than 0.60

$= a_{3-}b_3\sqrt{\frac{A_{dl}}{l_{dk}}}$ for longitudinal bulkhead with no lower stool, but is not to be taken asless than 0.55

$a_3 = 0.86 - \frac{0.35}{R_{bl}}$

= 0.6 for longitudinal bulkhead with no lower stool

$b_3 = -0.17 + \frac{0.10}{R_{bl}}$

= 0.13 for longitudinal bulkhead with no lower stool

$C_{m3} = a_{m3+}b_{m3}\sqrt{\frac{A_{dl}}{l_{dk}}}$but is not to be taken as less than 0.55

$= a_{m3-}b_{m3}\sqrt{\frac{A_{dl}}{l_{dk}}}$ for longitudinal bulkhead with no lower stool, but is not to be taken as less than 0.60

$a_{m3} = 0.32 + \frac{0.24}{R_{bl}}$

= 0.9 for longitudinal bulkhead with no lower stool

$b_{m3} = -0.12 - \frac{0.10}{R_{bl}}$

= 0.19 for longitudinal bulkhead with no lower stool

$R_{bt} = \frac{A_{bt}}{b_{ib}}\left(1 + \frac{l_{ib}}{b_{ib}}\right)\left(1 + \frac{b_{av-t}}{h_{st}}\right)$ for transverse bulkheads

$R_{bl} = \frac{A_{bl}}{l_{ib}}\left(1 + \frac{l_{ib}}{b_{ib}}\right)\left(1 + \frac{b_{av-l}}{h_{sl}}\right)$ for longitudinal bulkheads

A_{dt} cross sectional area enclosed by the moulded lines of the transverse bulkhead upper stool, in m^2= 0 if no upper stool is fitted

A_{dl} cross sectional area enclosed by the moulded lines of the longitudinal bulkhead upper stool, in m^2 = 0 if no upper stool is fitted

A_{bt} cross sectional area enclosed by the moulded lines of the transverse bulkhead lower stool, in m^2

A_{bl} cross sectional area enclosed by the moulded lines of the longitudinal bulkhead lower stool, in m^2

b_{av-t} average width of transverse bulkhead lower stool, in m. See Figure 2.2.13

b_{av-l} average width of longitudinal bulkhead lower stool, in m. See Figure 2.2.13

h_{st} height of transverse bulkhead lower stool, in m. See Figure 2.2.13

h_{sl}	height of longitudinal bulkhead lower stool, in m. See Figure 2.2.13
b_{ib}	breadth of cargo tank at the inner bottom level between hopper tanks, or between the hopper tank and centreline lower stool, in m. See Figure 2.2.13
b_{dk}	breadth of cargo tank at the deck level between upper wing tanks, or between the upper wing tank and centreline deck box or between the corrugation flanges if no upper stool is fitted, in m. See Figure 2.2.13
l_{ib}	length of cargo tank at the inner bottom level between transverse lower stools, in m. See Figure 2.2.13
l_{dk}	length of cargo tank at the deck level between transverse upper stools or between the corrugation flanges if no upper stool is fitted, in m. See Figure 2.2.13

2.5.7.7. For tanks with effective sloshing breadth, b_{slh}, greater than 0.56B or effective sloshing length l_{slh}, greater than 0.13L, in accordance with the requirements of IRS, additional sloshing analysis is to be carried out to assess the section modulus of the unit corrugation.

2.5.7.8. For ships with a moulded depth, see Chapter 1 Section 4/1.1.4, equal to or greater than 16m, a lower stool is to be fitted in compliance with the following requirements:

a. General:

- The height and depth are not to be less than the depth of the corrugation
- The lower stool is to be fitted in line with the double bottom floors or girders
- In order to provide appropriate load transmission to structures within the double bottom,the side stiffeners and vertical webs (diaphragms) within the stool structure are required to align with the structure below, as far as is practicable.

b. Stool top plating:

- The net thickness of the stool top plate is not to be less than that required for the attached corrugated bulkhead and is to be of at least the same material yield strength as the attached corrugation
- The extension of the top plate beyond the corrugation is not to be less than the as-built flange thickness of the corrugation.

c. Stool side plating and internal structure:

- Within the region of the corrugation depth from the stool top plate the net thickness of the stool side plate is not to be less than 90% of that required by 2.5.7.2 for the corrugated bulkhead flange at the lower end and is to be of at least the same material yield strength
- The net thickness of the stool side plating and the net section modulus of the stool side stiffeners is not to be less than that required by 2.5.2, 2.5.4 and 2.5.5 for transverse or longitudinal bulkhead plating and stiffeners
- The ends of stool side vertical stiffeners are to be attached to brackets at the upper and lower ends of the stool

- Continuity is to be maintained, as far as practicable, between the corrugation web and supporting brackets inside the stool. The bracket net thickness is not to be less than 80% of the required thickness of the corrugation webs and is to be of at least the same material yield strength

- Scallops in the diaphragms in way of the connections of the stool sides to the inner bottom and to the stool top plate are not permitted.

2.5.7.9. For ships with a moulded depth, see Chapter 1 Section 4/1.1.4, less than 16m, the lower stool may be eliminated provided the following requirements, in addition to the requirements of 2.5.7.6, are complied with:

a. general:

- Double bottom floors or girders are to be fitted in line with the corrugation flanges for transverse or longitudinal bulkheads, respectively

- Brackets/carlings are to be fitted below the inner bottom and hopper tank in line with corrugation webs.Where this is not practicable gusset plates with shedder plates are to be fitted, see item (c) below and Figure 2.2.13

- The corrugated bulkhead and its supporting structure is to be assessed by Finite Element (FE) analysis in accordance with Section 3/2. In addition the local scantlings requirements of 2.5.6.4 and 2.5.6.5 and the minimum corrugation depth requirement of 2.5.7.4 are to be applied.

b. Inner bottom and hopper tank plating:

- The inner bottom and hopper tank in way of the corrugation is to be of at least the same material yield strength as the attached corrugation.

c. Supporting structure:

- Within the region of the corrugation depth below the inner bottom the net thickness of the supporting double bottom floors or girders is not to be less than the net thickness of the corrugated bulkhead flange at the lower end and is to be of at least the same material yield strength

- The upper ends of vertical stiffeners on supporting double bottom floors or girders are to be bracketed to adjacent structure

- Brackets/carlings arranged in line with the corrugation web are to have a depth of not less than 0.5 times the corrugation depth and a net thickness not less than 80% of the net thickness of the corrugation webs and are to be of at least the same material yield strength

- Cut outs for stiffeners in way of supporting double bottom floors and girders in line with corrugation flanges are to be fitted with full collar plates

- The height of the gusset plate, see hg in in Figure 2.2.13, is is to be at least equal to the corrugation depth, and gussets with shedder plates are to be arranged in every corrugation where support is provided by gussets with shedder plates. The gusset plates are to be fitted in line with and between the corrugation flanges. The net thickness of the gusset and shedder plates is not to be less than 100% and 80%, respectively, of the net thickness of the corrugation flanges and is to be of at least the same material yield strength. Also see 2.5.7.11.

- Permission of the scallops in brackets, gusset plates and shedder plates in way of the connections to the inner bottom or corrugation flange and web are not to be given.

2.5.7.10. In general, an upper stool is to be fitted in compliance with the following requirements:

a. general:

- Finite element analysis is to be carried out in order to demonstrate the adequacy of the details and arrangements of the bulkhead support structure to the upper deck structure where no upper stool is fitted.
- side stiffeners and vertical webs (diaphragms) within the stool structure are to align with adjoining structure to provide for appropriate load transmission
- brackets are to be arranged in the intersections between the upper stool and the structure on deck

b. Stool bottom plating:

- The net thickness of the stool bottom plate is not to be less than that required for the attached corrugated bulkhead and is to be of at least the same material yield strength as the attached corrugation

- The extension of the bottom plate beyond the corrugation is not to be less than the attached as-built flange thickness of the corrugation.

c. Stool side plating and internal structure:

- Within the region of the corrugation depth above the stool bottom plate the net thickness of the stool side plate is to be not less than 80% of that required by 2.5.7.2 for the corrugated bulkhead flange at the upper end where the same material is used. If material of different yield strength is used the required thickness is to be adjusted by the ratio of the two material factors (k). k is defined in Chapter 1 Section 6/1.1.4.1

- The net thickness of the stool side plating and the net section modulus of the stool side stiffeners is not to be less than that required by 2.5.2, 2.5.4 and 2.5.5 for the transverse or longitudinal bulkhead plating and stiffeners

- The ends of stool side vertical stiffeners are to be attached to brackets at the upper and lower ends of the stool

- Permission of the scallops in the diaphragms in way of the connections of the stool sides to the deck and to the stool bottom plate is not to be given.

2.5.7.11. Appropriate means are to be provided to prevent the possibility of gas pockets being formed by these plates, where gussets with shedder plates or shedder plates (slanting plates) are fitted at the end connection of the corrugation to the lower stool or to the inner bottom.

2.5.7.12. Welding for all connections and joints is to comply with Chapter 1 Section 6/5.

2.5.8. Non-tight bulkheads

2.5.8.1. Wherever fitted, Non-tight bulkheads (wash bulkheads), are to be in line with transverse webs, bulkheads or similar structures and they are to be of plane construction, horizontally or vertically stiffened, and are to comply with the sloshing requirements given in 6.2. Openings in the non-tight bulkheads in general,are to have generous radii and their aggregate area is not to be less than 10% of the area of the bulkhead.

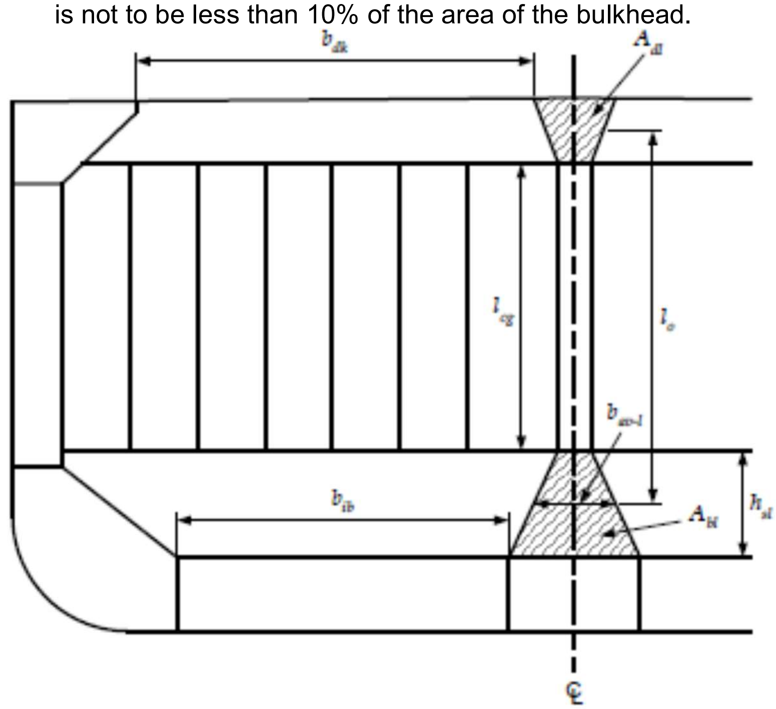
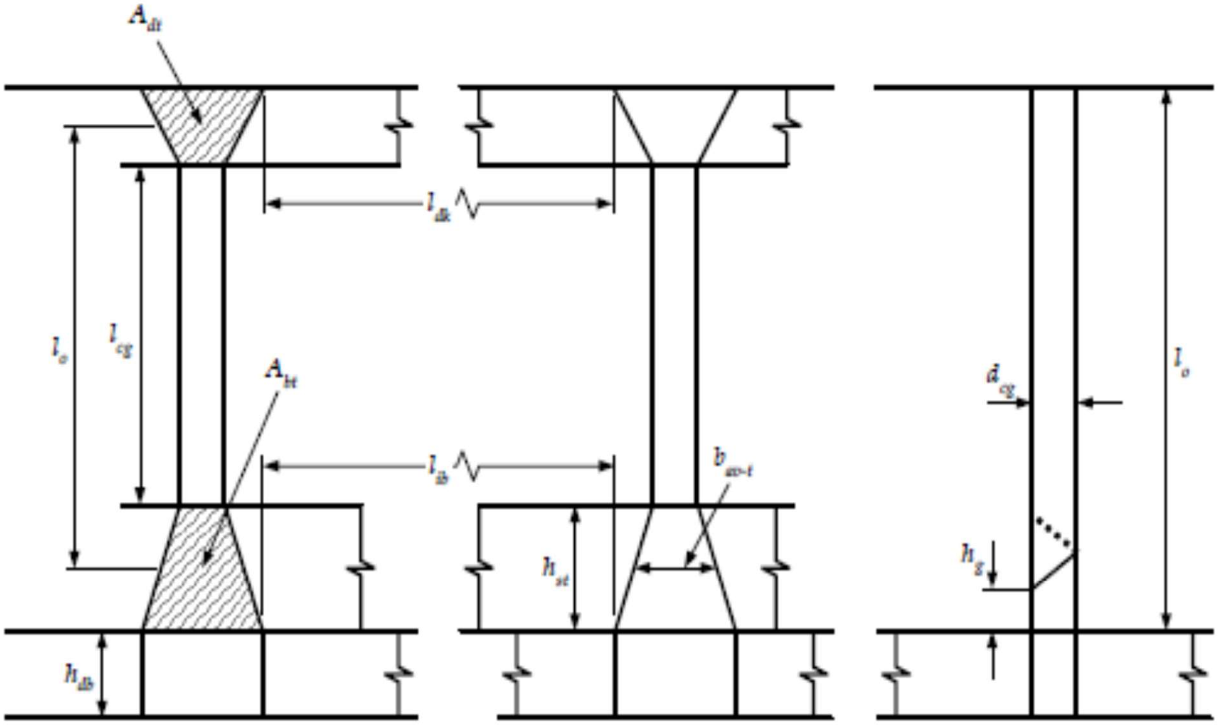


Figure 2.2.13: Definition of Parameters for Corrugated Bulkhead (Tankers with Longitudinal Bulkhead at Centreline)



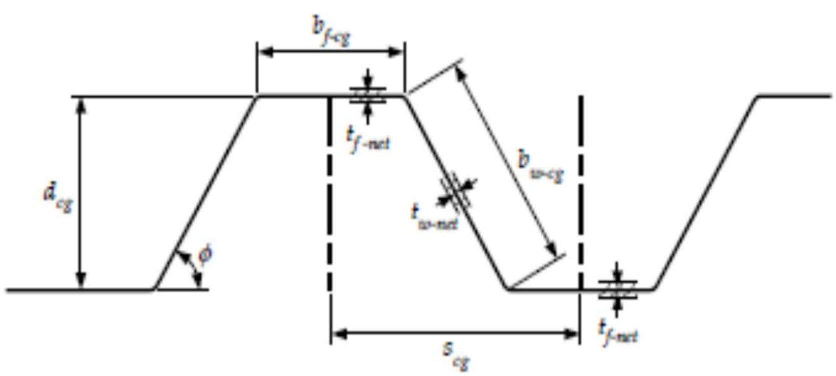


Figure 2.2.13: Definition of Parameters for Corrugated Bulkhead (Tankers with Longitudinal Bulkhead at Centreline) (continued)

Table 2.2.10: Thickness Requirements for Plating

The minimum net thickness, t_{net}, is to be taken as the greatest value for all applicable design load sets, as given in in Table 2.2.13,, and given by:

$t_{net} = 0.0158 a_p s \sqrt{\frac{|P|}{C_a \sigma_{yd}}}$ mm

where:

P design pressure for the design load set being considered and calculated at the load calculation point defined in Chapter 1 Section 3/5.1, in kN/m2

α_p correction factor for the panel aspect ratio

$1.2 - \frac{s}{2100 l_p}$ but is not to be taken as greater than 1.0

s as defined in Chapter 1 Section 4/2.2, in mm

l_p length of plate panel, to be taken as the spacing of primary support members, S, unless carlings are fitted, in m

σ_{yd} specified minimum yield stress of the material, in N/mm^2

C_a permissible bending stress coefficient for the design load set being considered

$= \beta_a - \alpha_a \left|\frac{\sigma_{hg}}{\sigma_{yd}}\right|$ but not to be taken greater than $C_{a\text{-}max}$

Acceptance Criteria Set	Structural Member		β_a	α_a	$C_{a\text{-}max}$
AC1	Longitudinal Strength Members	Longitudinally stiffened plating	0.9	0.5	0.8
		Transversely or vertically stiffened plating	0.9	1.0	0.8
	Other members		0.8	0	0.8
AC2	Longitudinal Strength Members	Longitudinally stiffened plating	1.05	0.5	0.95
		Transversely or vertically stiffened plating	1.05	1.0	0.95
	Other members, including watertight boundary plating		1.0	0	1.0

σ_{hg} hull girder bending stress for the design load set being considered and calculated at the load calculation point defined in Chapter 1 Section 3/5.1.2

$\left(\frac{(Z - Z_{NA-net50}) M_{v-t}}{I_{v-net}} - \frac{y M_{h-total}}{I_{h-net50}}\right) 10^{-3}$N/mm^2

$M_{v\text{-}total}$ design vertical bending moment at the longitudinal position under consideration for the design load set being considered, in kNm. The still water bending moment, $M_{sw\text{-}perm}$, is to be taken with the same sign as the simultaneously acting wave bending moment, M_{wv}, see Table 2.1.3

$M_{h\text{-}total}$ design horizontal bending moment at the longitudinal position under consideration for the design load set being considered, in kNm

$I_{v\text{-}net50}$ net vertical hull girder moment of inertia, at the longitudinal position being considered, as defined in Chapter 1 Section 4/2.6.1, in m^4

$I_{h\text{-}net50}$ net horizontal hull girder moment of inertia, at the longitudinal position being considered, as defined in Chapter 1 Section 4/2.6.2, in m^4

y transverse coordinate of load calculation point, in m

z vertical coordinate of the load calculation point under consideration, in m

$z_{NA\text{-}net50}$ distance from the baseline to the horizontal neutral axis, as defined in Chapter 1 Section 4/2.6.1, in m

Table 2.2.11: Section Modulus Requirements for Stiffeners

The minimum net section modulus, Z_{net}, is to be taken as the greatest value calculated for all applicable design load sets, as given in Table 2.2.13 and given by:

$$Z_{net} = \frac{|P| s l_{bdg}{}^2}{f_{bdg} C_s \sigma_{yd}} \text{ cm}^3$$

where:

P design pressure for the design load set being considered and calculated at the load calculation

point defined in Chapter 1 Section 3/5.2, in kN/m²

f_{bdg} bending moment factor:

for continuous stiffeners and where end connections are fitted consistent with idealisation of the stiffener as having as fixed ends:

= 12 for horizontal stiffeners

= 10 for vertical stiffeners

for stiffeners with reduced end fixity see Sub-section 1.

l_{bdg} effective bending span, in m, as defined in Chapter 1 Section 4/2.1.1

s as defined in Chapter 1 Section 4/2.2, in mm

σ_{yd} specified minimum yield stress of the material, see also Chapter 1 Section 3/5.2.6.5, in N/mm²

C_s permissible bending stress coefficient for the design load set being considered, to be taken as:

Sign of Hull Girder Bending Stress, σ_{hg}	Side Pressure Acting On	Acceptance Criteria
Tension (+ve)	Stiffener side	$C_s = \beta_s - \alpha_s \frac{\lvert\sigma_{hg}\rvert}{\sigma_{yd}}$
Comp ession (-ve)	Plate side	
Tension (+ve)	Plate side	$C_s = C_{s\text{-}max}$
Compression (-ve)	Stiffener side	

Acceptance Criteria Set	Structural Member	β_s	α_s	$C_{s\text{-}max}$
AC1	Longitudinal strength member	0.85	1.0	0.75
	Transverse or vertical member	0.75	0	0.75
AC2	Longitudinal strength member	1.0	1.0	0.9
	Transverse or vertical member	0.9	0	0.9
	Watertight boundary Stiffeners	0.9	0	0.9

σ_{hg} hull girder bending stress for the design load set being considered and calculated at the reference point defined in Chapter 1 Section 3/5.2.2.5

$$= \left(\frac{(Z - Z_{NA-net50}) M_{v-tot}}{I_{v-net50}} - \frac{y M_{h-tot}}{I_{h-net}}\right) 10^{-3} \quad \text{N/mm}^2$$

$M_{v\text{-}total}$ design vertical bending moment at longitudinal position under consideration for the design load set being considered, in Nm.

$M_{v\text{-}total}$ is to be calculated in accordance with Table 2.1.3 using the permissible hogging or sagging still water bending moment, $M_{sw\text{-}perm}$, to be taken as:

Stiffener Location	$M_{sw\text{-}perm}$	
	Pressure acting on Plate Side	**Pressure acting on Stiffener Side**
Above Neutral Axis	Sagging SWBM	Hogging SWBM
Below Neutral Axis	Hogging SWBM	Sagging SWBM

$M_{h\text{-}total}$ design horizontal bending moment at longitudinal position under consideration for the design load set being considered, see Table 2.1.3, in kNm

$I_{v\text{-}net50}$ net vertical hull girder moment of inertia, at the longitudinal position being considered, as defined in Chapter 1 Section 4/2.6.1, in m^4

$I_{h\text{-}net50}$ net horizontal hull girder moment of inertia, at the longitudinal position being considered, as defined in Chapter 1 Section 4/2.6.2, in m^4

y transverse coordinate of the reference point defined in Chapter 1 Section 3/5.2.2.5, in m

z vertical coordinate of the reference point defined in Chapter 1 Section 3/5.2.2.5, in m

$z_{NA\text{-}net50}$ distance from the baseline to the horizontal neutral axis, as defined in Chapter 1 Section 4/2.6.1, in m

Table 2.2.12: Web Thickness Requirements for Stiffeners

The minimum net web thickness, $t_{w\text{-}net}$, is to be taken as the greatest value calculated for all applicable design load sets, as given in Table 2.2.13, and given by:

$$t_{w-net} = \frac{f_{shr}|P|sl_{shr}}{d_{shr}C_t\tau_{yd}} \quad \text{mm}$$

where:

P design pressure for the design load set being considered and calculated at the load calculation Point defined in Chapter 1 Section 3/5.1, in kN/m^2

f_{shr} shear force distribution factor:
for continuous stiffeners and where end connections are fitted consistent with idealisation of thestiffener as having as fixed ends:
= 0.5 for horizontal stiffeners
= 0.7 for vertical stiffeners
for stiffeners with reduced end fixity, see Sub-section 1

d_{shr} as defined in Chapter 1 Section 4/2.4.2.2, in mm

C_t permissible shear stress coefficient for the design load set being considered, to be taken as:
= 0.75 for acceptance criteria set AC1
= 0.90 for acceptance criteria set AC2

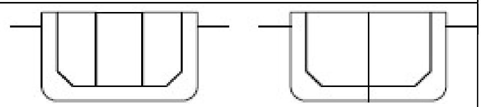
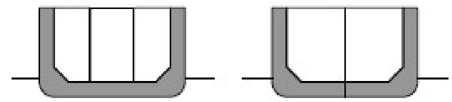
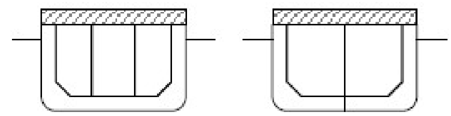
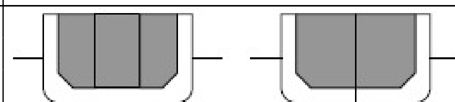
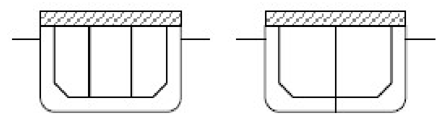
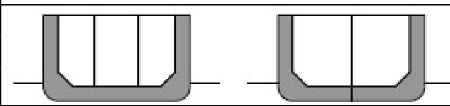
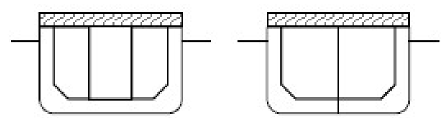
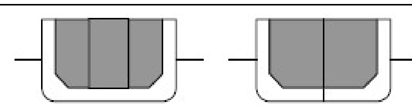
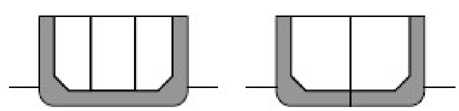
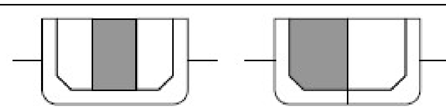
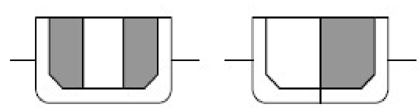
s as defined in Chapter 1 Section 4/2.2, in mm

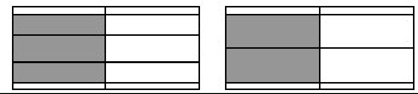
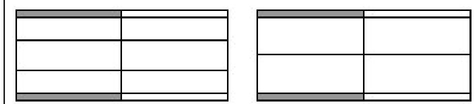
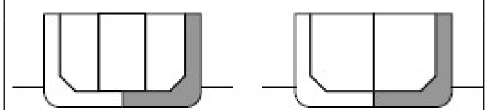
l_{hr} effective shear span, in m, see Chapter 1 Section 4/2.1.

$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}}$ N/mm^2

σ_{yd} specified minimum yield stress of the material, in N/mm^2

Table 2.2.13: Design Load Sets for Plating and Local Support Members

Structural Member	Design Load Set (1, 2, 3)	Load Component	Draught	Comment	Diagrammatic Representation
Keel, Bottom Shell, Bilge, Side Shell, Sheer strake	1	P_{ex}	T_{sc}	Sea pressure only	
	2	P_{ex}	T_{sc}		
	7	$P_{in} – P_{ex}$	T_{bal}	Net pressure difference between water ballast pressure and sea pressure	
	8	$P_{in} – P_{ex}$	$0.25T_{sc}$		
Deck – In way of cargo tanks	1	P_{ex}	T_{sc}	Green sea pressure only or other loads on deck	
	3	P_{in}	$0.6T_{sc}$	Cargo pressure only	
	4	P_{in}	-		
	11	$P_{in\text{-}flood}$	-		
Deck – In way of other tanks	1	P_{ex}	T_{sc}	Green sea pressure only or other loads on deck	
	5	P_{in}	T_{bal}	Water ballast or other liquid pressure only	
	6	P_{in}	$0.25T_{sc}$		
	11	$P_{in\text{-}flood}$	-		
Deck – Any location	9	P_{dk}	T_{bal}	Distributed or concentrated loads only. Simultaneously occurring green sea pressure may be ignored	
	10	P_{dk}	-		
Inner Bottom, Inner hull, Hopper side	3	P_{in}	$0.6T_{sc}$	Cargo pressure only	
	4	P_{in}	-		
	5	P_{in}	T_{bal}	Water ballast or other liquid pressure only	
	6	P_{in}	$0.25T_{sc}$		
	11	$P_{in\text{-}flood}$	-		
Longitudinal Bulkhead, Centreline Bulkhead	3	P_{in}	$0.6T_{sc}$	Pressure from one side only. Full cargo tank with adjacent cargo tank empty. Two cases are to be evaluated: Inner empty, outer full Inner full, outer empty	
	4	P_{in}	-		
	11	$P_{in\text{-}flood}$	-		

Transverse Bulkhead	In way of cargo tanks	3	P_{in}	$0.6T_{sc}$	Pressure from one side only. Full cargo tank with adjacent fwd or aft cargo tank empty. Need to evaluate 2 cases Fwd empty, aftfull Fwd full, aft Empty	
		4	P_{in}	-		
		11	$P_{in\text{-}flood}$	-		
	In way of other tanks	5	P_{in}	T_{bal}		
		6	P_{in}	$0.25T_{sc}$		
		11	$P_{in\text{-}flood}$	-		
Other tank boundaries, e.g. Girders, Floors, Stringers		5	P_{in}	T_{bal}	Pressure from one side only. Full tank with adjacent tank empty. Need to evaluate 2 cases, see above	
		6	P_{in}	$0.25T_{sc}$		
		11	$P_{in\text{-}flood}$	-		

Where:

T_{sc} scantling draught, in m, as defined in Chapter 1 Section 4/1.1.5.5

T_{bal} minimum design ballast draught, in m, as defined in Chapter 1 Section 4/1.1.5.2

Notes

1. Specification of design load combination, load component, acceptance criteria and other load parameters for each design load set are given in Table 2.2.14
2. When the ship's configuration cannot be described by the above, then the applicableDesign Load Sets to determine the scantling requirements of structural boundaries are to be selected so as to specify a full tank on one side with the adjacent tank or space empty. The boundary is to be evaluated for loading from both sides. Design Load Sets are to be selected based on the tank or space contents and is to maximize the pressure on the structural boundary, the draught to use is to be taken in accordance with the Design Load Set and this table. Design Load Sets covering the S and S+D design load combinations are to be selected. See Note 4 and Table 2.2.14.
3. The boundaries of void and dry space not forming part of the hull envelope are to be evaluated using Design Load Set 11. See Note 2.
4. Design load sets (DLS) for some structural members not covered by the above:

   For the boundaries of a stool water ballast tank with the cargo tank:

   — DLSs 5, 6 and 11 are to be applied for pressure from the WB tank side

   — DLSs 3, 4 and 11 for pressure from the cargo tank side

   For a double bottom girder separating two water ballast tanks or separating a water ballast and fuel oil tank:

   — DLSs 5, 6 and 11 are to be applied for pressure from each side in turn

   For the boundary of a stool void space to the cargo tank:

   — DLSs 3, 4 and 11 for pressure from the cargo tank side

   — DLS 11 for pressure from the void space side

Table 2.2.14: Specification of Design Load Combination, Acceptance Criteria and other Load Parameters for each Design Load Set

Design Load Set	Load Component (1)	Design Load Acceptance Combination Criteria Set(2)		Parameters for Calculating Load Components		
				DLCF (3)	GM	$r_{roll\text{-}gyr}$
Hull envelope (PSM and LSM)						
1	Sea pressures P_{ex}	S+D	AC2	Loaded DLCF	0.12B	0.35B
2		S	AC1			
Cargo tank boundaries (PSM and LSM)						
3	Cargo pressures P_{in}	S+D	AC2	Loaded DLCF	0.24B	0.40B
4		S	AC1			
Boundaries of water ballast and other tanks (PSM and LSM)						
5	Water ballast or other liquid tank pressures P_{in}	S+D	AC2	Ballast DLCF	0.33B	0.45B
6		S	AC1			
7	Net water ballast minus sea pressures $P_{in}– P_{ex}$	S+D	AC2	Ballast DLCF	0.33B	0.45B
8		S	AC1			
Decks (LSM and PSM)						
9	Distributed and concentrated loads on deck P_{dk}	S+D	AC2	Ballast DLCF	0.33B	0.45B
10		S	AC1			
Watertight boundaries (LSM and PSM)						
11	Accidental flooding $P_{in\text{-}flood}$	A	AC2			
Hull envelope (PSM)						
12	Net cargo pressure minus sea pressure $P_{in}– P_{ex}$	S+D	AC2	Loaded DLCF	0.24B	0.40B
13		S	AC1			
14	Average cargo and sea pressure $(P_{in} + P_{ex})/2$	S+D	AC2	Loaded DLCF	0.12B	0.35B
15		S+D	AC2	Loaded DLCF	0.24B	0.40B
16		S	AC1			

where:
PSM Primary Support Members
LSM Local Support Members
DLCF Dynamic Load Combination Factors
P_{in} P_{ex} P_{dk} $P_{in\text{- }flood}$ as given in Table 2.1.1 and as shown in Table 2.2.13 or Table 2.2.15
B moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.

Note
1. Structural members are to be designed using all design load sets which are applicable. This table gives the pressure load component of the design load set. The hull girder bending moments are given in Tables 2.2.10 and 2.2.11 for local support members.
2. This column specifies which column in the design load combination table is to be applied for each design load set, see Table 2.1.3. Where S denotes the static design load combination, S+D denotes the static plus dynamic design load combination and A denotes the accidental design load combination.
3. This column specifies which dynamic load combination factor table is to be used for the deviation of the pressure components and global load components, see Table 2.1.3

2.6. Primary Support Members

2.6.1. General

2.6.1.1. The scantlings of the primary support members in the cargo tank region for the extents shown in Figure 2.2.14 are to be in accordance with the requirements of 2.6.1.2 to 2.6.1.7.

2.6.1.2. Application of the section modulus and shear area criteria for primary support members contained in 2.6 are done to structural configurations shown in Figure 1.2.1 and are applicable to the following structural elements:

a) floors and girders within the double bottom;
b) deck transverses fitted below the upper deck;
c) side transverses within double side structure;
d) vertical web frames on longitudinal bulkheads with or without cross ties;
e) horizontal stringers on transverse bulkheads, except those fitted with buttresses or other intermediate supports; and
f) Cross ties in wing cargo and centre cargo tanks.

2.6.1.3. The scantlings of primary support members are to be verified by the Finite Element (FE) cargo tank structural analysis defined in Section 3/2.

2.6.1.4. The section modulus and/or shear area of a primary support member and/or the cross sectional area of a primary support member cross tie may be reduced to 85% of the prescriptive requirements provided that the reduced scantlings comply with the FE cargo tank structural analysis and with 2.1.6.

2.6.1.5. In general, arrangements of primary support members are to be provided in one plane to form continuous transverse rings. In accordance with Chapter 1 Section 4/3.3.3, brackets forming connections between primary support members of the ring shall be designed.

2.6.1.6. In accordance with Section 4/2.3, stiffening of webs of the primary support members is to be given.

2.6.1.7. Webs of the primary support members are to have a depth of not less than given by the requirements of 2.6.4.1, 2.6.6.1 and 2.6.7.1, as applicable. Lesser depths may be accepted where equivalent stiffness is demonstrated. See 3/5.3.3.4. Primary support members that have open slots for stiffeners are to have a depth not less than 2.5 times the depth of the slots.

2.6.1.8. In accordance with Sections 2/7,, 2.6.1.3, 2.6.1.4, 2.6.1.5, 2.6.1.6, 2.6.4.3 and 2.6.4.4. the scantlings of the first primary support members from the transverse bulkhead are to be done. In the application of 2.6.4.3 and 2.6.4.4 only the consideration of design green sea pressure is to be done.

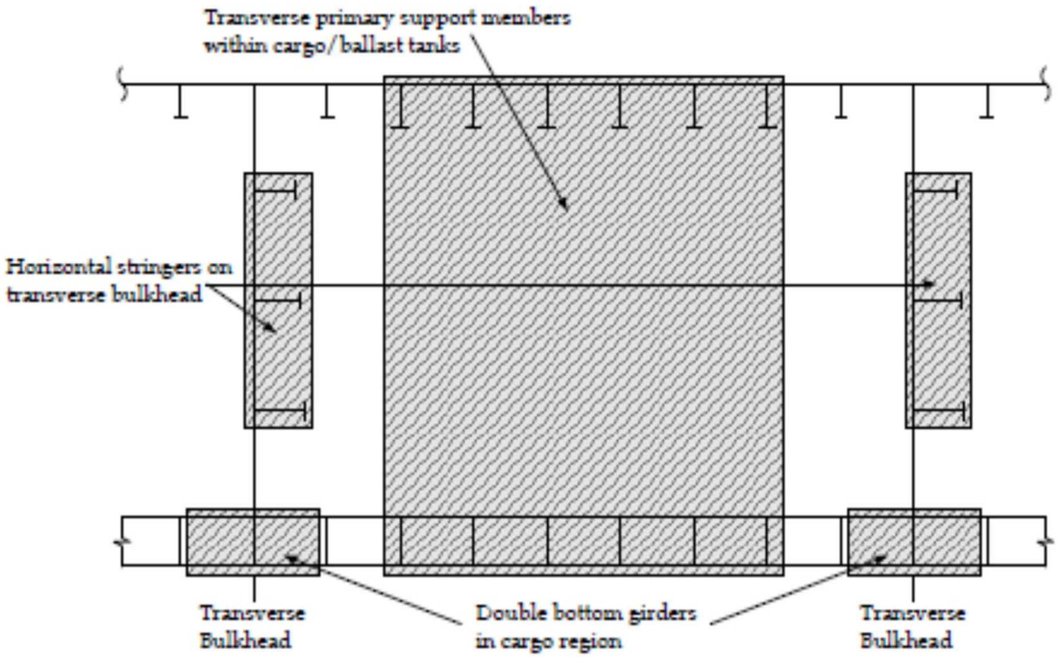


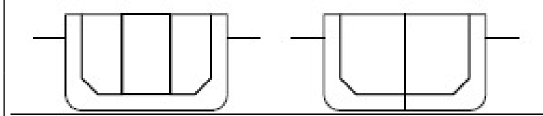
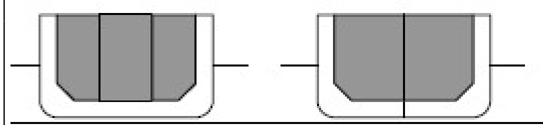
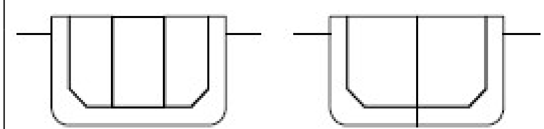
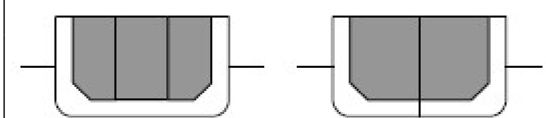
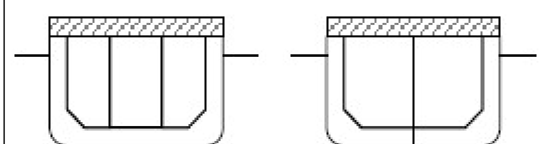
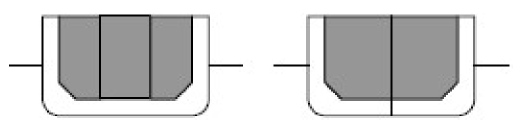
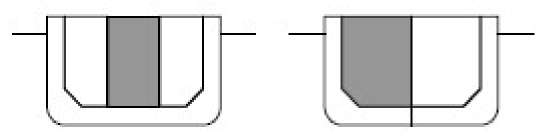
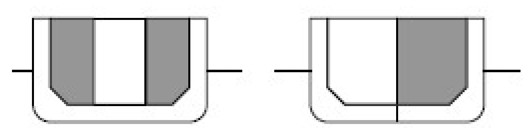
Figure 2.2.14: Depiction of Applicable Extents

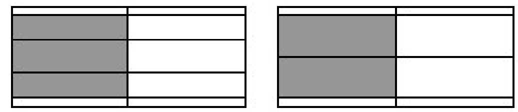
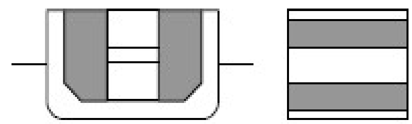
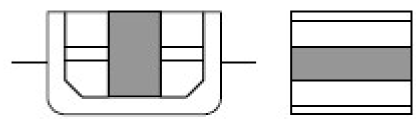
2.6.2. Design load sets and permissible stress coefficients for primary support members

2.6.2.1. The design load sets for the evaluation of the primary support members are given in Table 2.2.15.

2.6.2.2. The permissible bending and shear stress coefficients for the evaluation of the primary support members are given in Table 2.2.16.

Table 2.2.15: Design Load Sets for Primary Support Members

Structural Member	Design Load Set (1, 5, 6)	Load Component	Draught	Comment	Diagrammatic Representation
Double bottom floors and girders(3)	1	P_{ex}	$0.9T_{sc}$ (2)	Sea pressure only	
	2	P_{ex}	T_{sc}		
	12	$P_{in} – P_{ex}$	$0.6T_{sc}$	Net pressure difference betweencargo pressure and sea pressure	
	13	$P_{in} – P_{ex}$	(4)		
Side transverses(3)	1	P_{ex}	$0.9T_{sc}$	Sea pressure only	
	2	P_{ex}	T_{sc}		
	3	P_{in}	$0.6T_{sc}$	Cargo pressure only	
	4	P_{in}	-		
Deck transverses	1	P_{ex}	T_{sc}	Green sea pressureonly or other loads on deck	
	3	P_{in}	$0.6T_{sc}$	Cargo pressure only	
	4	P_{in}	-		
Vertical web frames on longitudinal bulkheads	3	P_{in}	$0.6T_{sc}$	Pressure from one side only. Full cargo tank withadjacent cargo tankempty	
	4	P_{in}	-		
	3	P_{in}	$0.6T_{sc}$	Pressure from oneside only. Full cargo tank withadjacent cargo tankempty	
	4	P_{in}	-		

Horizontal stringers on transverse bulkhead	3	P_{in}	$0.6T_{sc}$	Pressure from one side only. Full cargo tank with adjacent forward or aft cargo tank empty. Two cases are to be evaluated: 1. forward empty/aft full 2. forward full/aft empty	
	4	P_{in}	-		
	11	$P_{in-flood}$	-		
Cross ties in centre tanks	3	$\frac{P_{in-pt} + P_{in-}}{2}$	$0.6T_{sc}$	Full wing cargo tanks, centre tank empty.	
	4	Pin	-		
Cross ties in wing tanks	14	$\frac{P_{in+}P_{ex}}{2}$	T_{sc}	Full centre tank, wing cargo tanks empty.	
	15	$\frac{P_{in} + P_{ex}}{2}$	$0.6T_{sc}$		
	16	$\frac{P_{in} + P_{ex}}{2}$	T_{sc}		

where:

P_{in-pt} design pressure from port side wing cargo tank, in kN/m^2

P_{in-stb} design pressure from starboard side wing cargo tank, in kN/m^2

T_{sc} scantling draught, in m, as defined in Chapter 1 Section 4/1.1.5.5

T_{bal} minimum design ballast draught, in m, as defined in Chapter 1 Section 4/1.1.5.2

Notes

1. Specification of design load combination, load component, acceptance criteria set and otherload parameters for each design load set are given in Table 2.2.14.
2. See 1.1.2.9(b)
3. Draughts specified for bottom floors, girders and side transverses are based on operational limits specified in 1.1.2. Where the optional loading conditions exceed the minimum Rulerequired loading conditions the draughts will be subject to special consideration.
4. For tankers with two oil-tight longitudinal bulkheads, the draught is to be taken as $0.25T_{sc}$.

   For tankers with a centreline bulkhead, the draught is to be taken as $0.33T_{sc}$.
5. When the ship's configuration cannot be described by the structural members or structural configurations identified above, then the applicable Design Load Sets to determine thescantling requirements of primary support member are to be selected so as to specify allapplicable cases from the following:
   - a full tank on one side of the member with the tank or space on the other side empty
   - a full tank on one side of the member with the external pressure minimized
   - external pressure maximized with the adjacent tank or space empty

   The boundary is to be evaluated for loading from both sides. Design Load Sets are to be selected based on the tank or space contents and is to maximize the net pressure on the structural boundary, the draught to use is to be taken in accordance with the Design Load Set and this table. Design Load Sets covering the Sand S+D design load combinations are to be selected. Design Load Set 11 may also need to be applied, depending on the particular structural configuration. See Note 4 on Table 2.2.13 and Table 2.2.14.
6. For a void or dry space, the pressure component from the void side is to be ignored except where Design Load Set 11 needs to be applied.

Table 2.2.16: Permissible Stress Coefficients, C_{s-pr} and C_{t-pr}, for Primary Support Members		
Acceptance criteria set	**Permissible bending stress coefficient, C_{s-pr}**	**Permissible shear stress coefficient, C_{t-pr}**
AC1	0.70	0.70
AC2	0.85	0.85

2.6.3. Floors and girders in double bottom

2.6.3.1. Continuous double bottom girders are to be arranged at the centreline or duct keel, at the hopper side and in way of longitudinal bulkheads and bulkhead stools. Arrangement of Plate floors are to be povided in way of transverse bulkheads and bulkhead stools.

2.6.3.2. The net shear area, $A_{shr-net50}$, of the floors at any position in the floor is not to be less than:

$$A_{shr-net50} = \frac{10Q}{C_{t-pr}\tau_{yd}}$$

where:

Q design shear force

$$= f_{shr} P S l_{shr}$$

f_{shr} = shear force distribution factor

$$= f_{shr-i}\left(1 - \frac{2y_i}{l_{shr}}\right)$$

but not to be taken as less than 0.2

f_{shr-i} = shear force distribution factor at the end of the span, l_{shr}, as given in Table 2.2.17

l_{shr} = effective shear span, of the double bottom floor, in m, as shown in Figure 2.2.16. In way of bracket ends, the effective shear span is measured to the toes of the effective end bracket, as defined in Chapter 1 Section 4/ 2.1.5. Where the floor ends on a girder at a hopper or stool structure, the effective shear span is measured to a point that is one-half of the distance from the girder to the adjacent bottom and innerbottomlongitudinal, as shown in Figure 2.2.1.

y_i = distance from the considered cross-section of the floor to the nearest end of the effective shear span, l_{shr}, in m

S = primary support member spacing, in m, as defined in Chapter 1 Section 4/2.2.2

P = design pressure for the design load set being considered, calculated at midpoint of effective shear span, l_{shr}, of a floor located midway between transverse bulkheads or transverse bulkhead and wash bulkhead, where fitted, in kN/m^2

C_{t-pr} = permissible shear stress coefficient for primary support member as given in Table 2.2.16

$$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}} \text{N/mm}^2$$

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

Table 8.2.17: Shear Force Distribution Factors of Floors			
Structural Configuration	**Centre tank (f_{shr3} in Figure 2.2.15)**	**Wing Tank**	
		At inboard end (f_{shr2} in Figure 2.2.15)	**At hopper knuckle end (f_{shr1} in Figure 2.2.15)**
Ships with centreline longitudinal bulkhead	-	0.4	0.6
Ships with two longitudinal bulkheads	0.5	0.50	0.65

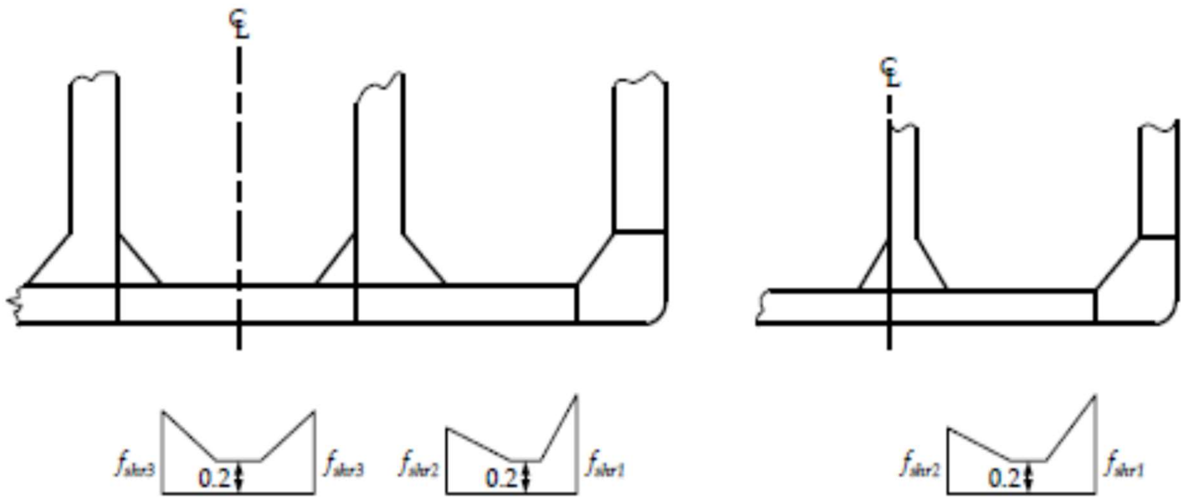


Figure 2.2.15: Floor Shear Force Distribution Factors of Floors

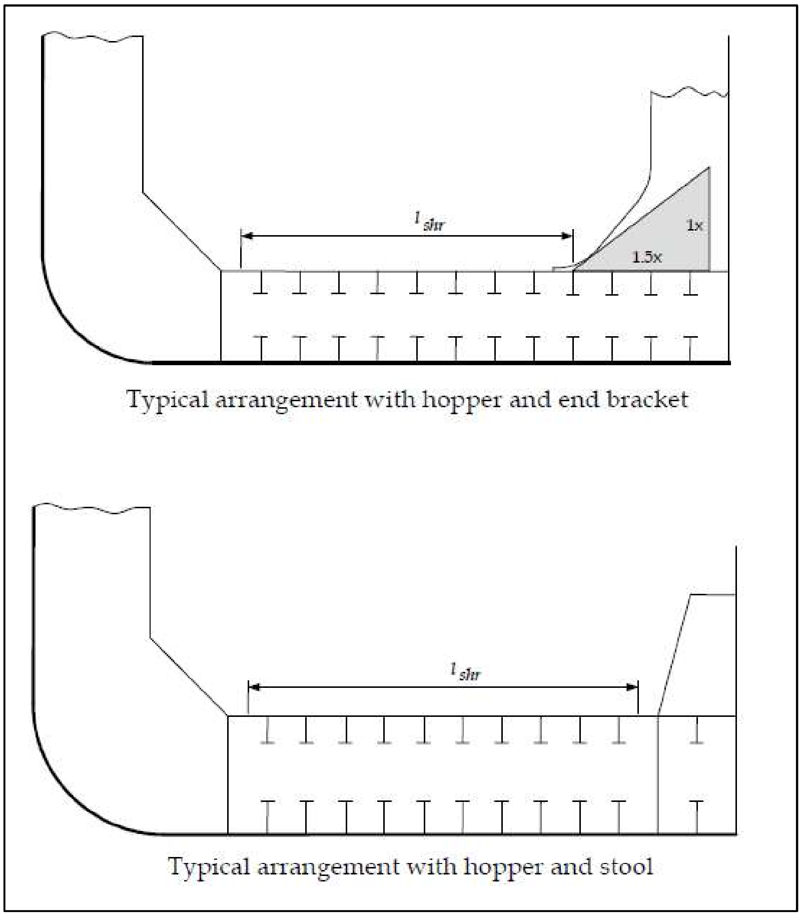


Figure 2.2.16: Effective Shear Span of Floors

2.6.3.3. For double bottom centre girders where no longitudinal bulkhead is fitted above, the net shear area, $A_{shr-net50}$, of the double bottom centre girder in way of the first bay from each transverse bulkhead and wash bulkhead, where fitted, is not to be less than:

$$A_{shr-net50} = \frac{10}{C_{t-pr}\tau_{yd}} \text{cm}^2$$

where:

Q = design shear force

$= 0.21\, n_1 n_2\, P l_{shr}^2$ kN

l_{shr} = effective shear span, of the double bottom floor, in m, as shown in Figure 2.2.16. In way of bracket ends, as defined in Chapter 1 Section 4/2.1.5, the effective shear span is measured to the toes of the effective end bracket. Where the floor ends on a girder at a hopper or stool structure, the effective shear span is measured to a point that is one-half of the distance from the girder to the adjacent bottom and inner-bottom longitudinal, as shown in Figure 2.2.16.

P = design pressure for the design load set being considered, calculated at midpoint of effective shear span, l_{shr}, of a floor located midway between transverse bulkheads or transverse bulkhead and wash bulkhead, where fitted, in kN/m^2

$$= 0.00935\left(\frac{l_{shr}}{S}\right)^2 - 0.163\left(\frac{l_{shr}}{S}\right) + 1.289$$

$$= 1.3 - \left(\frac{S}{12}\right)$$

S = double bottom floor spacing, in m, as defined in Chapter 1 Section 4/2.2.2

C_{t-pr} = permissible shear stress coefficient for primary support member as given in Table 2.2.16

$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}}$ N/mm²

σ_{yd}= specified minimum yield stress of the material, in N/mm²

2.6.3.4. For double bottom side girders where no longitudinal bulkhead is fitted above, the net shear area, $A_{shr-net50}$, of the double bottom side girder in way of the first bay from each transverse bulkhead and wash bulkhead, where fitted, is not to be less than:

$$A_{shr-net50} = \frac{10Q}{C_{t-pr}\tau_{yd}} \text{cm}^2$$

where:

Q = design shear force

$= 0.14\, n_3 n_4\, P l_{shr}^2$ kN

$$n_3 = 1.072 - 0.0357\left(\frac{l_{shr}}{S}\right)$$

$$n_4 = 1.2 - \left(\frac{S}{18}\right)$$

l_{shr} = effective shear span, of the double bottom floor, in m, as shown in Figure 2.2.16. In way of bracket ends, as defined in Chapter 1 Section 4/2.1.5, the effective shear span is measured to the toes of the effective end bracket. The effective shear span is measured to a point that is one-half of the distance from the girder to the adjacent bottom and inner-bottom longitudinal, where the floor ends on a girder at a hopper or stool structure, as shown in Figure 2.2.16.

S = double bottom floor spacing, in m, as defined in Chapter 1Section 4/2.2.2

P = design pressure for the design load set being considered, calculated at midpoint of effective shear span, l_{shr}, of a floor located midway between transverse bulkheads or transverse bulkhead and wash bulkhead, where fitted, in kN/m²

C_{t-pr} = permissible shear stress coefficient for primary support member as given in Table 2.2.16

$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}}$ N/mm²

σ_{yd} =specified minimum yield stress of the material, in N/mm²

2.6.4. Deck transverses

2.6.4.1. The web depth of deck transverses is not to be less than:

a. 0.20 l_{bdg-dt} for deck transverses in the wing cargo tanks of ships with two longitudinal bulkheads

b. 0.13 l_{bdg-dt} for deck transverses in the centre cargo tanks of ships with two longitudinal bulkheads. The web depth of deck transverses in the centre cargo tank is not to be less than 90% of that of the deck transverses in the wing cargo tank

c. 0.10 l_{bdg-dt} for the deck transverses of ships with a centreline longitudinal bulkhead.

d. See also 2.6.1.7

where:

l_{bdg-dt}= effective bending span of the deck transverse, in m, see Chapter 1 Section 4/2.1.4 and Figure 2.2.17, but is not to be taken as less than 60% of the breadth of the tank at the location being considered

2.6.4.2. The moment of inertia of the deck transverses, with associated deck plating, is to comply with Section 4/2.3.2.3 to control the overall deflection of the deck structure.

2.6.4.3. The net section modulus of deck transverses is not to be less than $Z_{in-net50}$ and $Z_{ex-net50}$ as given by the following. The net section modulus of the deck transverses in the wing cargo tanks is also not to be less than required for the deck transverses in the centre tanks.

$$Z_{in-net50} = \frac{1000M_{in}}{C_{s-pr}\sigma_{yd}} \text{cm}^3$$

$$Z_{ex-net50} = \frac{1000\quad_{ex}}{C_{s-pr}\sigma_{yd}} \text{cm}^3$$

where:

M_{in} design bending moment due to cargo pressure, in kNm, to be taken as:

a. For deck transverses in wing cargo tanks of ships with two longitudinal bulkheads, and for decktransverses in cargo tanks of ships with a centreline longitudinal bulkhead

$$= 0.042\varphi_t P_{in-d}\ Sl_{bdg-d}^2\ + M_{st}$$

but is not to be taken as less than M_o

b. for deck transverses in centre cargo tank of ships with two longitudinal bulkheads:

$$= 0.042\varphi_t P_{in-d}\ Sl_{bdg-}^2\quad + M_{vw}$$

but is not to be taken as less than M_o

M_{st}= bending moment transferred from the side transverse

$$= C_{st}\beta_{st}P_{in-s}\ Sl_{bdg-dt}^2 \text{kNm}$$

where a cross tie is fitted in a wing cargo tank and $l_{bdg-st-ct}$ is greater than $0.7l_{bdg-st}$, then l_{bdg-st} in the above formula may be taken as $l_{bdg-st-ct}$.

M_{vw} = bending moment transferred from the vertical web frame on the longitudinal bulkhead

$$= C_{vw}\beta_{st}P_{in-st}Sl_{bdg-dt}^2 \ \text{kNm}$$

where $l_{bdg-vw-ct}$ is greater than $0.7l_{bdg-vw}$, then l_{bdg-vw} in the above formula may be taken as $l_{bdg-vw-ct}$. For vertically corrugated bulkheads, M_{vw} is to be taken equal to bending moment in upper end of corrugation over the spacing between deck transverses

M_0 = minimum bending moment

$= 0.083P_{in-d}\ Sl_{bdg-}^2$ kNm

M_{ex} = design bending moment due to green sea pressure

P_{in-dt} = design cargo pressure for the design load set being considered, calculated at midpoint of effective bending span, l_{bdg-dt}, of the deck transverse located at mid tank, in kN/m²

P_{in-st} = corresponding design cargo pressure in wing cargo tank for the design load set being considered, calculated at the midpoint of effective bending span, l_{bdg-st}, of the side transverse located at mid tank, in kN/m²

P_{in-vw} = corresponding design cargo pressure in the centre cargo tank of ships with two longitudinal bulkheads for the design load set being considered, calculated at mid-point of effective bending span, l_{bdg-vw}, of the vertical web frame on the longitudinal bulkhead located at mid tank, in kN/m²

P_{ex-dt} = design green sea pressure for the design load set being considered, calculated at midpoint of effective bending span, l_{bdg-dt}, of the deck transverse located at mid tank, in kN/m²

$$\varphi_t = 1 - 5\left(\frac{y_{toe}}{l_{bdg-dt}}\right)$$

but is not to be taken as less than 0.6

y_{toe}= distance from the end of effective bending span, l_{bdg-dt}, to the toe of the end bracket of the deck transverse, in m

$$\beta_{st} = 0.9\left(\frac{l_{bdg-s}}{l_{bdg-dt}}\right)\left(\frac{I_{dt}}{I_{st}}\right)$$

But is not to be taken as less than 0.10 or greater than 0.65

$$\beta_{vw} = 0.9\left(\frac{l_{bdg-vw}}{l_{bdg-}}\right)\left(\frac{I_{dt}}{I_{vw}}\right)$$

But is not to be taken as less than 0.10 or greater than 0.50

S = primary support member spacing, in m, as defined in Chapter 1 Section 4/2.2.2

l_{bdg-dt} = effective bending span of the deck transverse, in m, see Chapter 1 Section 4/2.1.4 and Figure 2.2.17, but is not to be taken as less than 60% of the breadth of the tank at the location being considered

l_{bdg-st} = effective bending span of the side transverse, in m, between the deck transverse and the bilge hopper, see Chapter 1 Section 4/2.1.4 and Figure 2.2.17

$l_{bdg-st-ct}$ = effective bending span of the side transverse, in m, between the deck transverse and the mid depth of the cross tie, where fitted in wing cargo tank, see Chapter 1 Section 4/2.1.4

l_{bdg-vw} = effective bending span of the vertical web frame on the longitudinal bulkhead, in m, between the decktransverse and the bottom structure, see Chapter 1 Section 4/2.1.4 and Figure 2.2.17.

$l_{bdg-vw-ct}$ = effective bending span of the vertical web frame on longitudinal bulkhead, in m, between the decktransverse and the mid depth of the cross tie, see Chapter 1 Section 4/2.1.4

I_{dt} = net moment of inertia of the deck transverse with an effective breadth of attached plating specified in Chapter 1 Section 4/2.3.2.3, in cm^4

I_{st} = net moment of inertia of the side transverse with an effective breadth of attached plating specified in Chapter 1 Section 4/2.3.2.3, in cm^4

I_{vw} = net moment of inertia of the longitudinal bulkhead vertical web frame with an effective breadth of attached plating specified in Chapter 1 Section 4/2.3.2.3, in cm^4

c_{st} as defined in Table 2.2.18

c_{vw} as defined in Table 8.2.18

C_{s-pr} = permissible bending stress coefficient for primary support memberas given in Table 8.2.16

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

Table 2.2.18: Values of c_{st} and c_{vw} for Deck Transverses

Structural Configuration			**c_{st}**	**c_{vw}**
Ships with centreline longitudinal bulkhead			0.056	-
Ships with two Longitudinalbulkheads	Cross tie in centre cargo tank	M_{vw} based on $l_{bdg-vw-ct}$	-	0.044
		M_{st} based on l_{bdg-st} or M_{vw} based on l_{bdg-vw}	0.044	0.016
	Cross ties in wing cargo tanks	M_{st} based on $l_{bdg-st-ct}$ or M_{vw} based on $l_{bdg-vw-ct}$	0.044	0.044
		M_{st} based on l_{bdg-st} or M_{vw} based on l_{bdg-vw}	0.041	0.015

2.6.4.4. The net shear area of deck transverses is not to be less than $A_{shr-in-net50}$ and $A_{shr-ex-net50}$ as given by:

$$A_{shr-in-net50} = \frac{10\quad in}{C_{t-pr}\tau_{yd}} cm^2$$

$$A_{shr-ex-net50} = \frac{10Q_{ex}}{C_{t-pr}\tau_{yd}} cm^2$$

where:

Q_{in}= design shear force due to cargo pressure

$= 0.65P_{in-dt}\, Sl_{\,shr} + c_1\, Db_{ctr}\, S\, \rho\, g$ kN

Q_{ex}= design shear force due to green sea pressure

$= 0.65P_{ex-d}\ \ Sl_{\,shr}$ kN

$P_{in\text{-}dt}$ = design cargo pressure for the design load set being considered, calculated at midpoint of effective bending span, $l_{bdg\text{-}dt}$, of the deck transverse located at mid tank, in kN/m^2

$P_{ex\text{-}dt}$ = design green sea pressure for the design load set being considered, calculated at midpoint of effective bending span, $l_{bdg\text{-}dt}$, of the deck transverse located at mid tank, in kN/m^2

S = primary support member spacing, in m, as defined in Chapter 1 Section 4/2.2.2

l_{shr} = effective shear span, of the deck transverse, in m, see Chapter 1 Section 4/2.1.5

$l_{bdg\text{-}dt}$ = effective bending span of the deck transverse, in m, see Chapter 1 Section 4/2.1.4 and Figure 2.2.17, but is not to be taken as less than 60% of the breadth of the tank at the location being considered

c_1 = 0.04 in way of wing cargo tanks of ships with two longitudinal bulkheads

= 0.00 in way of centre tank of ships with two longitudinal bulkheads

= 0.00 for ships with a centreline longitudinal bulkhead

D = moulded depth, in m, as defined in Chapter 1 Section 4/1.1.4

b_{ctr} = breadth of the centre tank, in m

$\boldsymbol{\rho}$ = density of liquid in the tank, in $tonnes/m^3$, not to be taken less than 1.025, see Chapter 1 Section 3.1.8

g = acceleration due to gravity, 9.81 m/s^2

$C_{t\text{-}pr}$ = permissible shear stress coefficient for primary support member as given in Table 2.2.16

$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}}$ N/mm^2

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

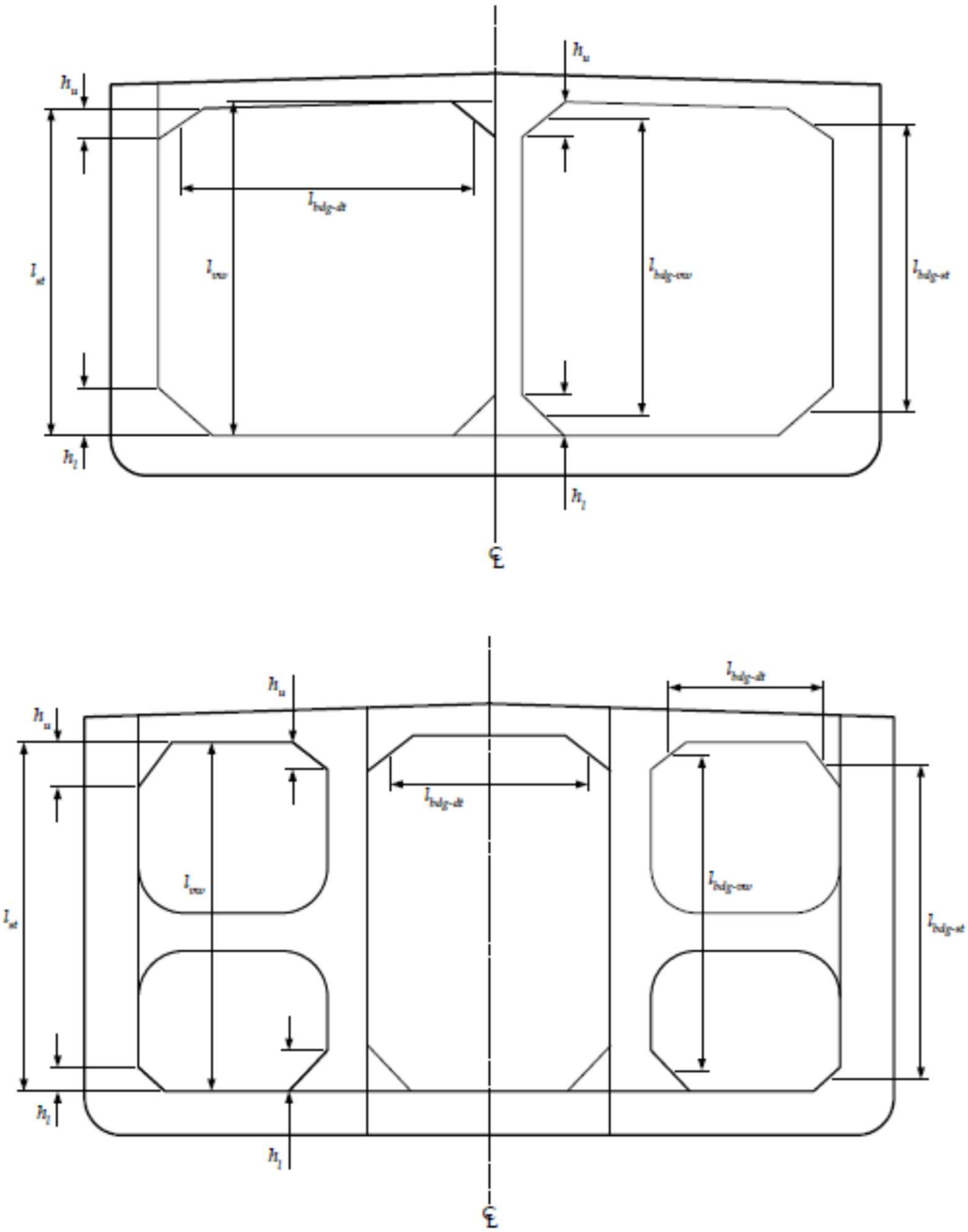


Figure 2.2.17: Definition of Spans of Deck, Side Transverses, Vertical Web Frames on Longitudinal Bulkheads and Horizontal Stringers on Transverse Bulkheads

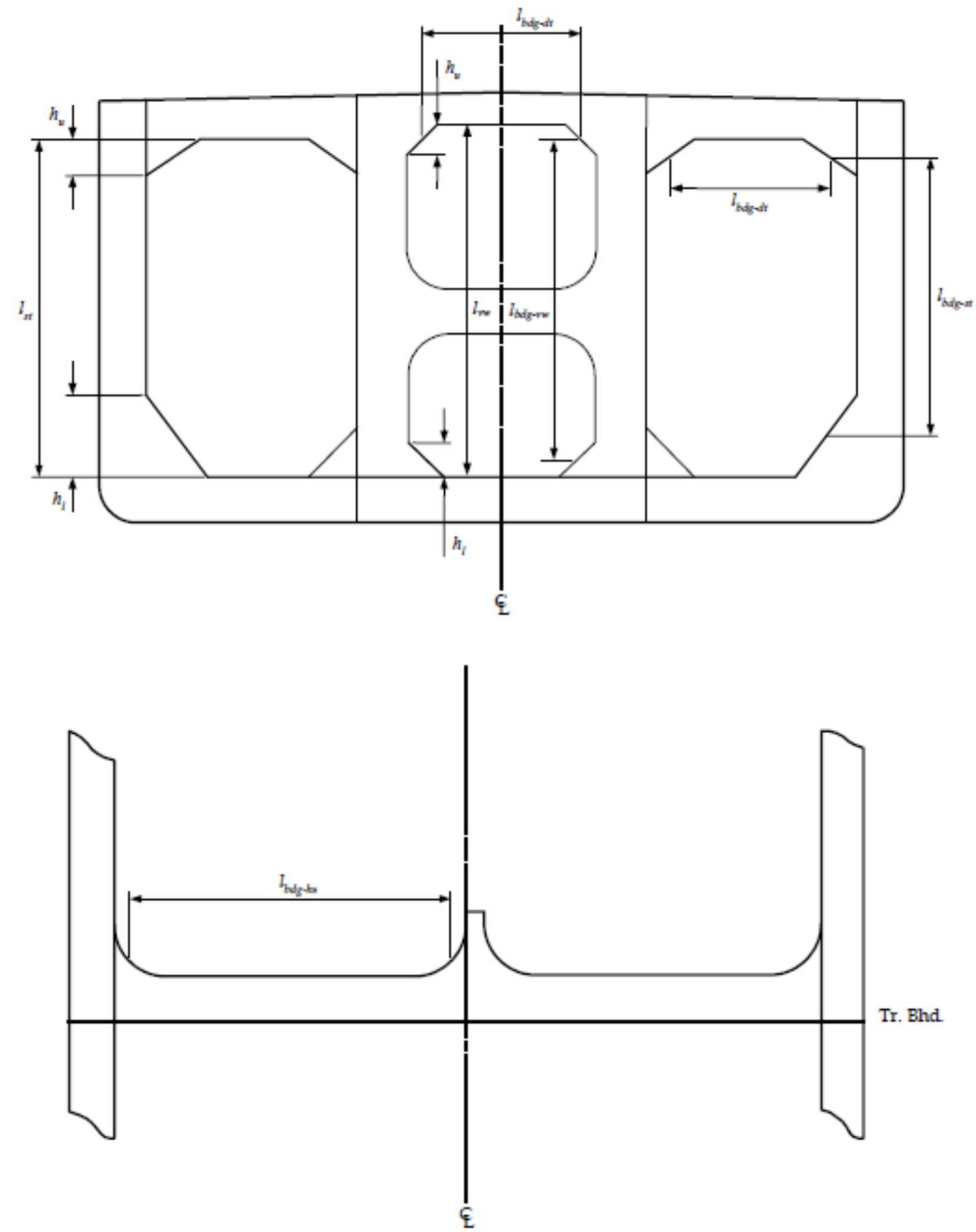


Figure 2.2.17: Definition of Spans of Deck, Side Transverses, Vertical Web Frames on Longitudinal Bulkheads and Horizontal Stringers on Transverse Bulkheads (Continued)

2.6.5. Side transverses

2.6.5.1. The net shear area, $A_{shr-net50}$, of side transverses is not to be less than:

$$A_{shr-net5} = \frac{10}{C_{t-pr}\tau_{yd}} \text{cm}^2$$

where:
Q = design shear force as follows, in kN:
= Q_u for upper part of the side transverse
= Q_l for lower part of the side transverse

$$Q_u = S\,[c_u l_{st}\,(P_u + P_l)\; - h_{\,u} P_u]$$

where a cross tie is fitted in a wing cargo tank and $l_{st\text{-}ct}$ is greater than $0.7l_{st}$, then l_{st} in the above formula is to be taken as $l_{st\text{-}ct}$.

Q_l to be taken as the greater of the following:

(a) $S[c_l l_{\,st}(P_u\; +\; P_l\,)\; -\; h_l\, P_l]$

(b) $0.35\; c_l\; S\; l_{st}\; (P_u + P_l\,)$

(c) $1.2\; Q_u$

where a cross tie is fitted in a wing cargo tank and $l_{st\text{-}ct}$ is greater than 0.7lst, then l_{st} in the above formula is to be taken as $l_{st\text{-}ct}$.

P_u= design pressure for the design load set being considered, in kN/m^2, calculated at mid tank as follows:

a. Where deck transverses are fitted below deck, P_u is to be calculated at mid height of upper bracket of the side transverse, h_u

b. Where deck transverses are fitted above deck, P_u is to be calculated at the elevation of the deck at side, except in cases where item (c) applies

c. Where deck transverses are fitted above deck and the inner hull longitudinal bulkhead is arranged with a top wing structure as follows:
   - the breadth at top of the wing structure is greater than 1.5 times the breadth of the double side and
   - the angle along a line between the point at base of the slope plate at its intersection with theinner hull longitudinal bulkhead and the point at the intersection of top wing structure and deck is 30 degrees or more to vertical

P_u is to be calculated at mid depth of the top wing structure

P_l= corresponding design pressure for the design load set being considered, calculated at mid height of bilge hopper, hl, located at mid tank, in kN/m^2.

l_{st}= length of the side transverse, in m, and is to be taken as follows:

a. Where deck transverses are fitted below deck, l_{st} is the length between the flange of the decktransverse and the inner bottom, see Figure 2.2.17
b. Where deck transverses are fitted above deck, l_{st} is the length between the elevation of the deck at side and the inner bottom

$l_{st\text{-}ct}$ = length of the side transverse, in m, and is to be taken as follows:

a. where deck transverses are fitted below deck, lst is the length between the flange of the deck transverse and mid depth of cross tie, where fitted in wing cargo tank
b. Where deck transverses are fitted above deck, lst is the length between the elevation of the deck at side and mid depth of the cross tie, where fitted in wing cargo tank

S = primary support member spacing, in m, as defined in Chapter 1 Section 4/2.2.2

h_u = effective length of upper bracket of the side transverse, in m, and is to be taken as follows:

a. Where deck transverses are fitted below deck, h_u is as shown in Figure 2.2.17 and as described in Chapter 1 Section 4/2.1.5.

b. Where deck transverses are fitted above deck, h_u is to be taken as 0.0, except in cases where item (c) applies.

c. Where deck transverses are fitted above deck and the inner hull longitudinal bulkhead is arranged with a top wing structure as follows:

- The breadth at top of the wing structure is greater than 1.5 times the breadth of the double side,and
- the angle along a line between the point at base of the slope plate at its intersection with the inner hull longitudinal bulkhead and the point at the intersection of top wing structure and the deck is 30 degrees or more to vertical

h_u is to be taken as the distance between the deck at side and the lower end of slope plate of the top wing structure.

h_l = height of bilge hopper, in m, as shown in Figure 2.2.17

c_u and c_l as defined in Table 2.2.19

$C_{t\text{-}pr}$ = permissible shear stress coefficient for primary support member as given in Table 2.2.16

$$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}} \text{N/mm}^2$$

σ_{yd} = specified minimum yield stress of the material, in N/mm^2

<table>
<tr><th colspan="7">Table 2.2.19: Values of c_u and c_l for Side Transverses</th></tr>
<tr><th colspan="3">Structural Configuration</th><th colspan="2">c_u</th><th colspan="2">c_l</th></tr>
<tr><th colspan="3">Number of side stringers</th><th>Less than three</th><th>Equal to or greater than three</th><th>Less than three</th><th>Equal to or greater than three</th></tr>
<tr><td colspan="3">Ships with a centreline longitudinal bulkhead</td><td rowspan="3">0.12</td><td rowspan="3">0.09</td><td rowspan="3">0.29</td><td rowspan="3">0.21</td></tr>
<tr><td rowspan="3">Ships with two longitudinal bulkheads</td><td colspan="2">Cross tie in centre cargo tank</td></tr>
<tr><td rowspan="2">Cross ties in wing cargo tanks</td><td>Q_u or Q_l based on $l_{st\text{-}ct}$</td></tr>
<tr><td>Q_u or Q_l based on l_{st}</td><td colspan="2">0.08</td><td colspan="2">0.20</td></tr>
</table>

2.6.5.2. The shear area over the length of the side transverse is to comply with the following:

a. Maintenance of the required shear area for the upper part is to be considered over the upper 0.2 l_{shr}

b. Maintenance of the required shear area for the lower part is to be considered over the lower 0.2 l_{shr}

c. Where Q_u and Q_l are determined based on l_{st-ct}, the maintenance of the required shear area for the lower part is also to be considered below the cross tie

d. For ships without cross ties in the wing cargo tanks, the required shear area between the upper and lower parts is to be reduced linearly towards 50% of the required shear area for the lower part at mid span

e. For ships with cross ties in the wing cargo tanks, the required shear area along the span is to be tapered linearly between the upper and lower parts

Note

When materials of different yield stress are employed, appropriate adjustments are to be made to account for differences in material yield stress

where:

l_{shr}= effective shear span of the side transverse, in m

$$= l_{st} - h_u - h_l$$

where Q_u and Q_l are determined based on l_{st}

$$= l_{st-c} \ - h_u$$

where Q_u and Q_l are determined based on l_{st-ct}

l_{st}, l_{st-ct}, h_u, h_l, Q_u and Q_l as defined in 2.6.5.1

2.6.6. Vertical web frames on longitudinal bulkhead

2.6.6.1. The web depth of the vertical web frame on the longitudinal bulkhead is not to be less than:

a. 0.14 l_{bdg-vw} for ships with a centreline longitudinal bulkhead
b. 0.09 l_{bdg-vw} for ships with two longitudinal bulkheads
c. see also 2.6.1.7

Where:

l_{bdg-vw} = effective bending span of the vertical web frame on the longitudinal bulkhead, see 2.6.6.2 and Figure 2.2.17

2.6.6.2. The net section modulus, Z_{net50}, of the vertical web frame is not to be less than:

$$Z_{net50} = \frac{1000M}{C_{s-pr}\sigma_{yd}} \text{cm}^3$$

where:

M design bending moment, in kNm, as follows:

$$= c_u PS\ {}^{2}_{bdg-vw} \quad \text{for upper part of the web frame}$$

$$= c_l PS\ {}^{2}_{bdg-} \quad \text{for lower part of the web frame}$$

where a cross tie is fitted and $l_{bdg-vw-ct}$ is greater than $0.7l_{bdg-vw}$, then lbdg-vw in the above formula is to be taken as $l_{bdg-vw-ct}$.

P = design pressure for the design load set being considered, calculated at midpoint of the effective bending span, l_{bdg-vw}, of the vertical web frame located at mid tank, in kN/m^2

l_{bdg-vw} = effective bending span of the vertical web frame on the longitudinal bulkhead, between the deck transverse and the bottom structure, in m, see Chapter 1 Section 4/2.1.4 and Figure 2.2.17.

$l_{bdg-vw-ct}$ = effective bending span of the vertical web frame on longitudinal bulkhead, between the deck transverse and mid depth of the cross tie on ships with two longitudinal bulkheads, in m, see Chapter 1 Section 4/2.1.4

S = primary support member spacing, in m, as defined in Chapter 1 Section 4/2.2.2

C_{s-pr} = permissible bending stress coefficient as given in Table 2.2.16

σ_{yd} = specified minimum yield stress of the material, in N/mm^2

c_u and c_l as defined in Table 2.2.20

Table 2.2.20: Values of c_u and c_l for Vertical Web Frame on Longitudinal Bulkheads

Structural Configuration			c_u	c_l
Ships with a centreline longitudinal bulkhead			0.057	0.071
Ships with two longitudinal bulkheads	Cross tie in centre cargo tank	M based on $l_{bdg-vw-ct}$	0.057	0.071
		M based on l_{bdg-vw}	0.012	0.028
	Cross ties in wing cargo tanks	M based on $l_{bdg-vw-ct}$	0.057	0.071
		M based on l_{bdg-vw}	0.016	0.032

2.6.6.3. The section modulus over the length of the vertical web frame on the longitudinal bulkhead is tocomply with the following:

a. Maintenance of the required section modulus for the upper part is to be considered over the upper 0.2 l_{bdg-vw} or 0.2 $l_{bdg-vw-ct}$, as per its application.
b. Maintenance of the required section modulus for the lower part is to be considered over the lower 0.2 l_{bdg-vw} or 0.2 $l_{bdg-vw-ct}$, , as per its application.
c. Where the required section modulus is determined based on $l_{bdg-vw-ct}$, Maintenance of the required section modulus for the lower part is also to be considered below the cross tie
d. Reduction of the required section modulus between the upper and lower parts is to be considered linearly to 70% of the required section modulus for the lower part at mid span

Note
Appropriate adjustments are to be made to account for differences in material yield stress when materials of different yield stress are employed.
Where:
l_{bdg-vw} and $l_{bdg-vw-ct}$ as defined in 2.6.6.2

2.6.6.4. The net shear area, $A_{shr-net50}$, of the vertical web frame is not to be less than:

$$A_{\text{shr-net50}} = \frac{10}{C_{t-pr}\tau_{yd}} \text{cm}^2$$

where:

Q = design shear force as follows, in kN:

= Q_u for upper part of the web frame

= Q_l for lower part of the web frame

$$Q_u = S\,[c_u l_{vw}\,(P_u + P_l) - h_u P_u]$$

where a cross tie is fitted in a centre or wing cargo tank and $l_{vw\text{-}ct}$ is greater than $0.7l_{vw}$, then l_{vw} in the above formula is to be taken as $l_{vw\text{-}ct}$.

Q_l to be taken as the greater of the following

a) $S[c_l l_{vw}(P_u + P_l) - h_l P_l]$

b) $c_w\,S\,c_l\,l_{vw}(P_u + P_l)$

c) $1.2Q_u$

where a cross tie is fitted in a centre or wing cargo tank and $l_{vw\text{-}ct}$ is greater than $0.7l_{vw}$, then l_{vw} inthe above formula is to be taken as $l_{vw\text{-}ct}$.

P_u= design pressure for the design load set being considered, calculated at mid height of upper bracketof the vertical web frame, h_u, located at mid tank, in kN/m^2

P_l= design pressure for the design load set being considered, calculated at mid height of lower bracketof the vertical web frame, h_l, located at mid tank, in kN/m^2

l_{vw}= length of the vertical web frame, in m, between the flange of the deck transverse and the innerbottom, see Figure 2.2.13

$l_{vw\text{-}ct}$ = length of the vertical web frame, in m, between the flange of the deck transverse and mid depth ofthe cross tie, where fitted

S = primary support member spacing, in m, as defined in Chapter 1 Section 4/2.2.2

h_u = effective length of upper bracket of the vertical web frame, in m, as shown in Figure 2.2.13 and asdescribed in Chapter 1 Section 4/2.1.5

h_l = effective length of lower bracket of the vertical web frame, in m, as shown in Figure 2.2.13 and asdescribed in Chapter 1 Section 4/2.1.5

c_u and c_l as defined in Table 2.2.21

c_w = 0.57 for ships with a centreline longitudinal bulkhead

= 0.50 for ships with two longitudinal bulkheads

$C_{t\text{-}pr}$ = permissible shear stress coefficient for primary support member as given in Table 2.2.16

$$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}}\ \text{N/mm}^2$$

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

Table 2.2.21: Values of c_u and c_l for Vertical Web Frame on Longitudinal Bulkhead

Structural Configuration		**c_u**	**c_l**
Ships with a centreline longitudinal bulkhead		0.17	0.28
Ships with two longitudinalbulkheads	Q_u or Q_l based on $l_{vw\text{-}ct}$		
	Q_u or Q_l based on l_{vw}	0.075	0.18

2.6.6.5. The shear area over the length of the vertical web frame on the longitudinal bulkhead is to comply with the following:

a. Maintenance of the required shear area for the upper part is to be considered over the upper 0.2 l_{shr}

b. Maintenance ofthe required shear area for the lower part is to be considered over the lower 0.2l_{shr}

c. Where Q_u and Q_l are determined based on l_{vw-ct}, Maintenance of the required shear area for the lower part is also to be considered below the cross tie

d. For ships without cross ties in the wing or centre cargo tanks, reduction of the required shear area between the upper and lower parts is to be considered linearly towards 50% of the required shear area for the lower part at mid span

e. For ships with cross ties in the wing or centre cargo tanks, tapering of the required shear area along the span is to be considered linearly between the upper and lower parts

Note

When materials of different yield stress are employed, appropriate adjustments are to be made to account for differences in material yield stress.

where:

l_{shr} = effective shear span of the side transverse

$$= l_{vw} - h_u - h_l$$

where Q_u and Q_l are determined based on l_{vw}

$$= l_{vw-c} - h_u$$

where Q_u and Q_l are determined based on l_{vw-ct}

l_{vw}, l_{vw-ct}, h_u, h_l, Q_u and Q_l as defined in 2.6.6.4

2.6.7. Horizontal stringers on transverse bulkheads

2.6.7.1. The web depth of horizontal stringers on transverse bulkhead is not to be less than:

a. 0.28 l_{bdg-hs} for horizontal stringers in wing cargo tanks of ships with two longitudinal bulkheads

b. 0.20 l_{bdg-hs} for horizontal stringers in centre tanks of ships with two longitudinal bulkheads, but the web depth of horizontal stringers in centre tank is not to be less than required depth for a horizontal stringer in wing cargo tanks

c. 0.20 l_{bdg-hs} for horizontal stringers of ships with a centreline longitudinal bulkhead

d. See also 2.6.1.7.

where:
l_{bdg-hs} = effective bending span of the horizontal stringer, in m, but is not to be taken as less than 50% of the breadth of the tank at the location being considered, see Chapter 1 Section 4/2.1.4 and Figure 2.2.17

2.6.7.2. The net section modulus, Z_{net50}, of the horizontal stringer over the end $0.2l_{bdg-hs}$ is not to be less than:

$$Z_{net50} = \frac{1000M}{C_{s-pr}\sigma_{yd}} \text{ cm}^3$$

where:

M design bending moment:

$$= c\ P\ S\ l_{bdg-h}^2 \text{ kN}$$

P = design pressure for the design load set being considered, calculated at mid-point of effective bending span, l_{bdg-hs}, and at midpoint of the spacing, S, of the horizontal stringer, in kN/m^2

S = sum of the half spacing (distance between stringers) on each side of the horizontal stringer under consideration, in m

l_{bdg-hs} = effective bending span of the horizontal stringer, in m, but is not to be taken as less than 50% of the breadth of the tank at the location being considered, see Chapter 1 Section 4/2.1.4 and Figure 2.2.17

c = 0.073 for horizontal stringers in cargo tanks of ships with a centreline bulkhead

= 0.083 for horizontal stringers in wing cargo tanks of ships with two longitudinal bulkheads

= 0.063 for horizontal stringers in the centre tank of ships with two longitudinal bulkheads

C_{s-pr} = permissible bending stress coefficient as given in Table 2.2.16

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

2.6.7.3. The required section modulus at mid effective bending span is to be taken as 70% of that required at the ends; intermediate values are to be obtained by linear interpolation. Appropriate adjustments are to be made to account for differences in material yield stress when materials of different yield stress are employed.

2.6.7.4. The net shear area, $A_{shr-net50}$, of the horizontal stringer over the end 0.2 l_{shr} is not to be less than:

$$A_{\text{shr}-\text{net50}} = \frac{10}{C_{t-pr}\tau_{yd}} \text{ cm}^2$$

where:

Q design shear force

$$= 0.5\ P\ S\ l_{shr} \text{ kN}$$

P = design pressure for the design load set being considered, calculated at mid-point of effective bending span, l_{bdg-hs}, and at mid-point of the spacing, S, of the horizontal stringer, in kN/m^2

S = sum of the half spacing (distance between stringers), on each side of the horizontal stringer under consideration, in m

l_{shr} = effective shear span of the horizontal stringer, in m, see Chapter 1 Section 4/2.1.5

C_{t-pr} = permissible shear stress coefficient as given in Table 2.2.16

$$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}} \text{N/mm}^2$$

σ_{yd} = specified minimum yield stress of the material, in N/mm^2

2.6.7.5. The required shear area at mid effective shear span is to be taken as 50% of that required in the ends, and linear interpolation shall be used to obtain the intermediate values. When materials of different yield stress are employed, appropriate adjustments are to be made to account for differences in material yield stress.

2.6.8. Cross ties

2.6.8.1. The maximum applied design axial load on cross ties, $W_{ct,}$ is to be less than or equal to the permissible load, $W_{ct-perm}$, as given by

$W_{ct} < W_{ct-perm}$

where:

W_{ct} = applied axial load

$= P b_{ct} S$ kN

$W_{ct-perm}$= permissible load

$= 0.1 A_{ct-net50} \eta_{ct} \sigma_{cr}$ kN

P = maximum design pressure for all the applicable design load sets being considered, calculated at centre of the area supported by the cross tie located at mid tank, in kN/m^2

b_{ct}= where cross tie is fitted in centre cargo tank:

$$= 0.5\, l_{bdg-vw}$$

where cross ties are fitted in wing cargo tanks:

= 0.5 l_{bdg-vw}, for design cargo pressure from the centre cargo tank

= 0.5 l_{bdg-st} for design sea pressure

l_{bdg-vw} = effective bending span of the vertical web frame on the longitudinal bulkhead, in m, see Chapter 1 Section 4/2.1.4 and Figure 2.2.17.

l_{bdg-st} = effective bending span of the side transverse, in m, see Chapter 1 Section 4/2.1 and Figure 2.2.17.

S = primary support member spacing, in m, as defined in Chapter 1 Section 4/2.2.2

η_{ct}= utilisation factor, to be taken as:

= 0.65 for acceptance criteria set AC1

= 0.75 for acceptance criteria set AC2

σ_{cr}= critical buckling stress in compression of the cross tie, in N/mm^2, as calculated using the net sectional properties in accordance with Section 4/3.5.1, where the effective length of the cross tie is to be taken as follows, in m:

a. For cross tie in centre tank:

Distance between the flanges of longitudinal stiffeners on the starboard and port longitudinal bulkheads to which the cross tie's horizontal stiffeners are attached

b. For cross tie in wing tank:

Distance between the flanges of longitudinal stiffeners on the longitudinal bulkhead to which the cross tie's horizontal stiffeners are attached, and the inner hull plating

$A_{ct-net50}$ = net cross sectional area of the cross tie, in cm^2

2.6.8.2. In order to provide effective means for transmission of the compressive forces into the webs special attention is to be paid to the adequacy of the welded connections for the transmission of the forces, and also to the stiffening arrangements. Particular attention is to be paid to the welding at the toes of all end brackets of the cross ties.

2.6.8.3. Horizontal stiffeners are to be located in line with, and attached to, the longitudinals at the ends of the cross ties.

2.6.9. Primary support members located beyond 0.4L amidships

2.6.9.1. when a cargo tank FE analysis is not available for the region outside of 0.4L amidships, the requirements given in 2.6.9.2 and 2.6.9.3 may be used to obtain the scantlings of primary support members located beyond 0.4L of amidships. Scantlings used for the 0.4L amidships are to be those required by Sections 2/2 and Section 3/2, see 2.6.1.3 and 2.6.1.4.

2.6.9.2. The net section modulus of primary support members, $Z_{end-net50}$, located beyond 0.4L of amidships is not to be less than:

$$Z_{end-net50} = \frac{Z_{mid-net50}\sigma_{yd-m} \quad M_{end}}{\sigma_{yd-e} \quad M_{mid}} \text{cm}^3$$

where:

M_{end} = bending moment, in kNm, for the structural member under consideration located beyond 0.4L amidships, calculated in accordance with corresponding requirements of 2.6.3 to 2.6.8 and using the design pressure specified for the given location

M_{mid}= bending moment, in kNm, for the corresponding structural member and location of cross section, amidships, obtained from the corresponding requirements of 2.6.2 to 2.6.8

$Z_{mid-net50}$ = net section modulus at the flange of the corresponding structural member and location of cross section amidships, in cm^3

σ_{yd-end} = specified minimum yield stress of the flange of the structural member under consideration located beyond 0.4L amidships, in N/mm^2

σ_{yd-mid} specified minimum yield stress of the flange of the structural member under consideration amidships, in N/mm^2

2.6.9.3. The net shear area for primary support members, $A_{shr-end-net50}$, located beyond 0.4L amidships is notto be less than:

$$A_{shr-end-net50} = \frac{A_{shr-mid-net50}\tau_{yd-mid}Q_{end}}{\tau_{yd-end}Q_{mid}} \text{ cm}^2$$

Q_{end}= shear force, in kN, for the structural member under consideration located beyond 0.4L of amidships, calculated in accordance with the corresponding requirements of 2.6.3 to 2.6.8 and using the design pressure, specified for the given location

Q_{mid}= shear force, in kN, for the corresponding structural member and corresponding location of cross section, amidships, obtained from the requirements of 2.6.2 to 2.6.8

$A_{shr-mid-net50}$ = shear area of corresponding structural member and location of cross section amidships, in cm^2

$$\tau_{yd-e} = \frac{\sigma_{yd-e}}{\sqrt{3}} \text{N/mm}^2$$

$$\tau_{yd-m} = \frac{\sigma_{yd-m}}{\sqrt{3}} \text{N/mm}^2$$

σ_{yd-end} = specified minimum yield stress of the structural member under consideration located beyond 0.4L amidships, in N/mm^2

σ_{yd-mid}= specified minimum yield stress of the structural member under consideration amidships, in N/mm^2

3. Forward of the Forward Cargo Tank

3.1. General

3.1.1. Application

3.1.1.1. The requirements of this Sub-Section apply to structure forward of the forward end of the foremost cargo tank. Where the forward end of the foremost cargo tank is aft of 0.1L of the ship's length, measured from the F.P., special consideration will be given to the applicability of these requirements and the requirements of Section 2/2.

3.1.1.2. The net scantlings described in this Sub-Section are related to gross scantlings as follows:

a. For application of the minimum thickness requirements of 3.1.4, the gross thickness is obtained from the applicable requirements by adding the full corrosion additions specified in Chapter 1Section 6/3.

b. For plating and local support members, the gross thickness and gross cross sectional properties are obtained from the applicable requirements by adding the full corrosion additions specified in Chapter 1 Section 6/3

c. For primary support members, the gross shear area, gross section modulus and other gross cross sectional properties are obtained from the applicable requirements by adding one half of the relevant full corrosion additions specified in Chapter 1 Section 6/3

d. For application of buckling requirements of Section 4/2 the gross thickness and gross cross sectional properties are obtained from the applicable requirements by adding the full corrosion additions specified in Chapter 1 Section 6/3.

3.1.2. General scantling requirements

3.1.2.1. The hull structure is to comply with the applicable requirements of:

a. Hull girder longitudinal strength, see Section 2/1
b. Strength against sloshing and impact loads, see Section 2/6
c. Buckling/ultimate strength, see Section 4.

3.1.2.2. Suitable reinforcing of the deck plating thickness and supporting structure are to be given in way of the anchor windlass and other deck machinery, and in way of cranes, masts and derrick posts. See Chapter 3 Section 1/3.

3.1.2.3. Determination of the net section modulus, shear area and other sectional properties of local and primary support members are to be provided in accordance with Chapter 1 Section 4/2.

3.1.2.4. Application of the section modulus and web thickness of the local support members are done to the areas clear of the end brackets. Application ofthe section modulus and cross sectional shear areas of the primary support members are to be done as required in the notes to Table 2.2.26.

3.1.2.5. The scantling criteria are based on assumptions that all structural joints and welded details are designed and fabricated such that they are compatible with the anticipated working stress levels at the locations considered. The loading patterns, stress concentrations and potential failure modes of structural joints and details during the design of highly stressed regions are to be considered. Structural design details are to comply with the requirements in Chapter 1 Section 4/3.

3.1.2.6. Limber, drain and air holes are to be cut in all parts of the structure, as required, to ensure free flow to the suction pipes and the escape of air to the vents. Arrangements are to be made for draining the spaces above deep tanks. See also Chapter 1 Section 4/3.

3.1.2.7. Web stiffeners are to be fitted on primary support members at each longitudinal on the side and bottom shell. Alternative arrangements may be accepted where adequacy of stiffener end connections and strength of adjoining web and bulkhead plating is demonstrated.

3.1.3. Structural continuity

3.1.3.1. Scantlings of the shell envelope, upper deck and inner bottom are to be tapered towards the forward end. See also 1.6.

3.1.3.2. In the transition zone aft of the fore peak into the forward cargo tank, due consideration is to be given to the arrangement of major longitudinal members in order to avoid abrupt changes in section. Scarphing of structures within the fore peak, such as flats, decks, horizontal ring frames or side stringers, are to be done effectively into the structure aft into the cargo tank. Where such structures are in line with longitudinal members aft of the forward cargo tank bulkhead fitting of tapered transition brackets may be used.

3.1.3.3. Adequate backing structure is to be provided together with tapering brackets to ensure continuity of strength where inner hull or longitudinal bulkhead structures terminate at the forward bulkhead of the forward cargo tank.

3.1.3.4. Longitudinal framing of the strength deck is to be carried as far forward as practicable.

3.1.3.5. All shell frames and tank boundary stiffeners are to be continuous, or are to be bracketed at their ends, except as permitted in Chapter 1 Sections 4/3.2.4 and 4/3.2.5.

3.1.4. Minimum thickness

3.1.4.1. In addition to the thickness, section modulus and stiffener web shear area requirements as given in this Sub-Section, the thickness of plating and stiffeners in the forward region are to comply with the appropriate minimum thickness requirements given in Table 2.2.22.

3.2. Bottom Structure

3.2.1. Plate keel

3.2.1.1. As far forward as practical,a flat plate keel is to be extended and is to satisfy the scantling requirements given in 2.2.1.

3.2.2. Bottom shell plating

3.2.2.1. The thickness of the bottom shell plating is to comply with the requirements in 3.9.2.1.

3.2.3. Bottom longitudinals

3.2.3.1. Bottom longitudinals are to be carried as far forward as practicable. Beyond this, suitably stiffened frames are to be fitted.

3.2.3.2. The section modulus and thickness of the bottom longitudinals are to comply with the requirements in 3.9.2.2 and 3.9.2.3.

Table 2.2.22: Minimum Net Thickness of Structure Forward of the Forward Cargo Tank

Scantling Location			Net Thickness (mm)
Plating	Shell	Keel plating	See 2.1.5.1
		Bottom shell/bilge/side shell plating	See 2.1.5.1
	Upper deck		See 2.1.5.1
	Other structure	Hull internal tank boundaries	See 2.1.5.1
		Non-tight bulkheads, bulkheads between dry spaces and other plates in general	See 2.1.5.1
		Pillar bulkheads	7.5
		Breasthooks	6.5
Floors and bottom girders			$5.5 + 0.02L_2$
Web plating of primary support members			$6.5 + 0.015L_2$
Local support members			See 2.1.5.1
Tripping brackets			See 2.1.5.1
where:			
L_2 rule length, L, in m, as defined in Chapter 1 Section 4/1.1.1.1, but need not be taken greater than 300m			

3.2.4. Bottom floors

3.2.4.1. Bottom floors are to be fitted at each web frame location. The minimum depth of the floor at the centreline is to be not to be less than the required depth of the double bottom of the cargo tank region. See Chapter 1 Section 5/3.2.1.1.

3.2.5. Bottom girders

3.2.5.1. Either by extending the centreline girder to the stem or by providing a deep girder or centreline bulkhead, a supporting structure is to be provided at the centreline.

3.2.5.2. The minimum depth and thickness is not to be less than that required for the depth of the double bottom in the cargo tank region, and the upper edge is to be stiffened where a centreline girder is fitted. Where a centreline wash bulkhead is fitted, the lowest strake is to have thickness not less than required for a centreline girder.

3.2.5.3. Where a longitudinal wash bulkhead supports bottom transverses, the details and arrangements of openings in the bulkhead are to be configured to avoid areas of high stresses in way of the connection of the wash bulkhead with bottom transverses.

3.2.6. Plate stems

3.2.6.1. Plate stems are to be supported by stringers and flats, and by intermediate breast hook diaphragms spaced not more than 1500mm apart, measured along the stem. Where the stem radius is large, a centreline support structure is to be fitted.

3.2.6.2. Between the minimum design ballast draught, T_{bal}, at the stem and the scantling draught, T_{sc}, the plate stem net thickness, $t_{stem-net}$, is not to be less than:

$$t_{stem-net} = \frac{L_2\sqrt{\frac{235}{\sigma_{yd}}}}{12} \text{mm}$$

but need not be taken as greater than 21mm

where:

L_2 = rule length, L, in m, as defined in Chapter 1 Section 4/1.1.1.1, but need not be taken greater than 300m

σ_{yd} = specified minimum yield stress of the material, in N/mm^2

Above the scantling draught the thickness of the stem plate may be tapered to the requirements for the shell plating at the upper deck.

Below the minimum design ballast draught the thickness of the stem plate may be tapered to the requirements for the plate keel.

3.2.7. Floors and girders in spaces aft of the collision bulkhead

3.2.7.1. Floors and girders which are aft of the collision bulkhead and forward of the forward cargo tank, are to comply with the requirements in 3.2.4 and 3.2.5 and are to comply with the shear area requirements in 3.9.3.3.

3.3. Side Structure

3.3.1. Side shell plating

3.3.1.1. The thickness of the side shell plating is to comply with the requirements in 3.9.2.1. Where applicable, the thickness of the side shell plating is to comply with the requirements in 2.2.4.2.

3.3.1.2. Where a forecastle is fitted, applications of the side shell plating requirements are to be done to the plating extending to the forecastle deck elevation.

3.3.2. Side shell local support members

3.3.2.1. Longitudinal framing of the side shell is to be carried as far forward as practicable.

3.3.2.2. The section modulus and thickness of the hull envelope framing is to comply with the requirements in 3.9.2.2 and 3.9.2.3.

3.3.2.3. End connections of longitudinals at transverse bulkheads are to provide adequate fixity, lateral support, and where not continuous are to be provided with soft-nosed brackets. Brackets lapped onto the longitudinals are not to be used.

3.3.3. Side shell primary support structure

3.3.3.1. In general, the spacing of web frames, S as defined in Chapter 1 Section 4/2.2.2, is to be taken as:

$$S = 2.6 + 0.005L_2 \text{m}$$

but not to be taken greater than 3.5m

where:

L_2= rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but is not to be taken greater than 300m

3.3.3.2. In general, the transverse framing forward of the collision bulkhead stringers are to be spaced approximately 3.5m apart. Stringers are to have an effective span not greater than 10m, and are to be adequately supported by web frame structures. Aft of the collision bulkhead, where transverse framing is adopted, the spacing of stringers may be increased.

3.3.3.3. Perforated flats are to be fitted to limit the effective span of web frames to not greater than 10m.

3.3.3.4. The scantlings of web frames supporting longitudinal frames, and stringers and/or web frames supporting transverse frames in the forward region are to be determined from 3.9.3, with the following additional requirements:

a. where no cross ties are fitted:

- The required section modulus of the web frame is to be maintained for 60% of the effective span for bending, measured from the lower end. Reduction of the value of the bending moment used for calculation of the required section modulus of the remainder of the web frame may be considered appropriately, but not greater than 20%

- The required shear area of the lower part of the web frame is to be maintained for 60% of the shear span measured from the lower end.

b. Where one cross tie is fitted:

- By ignoring the presence of the cross tie;the effective spans for bending and shear of a web frame or stringer are to be taken. The shear forces and bending moments may be reduced to 50% of the values that are calculated ignoring the presence of the cross ties. For a web frame, the required section modulus and shear area of the lower part of the web frame is to be maintained up to the cross tie, and the required section modulus and shear area of the upper part of the web frame is to be maintained for the section above the cross tie

- Cross ties are to satisfy the requirements of 2.6.8 using the design loads specified in Table 2.2.29.

c. Configurations with multiple cross ties are to be specially considered, in accordance with 3.3.3.4(d)

d. Where complex grillage structures are employed the suitability of the scantlings of the primary supportmembers is to be determined by more advanced calculation methods.

3.3.3.5. The web depth of primary support members is not to be less than 14% of the bending span and is to be at least 2.5 times as deep as the slots for stiffeners if the slots are not closed.

3.4. Deck Structure

3.4.1. Deck plating

3.4.1.1. The thickness of the deck plating is to comply with the requirements in 3.9.2.1 with the applicable lateral pressure, green sea and deck loads.

3.4.2. Deck stiffeners

3.4.2.1. The section modulus and thickness of deck stiffeners are to comply with the requirements in 3.9.2.2 and 3.9.2.3, with the applicable lateral pressure, green sea and deck loads.

3.4.3. Deck primary support structure

3.4.3.1. The section modulus and shear area of primary support members are to comply with the requirements in 3.9.3.

3.4.3.2. The web depth of primary support members is not to be less than 10% and 7% of the unsupported span in bending in tanks and in dry spaces, respectively, and is not to be less than 2.5 times the depth of the slots if the slots are not closed. Unsupported span in bending is bending span as defined in Chapter 1 Section 4/2.1.4 or in case of a grillage structure, the distance between connections to other primary support members.

3.4.3.3. In way of concentrated loads from heavy equipment, the scantlings of the deck structure are to be determined based on the actual loading. See also Chapter 3 Section 11/3.

3.4.4. Pillars

3.4.4.1. Pillars are to be fitted in the same vertical line wherever possible and effective arrangements are to be made to distribute the load at the heads and heels of all pillars. Where pillars support eccentric loads, they are to be strengthened for the additional bending moment imposed upon them.

3.4.4.2. Tubular and hollow square pillars are to be attached at their heads and heels by efficient brackets or doublers/insert plates, where applicable, to transmit the load effectively. Pillars are to be attached at their heads and heels by continuous welding. At the heads and heels of pillars built of rolled sections, the load is to be distributed by brackets or other equivalent means.

3.4.4.3. Pillars in tanks are to be of solid section. Where the hydrostatic pressure may result in tensile stresses in the pillar, the tensile stress in the pillar and its end connections is not to exceed 45% of the specified minimum yield stress of the material.

3.4.4.4. The scantlings of pillars are to comply with the requirements in 3.9.5.

3.4.4.5. Where the loads from heavy equipment exceed the design load of 3.9.5, the pillar scantlings are to be determined based on the actual loading.

3.5. Tank Bulkheads

3.5.1. General

3.5.1.1. Tanks may be required to have divisions or deep wash plates in order to minimise the dynamic stress on the structure.

3.5.2. Construction

3.5.2.1. In no case are the scantlings of tank boundary bulkheads to be less than the requirements for watertight bulkheads.

3.5.3. Scantlings of tank boundary bulkheads

3.5.3.1. The thickness of tank boundary plating is to comply with the requirements in 3.9.2.1.

3.5.3.2. The section modulus and thickness of stiffeners are to comply with the requirements in 3.9.2.2 and 3.9.2.3.

3.5.3.3. The section modulus and shear area of primary support members are to comply with the requirements in 3.9.3.

3.5.3.4. Web plating of primary support members is to have a depth of not less than 14% of the unsupported span in bending, and is not to be less than 2.5 times the depth of the slots if the slots are not closed.

3.5.3.5. Scantlings of corrugated bulkheads are to comply with the requirements in 3.9.4.

3.6. Watertight Boundaries

3.6.1. General

3.6.1.1. Watertight boundaries are to be fitted in accordance with Chapter 1 Section 5/2.

3.6.2. Collision bulkhead

3.6.2.1. The scantlings of structural components of the collision bulkheads are to comply with the requirements in 3.6.3, as applicable. Additionally, the collision bulkhead is to comply with the requirements in 3.6.2.2 to 3.6.2.4.

3.6.2.2. The position of the collision bulkhead is to be in accordance with Chapter 1 Section 5/2.2.

3.6.2.3. Doors, manholes, permanent access openings or ventilation ducts are not to be cut in the collision bulkhead below the freeboard deck. The number of openings in the extension is to be kept to a minimum compatible with the design and proper working of the ship where the collision bulkhead is extended above the freeboard deck. Fitting of the openings are to be given with weather tight closing appliances. The collision bulkhead may be pierced by pipes necessary for dealing with the contents of tanks forward of the bulkhead, provided the pipes are fitted with valves capable of being operated from above the freeboard deck. Fitting of the valves are generally to be provided on the collision bulkhead inside the fore peak and are not to be fitted inside the cargo tank.

3.6.2.4. Arrangement of compartments forward of the collision bulkhead may not be considered for the carriage of flammable liquids.

3.6.3. Scantlings of watertight boundaries

3.6.3.1. The thickness of boundary plating is to comply with the requirements in 3.9.2.1.

3.6.3.2. The section modulus and thickness of stiffeners are to comply with the requirements in 3.9.2.2 and 3.9.2.3.

3.6.3.3. The section modulus and shear area of primary support members are to comply with the requirements in 3.9.3.

3.6.3.4. Web plating of primary support members is to have a depth of not less than 10% of the unsupported span in bending, and is not to be less than 2.5 times the depth of the slots if the slots are not closed.

3.6.3.5. Scantlings of corrugated bulkheads are to comply with the requirements in 3.9.4.

3.7. Superstructure

3.7.1. Forecastle structure

3.7.1.1. Forecastle structures are to be supported by girders with deep beams and web frames, and in general, arranged in complete transverse belts and supported by lines of pillars extending down into the structure below. Deep beams and girders are to be arranged, where practicable, to limit the spacing between deep beams, web frames, and/or girders to about 3.5m. Pillars are to be provided as required by 3.4.4. Developments of main structural intersections are to be done carefully with special attention given to pillar head and heel connections, and to the avoidance of stress concentrations.

3.7.2. Forecastle end bulkhead

3.7.2.1. The details and scantlings of the forecastle end bulkhead are to meet the requirements of Chapter 3 Section 11/ 1.4.

3.8. Miscellaneous Structures

3.8.1. Pillar bulkheads

3.8.1.1. Bulkheads that support girders or pillars and longitudinal bulkheads which are fitted in lieu of girders are required to be stiffened in order to provide supports not less effective than required for stanchions or pillars. The acting load and the required net cross sectional area of the pillar section are to be determined using the requirements of 3.4.4. The net moment of inertia of the stiffener is to be calculated with a width of 40 t_{net}, where t_{net} is the net thickness of plating, in mm.

3.8.1.2. Pillar bulkheads are to comply with the following requirements:

a. The distance between bulkhead stiffeners is not to exceed 1500mm
b. Where corrugated, the depth of the corrugation is not to be less than 100mm.

3.8.2. Bulbous bow

3.8.2.1. Where a bulbous bow is fitted, the structural arrangements are to be such that the bulb is adequately supported and integrated into the fore peak structure.

3.8.2.2. At the forward end of the bulb the structure is generally to be supported by horizontal diaphragm plates spaced about 1m apart in conjunction with a deep centreline web.

3.8.2.3. In general, vertical transverse diaphragm plates are to be arranged in way of the transition from the peak framing to the bulb framing.

3.8.2.4. In way of a wide bulb, additional strengthening in the form of a centreline wash bulkhead is generally to be fitted.

3.8.2.5. In way of a long bulb, additional strengthening in the form of transverse wash bulkheads or substantial web frames is to be fitted.

3.8.2.6. The shell plating is to be increased in thickness at the forward end of the bulb and also in areas likely to be subjected to contact with anchors and chain cables during anchor handling. The increased plate thickness is to be the same as that required for plated stems given in 3.2.6.

3.8.3. Chain lockers

3.8.3.1. Chain lockers are to meet the requirements of Chapter 3 Section 1/4.2.9.

3.8.4. Bow thruster tunnels

3.8.4.1. The net thickness of the tunnel plating, $t_{tun\text{-}net}$, is not to be less than as required for the shell plating in the vicinity of the bow thruster. In addition, $t_{tun\text{-}net}$ is not to be taken less than:

$$t_{tun-n} \quad = 0.008 d_{tun} + 1.8 \text{ mm}$$

where:

d_{tun}= inside diameter of the tunnel, in mm, but not to be taken less than 970mm

3.8.4.2. Where the outboard ends of the tunnel are provided with bars or grids, the bars or grids are to beeffectively secured.

3.9. Scantling Requirements

3.9.1. General

3.9.1.1. Application of the design load sets are to be done to the structural requirements for the local support and primary support members as given in Table 2.2.29. The static and dynamic load components are to be combined in accordance with Table 2.1.3 and the procedure given in Section 1/6.3.

3.9.2. Plating and local support members

3.9.2.1. For plating subjected to lateral pressure, the net plating thickness, tnet, is to be taken as the greatest value calculated for all applicable design load sets, as given in Table 2.2.29,, and given by:

$$t_{net} = 0.0158\alpha_p s\sqrt{\frac{|P|}{C_a\sigma_{yd}}}\text{mm}$$

where:

α_p = correction factor for the panel aspect ratio

$$= 1.2 - \frac{s}{2100l_p}$$

but not to be greater than 1.0

P = design pressure for the design load set being considered, calculated at the load calculation point defined in Chapter 1 Section 3/5.1.2, in kN/m^2

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

l_p= length of plate panel, to be taken as the spacing of primary support members, unless carlings are fitted, in m

C_a= permissible bending stress coefficient for the acceptance criteria set being considered, as given in Table 2.2.23

σ_{yd}= specified minimum yield stress of the material, in N/mm

Table 2.2.23: Permissible Bending Stress Coefficient for Plating

Acceptance criteria set	Structural member	C_a
AC1	All plating	0.80
AC2	Hull envelope plating	0.95
	Internal boundary plating (1)	1.00

Note

(1) Collision bulkhead plating is to be evaluated for design load set 11 (accidental flooding) using acceptance criteria set AC1

3.9.2.2. For stiffeners subjected to lateral pressure, the net section modulus, Z_{net}, is to be taken as the greatest value calculated for all applicable design load sets, as given in Table 2.2.29, and given by:

$$Z_{net} = \frac{|P|sl_{bdg}^2}{f_{bdg}C_s\sigma_{yd}}\text{cm}^3$$

where:

P = design pressure for the design load set being considered, calculated at the load calculation point defined in Chapter 1 Section 3/5.2.2, in kN/m^2

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

l_{bdg}= effective bending span, as defined in Chapter 1 Section 4/2.1.1, in m

f_{bdg}= bending moment factor:

For continuous stiffeners and where end connections are fitted consistent with idealisation of the stiffener as having fixed ends:

12 for horizontal stiffeners

10 for vertical stiffeners

For other configurations the bending moment factor may be taken as in Table 2.2.26.

C_s= permissible bending stress coefficient for the acceptance criteria set being considered, as given inTable 2.2.24

σ_{yd} =specified minimum yield stress of the material, in N/mm^2

Table 2.2.24: Permissible Bending Stress Coefficient for Stiffeners

Acceptance criteria set	**Structural member**	**C_s**
AC1	All stiffeners	0.75
AC2	All stiffeners (1)	0.90

Note

(1) Collision bulkhead stiffeners are to be evaluated for design load set 11 (accidental flooding) using acceptance criteria set AC1

3.9.2.3. For stiffeners subjected to lateral pressure, the net web thickness based on shear area requirements, t_{w-net}, is to be taken as the greatest value calculated for all applicable design load sets, as given in Table 2.2.29, and given by:

$$t_{w-net} = \frac{f_{shr}|P|s l_{shr}}{d_{shr} C_t \tau_{yd}} \text{ mm}$$

where:

P = design pressure for the design load set being considered, calculated at the load calculation point defined in Chapter 1 Section 3/5.2.2, in kN/m^2

f_{shr}= shear force factor:

For continuous stiffeners and where end connections are fitted consistent with idealizations of the stiffener as having fixed ends:

0.5 for horizontal stiffeners

0.7 for vertical stiffeners

For other configurations the shear force factor may be taken as in Table 2.2.26.

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

l_{shr} = effective shear span, as defined in Chapter 1 Section 4/2.1.2, in m

d_{shr} = effective web depth of stiffeners, in mm, as defined in Chapter 1 Section 4/2.4.2.2

C_t = permissible shear stress coefficient for the acceptance criteria set being considered, as given in Table 2.2.25

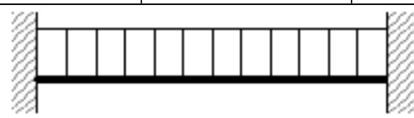
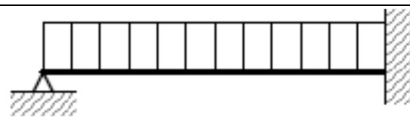
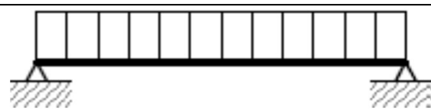
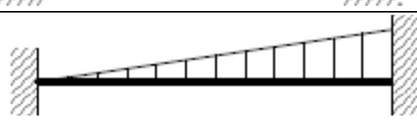
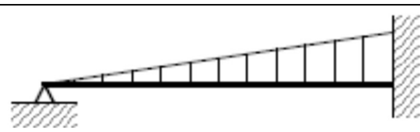
$$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}} \text{N/mm}^2$$

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

Table 2.2.25: Permissible Shear Stress Coefficient for Stiffeners		
Acceptance criteria set	**Structural member**	**C_t**
AC1	All stiffeners	0.75
AC2	All stiffeners [(1)]	0.90

Note
(1) Collision bulkhead stiffeners are to be evaluated for design load set 11 (accidental flooding) using acceptance criteria set AC1

Table 2.2.26: Bending Moment and Shear Force Factors, f_{bdg} and f_{shr}

	Load and boundary condition			**Bending moment and shear force factor (based on load at mid span, where load varies)**		
Load model	**Position**			**1**	**2**	**3**
	1 Support	**2 Field**	**3 Support**	**f_{bdg1} f_{shr1}**	**f_{bdg2} -**	**f_{bdg3} f_{shr3}**
A				12.0 0.50	24.0 -	12.0 0.50
B				- 0.38	14.2 -	8.0 0.63
C				- 0.50	8.0 -	- 0.50
D				15.0 0.30	23.3 -	10.0 0.70
E				- 0.20	16.8 -	7.5 0.80

Note

1. The bending moment factor f_{bdg} for the support positions are applicable for a distance of $0.2l_{bdg}$ from the end of the effective bending span for both local and primary support members.
2. The shear force factor f_{shr} for the support positions are applicable for a distance of $0.2l_{shr}$from the end of the effective shear span for both local and primary support members.
3. Application of f_{bdg} and f_{shr} for local support members:
   a. The section modulus requirement of local support members is to be determined using the lowest value of f_{bdg1} , f_{bdg2} and f_{bdg3}
   b. The shear area requirement of local support members is to be determined using the greatest value of f_{shr1} and f_{shr3}.
4. Application of fbdg and f_{shr} for primary support members:
   a. the section modulus requirement within $0.2l_{bdg}$ from the end of the effective span is generally to be determined using the applicable f_{bdg1} and f_{bdg3}, however f_{bdg} is not to be taken greater than 12
   b. the section modulus of mid span area is to be determined using f_{bdg} =24, or f_{bdg2} from the table if lesser
   c. the shear area requirement of end connections within $0.2l$shr from the end of the effective span is to be determined using f_{shr} = 0.5 or the applicable f_{shr1} or f_{shr3}, whichever is greater
   d. For models A through E the value of f_{shr} may be gradually reduced outside of $0.2l_{shr}$ towards $0.5f_{shr}$ at mid span where f_{shr} is the greater value of f_{shr1} and f_{shr3}.
5. For other load models see Table 2.2.38.

3.9.3. Primary support members

3.9.3.1. For primary support members intersecting with or in way of curved hull sections, the effectiveness of end brackets is to include allowance for the curvature of the hull. For side transverse frames, reduction of the requirements may be done due to the presence of cross ties, see 3.3.3.4.

3.9.3.2. For primary support members subjected to lateral pressure, the net section modulus, Z_{net50}, is to be taken as the greatest value for all applicable design load sets, as given in Table 2.2.29, and given by:

$$Z_{net} = 1000\frac{|P|sl_{bdg}^2}{f_{bdg}C_s\sigma_{yd}}\text{cm}^3$$

where:

P = design pressure for the design load set being considered, calculated at the load calculation point defined in Chapter 1 Section 3/5.3.3, in kN/m^2

S = primary support member spacing, in m, as defined in Chapter 1 Section 4/2.2.2

l_{bdg} = effective bending span, as defined in Chapter 1 Section 4/2.1.4, in m

f_{bdg}= bending moment factor, as given in Table 2.2.26

C_s= permissible bending stress coefficient for the acceptance criteria set being considered, as given in Table 2.2.27

σ_{yd} = specified minimum yield stress of the material, in N/mm^2

Table 2.2.27: Permissible Bending Stress Coefficient for Primary Support Members

Acceptance criteria set	Structure attached to primary support member	C_s
AC1	All boundaries, including decks and flats	0.70
AC2	All boundaries, including decks and flats (1)	0.85

Note

(1) Collision bulkhead primary support members are to be evaluated for design load set 11 (accidental flooding) using acceptance criteria set AC1

3.9.3.3. For primary support members subjected to lateral pressure, the effective net shear area, $A_{shr-net50}$, is to be taken as the greatest value for all applicable design load sets, as given in Table 2.2.29, and given by:

$$A_{shr-net50} = 10\frac{f_{shr}|P|Sl_{shr}}{C_t\tau_{yd}}\text{cm}^2$$

where:

P = design pressure for the design load set being considered, calculated at the load calculation point defined in Chapter 1 Section 3/5.3.2, in kN/m^2

S = primary support member spacing, in m, as defined in Chapter 1 Section 4/2.2.2

l_{shr} = effective shear span, as defined in Chapter 1 Section 4/2.1.5, in m

f_{shr} = shear force factor, as given in Table 2.2.26

C_t= permissible shear stress coefficient for the acceptance criteria set being considered, as given in Table 2.2.28

$$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}}\text{ N/mm}^2$$

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

Table 2.2.28: Permissible Shear Stress Coefficient for Primary Support Members

Acceptance criteria set	Structure attached to primary support member	C_t
AC1	All boundaries, including decks and flats	0.70
AC2	All boundaries, including decks and flats [(1)]	0.85

Note

1) Collision bulkhead primary support members are to be evaluated for design load set 11 (accidental flooding) using acceptance criteria set AC1

3.9.3.4. As described for the particular structure type,primary support members are to generally be analysed with the specific methods. More advanced calculation methods may be necessary in order to ensure that nominal stress level for all primary support members are less than the permissible stresses and stress coefficients given in 3.9.3.2 and 3.9.3.3 when subjected to the applicable design load sets.

3.9.4. Corrugated bulkheads

3.9.4.1. Special consideration will be given to the approval of corrugated bulkheads where fitted.

note:

Scantling requirements of corrugated bulkheads in the cargo tank region may be used as a basis, see 2.5.6 and 2.5.7.

3.9.5. Pillars

3.9.5.1. The maximum load on a pillar, W_{pill}, is to be taken as the greatest value calculated for all applicable design load sets, as given in Table 2.2.29, and is to be less than or equal to the permissible pillar load as given by the following equation, where $W_{pill\text{-}perm}$ is based on the net properties of the pillar.

$W_{pill} \leq W_{pill\text{-}perm}$

where:

W_{pill} = applied axial load on pillar

$= P b_{a-sup} l_{a-sup} + W_{pill-upr}$ kN

$W_{pill\text{-}perm}$= permissible load on a pillar

$= 0.1 A_{pill-net50} \eta_{pill} \sigma_{crb}$ kN

P = design pressure for the design load set being considered, calculated at centre of the deck area supported by the pillar being considered, in kN/m^2

$b_{a\text{-}sup}$= mean breadth of area supported, in m

$l_{a\text{-}sup}$ = mean length of area supported, in m

$W_{pill\text{-}upr}$ = axial load from pillar or pillars above, in kN

$A_{pill\text{-}net50}$ = net cross section area of the pillar, in cm^2

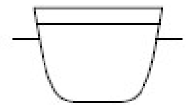
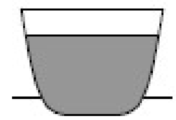
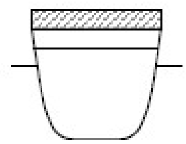
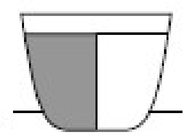
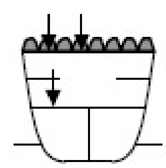
η_{pill}= utilisation factor for the design load set being considered:

= 0.5 for acceptance criteria set AC1

= 0.6 for acceptance criteria set AC2

σ_{crb}= critical buckling stress in compression of pillar based on the net sectional properties calculated in accordance with Section 4/3.5.1, in N/mm^2

Table 2.2.29: Design Load Sets for Plating, Local Support Members and Primary Support Members

Type of Local Support and Primary Support Member	Design Load Set (1)	Load Component	External Draught	Comment	Diagrammatic Representation
Shell Envelope	1	P_{ex}	T_{sc}	Sea pressure only	
	2	Pex	T_{sc}		
	5	P_{in}	T_{bal}	Tank pressure only. Sea pressure to beignored	
	6	P_{in}	$0.25T_{sc}$		
External Decks	1	P_{ex}	T_{sc}	Green sea pressure only	
Tank Boundaries and/ or Watertight Boundaries	5	P_{in}	T_{bal}	Pressure from oneside only Full tank with adjacenttank empty	
	6	P_{in}	$0.25T_{sc}$		
	11	$P_{in\text{-}flood}$	-		
Internal and External Decks or Flats	9	P_{dk}	T_{bal}	Distributed orconcentrated loads only. Adjacent tanks empty.Green sea pressure maybe ignored	
	10	P_{dk}	T_{bal}		

where:

T_{sc}scantling draught, in m, as defined in Chapter 1 Section 4/1.1.5.5

T_{bal}minimum design ballast draught, in m, as defined in Chapter 1 Section 4/1.1.5.2

Notes

1. The specification of design load combinations and other load parameters for the design load setsare given inTable 2.2.14
2. When the ship's configuration cannot be described by the above, then the applicable Designload Sets to determine the scantling requirements of structural boundaries are to be selected so as to specify a full tank on one side with the adjacent tank or space empty. The boundary is to be evaluated for loading from both sides. Design Load Sets are to be selected based on the tank or spaces contents and are to maximize the pressure on the structural boundary, the draught to use is to be taken in accordance with the Design Load Set and this table. Design Load Sets covering the S and S+D design load combinations are to be selected. See Note 4 on Table 2.2.13 and Table 2.2.14.
3. The boundaries of void and dry space not forming part of the hull envelope are to be evaluated using Design Load Set 11. See Note 2.

4. Machinery Space

4.1. General

4.1.1. Application

4.1.1.1. Application of the requirements of this Sub-Section are covering machinery spaces situated in the aft end region, aft of the aftermost cargo tank bulkhead and forward of, and including, the aft peak bulkhead.

4.1.1.2. The net scantlings described in this Sub-Section are related to gross scantlings as follows:

a. For application the minimum thickness requirements of 4.1.5, the gross thickness is obtained from the applicable requirements by adding the full corrosion additions as specified in Chapter 1 Section 6/3.

b. For plating and local support members, the gross thickness and gross cross sectional properties are obtained from the applicable requirements by adding the full corrosion additions as specified in Chapter 1 Section 6/3.

c. For primary support members, the gross shear area, gross section modulus and other gross cross sectional properties are obtained from the applicable requirements by adding one half of the relevant full corrosion additions as specified in Chapter 1 Section 6/3.

d. For application of buckling requirements of Section 4/2 the gross thickness and gross cross sectional properties are obtained from the applicable requirements by adding the full corrosion additions as specified in Chapter 1 Section 6/3.

4.1.2. General scantling requirements

4.1.2.1. The hull structure is to comply with the applicable requirements of:

a. Hull girder longitudinal strength, see Section 2/1

b. Strength against sloshing and impact loads, see Section 2/6

c. Buckling/ultimate strength, see Section 4.

4.1.2.2. The net section modulus, shear area and other sectional properties of local and primary support members are to be determined in accordance with Chapter 1 Section 4/2.

4.1.2.3. Application of the section modulus and web thickness of the local support members are considered for the areas clear of the end brackets. The section modulus and cross sectional shear areas of the primary support members are to be covered as given in the notes to Table 2.2.26.

4.1.2.4. The scantling criteria are based on assumptions that all structural joints and welded details are designed and fabricated such that they are compatible with the anticipated working stress levels at the locations considered. The loading patterns, stress concentrations and potential failure modes of structural joints and details during the design of highly stressed regions are to be considered. Structure design details are to comply with the requirements in Chapter 1 Section 4/3.

4.1.2.5. Limber, drain and air holes are to be cut in all parts of the structure, as required, to ensure the free flow to the suction pipes and the escape of air to the vents. Arrangements are to be made for draining the spaces above tanks. See also Chapter 1 Section 4/3..

4.1.3. Structural continuity

4.1.3.1 Scantlings of the shell envelope, upper deck and inner bottom are to be properly tapered towards the aft end. See also 1.6.

4.1.3.2 In order to ensure continuity of strength and the avoidance of abrupt discontinuities,suitable arrangements are to be madewhen structure that contributes to the main longitudinal strength of the ship is omitted in way of the machinery space.

4.1.3.3 Where inner hull or longitudinal bulkhead structures terminate at the forward engine room bulkhead, adequate backing structure is to be provided together with tapering brackets to ensure continuity of strength.

4.1.3.4 All shell frames and tank boundary stiffeners are to be continuous throughout, or are to be bracketed at their ends, except as permitted in Chapter 1 Sections 4/3.2.4 and 4/3.2.5.

4.1.3.5 Longitudinal primary support members, lower decks, and bulkheads arranged in the engine room are to be aligned with similar structures in the cargo tank region, as far as practicable. Where direct alignment is not possible, suitable scarphing arrangements such as taper brackets are to be provided.

4.1.4. Arrangements

4.1.4.1 Where openings in decks/bulkheads are provided in the machinery space, the arrangements are to ensure support for deck, side, and bottom structure.

4.1.4.2 All parts of the machinery, shafting, etc., are to be supported to distribute the loads into the ship’s structure. The adjacent structure is to be suitably stiffened.

4.1.4.3 Primary support members are to be positioned giving consideration to the provision of through stiffeners and in-line pillar supports to achieve an efficient structural design.

4.1.4.4 These requirements are formulated assuming conventional single screw, single engine propulsion arrangements. Twin-screw or multi-engine vessels, or vessels of higher power, may require additions to the scantlings of the structure and the area of attachments, which are proportional to the weight, power and proportions of the machinery especially where the engines are positioned relatively high in proportion to the width of the bed plate.

4.1.4.5 Maintenance of the required alignment and rigidity under all anticipated conditions of loading are to be covered by the foundations for main propulsion units, reduction gears, shaft and thrust bearings, and the structure supporting those foundations. Consideration is to be given to the submittal of the following plans to the machinery manufacturer for review:

1) Foundations for main propulsion units
2) Foundations for reduction gears
3) Foundations for thrust bearings
4) Structure supporting (a), (b) and (c).

4.1.4.6 A cofferdam is to be provided to separate the cargo tanks from the machinery space. Pump room, ballast tanks, or fuel oil tanks may be considered as cofferdams for this purpose.

4.1.5. Minimum thickness

4.1.5.1. In addition to the requirements for thickness, section modulus and shear area, as given in 4.2 to 4.8, the thickness of plating and stiffeners in the machinery space is to comply with applicable minimum thickness requirements given in Table 2.2.30.

Table 2.2.30: Minimum Net Thickness of Structure in the Machinery Space

Scantling Location			Net Thickness (mm)
Plating	Shell	Keel plating	See 2.1.5.1
		Bottom shell/bilge/side shell plating	See 2.1.5.1
	Upper deck		See 2.1.5.1
	Other structure	Hull internal tank boundaries	See 2.1.5.1
		Non-tight bulkheads, bulkheads between dry spaces and other plates in general	See 2.1.5.1
		Lower decks and flats	$3.3 + 0.0067s$
		Inner bottom	$6.5 + 0.02L_2$
Bottom centreline girder			See 2.1.6.1
Floors and bottom longitudinal girders off centreline			$5.5 + 0.02L_2$
Web plating of primary support members			$5.5 + 0.015\ L_2$
Local support members			See 2.1.5.1
Tripping brackets			See 2.1.5.1
where: L_2 rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but need not be taken greater than 300m s stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2			

4.2. Bottom Structure

4.2.1. General

4.2.1.1. In general, a double bottom is to be fitted in the machinery space. The depth of the double bottom is to be at least the same as required in the cargo tank region, see Chapter 1 Section 5/3.2.1. Where the depth of the double bottom in the machinery space differs from that in the adjacent spaces, continuity of the longitudinal material is to be maintained by sloping the inner bottom over a suitable longitudinal extent. Lesser double bottom height may be accepted in local areas provided that the overall strength of the double bottom structure is not thereby impaired.

4.2.2. Bottom shell plating

4.2.2.1 The keel plate breadth is to comply with the requirements in Chapter 1 Section 8/2.2.1.1.

4.2.2.2 The thickness of the bottom shell plating (including keel plating) is to comply with the requirements in 4.8.1.1.

4.2.3. Bottom shell stiffeners

4.2.3.1 The section modulus and thickness of bottom shell stiffeners are to comply with the requirements in 4.8.1.2 and 4.8.1.3.

4.2.4. Girders and floors

4.2.4.1. The double bottom is to be arranged with a centreline girder.

4.2.4.2. Full depth bottom girders are to be arranged in way of the main machinery to effectively distribute its weight, and to ensure rigidity of the structure. The girders are to be carried as far forward and aft as practicable, and suitably supported at their ends to provide distribution of loads from the machinery. The girders are to be tapered beyond their required extent.

4.2.4.3. Side girders are to be aligned with the bottom side girders in the adjacent space wherever they are fitted.

4.2.4.4. Where the double bottom is transversely framed, fitting of the plate floors are to be done at every frame.

4.2.4.5. Where the double bottom is longitudinally framed, plate floors are to be fitted at every frame under the main engine and thrust bearing. Outboard of the engine and bearing seatings, the floors may be fitted at alternate frames.

4.2.4.6. Where heavy equipment is mounted directly on the inner bottom, the thickness of the floors and girders is to be suitably increased.

4.2.5. Inner bottom plating

4.2.5.1. Where main engines or thrust bearings are bolted directly to the inner bottom, the net thickness of the inner bottom plating is to be at least 19mm. Hold-down bolts are to be arranged as close as possible to floors and longitudinal girders. Plating thickness and the arrangements of hold-down bolts are also to consider the manufacturer’s recommendations.

4.2.6. Sea chests

4.2.6.1. Where the inner bottom or double bottom structure forms part of a sea chest, the thickness of the plating is not to be less than that required for the shell at the same location, taking into account the maximum unsupported width of the plating.

4.3. Side Structure

4.3.1. General

4.3.1.1. The scantlings of the side shell plating and longitudinals are to be properly tapered from the midship region towards the aft end.

4.3.1.2. Arrangement of a suitable scarphing arrangement of the longitudinal framing is to be given where the longitudinal framing terminates and is replaced by transverse framing.

4.3.1.3. Stiffeners and primary support members are to be supported at their ends.

4.3.2. Side shell plating

4.3.2.1. The thickness of the side shell plating is to comply with the requirements in 4.8.1.1. The thickness of the side shell plating is to comply with the requirements in 2.2.4.2 wherever applicable.

4.3.3. Side shell local support members

4.3.3.1. The section modulus and thickness of side longitudinal and vertical stiffeners are to comply with the requirements in 4.8.1.2 and 4.8.1.3.

4.3.3.2. End connections of longitudinals at transverse bulkheads are to provide sufficient fixity, lateral support, and when not continuous are to be provided with soft-nosed brackets. Brackets lapped onto the longitudinals are not to be avoided.

4.3.4. Side shell primary support members

4.3.4.1. Web frames are to be connected at the top and bottom to members of suitable stiffness, and supported by deck transverses.

4.3.4.2. The spacing of web frames in way of transversely framed machinery spaces is generally not to exceed five transverse frame spaces.

4.3.4.3. The section modulus and shear area of primary support members are to comply with the requirements in 4.8.2.

4.3.4.4. The web depth is to be not less than 2.5 times the web depth of the adjacent frames if the slots are not closed.

4.3.4.5. Web plating of primary support members is to have a depth of not less than 14% of the unsupported span in bending.

4.4. Deck Structure

4.4.1. General

4.4.1.1. Framing for all openings are to be given. Attention is to be paid to structural continuity. Abrupt changes of shape, section or plate thickness are to be avoided.

4.4.1.2. The corners of the machinery space openings are to be of suitable shape and design to minimize stress concentrations.

4.4.1.3. In way of machinery openings, deck or flats are to have sufficient strength where they are intended as effective supports for side transverse frames or web frames.

4.4.1.4. Where a transverse framing system is adopted, deck stiffeners are to be supported by a suitable arrangement of longitudinal girders in association with pillars or pillar bulkheads.The deck transverses are to be arranged in line with web frames to provide end fixity and transverse continuity of strength.

4.4.1.5. Deck longitudinals are to be supported by deck transverses in line with web frames in association with pillars or pillar bulkheads where a longitudinal framing system is adopted.

4.4.1.6. With the help of suitable arrangement of deck transverses and longitudinal girders in association with pillars or pillar bulkheads machinery casings are required to be supported. In way of particularly large machinery casing openings, cross ties may be required. These are to be arranged in line with deck transverses.

4.4.1.7. The structural scantlings are to be not less than the requirement for tank boundaries if the deck forms the boundary of a tank.

4.4.1.8. The structural scantlings are to be not less than the requirement for watertight bulkheads when the deck forms the boundary of a watertight space.

4.4.2. Deck scantlings

4.4.2.1. The plate thickness of deck plating is to comply with the requirements in 4.8.1.1.

4.4.2.2. The section modulus and thickness of deck stiffeners are to comply with the requirements in 4.8.1.2 and 4.8.1.3.

4.4.2.3. The web depth of deck stiffeners is to be not less than 60mm.

4.4.2.4. The section modulus and shear area of primary support members are to comply with the requirements in 4.8.2.

4.4.2.5. The web depth of primary support members is not to be less than 10% and 7% of the unsupported span in bending in tanks and in dry spaces, respectively, and is not to be less than 2.5 times the depth of the slots when the slots are not closed. Unsupported span in bending is bending span as defined in Chapter 1 Section 4/2.1.4 or in case of a grillage structure the distance between connections to other primary support members.

4.4.2.6. In way of concentrated loads from heavy equipment, the scantlings of the deck structure are to be determined based on the actual loading.

4.4.3. Pillars

4.4.3.1. Pillars are to be fitted in the same vertical line wherever possible, and effective arrangements are to be made to distribute the load at the heads and heels of all pillars. Where pillars support eccentric loads, they are to be strengthened for the additional bending moment imposed upon them.

4.4.3.2. Tubular and hollow square pillars are to be attached at their heads and heels by efficient brackets, or doublers/insert plates, where applicable, to transmit the load effectively. Pillars are to be attached at their heads and heels by continuous welding. At the heads and heels of pillars built of rolled sections, the load is to be distributed by brackets or other equivalent means.

4.4.3.3. In double bottoms under widely spaced pillars, the connections of the floors to the girders, and of the floors and girders to the inner bottom, are to be suitably increased. Where pillars are not directly above the intersection of plate floors and girders, partial floors and intercostals are to be fitted as necessary to support the pillars. Manholes are not to be cut in the floors and girders below the heels of pillars.

4.4.3.4. Pillars in tanks are to be of solid section. Where the hydrostatic pressure may result in tensile stresses in the pillar, the tensile stress in the pillar and its end connections is not to exceed 45%of the specified minimum yield stress of the material.

4.4.3.5. The scantlings of pillars are to comply with the requirements in 4.8.4.

4.4.3.6. Where the pillar loads from heavy equipment exceed the design load required by 4.8.4, the pillar scantlings are to be determined based on the actual loading.

4.5. Machinery Foundations

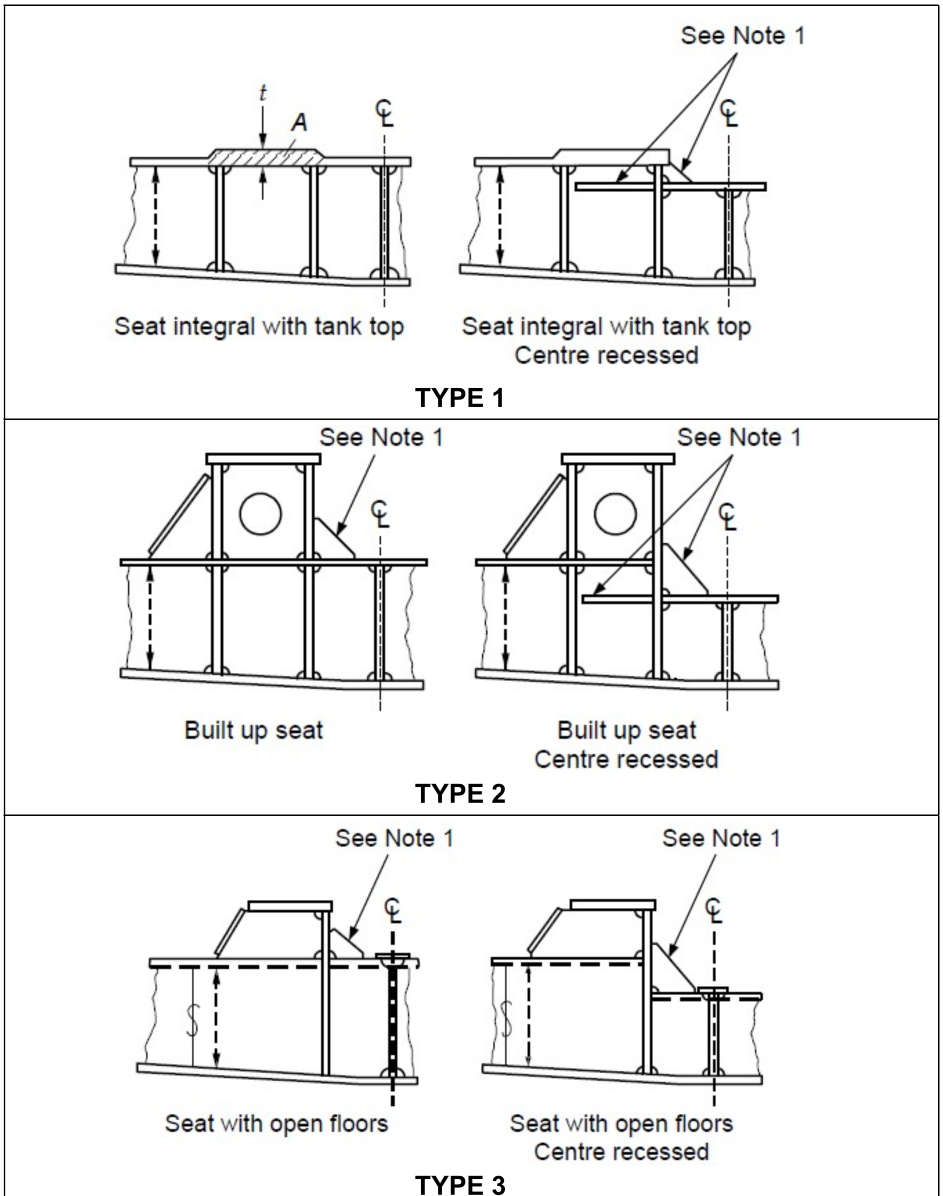
4.5.1. General

4.5.1.1. Main engines and thrust bearings are to be effectively secured to the hull structure by foundations of strength that is sufficient to resist the various gravitational, thrust, torque, dynamic, and vibratory forces which may be imposed on them.

4.5.1.2. In the case of higher power internal combustion engines or turbine installations, the foundations are generally to be integral with the double bottom structure. Consideration is to be given to substantially increase the inner bottom plating thickness in way of the engine foundation plate or the turbine gear cases, and the thrust bearing, see 2.2.30, Type 1.

4.5.1.3. For main machinery supported on foundations of Type 2, as shown in Figure 2.2.30, the forces from the engine into the adjacent structure are to be distributed as uniformly as possible. Longitudinal members supporting the foundation are to be aligned with girders in the double bottom, and transverse stiffening is to be arranged in line with the floors, see Figure 2.2.30, Type 2.

4.5.1.4. For ships with open floors in the machinery space, arrangement of the foundations are generally to be considered above the level of the top of the floors and securely bracketed, see Figure 2.2.30, Type 3.



Note:

1) Brackets are to be as large as possible. Brackets may be omitted to avoid interference with the girders of the engine foundation, in accordance with recommendations of the engine manufacturer.

Figure 2.2.30: Machinery Foundations

4.5.2. Foundations for internal combustion engines and thrust bearings

4.5.2.1. In determining the scantlings of foundations for internal combustion engines and thrust bearings, consideration is to be given to the general rigidity of the engine and to design characteristics with regard to out of balance forces.

4.5.2.2. Generally two girders are to be fitted in way of the foundation for internal combustion engines and thrust bearings.

In general, the gross thickness of foundation top plates is not to be less than 45mm, where the maximum continuous output of thepropulsion machinery is 3500kw or greater.

4.5.3. Auxiliary foundations

4.5.3.1. Auxiliary machinery is to be secured on foundations that are of suitable size and arrangement to distribute the loads from the machinery evenly into the supporting structure.

4.6. Tank Bulkheads

4.6.1. General

4.6.1.1. Tanks may be required to have divisions or deep wash plates to minimise the dynamic stress on the structure.

4.6.2. Construction

4.6.2.1. In no case are the scantlings of tank boundary bulkheads to be less than the requirements for watertight bulkheads.

4.6.3. Scantlings of tank boundary bulkheads

4.6.3.1. The thickness of tank boundary plating is to comply with the requirements in 4.8.1.1.

4.6.3.2. The section modulus and thickness of stiffeners are to comply with the requirements in 4.8.1.2 and 4.8.1.3.

4.6.3.3. The section modulus and shear area of primary support members are to comply with the requirements in 4.8.2.

4.6.3.4. Web plating of primary support members is to have a depth of not less than 14% of the unsupported span in bending and not less than 2.5 times the depth of the slots if the slots are not closed.

4.7. Watertight Boundaries

4.7.1. General

4.7.1.1. Watertight boundaries within the machinery space are to be fitted in accordance with Chapter 1 Section 5/2.

4.7.2. Scantlings of watertight boundaries

4.7.2.1. The thickness of watertight boundary plating is to comply with the requirements in 4.8.1.1.

4.7.2.2. The section modulus and thickness of stiffeners are to comply with the requirements in 4.8.1.2 and 4.8.1.3.

4.7.2.3. The section modulus and shear area of primary support members are to comply with the requirements in 4.8.2.

4.7.2.4. Web plating of primary support members is to have a depth of not less than 10% of the unsupported span in bending and not less than 2.5 times the depth of the slots if the slots are not closed.

4.8. Scantling Requirements

4.8.1. Plating and local support members

4.8.1.1. For plating subjected to lateral pressure the net plating thickness is to comply with the requirements in 3.9.2.1, but using the permissible bending stress coefficient, C_a, defined in Table 2.2.31.

4.8.1.2. For stiffeners subjected to lateral pressure the net section modulus requirement is to comply with the requirements in 3.9.2.2, but using the permissible bending stress coefficient, C_s, defined in Table 2.2.32.

4.8.1.3. For stiffeners subjected to lateral pressure the net web thickness based on shear area requirements is to comply with the requirements in 3.9.2.3.

Table 2.2.31: Permissible Bending Stress Coefficient for Plating

The permissible bending stress coefficient, C_a, for the design load set being considered is to be taken as: $C_a = \beta_a - \frac{|\sigma_{hg}|}{\sigma_{yd}}$ but not to be taken greater than C_{a-max}

where:

$\beta_a, \alpha_a, C_{a-\max}$

Acceptance Criteria Set	Structural Member		β_a	α_a	C_{a-max}
AC1	Longitudinal Strength Members	Longitudinally stiffened plating	0.9	0.5	0.8
		Transversely or vertically stiffened plating	0.9	1.0	0.8
	Other members		0.8	0	0.8
AC2	Longitudinal Strength Members	Longitudinally stiffened plating	1.05	0.5	0.95
		Transversely or vertically stiffened plating	1.05	1.0	0.95
	Other members, including watertight boundary plating		1.0	0	1.0

σ_{hg} hull girder bending stress for the design load set being considered and calculated at the loadcalculation point defined in Chapter 1 Section 3/5.1.

$= \frac{(Z-Z_{NA-net50})M_{v-total}}{I_{v-net50}} 10^{-3}$ N/mm²

$M_{v-total}$ design vertical bending moment at the longitudinal position under consideration for the design load set being considered, in kNm. The still water bending moment,

$M_{sw-perm}$, is to be taken with the same sign as the simultaneously acting wave bending moment, M_{wv}, see Table 2.1.3

$I_{v-net50}$ net vertical hull girder moment of inertia, at the longitudinal position being considered, as defined in Chapter 1 Section 4/2.6.1, in m^4

z vertical coordinate of the load calculation point under consideration, in m

$z_{NA-net50}$ distance from the baseline to the horizontal neutral axis, as defined in Chapter 1 Section 4/2.6.1, in m

σ_{yd} specified minimum yield stress of the material, in N/mm²

Table 2.2.32: Permissible Bending Stress Coefficient for Stiffeners

The permissible bending stress coefficient C_s is to be taken as:

Sign of Hull Girder Bending Stress, σ_{hg}	**Side that Pressure is Acting On**	**Acceptance Criteria**
Tension (+ve)	Stiffen r side	$C_s = \beta_{s-a_s} \frac{\lvert\sigma_{hg}\rvert}{\sigma_{yd}}$ but not to be taken greater than C_{s-max}
Compression (-ve)	Plate side	
Tension (+ve)	Plate side	$C_s = C_{s-max}$
Compression (-ve)	Stiffener side	

where:

β_s , α_s , C_{s-max}permissible bending stress factors and are to be taken as:

Acceptance Criteria Set	**Structural Member**	**β_s**	**α_s**	**C_{s-max}**
AC1	Longitudinally effective stiffeners	0.85	1.0	0.75
	Other stiffeners	0.75	0	0.75
AC2	Longitudinally effective stiffeners	1.0	1.0	0.9
	Other stiffeners	0.9	0	0.9
	W ertight boundary stiffeners	0.9	0	0.9

σ_{hg} hull girder bending stress for the design load set being considered and calculated at the reference point defined in Chapter 1 Section 3/5.2.2.5

$$= \left(\frac{(Z-Z_{NA-net50})M_{v-total}}{I_{v-net50}}\right)10^{-3}\text{N/mm}^2$$

$M_{v-total}$design vertical bending moment at longitudinal position under consideration for the design load set being considered, in kNm

$M_{v-total}$ is to be calculated in accordance with Table 2.1.3 using the sagging or hogging still water bending moment

Stiffener Location	$M_{sw-perm}$	
	Pressure acting on Plate Side	Pressure acting on Stiffener Side
Above Neutral Axis	Sagging SWBM	Hogging SWBM
Below Neutral Axis	Hogging SWBM	Sagging SWBM

$I_{v-net50}$net vertical hull girder moment of inertia, at the longitudinal position being considered, as defined in Chapter 1 Section 4/2.6.1, in m^4

z vertical coordinate of the reference point defined in Chapter 1 Section 3/5.2.2.5, in m

$z_{NA-net50}$ distance from the baseline to the horizontal neutral axis, as defined in Chapter 1 Section 4/2.6.1, in m

σ_{yd}specified minimum yield stress of the material, in N/mm^2

4.8.2. Primary support members

4.8.2.1. For primary support members which intersect with or in way of curved hull sections, the effectiveness of end brackets is to include allowance for the curvature of the hull.

4.8.2.2. For primary support members subjected to lateral pressure the net section modulus requirement is to comply with the requirements in 3.9.3.2.

4.8.2.3. For primary support members subjected to lateral pressure the net cross sectional area of the web is to comply with the requirements in 3.9.3.3.

4.8.2.4. Generally, primary support members are to be analysed with the specific methods as described for the particular structure type. More advanced calculation methods may be required in order to ensure that nominal stress level for all primary support members are less than permissible stresses and stress coefficients given in 3.9.3.2 and 3.9.3.3 when subjected to the applicable design load sets.

4.8.3. Corrugated bulkheads

4.8.3.1. Where fitted, special consideration will be given to the approval of corrugated bulkheads.

Note:

Scantling requirements of corrugated bulkheads in the cargo tank region may be used as a basis, see 2.5.6 and 2.5.7.

4.8.4. Pillars

4.8.4.1. The maximum load on a pillar is to be less than the permissible pillar load as given by the requirements in 3.9.5.

5 Aft End

5.1. General

5.1.1. Application

5.1.1.1. The requirements of this Sub-Section apply to structure located between the aft peak bulkhead and the aft end of the ship.

5.1.1.2. Application of the requirements of this Sub-Section are not covered to the following:

a. Rudder horns
b. Structures which are not integral with the hull, such as rudders, steering nozzles and propellers
c. Other appendages permanently attached to the hull.

Where such items are fitted, the requirements of IRS are to be complied with.

5.1.1.3. The net scantlings described in 5.1 to 5.7 are related to gross scantlings as follows:

a. For application the minimum thickness requirements of 5.1.4, the gross thickness is obtained from the applicable requirements by adding the full corrosion additions specified in Chapter 1 Section 6/3.

b. For plating and local support members, the gross thickness and gross cross sectional properties are obtained from the applicable requirements by adding the full corrosion additions specified in Chapter 1 Section 6/3

c. For primary support members, the gross shear area, gross section modulus and other gross cross sectional properties are obtained from the applicable requirements by adding one half of the relevant full corrosion additions specified in Chapter 1 Section 6/3

d. For application of buckling requirements of Section 4/2 the gross thickness and gross cross sectional properties are obtained from the applicable requirements by adding the full corrosion additions specified in Chapter 1 Section 6/3.

5.1.2. General scantling requirements

5.1.2.1. The hull structure is to comply with the applicable requirements of:

a. Hull girder longitudinal strength, see Section 2/1
b. Strength against sloshing and impact loads, see Section 2/6
c. Buckling/ultimate strength, see Section 4.

5.1.2.2. Reinforcement of the deck plating thickness and supporting structure are to be done suitablyfor the steering gear, mooring windlasses, and other deck machinery. See Chapter 3 Section 1/3.

5.1.2.3. Determination of the net section modulus, shear area and other sectional properties of local and primary support members are to be done obtained in accordance with Chapter 1 Section 4/2.

5.1.2.4. Application of the section modulus and web thickness of the local support members are covered to the areas clear of the end brackets. The section modulus and cross sectional shear areas of the primary support members are to be complied as required in the notes to Table 2.2.26.

5.1.2.5. The scantling criteria are based on assumptions that all structural joints and welded details are designed and fabricated such that they are compatible with the anticipated working stress levels at the locations considered. Consideration of the loading patterns, stress concentrations and potential failure modes of structural joints and details during the design of highly stressed regions are to be given. Structure design details are to comply with the requirements in Chapter 1 Section 4/3.

5.1.2.6. In order to ensure the free flow to the suction pipes and the escape of air to the vents, Limber, drain and air holes are to be cut in parts of the structure, as required. Arrangements are to be made for draining the spaces above deep tanks. See also Chapter 1 Section 4/3.

5.1.3. Structural continuity

5.1.3.1. Tapering of scantlings of the shell envelope, upper deck and inner bottom are to be carried out towards the aft end. See also 1.6.

5.1.3.2. Due consideration is to be given to the tapering of primary support members in transition zones forward of the aft peak into the machinery space.

5.1.3.3. Longitudinal framing of the strength deck is to be carried aft to the stern.

5.1.3.4. All shell frames and tank boundary stiffeners are in general to be continuous, or are to be bracketed at their ends, except as permitted in Chapter 1 Sections 4/3.2.4 and 4/3.2.5.

5.1.4. Minimum thickness

5.1.4.1. In addition to the thickness, section modulus and stiffener web shear area requirements as given in 5.2 to 5.7, the thickness of plating and stiffeners in the aft end region is to comply with the appropriate minimum thickness requirements given in Table 2.2.33.

Table 2.2.33: Minimum Net Thickness of Structure Aft of the Aft Peak Bulkhead

Scantling Location			Net Thickness (mm)
Plating	Shell	Keel plating	See 2.1.5.1
		Bottom shell/bilge/side shell plating	See 2.1.5.1
	Upper deck		See 2.1.5.1
	Other structure	Hull internal tank boundaries	See 2.1.5.1
		Non-tight bulkheads, bulkheads between dry spaces and other plates in general	See 2.1.5.1
		Pillar bulkheads	7.5
Bottom girders and aft peak floors			$5.5 + 0.02L_2$
Web plating of primary support members			$6.5 + 0.015L_2$
Local support members			See 2.1.5.1
Tripping brackets			See 2.1.5.1
where: L_2 rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but need not be taken greater than 300m			

5.2. Bottom Structure

5.2.1. General

5.2.1.1. Fitting of the floors are to be done at each frame space in the aft peak and carried to a height at least above the stern tube. Where floors do not extend to flats or decks they are to be stiffened by flanges at their upper end.

5.2.1.2. The centreline bottom girder is to extend as far aft as is practicable and is to be attached to the stern frame.

5.2.2. Aft peak floors and girders

5.2.2.1. The height of stiffeners, h_{stf}, on the floors and girders are to be not less than:

$h_{stf} = 80.0\ l_{stf}$ mm, for flat bar stiffeners

$h_{stf} = 70.0\ l_{stf}$ mm, for bulb profiles and flanged stiffeners

where:

l_{stf} length of stiffener as shown in Figure 2.2.33, in m

5.2.2.2. In conjunction with the requirements of 5.2.2.1, stiffeners are to be provided with end brackets as follows:

a. Brackets are to be fitted at the lower and upper ends when l_{stf-t} exceeds 4m
b. Brackets are to be fitted at the lower end when l_{stf-t} exceeds 2.5m.

where:
l_{stf-t} = total length of stiffener as shown in Figure 2.2.18, in m

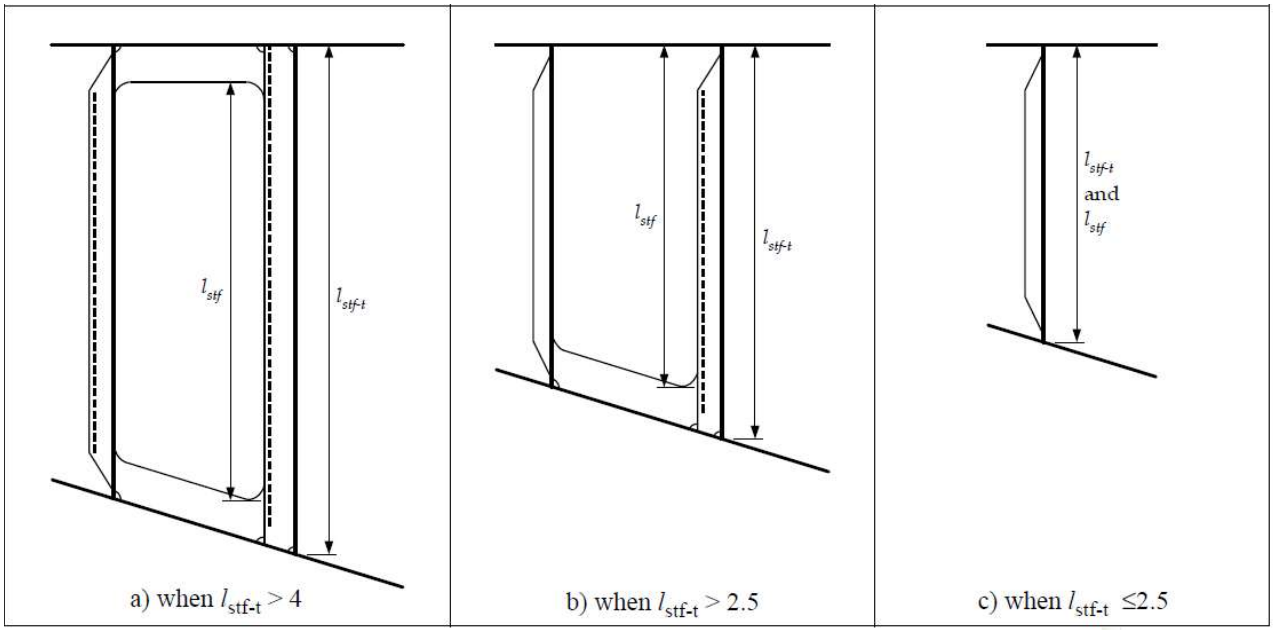


Figure 2.2.18: Stiffening of Floors and Girders in the Aft Peak

5.2.2.3. Fitting of heavy plate floors are to be provided in way of the aft face of the horn and in line with the webs in the rudder horn. They may be required to be carried up to the first deck or flat. In this area, cut outs, scallops or other openings are to be kept to a minimum.

5.2.3. Stern frames

5.2.3.1. Stern frames may be fabricated from steel plates or made of cast steel. For applicable material specifications and steel grades see Table 1.6.3. Special considered Stern frames of other material or construction will be given.

5.2.3.2. Scantlings below the propeller boss on stern frames for single screw vessels are to comply with the requirements in 5.2.3.3 or 5.2.3.4, as applicable.

5.2.3.3. Fabricated stern frames are to satisfy the following criteria:

a) $t_{grs} \geq 2.25\sqrt{L}$mm

b) $w_{stn} \geq 450$mm

$$t_{grs} \geq \frac{C_f L^{1.5}}{w_{stn}^2 \sqrt{1 + \left(\frac{2 l_{stn}}{w_{stn}}\right)^2}}$$

where:
t_{grs} = gross thickness of side plating, in mm
w_{stn} = width of stern frame, in mm, see Figure 2.2.19a
l_{stn} = length of stern frame, in mm, see Figure 2.2.19a

L = rule length, as defined in Chapter 1 Section 4/1.1.1.1
C_f = 9600

5.2.3.4. Cast stern frames are to satisfy the following criteria:

a) $t_{1-grs} \geq 3.0\sqrt{L}$mm, but not to be less than 25mm

b) $t_{2-grs} \geq 1.25 t_{1-grs}$mm

c) $\frac{t_{1-grs}+t_{2-grs}}{2} \geq \frac{C_f L^{1.5}}{w_{stn}^2 \sqrt{1+\left(\frac{2 l_{stn}}{w_{stn}}\right)^2}}$

where:
t_{1-grs} = gross thickness of casting at end, in mm, see Figure 2.2.19b
t_{2-grs} = gross thickness of casting at mid length, in mm, see Figure 2.2.19b
w_{stn} = width of stern frame, in mm, see Figure 2.2.19b
l_{stn} = length of stern frame, in mm, see Figure 2.2.19b
L = rule length, as defined in Chapter 1 Section 4/1.1.1.1
C_f = 8400

The thickness of butt welding to shell plating may be tapered below t_1 with a length of taper that is at least three times the offset. The castings are to be cored out in order to avoid large masses of thick material likely to contain defects and are to maintain a relatively uniform section throughout. In way of changes in section suitable radii are required to be provided.

5.2.3.5. Above the propeller boss, the scantlings are to be in accordance with 5.2.3.2 to 5.2.3.4 except that in the upper part of the propeller aperture, where the hull form is full and centreline supports are provided, the thickness may be reduced to 80% of the applicable requirements in 5.2.3.2 to 5.2.3.4.

5.2.3.6. Where round bars are used at the aft edge of stern frames, their scantlings and connection details are to facilitate welding.

5.2.3.7. Ribs or horizontal brackets of thickness not less than $0.8t_{grs}$ or $0.8t_{1-grs}$ are to be provided at suitable intervals, where t_{grs} and t_{1-grs} are as defined in 5.2.3.3 and 5.2.3.4. When t_{grs} or t_{1-grs} is reduced in accordance with 5.2.3.5, a proportionate reduction in the thickness of ribs or horizontal brackets may be made.

5.2.3.8. Rudder gudgeons are to be an integral part of the stern frame and are to meet the requirements of IRS

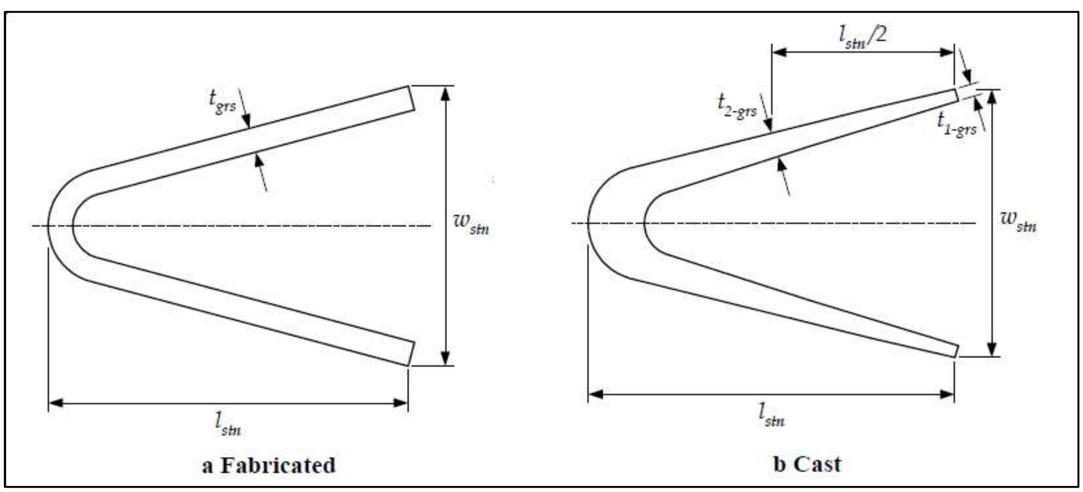


Figure 2.2.19: Stern Frame

5.3. Shell Structure

5.3.1. Shell plating

5.3.1.1. The net thickness of the side shell and transom plating, tnet, is to comply with the requirements in 3.9.2.1 and is not to be less than:

$$t_{net} = 0.035(L_2 - 42) + 0.009s\text{mm}$$

where:

L_2= rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but need not be taken greater than 300m

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

5.3.1.2. The net plating thickness of shell, tnet, attached to the stern frame is to comply with the requirements in 3.9.2.1 and is not to be less than:

$$t_{net} = 0.105(L_2 - 47) + 0.011s\text{mm}$$

where:

L_2 = rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but need not be taken greater than 300m

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

5.3.1.3. In way of the boss and heel plate, the shell net plating thickness, tnet, is not to be less than:

$$t_{net} = 0.094(L_2 - 43) + 0.009s$$

where:

L_2= rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but need not be taken greater than 300m

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

5.3.1.4. Within the extents specified in 2.2.4.3, the thickness of the side shell plating is to comply with the requirements in 2.2.4.2.

5.3.1.5. Fitting of heavy shell plates are to be provided locally in way of the heavy plate floors as required by 5.2.2.3.Outboard of the heavy floors, the heavy shell plates may be reduced in thickness in as gradual a manner as practicable. Where the horn plating is radiused into the shell plating, the radius at the shell connection, r, is not to be less than:

$$r = 150 + 0.8L_2\text{mm}$$

where:
L_2= rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but need not be taken greater than 300m

5.3.2. Shell local support members

5.3.2.1. The section modulus and thickness of the hull envelope framing are to comply with the requirements in 3.9.2.2 and 3.9.2.3.

5.3.3. Shell primary support members

5.3.3.1. The requirements of 5.3.3 apply to single side skin construction supported by system of vertical webs and/or horizontal stringers or flats.

5.3.3.2. Where a longitudinal framing system is adopted, longitudinals are to be supported by vertical primary support members extending from the floors to the upper deck. Deck transverses are to be fitted in line with the web frames.

5.3.3.3. Where a transverse framing system is adopted, frames are to be supported by horizontal primary support members spanning between the vertical primary support members.

5.3.3.4. The scantlings of web frames supporting; longitudinal framing, stringers and transverse framing are to be determined from 3.9.3.

5.3.3.5. The web depth of primary support members is not to be less than 14% of the bending span and is to be at least 2.5 times as deep as the slots for stiffeners if the slots are not closed.

5.4. Deck Structure

5.4.1. Deck plating

5.4.1.1. The thickness of the deck plating is to comply with the requirements in 3.9.2.1.

5.4.2. Deck stiffeners

5.4.2.1. The section modulus and thickness of deck stiffeners are to comply with the requirements in 3.9.2.2 and 3.9.2.3.

5.4.3. Deck primary support members

5.4.3.1. The section modulus and shear area of primary support members are to comply with the requirements in 3.9.3.

5.4.3.2. The web depth of primary support members is not to be less than 10% and 7% of the unsupported span in bending in tanks and in dry spaces, respectively, and is not to be less than 2.5 times the depth of the slots if the slots are not closed. Unsupported span in bending is bending span as defined in Chapter 1 Section 4/2.1.4 or in case of a grillage structure the distance between connections to other primary support members.

5.4.3.3. In way of concentrated loads from heavy equipment, determinations of the scantlings of the deck structure are to be obtained on the basis on the actual loading. See also Chapter 1 Section 11/3.

5.4.4. Pillars

5.4.4.1. Fitting of the pillars are to be done in the same vertical line wherever possible and effective arrangements are to be made to distribute the load at the heads and heels of all pillars. Where pillars support eccentric loads, they are to be strengthened for the additional bending moment imposed upon them.

5.4.4.2. Tubular and hollow square pillars are to be attached at their heads and heels by efficient brackets, or doublers/insert plates, where applicable, to transmit the load effectively. Pillars are to be attached at their heads and heels by continuous welding. At the heads and heels of pillars built of rolled sections, the load is to be distributed by brackets or other equivalent means.

5.4.4.3. Pillars in tanks are to be of solid section. Where the hydrostatic pressure may result in tensile stresses in the pillar, the tensile stress in the pillar and its end connections is not to exceed 45%of the specified minimum yield stress of the material.

5.4.4.4. The scantlings of pillars are to comply with the requirements in 3.9.5.

5.4.4.5. Where the loads from heavy equipment exceed the design load of 3.9.5, the pillar scantlings are to be determined based on the actual loading.

5.5. Tank Bulkheads

5.5.1. General

5.5.1.1. Tanks may be required to have divisions or deep wash structures to minimise the dynamic stress on the structure.

5.5.2. Construction

5.5.2.1. In no case are the scantlings of tank boundary bulkheads to be less than the requirements for watertight bulkheads.

5.5.3. Scantlings of tank boundary bulkheads

5.5.3.1. The thickness of tank boundary plating is to comply with the requirements in 3.9.2.1.

5.5.3.2. The section modulus and thickness of stiffeners are to comply with the requirements in 3.9.2.2 and 3.9.2.3.

5.5.3.3. The section modulus and shear area of primary support members are to comply with the requirements in 3.9.3.

5.5.3.4. Web plating of primary support members is to have a depth of not less than 14% of the unsupported span in bending and not less than 2.5 times the depth of the slots if the slots are not closed.

5.6. Watertight Boundaries

5.6.1. General

5.6.1.1. Watertight boundaries are to be fitted in accordance with Chapter 1 Section 5/2.

5.6.1.2. The number of openings in watertight bulkheads is to be kept to a minimum compatible with the design and operation of the ship. Arrangements are to be made to maintain the watertight integrity where penetrations of watertight bulkheads and internal decks are necessary for access, piping, ventilation, electrical cables, etc...

5.6.2. Aft peak bulkhead

5.6.2.1. An aft peak bulkhead complying with Chapter 1 Section 5/2.3 is to be provided.

5.6.2.2. The scantlings of structural components of the aft peak bulkhead are to comply with the requirements in 5.5 and 5.6.3, as applicable.

5.6.3. Scantlings of watertight boundaries

5.6.3.1. The thickness of boundary plating is to comply with the requirements in 3.9.2.1.

5.6.3.2. The section modulus and thickness of stiffeners are to comply with the requirements in 3.9.2.2 and 3.9.2.3.

5.6.3.3. The section modulus and shear area of primary support members are to comply with the requirements in 3.9.3.

5.6.3.4. Web plating of primary support members is to have a depth of not less than 10% of the unsupported span in bending and not less than 2.5 times the depth of the slots if the slots are not closed.

5.7. Miscellaneous Structures

5.7.1. Pillar bulkheads

5.7.1.1. Bulkheads that support girders or pillars and longitudinal bulkheads which are fitted in lieu of girders are to be stiffened to provide supports not less effective than required for stanchions or pillars. The acting load and the required net cross sectional area of the pillar section is to be determined using the requirements of 5.4.4. The net moment of inertia of the stiffener is to be calculated with a width of 40tnet of the plating, where tnet is net plating thickness in mm.

5.7.1.2. Pillar bulkheads are to meet the following requirements:

(a) The distance between bulkhead stiffeners is not to exceed 1500mm

(b) Where corrugated, the depth of the corrugation is not to be less than 100mm.

5.7.2. Rudder trunk

5.7.2.1. The scantlings of the rudder trunk are to be in accordance with the shell plating and framing in 5.3.1 and 5.3.2. Where the rudder trunk is open to the sea, a seal or stuffing box is to be fitted above the deepest load waterline to prevent water from entering the steering gear compartment.

5.7.3. Stern thruster tunnels

5.7.3.1. The net thickness of the tunnel plating, $t_{tun\text{-}net}$, is not to be less than required for shell plating in the vicinity of the thruster. In addition $t_{tun\text{-}net}$ is not to be taken less than:

$$t_{tun-net} = 0.008 d_{tun} + 1.8\text{mm}$$

6 Evaluation of Structure for Sloshing and Impact Loads

6.1. General

6.1.1. Application

6.1.1.1. The requirements of this Sub-Section cover the strengthening requirements for localised sloshing loads that may occur in tanks carrying liquid and local impact loads that may occur in the forward structure. The sloshing and impact loads to be applied in 6.2 to 6.4 are described in Section 7/4.

6.1.1.2. The net scantlings described in this Sub-Section are related to gross scantlings as follows:

(a) for plating and local support members, the gross thickness and gross cross sectional properties are obtained from the applicable requirements by adding the full corrosion additions specified in Chapter 1 Section 6/3

(b) for primary support members, the gross sectional area, gross section modulus and other gross cross sectional properties are obtained from the applicable requirements by adding one half of the full corrosion additions specified in Chapter 1 Section 6/3.

6.1.2. General scantling requirements

6.1.2.1. The requirements of 6.2 to 6.4 are to be applied in addition to the applicable requirements in Section 2.

6.1.2.2. Local scantling increases due to impact or sloshing loads are to be made with due consideration given to details and avoidance of hard spots, notches and other harmful stress concentrations.

6.2. Sloshing in Tanks

6.2.1. Scope and limitations

6.2.1.1. The requirements of 6.2 specify the scantling requirements for boundary and internal structure of tanks subject to sloshing loads, as given in Section 1/4.2, due to the free movement of liquid in tanks.

6.2.1.2. The structure of cargo tanks, slop tanks, ballast tanks and large deep tanks, e.g. fuel oil bunkering tanks and main fresh water tanks, are to be assessed for sloshing. Small tanks do not need to be assessed for sloshing pressures.

6.2.1.3. All cargo and ballast tanks are to have scantlings suitable for unrestricted filling heights.

6.2.1.4. The following structural members are to be assessed:

(a) Plates and stiffeners forming boundaries of tanks
(b) Plates and stiffeners on wash bulkheads
(c) Web plates and web stiffeners of primary support members located in tanks
(d) Tripping brackets supporting primary support members in tanks.

6.2.1.5. For tanks with effective sloshing breadth, b_{slh}, greater than 0.56B or effective sloshing length, l_{slh},greater than 0.13L, an additional sloshing impact assessment is to be carried out in accordance with the individual IRS procedures. The effective sloshing length, l_{slh}, and breadth, b_{slh}, are definedin Section 1/4.2.2 and Section 1/4.2.3 respectively.

6.2.2. Application of sloshing pressure

6.2.2.1. The following tanks are to be assessed for the design sloshing pressures $P_{slh-lng}$ and P_{slh-t} in accordance with 6.2.2.2 to 6.2.2.5:

a. cargo and slop tanks
b. fore peak and aft peak ballast tanks
c. other tanks which allow free movement of liquid, except as follows:
    - Where the effective sloshing length is less than 0.03L, calculations involving $P_{slh-lng}$ are not required and
    - Where the effective sloshing breadth is less than 0.32B, calculations involving P_{slh-t} are not required.

The design sloshing pressure for other tanks mentioned in 6.2.1.2 is to be taken as the minimum sloshing pressure, $P_{slh-min}$, as defined in Chapter 2 Section 2/4.2.4.

6.2.2.2. The design sloshing pressure due to longitudinal liquid motion, $P_{slh-lng}$, as defined in Section 1/4.2.2.1 is to be applied to the following members as shown in Figure 2.2.20

a. Transverse tight bulkheads
b. Transverse wash bulkheads
c. Stringers on transverse tight and wash bulkheads

d. Plating and stiffeners on the longitudinal bulkheads, deck and inner hull which are between the transverse bulkhead and the first web frame from the bulkhead or the bulkhead and 0.25*lslh*, whichever is lesser.

6.2.2.3. In addition to 6.2.2.2, the first web frame next to a transverse tight or wash bulkhead if the web frame is located within $0.25l_{slh}$ from the bulkhead, as shown in Figure 2.2.20, is to be assessed for the web frame reflected sloshing pressure, $P_{slh\text{-}wf}$, as defined in Section 7/4.2.2.5.

6.2.2.4. The minimum sloshing pressure, $P_{slh\text{-}min}$, as defined in Section 1/4.2.4 is to be applied to all other members.

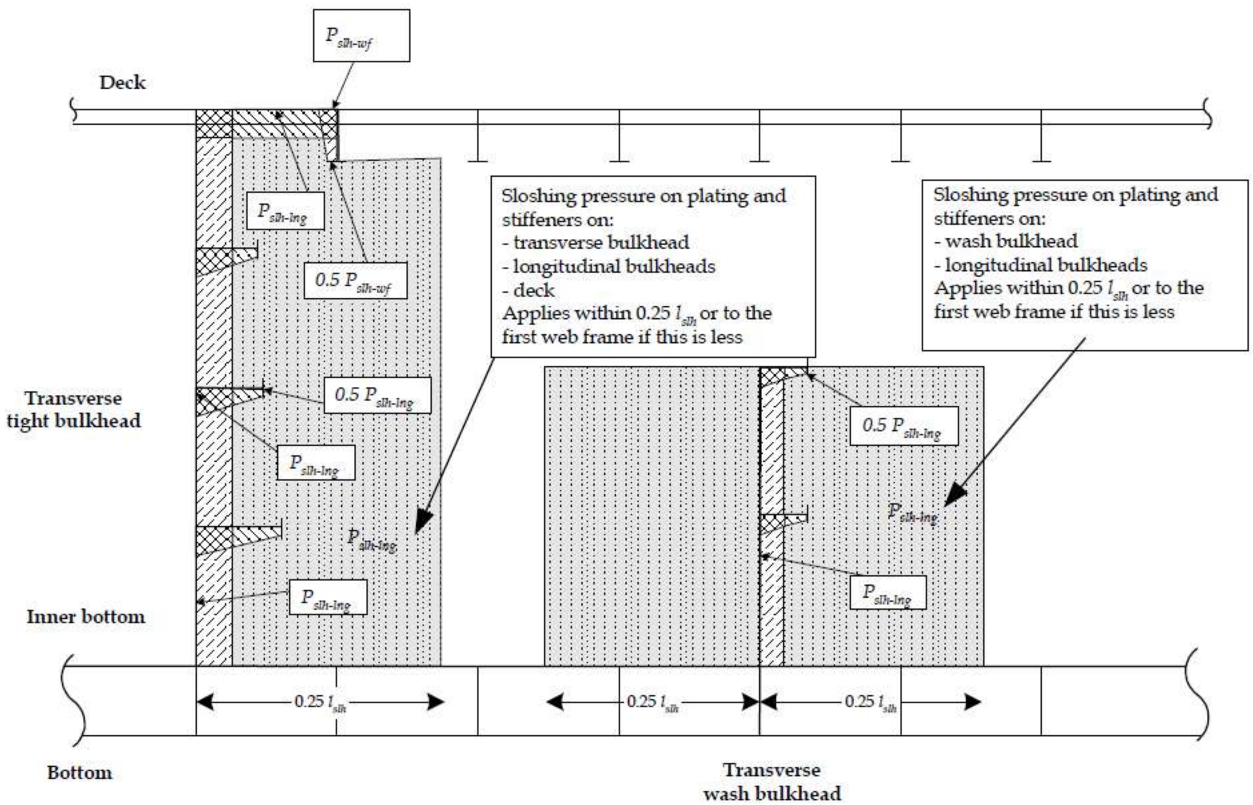


Figure 2.2.20: Application of Sloshing Loads due to Longitudinal Liquid Motion

6.2.2.5. The design sloshing pressure due to transverse liquid motion, $P_{shl\text{-}t}$, as defined in Section 1/4.2.3.1, is to be applied to the following members as shown in Figure 2.2.21:

1) Longitudinal tight bulkhead
2) Longitudinal wash bulkhead
3) Horizontal stringers on longitudinal tight and wash bulkheads
4) Plating and stiffeners on the transverse tight bulkheads including stringers and deck which are between the longitudinal bulkhead and the first girder from the bulkhead or the bulkhead and $0.25b_{slh}$whichever is lesser.

6.2.2.6. In addition to 6.2.2.5, the first girder next to longitudinal tight or wash bulkhead if the girder is located within $0.25b_{slh}$ from the longitudinal bulkhead, as shown in Figure 2.2.21, is to be assessed for the reflected sloshing pressure, $P_{slh\text{-}grd}$ as defined in Section 1/4.2.3.5.

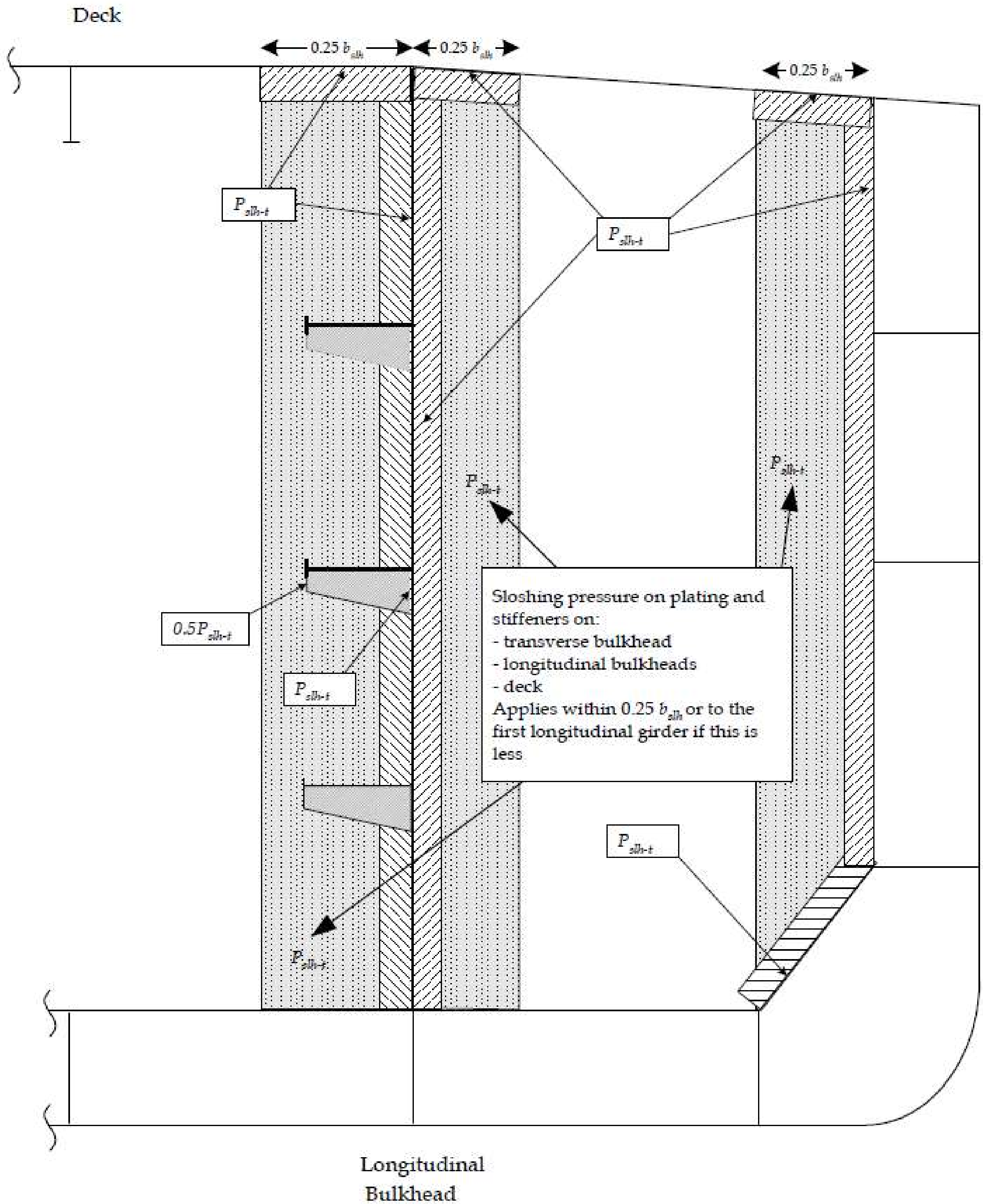


Figure 2.2.21: Application of Sloshing Loads due to Transverse Liquid Motion

6.2.2.7. The minimum sloshing pressure, $P_{slh-min}$, as defined in Section 1/4.2.4 is to be applied to all other members.

6.2.2.8. The sloshing pressures due to transverse and longitudinal fluid motion are assumed to act independently. Structural members are therefore to be evaluated based on the greatest sloshing pressure due to longitudinal and transverse fluid motion.

6.2.3. Sloshing assessment of plating forming tank boundaries and wash bulkheads

6.2.3.1. The net thickness of plating forming tank boundaries and wash bulkheads, tnet, subjected to sloshing pressures is not to be less than:

$$t_{net} = 0.0158\alpha_p s\sqrt{\frac{P_{slh}}{C_a\sigma_{yd}}}\text{mm}$$

where:
α_p= correction factor for the panel aspect ratio

$$= 1.2 - \frac{s}{2100 l_p}$$

but not to be taken as greater than 1.0
s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2
l_p= length of plate panel, to be taken as the spacing of primary support members, S, unless carlings are fitted, in m
P_{slh} the greater of $P_{slh-lng}$, P_{slh-t} or $P_{slh-min}$ as specified in 6.2.2
C_a= permissible plate bending stress coefficient as given in Table 2.2.34
σ_{yd} = specified minimum yield stress of the material, in N/mm^2

6.2.4. Sloshing assessment of stiffeners on tank boundaries and wash bulkheads

6.2.4.1. The net section modulus, Z_{net}, of stiffeners on tank boundaries and wash bulkheads subjected to sloshing pressures is not to be less than:

$$Z_{net} = \frac{P_{slh} s l_{bdg}^2}{f_{bdg} C_s \sigma_{yd}}\text{cm}^3$$

where:
l_{bdg} = effective bending span, of stiffener, as defined in Chapter 1 Section 4/2.1, in m
C_s = permissible bending stress coefficient as given in Table 2.2.35
P_{slh} = the greater of Pslh-lng, Pslh-t or Pslh-min as specified in 6.2.2
s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2
σ_{yd}= specified minimum yield stress of the material, in N/mm^2
f_{bdg} = bending moment factor:
= 12 for stiffeners fixed against rotation at each end. This is generally to be applied for scantlings of all continuous stiffeners
= 8 for stiffeners with one or both ends not fixed against rotation. This is generally to be applied to discontinuous stiffeners

For other configurations the bending moment factor may be taken as given in Table2.2.26

6.2.5. Sloshing assessment of primary support members

6.2.5.1. Web plating, web stiffeners and tripping brackets on stringers, girders and web frames in cargo and ballast tanks are to be assessed based on sloshing pressures as given in 6.2.2.

6.2.5.2. The web plating net thickness of primary support members, t_{net}, is not to be less than:

$$t_{net} = 0.0158\alpha_p s\sqrt{\frac{P_{sl}}{C_a\sigma_{yd}}}\text{mm}$$

where:
α_p= correction factor for the panel aspect ratio

$$= 1.2 - \frac{s}{2100 l_p}$$

but not to be taken as greater than 1.0

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

l_p= length of plate panel, mean spacing between local support members on the long edges of the panel, typically between tripping brackets, in m

P_{slh} the greater of $P_{slh\text{-}lng}$, $P_{slh\text{-}t}$, $P_{slh\text{-}wf}$, $P_{slh\text{-}grd}$ or $P_{slh\text{-}min}$ as specified in 6.2.2. The pressure is to be calculated at the load application point, defined in Chapter 1 Section 3/5.1.2, taking into account the distribution over the height of the member, as shown in Figure 2.2.20

C_a = permissible plate bending stress coefficient as given in Table 2.2.34

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

6.2.5.3. The net section modulus, Z_{net}, of each individual stiffener on the web plating of primary support members subjected to sloshing pressures is not to be less than:

$$Z_{net} = \frac{P_{sl} \; s l_{bdg}^2}{f_{bdg} C_s \sigma_{yd}} \text{cm}^3$$

where:

P_{slh} the greater of $P_{slh\text{-}lng}$, $P_{slh\text{-}t}$, $P_{slh\text{-}wf}$, $P_{slh\text{-}grd}$ or Pslh-min as specified in 6.2.2. The pressure is to be calculated at the load application point taking into account the distribution over the height of the member, as shown in Figure 2.2.20 and 2.2.21.

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

l_{bdg} = effective bending span, in m, of web stiffener as defined in Chapter 1 Section 4/2.1

C_s = permissible bending stress coefficient as given in Table 2.2.35

f_{bdg} = bending moment factor

= 12 for stiffeners fixed against rotation at each end. This is generally to be applied for scantlings ofall continuous stiffeners

= 8 for stiffeners with one or both ends not fixed against rotation. This is generally to be applied todiscontinuous stiffeners

For other configurations the bending moment factor may be taken as given in Table 2.2.26

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

6.2.5.4. The net section modulus, Z_{net}, in way of the base of tripping brackets supporting primary supportmembers in cargo and ballast tanks is not to be less than:

$$Z_{net} = \frac{1000 P_{sl} \; s_{trip} l_{trip}^2}{2 C_s \sigma_{yd}} \text{cm}^3$$

where:

P_{slh} the greater of $P_{slh\text{-}lng}$, $P_{slh\text{-}t}$, $P_{slh\text{-}wf}$, $P_{slh\text{-}grd}$ and $P_{slh\text{-}min}$ as defined in 6.2.2. The average pressure may be calculated at midpoint of the tripping bracket taking into account the distribution as shown in Figure

2.2.20 and 2.2.21

s_{trip} = mean spacing, between tripping brackets or other primary support members or bulkheads, in m

l_{trip} = length of tripping bracket, see Figure 2.2.22, in m

C_s= permissible bending stress coefficient for tripping brackets

= 0.75

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

bis The effective breadth of the attached plate to be used for calculating the section modulus of the tripping bracket supporting primary support members is to be taken as 1/3 the length of the tripping bracket, ltrip, as given in 2/6.2.5.4.

6.2.5.5. The net shear area, $A_{shr-net}$, after deduction of cut-outs and slots, of tripping brackets supporting primary support members in cargo and ballast tanks is not to be less than:

$$A_{shr-net} = 10\frac{P_{slh}s_{trip}l_{trip}}{C_t\tau_{yd}}\text{cm}^2$$

where:

P_{slh} the greater of $P_{slh-lng}$, P_{slh-t}, P_{slh-wf}, $P_{slh-grd}$ and $P_{slh-min}$ as defined in 6.2.2. The average pressure maybe calculated at midpoint of the tripping bracket taking into account the distribution as shown in Figure 2.2.20 and 2.2.21

s_{trip}= mean spacing, between tripping brackets or other primary support members or bulkheads, in m

l_{trip} = length of tripping bracket, see Figure 2.2.22, in m

C_t = permissible shear stress coefficient, as given in Table 2.2.36

$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}}$ N/mm^2

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

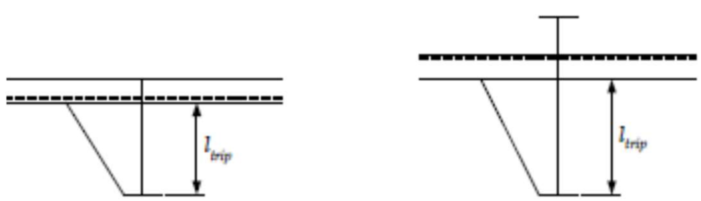


Figure 2.2.22 Effective Length of Tripping Bracket

Table 2.2.34: Allowable Plate Bending Stress Coefficient, C_a, for Assessment of Sloshing on Plates
The permissible bending stress coefficient for the design load set being considered is to be taken as: $$C_a = \beta_a - \alpha_a\frac{\lvert\sigma_{hg}\rvert}{\sigma_{yd}}$$ but not to be taken greater than C_{a-max} where: α_a, β_a, C_{a-max}permissible bending stress factors and are to be taken as follows

Acceptance Criteria Set	Structural Member		β_a	α_a	C_{a-max}
AC1	Longitudinal strength members in the cargo tank region including but not limited to: • deck • longitudinal plane bulkhead • horizontal corrugated longitudinal bulkhead • longitudinal girders and stringers within the cargo tank region	Longitudinally stiffened plating	0.9	0.5	0.8
		Transversely or vertically stiffened plating	0.9	1.0	0.8
	Other strength members including: • vertical corrugated longitudinal bulkhead • transverse plane bulkhead • transverse corrugated bulkhead • transverse stringers and web frames • plating of tank boundaries and primary support members outside the cargo tank region		0.8	0	0.8

σ_{hg} hull girder bending stress for the design load set being considered and calculated at the load calculation point defined in Chapter 1 Section 3/5.1.2

$$= \left(\frac{(Z-Z_{NA-net50})M_{sw-perm-se}}{I_{v-net50}}\right)10^{-3}\ \text{N/mm}^2$$

z vertical coordinate of the load calculation point under consideration, in m

$z_{NA-net50}$ distance from the baseline to the horizontal neutral axis, as defined in Chapter 1 Section 4/2.6.1, in m

$M_{sw-perm-sea}$ permissible hull girder hogging and sagging still water bending moment for seagoing operation at the location being considered, in kNm. The greatest of the sagging and hogging bending moment is to be used, see Section 1/2.1.

$I_{v-net50}$ net vertical hull girder moment of inertia, at the longitudinal position being considered, as defined in Chapter 1 Section 4/2.6.1, in m^4

σ_{yd} specified minimum yield stress of the material, in N/mm^2

Table 2.2.35: Allowable Bending Stress Coefficient, C_s, for Assessment of Sloshing on Stiffeners

The permissible bending stress coefficient for the design load set being considered is to be taken as:

$$C_s = \beta_s - a_s \frac{|\sigma_{hg}|}{\sigma_{yd}}$$

but not to be taken greater than $C_{s\text{-}max}$

where:

α_s, β_s, $C_{s\text{-}max}$ permissible bending stress factors and are to be taken as follows:

Acceptance Criteria Set	Structural Member		β_s	α_s	$C_{s\text{-}max}$
AC1	Longitudinal strength members in the cargo tank region including but not limited to: — deck stiffeners — stiffeners on longitudinal bulkheads — stiffeners on longitudinal girders and stringers within the cargo tank region	Longitudinal stiffeners	0.85	1.0	0.75
		Transverse or vertical stiffeners	0.7	0	0.7
	Other strength members including: — stiffeners on transverse bulkheads — stiffeners on transverse stringers and web frames — stiffeners on tank boundaries and primary support members outside the cargo tank region		0.75	0	0.75

σ_{hg} hull girder bending stress for the design load set being considered at the reference point defined in Chapter 1 Section 3/5.2.2.5

$$= \left(\frac{(Z - Z_{NA-net50}) M_{sw-perm-sea}}{I_{v-net}}\right) 10^{-3} \text{N/mm}^2$$

z vertical coordinate of the reference point defined in Chapter 1 Section 3/5.2.2.5, in m

$Z_{NA\text{-}net50}$ distance from the baseline to the horizontal neutral axis, as defined in Chapter 1 Section 4/2.6.1, in m

$M_{sw\text{-}perm\text{-}sea}$ permissible hull girder hogging and sagging still water bending moment for seagoing operation at the location being considered, in kNm.

Stiffener Location	$M_{sw\text{-}perm\text{-}sea}$	
	Pressure acting on Plate Side	**Pressure acting on Stiffener Side**
Above Neutral Axis	Sagging SWBM	Hogging SWBM
Below Neutral Axis	Hogging SWBM	Sagging SWBM

$I_{v\text{-}net50}$ net vertical hull girder moment of inertia, at the longitudinal position being considered, as defined in Chapter 1 Section 4/2.6.1, in m^4

σ_{yd} specified minimum yield stress of the material, in N/mm^2

Table 2.2.36 Permissible Shear Stress Coefficient

Acceptance Criteria Set	Structural member	C_t
AC1	Tripping brackets	0.75

6.3. Bottom Slamming

6.3.1. Application

6.3.1.1. Where the minimum draughts forward, T_{FP-mt} or $T_{FP-full}$, as specified in Section 1/4.3.2.1, is less than 0.045L, the bottom forward is to be additionally strengthened to resist bottom slamming pressures.

6.3.1.2. The draughts for which the bottom has been strengthened are to be indicated on the shell expansion plan and loading guidance information, see 1.1.

6.3.1.3. The scantlings described in 6.3 are net scantlings, which are related to gross scantlings as described in 6.1.1.2. The section modulus and shear area of the primary support members is to be determined as specified in Chapter 1 Section 4/2.5.

6.3.1.4. The section modulus and web thickness of the local support members apply to the areas clear of the end brackets. The cross sectional shear areas of primary support members are to be applied as required by 6.3.7.3 and 6.3.7.4.

6.3.2. Extent of strengthening

6.3.2.1. The strengthening is to extend forward of 0.3L from the F.P. over the flat of bottom and adjacent plating with attached stiffeners up to a height of 500mm above the baseline, see Figure 2.2.23.

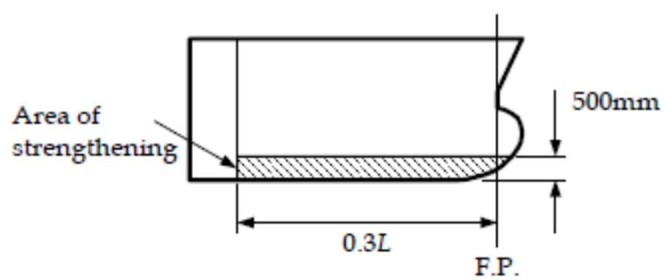


Figure 2.2.23: Extent of strengthening against bottom slamming

6.3.2.2. Outside the region strengthened to resist bottom slamming the scantlings are to be tapered to maintain continuity of longitudinal and/or transverse strength.

6.3.3. Design to resist bottom slamming loads

6.3.3.1. The design of end connections of stiffeners in the bottom slamming region is to ensure end fixity, either by making the stiffeners continuous through supports or by providing end brackets complying with Chapter 1 Section 4/3.2.3. Where it is not practical to comply with this requirement the net plastic section modulus, $Z_{pl-alt-net}$, for alternative end fixity arrangements is not to be less than:

$$Z_{pl-alt-net} = \frac{16 Z_{pl-net}}{f_{bdg}} \text{ cm}^3$$

where:
Z_{pl-net} = net plastic section modulus, in cm^3, as required by 6.3.5.1
f_{bdg}= bending moment factor
$$= 8\left(1 + \frac{n_s}{2}\right)$$
n_s = 0 for both ends with low end fixity (simply supported)
= 1 for one end equivalent to be built in and one end simply supported

6.3.3.2. Scantlings and arrangements at primary support members, including bulkheads, are to comply with 6.3.7.

6.3.4. Hull envelope plating

6.3.4.1. The net thickness of the hull envelope plating, tnet, is not to be less than:

$$t_{net} = \frac{0.0158\alpha_p s}{C_d}\sqrt{\frac{P_{slm}}{C_a\sigma_{yd}}}\text{mm}$$

where:

α_p= correction factor for the panel aspect ratio

$$= 1.2 - \frac{s}{2100l_p}$$

but not to be taken as greater than 1.0

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

l_p = length of plate panel, to be taken as the spacing between primary support members (see Section Chapter 1 4/2.2.2) or panel breakers, in m

P_{slm} = bottom slamming pressure as given in Section 1/4.3 and calculated at the load calculation pointdefined in Chapter 1 Section 3/5.1.2, in kN/m^2

C_d = plate capacity correction coefficient
= 1.3
C_a= permissible bending stress coefficient
= 1.0 for acceptance criteria set AC3
σ_{yd}= specified minimum yield stress of the material, in N/mm^2

6.3.5. Hull envelope stiffeners

6.3.5.1. The net plastic section modulus, $Z_{pl\text{-}net}$, of each individual stiffener, is not to be less than:

$$Z_{net} = \frac{P_{slm}sl_{bdg}^2}{f_{bdg}C_s\sigma_{yd}}\text{cm}^3$$

where:
P_{slm} = bottom slamming pressure as given in Section 1/4.3 and calculated at the load calculation pointdefined in Chapter 1 Section 3/5.2.2, in kN/m^2
s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2
l_{bdg}= effective bending span, as defined in Chapter 1 Section 4/2.1.1, in m
f_{bdg}= bending moment factor

$$= 8\left(1 + \frac{n_s}{2}\right)$$

n_s = 2.0 for continuous stiffeners or where stiffeners are bracketed at both ends
See 6.3.3.1 for alternative arrangements
C_s= permissible bending stress coefficient
= 0.9 for acceptance criteria set AC3
σ_{yd}= specified minimum yield stress of the material, in N/mm^2

6.3.5.2. The net web thickness, $t_{w\text{-}net}$, of each longitudinal is not to be less than:

$$t_{w-net} = \frac{P_{slm} s l_{shr}}{2 d_{shr} C_t \tau_{yd}} \text{mm}$$

where:
l_{shr} = effective shear span, as defined in Chapter 1 Section 4/2.1.2, in m
s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2
P_{slm} = bottom slamming pressure as given in Section 1/4.3 and calculated at the load calculation point defined in Chapter 1 Section 3/5.2.2, in kN/m²
d_{shr} = effective web depth of stiffener, in mm, as defined in Chapter 1 Section 4/2.4.2.2
C_t= permissible shear stress coefficient
= 1.0 for acceptance criteria set AC3

$$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}} \text{ N/mm}^2$$

σ_{yd}= specified minimum yield stress of the material, in N/mm²

6.3.5.3. The slenderness ratio of each longitudinal is to comply with Section 4/2.

6.3.6. Definition of idealized bottom slamming load area for primary support members

6.3.6.1. The scantlings of items in 6.3.7 are based on the application of the slamming pressure defined in Section 1/4.3 to an idealized area of hull envelope plating, the slamming load area, A_{slm}, given by:

$$A_{slm} = \frac{1.1.LBC_b}{1000} \text{m}^2$$

where:
L = rule length, as defined in Chapter 1 Section 4/1.1.1.1
B = moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.1
C_b= block coefficient, as defined in Chapter 1 Section 4/1.1.9.1

6.3.7. Primary support members

6.3.7.1. The size and number of openings in web plating of the floors and girders is to be minimized considering the required shear area as given in 6.3.7.2.

6.3.7.2. The net shear area, $A_{shr-net50}$, of each primary support member web at any position along its span is not to be less than:

$$A_{shr-net50} = 10 \frac{Q_{slm}}{C_t \tau_{yd}} \text{ cm}^2$$

where:
Q_{slm}= the greatest shear force due to slamming for the position being considered, in kN, based on theapplication of a patch load, F_{slm} to the most onerous location, as determined in accordance with 6.3.7.3
C_t= permissible shear stress coefficient
= 0.9 for acceptance criteria set AC3

$$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}} \text{ N/mm}^2$$

σ_{yd} =specified minimum yield stress of the material, in N/mm²

6.3.7.3. For simple arrangements of primary support members, where the grillage affect may be ignored, the shear force, Q_{slm}, is given by:

$$Q_{slm} = f_{pt} f_{dist} F_{slm} \text{kN}$$

where:
f_{pt} = Correction factor for the proportion of patch load acting on a single primary support member

$$= 0.5(f_{slm}^3 - 2f_{slm}^2 + 2)$$

f_{slm} = patch load modification factor

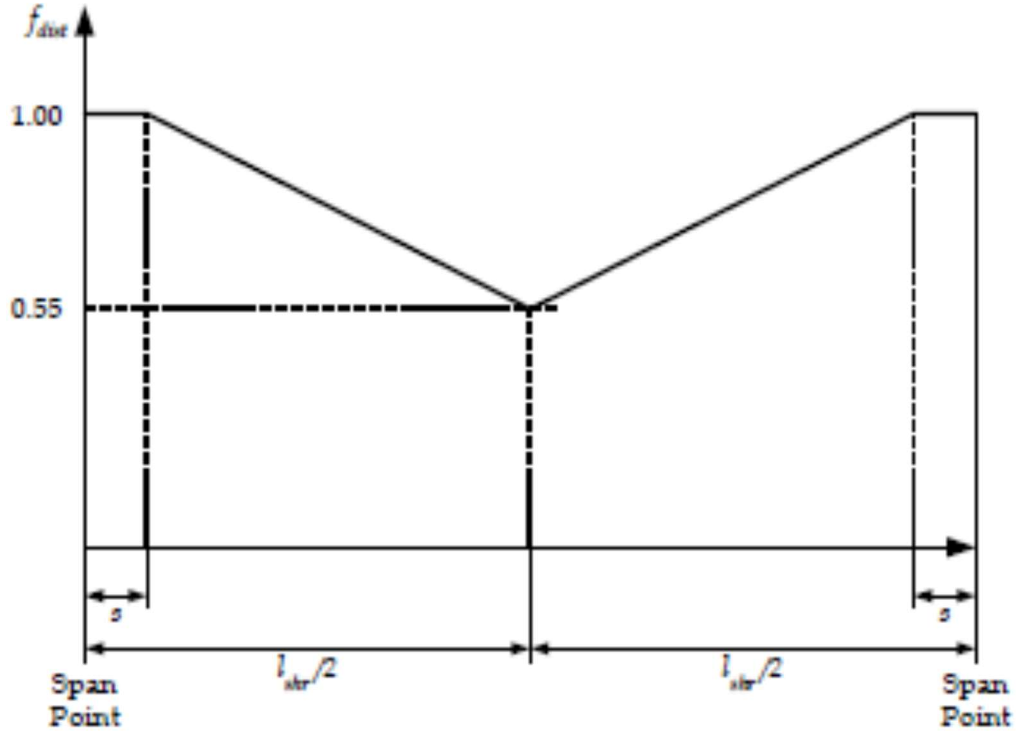
$= 0.5 \frac{b_{slm}}{S}$, but not to be greater than 1.0

f_{dist}= factor for the greatest shear force distribution along the span, see Figure 2.2.24

$$F_{slm} = P_{slm}\, l_{slm}\, b_{slm}$$

P_{slm}= bottom slamming pressure as given in Section 1/4.3 and calculated at the load calculation point defined in Chapter 1 Section 3/5.3.2, in kN/m^2

l_{slm}= extent of slamming load area along the span
= $\sqrt{A_{slm}}$m, but not to be greater than l_{shr}
l_{shr} effective shear span, as defined in Chapter 1 Section 4/2.1.5, in m
b_{slm} = breadth of impact area supported by primary support member
= $\sqrt{A_{slm}}$m, but not to be greater than S
A_{slm} as defined in 6.3.6.1
S = primary support member spacing, in m, as defined in Chapter 1 Section 4/2.2.2



Where:
s = stiffener spacing
l_{shr} = effective shear span, in m, as defined in Section 4/2.1.5

Figure 2.2.24: Distribution of fdist along the Span of Simple Primary Support Members

6.3.7.4. For complex arrangements of primary support members, the greatest shear force, Q_{slm}, at any location along the span of each primary support member is to be derived by direct calculation in accordance with Table 2.2.37.

Table 2.2.37: Direct Calculation Methods for Derivation of Q_{slm}		
Type of analysis	**Beam theory**	**Double bottom grillage**
Model extent	Overall span of member between effective bending supports	Longitudinal extent to be one cargo tank length Transverse extent to be between inner hopper knuckle and centreline
Assumed end fixity of floors	Fixed at ends	Floors and girders to be fixed at boundaries of the model
Note 1) The envelope of greatest shear force along each primary support member is to be derived by applying the load patch to a number of locations along the span, see 6.3.7.2.		

6.3.7.5. The net web thickness, t_{w-net}, of primary support members adjacent to the shell is not to be less than:

$$t_{w-net} = \frac{s}{70}\sqrt{\frac{\sigma_{yd}}{235}} \text{ mm}$$

where:
s_w= plate breadth, in mm, taken as the spacing between the web stiffening
σ_{yd} = specified minimum yield stress of the material, in N/mm^2

6.3.8. Connection of longitudinals to primary support members

6.3.8.1. Longitudinals are, in general, to be continuous. Where this not practicable end brackets complying with Chapter 1 Section 4/3.2.3 are to be provided.

6.3.8.2. The scantlings in way of the end connections of each longitudinal are to comply with the requirements of Chapter 1 Section 4/3.4.

6.4. Bow Impact

6.4.1. Application

6.4.1.1. The side structure in the area forward of 0.1L from the F.P. is to be strengthened against bow impact pressures.

6.4.1.2. The scantlings described in 6.4 are net scantlings, which are related to gross scantlings as described in 6.1.1.2.

6.4.1.3. The section modulus and web thickness of the local support members apply to the areas clear of the end brackets. The section modulus of the primary support member is to apply along the bending span clear of end brackets and cross sectional areas of the primary support member is to be applied at the ends/supports and may be gradually reduced along the span and clear of the ends/supports following the distribution of fdistindicated in Figure 2.2.24.

6.4.2. Extent of strengthening

6.4.2.1. The strengthening is to extend forward of 0.1L from the F.P. and vertically above the minimum design ballast draught, T_{bal}, defined in Chapter 1 Section 4/1.1.5.2. See Figure 2.2.25.

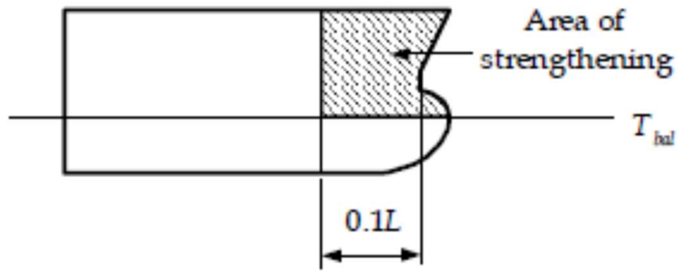


Figure 2.2.25: Extent of Strengthening Against Bow Impact

6.4.2.2. Outside the strengthening region as given in 6.4.2.1 the scantlings are to be tapered to maintain continuity of longitudinal and/or transverse strength.

6.4.3. Design to resist bow impact loads

6.4.3.1. In the bow impact region, longitudinal framing is to be carried as far forward as practicable.

6.4.3.2. The design of end connections of stiffeners in the bow impact region are to ensure end fixity, eitherby making the stiffeners continuous through supports or by providing end brackets complying with Chapter 1 Section 4/ 3.2.3. Where it is not practical to comply with this requirement the net plastic section modulus, $Z_{pl-alt-net}$, for alternative end fixity arrangements is not to be less than:

$$Z_{pl-alt-net} = \frac{16Z_{pl-net}}{f_{bdg}} \text{cm}^3$$

where:

Z_{pl-net}= effective net plastic section modulus, required by 6.4.5, in cm^3

f_{bdg}= bending moment factor

$$= 8\left(1 + \frac{n_s}{2}\right)$$

n_s = 0 for both ends with low end fixity (simply supported)

= 1.0 for one end equivalent to be built in and one end simply supported

6.4.3.3. Scantlings and arrangements at primary support members, including decks and bulkheads, are to comply with 6.4.7. In areas of greatest bow impact load the adoption of web stiffeners arranged perpendicular to the hull envelope plating and the provision of double sided lug connections are, in general to be applied.

6.4.3.4. The main stiffening direction of decks and bulkheads supporting shell framing is to be arranged parallel to the span direction of the supported shell frames, to protect against buckling.

6.4.4. Side shell plating

6.4.4.1. The net thickness of the side shell plating, t_{net}, is not to be less than:

$$t_{net} = 0.0158\alpha_p s\sqrt{\frac{P_{im}}{C_a\sigma_{yd}}} \text{mm}$$

where:

α_p = correction factor for the panel aspect ratio

$$= 1.2 - \frac{s}{2100 l_p}$$

but is not to be taken as greater than 1.0

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

l_p= length of plate panel, to be taken as the spacing between the primary support members, see Chapter 1 Section 4/2.2.2, or panel breakers, in m

P_{im}= bow impact pressure as given in Section 1/4.4 and calculated at the load calculation point defined in Chapter 1 Section 3/5.1.2, in kN/m^2

C_a= permissible bending stress coefficient

= 1.0 for acceptance criteria set AC3

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

6.4.5. Side shell stiffeners

6.4.5.1. The effective net plastic section modulus, Z_{pl-net}, of each stiffener, in association with the effective plating to which it is attached, is not to be less than:

$$Z_{pl-n} = \frac{P_{im} s l_{bdg}^2}{f_{bdg} C_s \sigma_{yd}} \text{cm}^3$$

where:

P_{im}= bow impact pressure as given in Section 1/4.4 and calculated at the load calculation point defined in Chapter 1 Section 3/5.2.2, in kN/m^2

s =stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

l_{bdg}= effective bending span, as defined in Chapter 1 Section 4/2.1.1, in m

f_{bdg}= bending moment factor

$$= 8\left(1 + \frac{n_s}{2}\right)$$

n_s = 2.0 for continuous stiffeners or where stiffeners are bracketed at both ends

see 6.3.3.1 for alternative arrangements

C_s= permissible bending stress coefficient

= 0.9 for acceptance criteria set AC3

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

6.4.5.2. The net web thickness, t_{w-net}, of each stiffener is not to be less than:

$$t_{w-net} = \frac{P_{im} s l_{shr}}{2 d_{shr} C_t \tau_{yd}} \text{mm}$$

where:

l_{shr} = effective shear span, as defined in Chapter 1 Section 4/2.1.2, in m

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

P_{im}= bow impact pressure as given in Section 1/4.4 and calculated at the load calculation point defined in Chapter 1 Section 3/5.2.2, in kN/m^2

d_{shr}= effective web depth of stiffener, in mm, as defined in Chapter 1 Section 4/2.4.2.2

C_t= permissible shear stress coefficient

= 1.0 for acceptance criteria set AC3

$$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}} \text{ N/mm}^2$$

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

6.4.5.3. The slenderness ratio of each longitudinal is to comply with Section 4/2.

6.4.5.4. The minimum net thickness of breast hooks/diaphragm plates, t_{w-net}, is not to be less than:

$$t_{w-net} = \frac{s}{70}\sqrt{\frac{\sigma_{yd}}{235}} \text{ mm}$$

where:

s = spacing of stiffeners on the web, as defined in Chapter 1 Section 4/2.2, in mm. Where no stiffeners are fitted s is to be taken as the depth of the web

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

6.4.6. Definition of idealized bow impact load area for primary support members

6.4.6.1. The scantlings of items in 6.4.7 are based on the application of the bow impact pressure, as defined in Section 1/4.4, to an idealised area of hull envelope plating, where the bow impact load area, A_{slm}, is given by:

$$A_{slm} = \frac{1.1.LBC_b}{1000} \text{m}^2$$

where:
L = rule length, as defined in Chapter 1 Section 4/1.1.1.1
B = moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.1
C_b = block coefficient, as defined in Chapter 1 Section 4/1.1.9.1

6.4.7. Primary support members

6.4.7.1. Primary support members in the bow impact region are to be configured to ensure effective continuity of strength and the avoidance of hard spots.

6.4.7.2. To limit the deflections under extreme bow impact loads and ensure boundary constraint for plate panels, the spacing, S, measured along the shell girth of web frames supporting longitudinal framing or stringers supporting transverse framing is not to be greater than:

$$S = 3 + 0.008L_2 \text{ m}$$

where:
L_2= rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but not to be taken greater than 300m

6.4.7.3. End brackets of primary support members are to be suitably stiffened along their edge. Consideration is to be given to the design of bracket toes to minimise abrupt changes of cross-section.

6.4.7.4. Tripping arrangements are to comply with Section 4/2.3.3. In addition, tripping brackets are to be fitted at the toes of end brackets and at locations where the primary support member flange is knuckled or curved.

6.4.7.5. The net section modulus of each primary support member, Z_{net50}, is not to be less than:

$$Z_{net} = 1000\frac{f_{bdg-pt}P_{im}b_{slm}f_{slm}l_{bdg}^2}{f_{bdg}C_s\sigma_{yd}} \text{cm}^3$$

where:
f_{bdg-pt} = correction factor for the bending moment at the ends and considering the patch load

$$= 3f_{slm}^3 + 8f_{slm}^2 + 6f_{slm}$$

f_{slm} = patch load modification factor

$$= \frac{l_{slm}}{l_{bdg}}$$

l_{slm} = extent of bow impact load area along the span

$$= \sqrt{A_{slm}}$$

m, but not to be taken as greater than l_{bdg}
A_{slm}= bow impact load area, in m^2, as defined in 6.4.6.1
l_{bdg}= effective bending span, as defined in Chapter 1 Section 4/2.1.4, in m
P_{im}= bow impact pressure as given in Section 1/4.4 and calculated at the load calculation point defined in Chapter 1 Section 3/5.3.3, in kN/m^2
b_{slm}= breadth of impact load area supported by the primary support member, to be taken as the spacing between primary support members as defined in Chapter 1 Section 4/2.2.2, but not to be taken as greater than l_{slm}, in m

f_{bdg}= bending moment factor

= 12 for primary support members with end fixed continuous face plates, stiffeners or where stiffenersare bracketed in accordance with Chapter 1 Section 4/3.3 at both ends

C_s= permissible bending stress coefficient

= 0.8

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

6.4.7.6. The net shear area of the web, $A_{shr-net50}$, of each primary support member at the support/toe of end brackets is not to be less than:

$$A_{shr-net50} = \frac{5 f_{pt} P_{im} b_{slm} l_{shr}}{C_t \tau_{yd}} \text{cm}^2$$

where:

f_{pt}= patch load modification factor

$$= \frac{l_{slm}}{l_{shr}}$$

l_{slm}= extent of bow impact load area along the span

$$= \sqrt{A_{slm}}$$

m, but not to be taken as greater than l_{shr}

l_{shr}= effective shear span, as defined in Chapter 1 Section 4/2.1.5, in m

P_{im}= bow impact pressure as given in Section 1/4.4 and calculated at the load calculation point defined in Chapter 1 Section 3/5.3.2, in kN/m^2

b_{slm}= breadth of impact load area supported by the primary support member, to be taken as the spacing between primary support members as defined in Chapter 1 Section 4/2.2.2, but not to be taken as greater than l_{slm}, in m

C_t = permissible shear stress coefficient

= 0.75 for acceptance criteria set AC3

$$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}} \text{ N/mm}^2$$

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

6.4.7.7. The net web thickness of each primary support member, t_{w-net}, including decks/bulkheads in way of the side shell is not to be less than:

$$t_{w-net} = \frac{P_{im} b_{slm}}{\sin \varphi_w \, \sigma_{crb}}$$

where:

P_{im}= bow impact pressure as given in Section 1/4.4 and calculated at the load calculation point defined in Chapter 1 Section 3/5.3.2 or at the intersection of the side shell with the deck/bulkhead, in kN/m^2

b_{slm}= breadth of impact load area supported by the primary support member, to be taken as spacing between primary support members as defined in Chapter 1 Section 4/2.2.2, but not to be taken as greater than l_{slm}, in m

φ_w= angle, in degrees, between the primary support member web and the shell plate, see Figure 2.2.26

σ_{crb}= critical buckling stress in compression of the web of the primary support member or deck/bulkheadpanel in way of the applied load given by Section 4/3.2.1, in N/mm^2

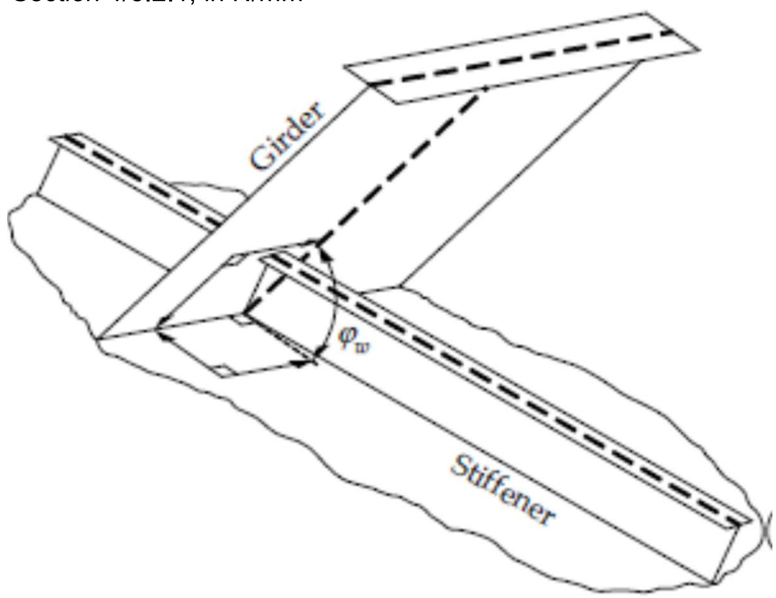


Figure 2.2.26: Angle between Shell Primary Member and Shell Plate

6.4.8. Connection of stiffeners to primary support members

6.4.8.1. Stiffeners are, in general, to be continuous. Where this not practicable end brackets complying with Chapter 1 Section 4/3.2.3 are to be provided.

6.4.8.2. The scantlings of the end connection of each stiffener are to comply with Chapter 1 Section 4/3.4.

7 Application of Scantling Requirements to Other Structure

7.1. General

7.1.1. Application

7.1.1.1. Application of the requirements of this Sub-Section are covered to plating, local and primary support members where the basic structural configurations or strength models assumed in Section 2/2 to 2/5 are not appropriate. These are general purpose strength requirements to cover various load assumptions and end support conditions. These requirements are not to be used as an alternative to the requirements of Section 2/2 to 2/5 where those sections can be applied.

7.1.1.2. The net scantlings described in 7.2 are related to gross scantlings as follows:

a. For plating and local support members, the gross thickness and gross cross- sectional properties are obtained from the requirements of 7.2.2 by adding the full corrosion additions specified in Chapter 1 Section 6/3.

b. For primary support members, the gross shear area, gross section modulus and other gross cross-sectional properties are obtained from the requirements of 7.2.3 by adding one half of the relevant full corrosion additions specified in Chapter 1 Section 6/3.

7.1.1.3. These requirements are to be applied in conjunction with all other appropriate requirements in Sections 2, 3 and 4 for the particular structural member under consideration, including longitudinal strength, minimum thickness, proportions and structural stability, strength assessment (FEM), fatigue and hull girder ultimate strength.

7.1.1.4. The requirements for local and primary support members are to be specially considered when the member is:

a. Part of a grillage structure
b. Subject to large relative deflection between end supports
c. Where the load model or end support condition is not given in Table 2.2.38.

7.1.1.5. The application of alternative or more advanced calculation methods will be specially considered.

7.2. Scantling Requirements

7.2.1. General

7.2.1.1. The design load sets to be applied to the structural requirements for the local and primary support members are given in Table 2.2.39, as applicable for the particular structure under consideration. The static and dynamic load components are to be combined in accordance with Table 2.1.3 and the requirements given in Section 1/6.3.

7.2.2. Plating and local support members

7.2.2.1. For plating subjected to lateral pressure the net thickness, tnet, is to be taken as the greatest value for all applicable design load sets given in Table 2.2.39, and given by:

$$t_{net} = 0.0158\alpha_p s\sqrt{\frac{|P|}{C_a\sigma_{yd}}}\ \text{mm}$$

where:

α_p = correction factor for the panel aspect ratio

$$= 1.2 - \frac{s}{2100 l_p}$$

P = design pressure for the design load set being considered, calculated at the load calculation point defined in Chapter 1 Section 3/5.1.2, in kN/m^2

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

l_p = length of plate panel, to be taken as the spacing of primary support members, S, unless carlings are fitted, in m

C_a = permissible bending stress coefficient for the design load set being considered, as given in Tables 2.2.10, 2.2.23 or 2.2.31, as applicable for the individual member being considered

σ_{yd} = specified minimum yield stress of the material, in N/mm^2

7.2.2.2. For stiffeners subjected to lateral pressure, point loads, or some combination thereof, the net section modulus requirement, Z_{net}, is to be taken as the greatest value for all applicable design load sets given in Table 2.2.39,, and given by:

$$Z_{net} = \frac{|P| s l_{bdg}^2}{f_{bdg} C_s \sigma_{yd}} \text{cm}^3$$

For lateral pressure loads

$$Z_{net} = \frac{1000 |F| s l_{bdg}}{f_{bdg} C_s \sigma_{yd}} \text{cm}^3$$

For point loads

$$Z_{net} = \frac{\left|\sum \frac{P_i s l_{bdg}^2}{f_{bdg-i}}\right| + \left|\sum \frac{1000\, F_j l_{bdg}}{f_{bdg-j}}\right|}{C_s \sigma_{yd}} \text{cm}^3$$

For a combination of loads

where:

P = design pressure for the design load set being considered, calculated at the load calculation point defined in Chapter 1 Section 3/5.2.2, in kN/m^2

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2

l_{bdg} = effective bending span, as defined in Chapter 1 Section 4/2.1.1

f_{bdg} = bending moment factor

For continuous stiffeners and where end connections are fitted consistent with idealisation of the stiffener as having fixed ends:

= 12 for horizontal stiffeners

= 10 for vertical stiffeners

For other configurations the bending moment factor may be taken as in Table 2.2.38

C_s = permissible bending stress coefficient for the design load set being considered as given in Tables 2.2.11, 2.2.24 or 2.2.32, as applicable for the individual member being considered

σ_{yd}= specified minimum yield stress of the material, in N/mm^2
F = point load for the design load set being considered, in kN
i = indices for load component i
j = indices for load component j

7.2.2.3. For stiffeners subjected to lateral pressure, point loads, or some combination thereof, the net web thickness, t_{w-net}, based on shear area requirements is to be taken as the greatest value for all applicable design load sets given in Table 2.2.39, and given by:

$$t_{w-net} = \frac{f_{shr}|P|sl_{shr}}{d_{shr}C_t\tau_{yd}}$$

mm, for lateral pressure loads

$$t_{w-net} = \frac{1000\, f_{shr}|F|}{d_{shr}C_t\tau_{yd}}$$

mm, for point loads

$$t_{w-net} = \frac{\left|\sum f_{shr-i}P_i sl_{shr} + \sum 1000 f_{shr-j}F_j\right|}{d_{shr}C_t\tau_{yd}}$$

mm, for a combination of loads

where:

P = design pressure for the design load set being considered, calculated at the load calculation point defined in Chapter 1 Section 3/5.2.2, in kN/m^2

f_{shr} = shear force factor

For continuous stiffeners and where end connections are fitted consistent with idealization of the stiffener as having fixed ends:

= 0.5 for horizontal stiffeners

= 0.7 for vertical stiffeners

For other configurations the shear force factor may be taken as in Table 2.2.38.

s = stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2
l_{shr} = effective shear span, as defined in Chapter 1 Section 4/2.1.2
d_{shr} as defined in Chapter 1 Section 4/2.4.2.2
C_t permissible shear stress coefficient for the design load set being considered as given in Tables 2.2.12 or 2.2.25, as applicable for the individual member being considered
$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}}$ N/mm^2
σ_{yd}= specified minimum yield stress of the material, in N/mm^2
F = point load for the design load set being considered, in kN
i = indices for load component i
j = indices for load component j

7.2.3. Primary support members

7.2.3.1. The requirements in 7.2.3 are applicable where the primary support member is idealised as a simple beam. More advanced calculation methods may be required to ensure that nominal stress level for all primary support members are less than the permissible stresses and stress coefficients given in 7.2.3.4 and 7.2.3.5 when subjected to the applicable design load sets. See also 7.1.1.4.

7.2.3.2. The section modulus and web thickness of the local support members apply to the areas clear of the end brackets. The section modulus and cross sectional shear areas of the primary support member are to be applied as required in the notes of Table 2.2.38

7.2.3.3. For primary support members intersecting with or in way of curved hull sections, the effectiveness of end brackets is to include an allowance for the curvature of the hull.

7.2.3.4. For primary support members the net section modulus requirement, Z_{net50}, is to be taken as the greatest value for all applicable design load sets given in Table 2.2.39, and given by:

$$Z_{net5} = \frac{1000|P|Sl_{bdg}^2}{f_{bdg}C_s\sigma_{yd}}\text{cm}^3$$

For lateral pressure loads

$$Z_{net50} = \frac{1000|F|l_{bdg}}{f_{bdg}C_s\sigma_{yd}}\text{cm}^3$$

For point loads

$$Z_{net50} = \frac{\left|\sum\frac{1000\quad _isl_{bdg}^2}{f_{bdg-i}}\right|+\left|\sum\frac{1000\,F_jl_{bdg}}{f_{bdg-j}}\right|}{C_s\sigma_{yd}}\text{cm}^3$$

For a combination of loads

where;

P = design pressure for the design load set being considered, calculated at the load calculation point defined in Chapter 1 Section 3/5.3.2, in kN/m^2

S = primary support member spacing, in m, as defined in Chapter 1 Section 4/2.2.2

l_{bdg} = effective bending span, as defined in Chapter 1 Section 4/2.1.4

f_{bdg} = bending moment factor, as given in Table 2.2.38.

C_s = permissible bending stress coefficient for the design load set being considered as given in Tables 2.2.16 or 2.2.27, as applicable for the individual member being considered

σ_{yd}= specified minimum yield stress of the material, in N/mm^2

F = point load for the design load set being considered, in kN

i = indices for load component i

j = indices for load component j

7.2.3.5. For primary support members the net shear area of the web, $A_{shr-net50}$, is to be taken as the greatestvalue for all applicable design load sets given in Table 2.2.38, and given by:

$$A_{shr-net50} = \frac{10f_{shr}|P|Sl_{shr}}{C_t\tau_{yd}}\text{ cm}^2$$

For lateral pressure loads

$$A_{shr-net50} = \frac{10\quad _{shr}|F|}{C_t\tau_{yd}}\text{ cm}^2$$

For point loads

$$A_{shr-net50} = \frac{\left|\sum 10f_{shr-i}P_il_{shr}+\sum 10\quad _{shr-j}F_j\right|}{C_t\tau_{yd}}\text{cm}^2$$

For a combination of loads

where:

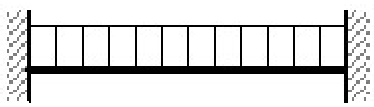
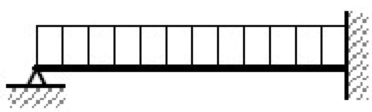
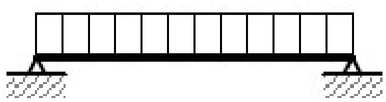
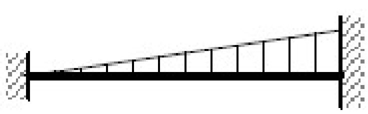
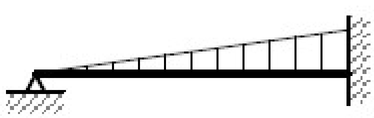
P = design pressure for the design load set being considered, calculated at the load calculation point defined in Chapter 1 Section 3/5.3.2, in kN/m^2

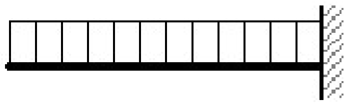
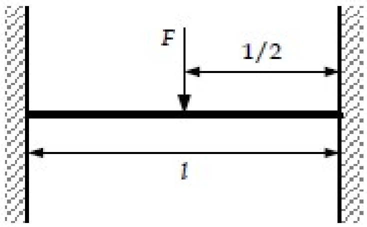
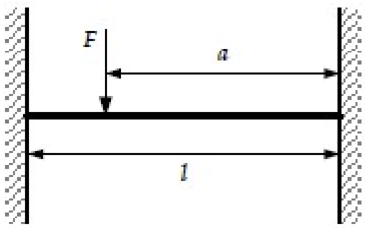
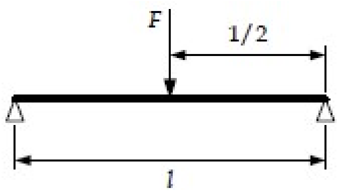
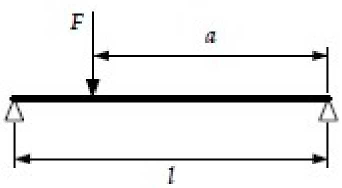
S = primary support member spacing, in m, as defined in Chapter 1 Section 4/2.2.2
l_{shr} = effective shear span, as defined in Chapter 1 Section 4/2.1.5
f_{shr} = shear force factor, as given in Table 2.2.38
C_t = permissible shear stress coefficient for the design load set being considered as given in Tables 2.2.16 or 2.2.28, as applicable for the individual member being considered

$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}}$ N/mm^2

σ_{yd} = specified minimum yield stress of the material, in N/mm^2
F = point load for the design load set being considered, in kN
i = indices for load component i
j = indices for load component j

Table 2.2.38: Values of f_{bdg} and f_{shr}

Load and boundary conditions				Bending moment and shear force factor (based on load at mid span where load varies)			Application
Load mode I	Position (1)			1	2	3	
	1 Support	2 Field	3 Support	f_{bdg1} f_{shr1}	f_{bdg2} -	f_{bdg3} f_{shr3}	
A				12.0 0.50	24.0 -	12.0 0.50	Built in at both ends. Uniform pressure distribution
B				- 0.38	14.2 -	8.0 0.63	Built in one end plus simply supported one end. Uniform pressure distribution
C				- 0.50	8.0 -	- 0.50	Simply supported, (bothends are free to rotate). Uniform pressure distribution
D				15.0 0.30	23.3 -	10.0 0.70	Built in both ends. Linearly varying pressure distribution
E				- 0.20	16.8 -	7.5 0.80	Built in one end plus simply supported one end. Linearly varying pressure

					distribution
F		- -	- -	2.0 1.0	Cantilevered beam. Uniform pressure distribution
G		8.0 0.5	8.0 -	8.0 0.5	Built in at both ends. Single point load in the centre of the span
H		$\frac{l^3}{a^2(l-a)}$ $\frac{a^2(3l-2a}{l^3}$	$\frac{l^4}{2a^2(l-a)^2}$ -	$\frac{l^3}{a(l-a)^2}$ $\frac{(l-a)^2(l}{l^3}$	Built in at both ends. Single point load, with Load anywhere in the span
I		- 0.5	4 -	- 0.5	Simply supported. Single point load in the centre of the span
J		- $\frac{a}{l}$	$\frac{l^2}{a(l-a)}$ -	- $\frac{l-a}{l}$	Simply supported. Single point load, load anywhere along the span

Note

1. The bending moment factor f_{bdg} for the support positions are applicable for a distance of $0.2l_{bdg}$ from the end ofthe effective bending span for both local and primary support members.
2. The shear force factor f_{shr} for the support positions are applicable for a distance of $0.2l_{shr}$ from the end of the effective shear span for both local and primary support members.
3. Application of f_{bdg} and f_{shr} for local support members:
   a) the section modulus requirement of local support members is to be determined using thelowest value of f_{bdg1} , f_{bdg2} and fb_{dg3}
   b) the shear area requirement of local support members is to be determined using thegreatest value of f_{shr1} and f_{shr3}.
4. Application of f_{bdg} and f_{shr} for primary support members:
   a) the section modulus requirement within $0.2l_{bdg}$ from the end of the effective span is generally to be determined using the applicable f_{bdg1} and f_{bdg3}, however fbdg is not to be taken greater than 12
   b) the section modulus of mid span area is to be determined using f_{bdg} =24, or f_{bdg2} from the table if lesser
   c) the shear area requirement of end connections within 0.2*l*shr from the end of the effective span is to be determined using f_{shr} = 0.5 or the applicable f_{shr1} or f_{shr3}, whichever is greater
   d) for models A through F the value of f_{shr} may be gradually reduced outside of $0.2l_{shr}$towards $0.5f_{shr}$ at mid span where f_{shr} is the greater value of f_{shr1} and f_{shr3}.

where:

l effective span, l_{bdg} and l_{shr} as applicable

l_{bdg} as defined in Chapter 1 Section 4/2.1.1 for local support members and Chapter 1 Section 4/2.1.4 for primary supportmembers

l_{shr}as defined in Chapter 1 Section 4/2.1.2 for local support members and Chapter 1 Section 4/2.1.5 for primary supportmembers

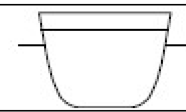
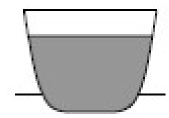
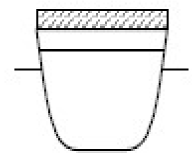
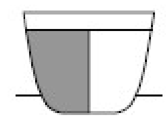
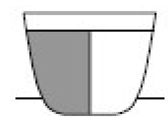
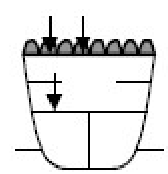
Type of Local Support and Primary Support Member	Design Load Set (1)	Load Component	External Draught	Comment	Diagrammatic Representation
Shell Envelope	1	P_{ex}	T_{sc}	Sea pressure only	
	2	P_{ex}	T_{sc}		
	5	P_{in}	T_{bal}	Tank pressure only. Sea pressure to be ignored	
	6	P_{in}	$0.25T_{sc}$		
External Decks	1	P_{ex}	T_{sc}	Green sea pressure only	
Cargo Tank Boundaries	3	P_{in}	$0.6T_{sc}$	Pressure from one side only Full tank with adjacent tank empty	
	4	P_{in}	-		
	11	$P_{in\text{-}flood}$	-		
Other Tank Boundaries or Watertight Boundaries	5	P_{in}	T_{bal}	Pressure from one side only Full tank with adjacent tank empty	
	6	P_{in}	$0.25T_{sc}$		
	11	$P_{in\text{-}flood}$	-		
Internal and External Decks or Flats	9	P_{dk}	T_{bal}	Distributed or concentrated loads only. Adjacent tanks empty. Green sea pressure may be ignored	
	10	P_{dk}	T_{bal}		

Table 2.2.39: Design Load Sets for Plating, Local Support Members and Primary Support Members

Where:

T_{sc}scantling draught, in m, as defined in Chapter 1 Section 4/1.1.5.5

T_{bal}minimum design ballast draught, in m, as defined in Chapter 1 Section 4/1.1.5.2

Notes

1. The specification of design load combinations, and other load parameters for the design loadsets are given in Table 2.2.14
2. When the ship's configuration cannot be described by the above, then the applicable Design Load Sets to determine the scantling requirements of structural boundaries are to be selected so as to specify a full tank onone side with the adjacent tank or space empty. The boundary is to be evaluated for loading from both sides.Design Load Sets are to be selected based on the tank or spaces contents and are to maximize the pressure on thestructural boundary, the draught to use is to be taken in accordance with the Design Load Set and this table. Design Load Sets covering the S and S+D design load combinations are to be selected. SeeNote 4 on Table 2.2.13 and Table 2.2.14.
3. The boundaries of void and dry space not forming part of the hull envelope are to beevaluated using Design Load Set 11. See Note 2.

SECTION 3 DESIGN VERIFICATION

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1. Hull Girder Ultimate Strength 345
2. Strength Assessment (FEM) 346
3. Fatigue Strength 357

1. Hull Girder Ultimate Strength

1.1. General

1.1.1. Application

1.1.1.1. The hull girder ultimate bending capability in sagging is to be assessed and tested to confirm that it fulfills the following criteria. The criteria are related to intact ship structures, in extreme at sea conditions. They do not cover hogging, harbour or damaged conditions.

1.1.1.2. In this Sub-Section the scantling requirements are to be applied within 0.4L amidships and additionally are to all other requirements within the rules.

1.1.1.3. The plate and stiffeners may be step by step reduced outside the 0.4L region of amidships towards the local requirements at the ends.

1.2. Rule Criteria

1.2.1. Vertical hull girder ultimate bending capacity

1.2.1.1. It is required that the ultimate bending capacity of vertical hull girder complies the following criteria:

$$\gamma_S M_{sw} + \gamma_W M_{w-sag} \leq \frac{M_U}{\gamma_R}$$

where

M_{sw} sagging still water bending moment, in kNm, to be taken as specified in Table 2.3.1.

M_{w-sag} sagging vertical wave bending moment, in kNm, to be taken as the midship sagging valuedefined in Section 1/3.4.1.1

M_u sagging vertical hull girder ultimate bending capacity, in kNm, as defined in Chapter 4 Section 1/1.1.1

γ_S,γ_W, γ_R are the partial safety factors for the design load combinations given in 1.4

1.3. Hull Girder Bending Moment Capacity

1.3.1. Calculation of capacity

1.3.1.1. According to Chapter 4 Section 1/1.1.1, the hull girder ultimate bending capacity, M_U, in sagging is to be calculated.

1.3.1.2. In Section 2/ 1.2.1, the effective area for the hull girder ultimate strength capacity assessment is mentioned.

1.3.1.3. Corrosion addition, $0.5t_{corr}$ (Chapter 1 Section 6/3.2), should be the basis for the estimation of the Net Scantlings

1.4. Partial Safety Factors

1.4.1. General

1.4.1.1. According to the single step method the partial safety factors given in Table 9.1.1 shall be applied when M_U is calculated in Chapter 4 Section 1/2.1 or in the incremental method in Chapter 4 Section 1/2.2.. For two dissimilar designs load combinations, the partial safety factors are given and in this case both combinations are to be confirmed.
Note that the definition of M_{sw} is different for each combination.

Table 2.3.1 Partial Safety Factors

Design load combination	*Definition of Still Water Bending Moment, M_{sw}*	γ_S	γ_W	γ_R
a)	Permissible sagging still water bending moment, $M_{swperm\text{-}sea}$, in kNm, see Section 1/2.1.1	1.0	1.2	1.1
b)	Maximum sagging still water bending moment for operational seagoing homogeneous full load condition, $M_{sw\text{-}full}$, in kNm, see note 1	1.0	1.3	1.1

where:
γ_S partial safety factor for the sagging still water bending moment
γ_W partial safety factor for the sagging vertical wave bending moment covering environmental and wave load prediction uncertainties
γ_R partial safety factor for the sagging vertical hull girder bending capacity covering material, geometric and strength prediction uncertainties

Notes
1) The maximum sagging still water bending moment is to be taken from the departure condition with the ship homogeneously loaded at maximum draught and corresponding arrival and any mid-voyage conditions.

2. Strength Assessment (FEM)

2.1. General

2.1.1. Application

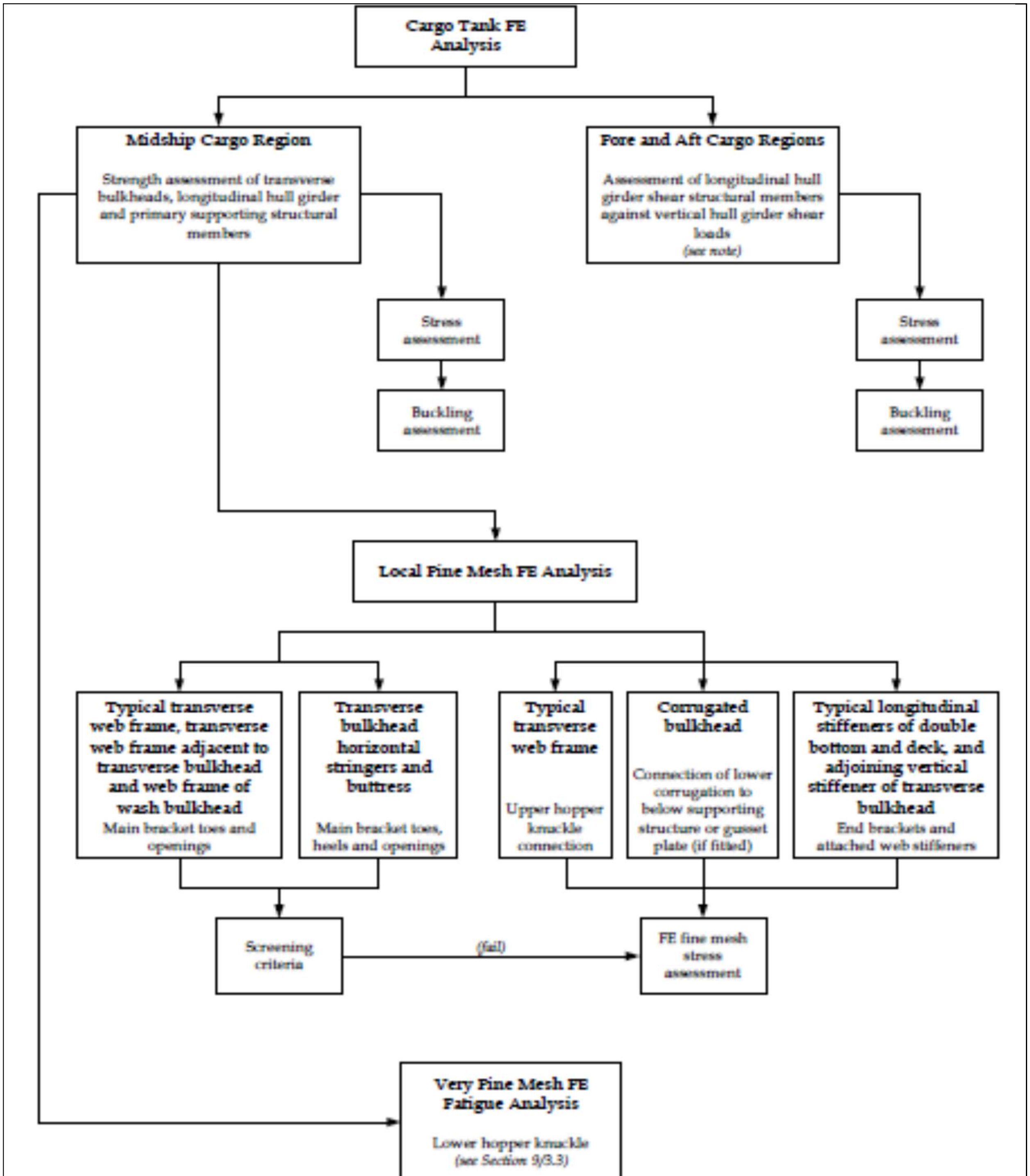
2.1.1.1. It is compulsory to have a strength assessment of the hull structure using finite element analysis

2.1.1.2. The finite element analysis is comprise of two parts:
a) Cargo tank analysis in order to evaluate the strength of longitudinal hull girder structural members, primarily supporting structural members and transverse bulkheads.
b) Fine mesh analysis in order to evaluate detailed stress levels in local structural details.

2.1.1.3. In Figure 2.3.1, a flow diagram is drawn to show the minimum requirement of finite element analysis.

2.1.1.4. In accordance with the requirements given in Chapter 4 Section 2,, the structural assessment is to be assessed. As specified in 2.2.5 and 2.3.5, the structural assessment is to confirm that the acceptance criteria are fulfilled.

2.1.1.5. According to 2.4, the structural assessment verified the application of the scantlings within the cargo tank region.



Note

1) The strength assessment of longitudinal hull girder shear structural members, as defined in 2.2.1.1 and Chapter 1 Section 4/Table 1.4.1, against hull girder vertical shear loads in way of transverse bulkheads may be based on the midship cargo tank finite element model with modification of plate and stiffener properties where appropriate, see Chapter 4 Section 2/1.1.1 and Chapter 4 Section 4/2.2.1.

Figure 2.3.1 Minimum Requirement on Finite Element Analysis

2.1.2. Submission of results

2.1.2.1. It is required to submit a detailed report of the structural analysis in order to verify whether the rules applicable have been complied with the specified structural design criteria. The following information shall be comprised in this report:

a) List of plans used including dates and versions,
b) Detailed description of structural modelling including all modelling assumptions and any deviations ingeometry and arrangement of structure compared with plans,
c) Plots to demonstrate correct structural modelling and assigned properties,
d) Details of material properties, plate thickness, beam properties used in the model,
e) Details of boundary conditions,
f) Details of all loading conditions reviewed with calculated hull girder shear force and bending momentdistributions,
g) Details of applied loads and confirmation that individual and total applied loads are correct,
h) Plots and results that demonstrate the correct behaviour of the structural model under the applied loads,
i) Summaries and plots of global and local deflections,
j) Summaries and sufficient plots of stresses to demonstrate that the design criteria are not exceeded in anymember,
k) Plate and stiffened panel buckling analysis and results,
l) Tabulated results showing compliance, or otherwise, with the design criteria,
m) Proposed amendments to structure where necessary, including revised assessment of stresses, buckling andfatigue properties showing compliance with design criteria.

2.1.3. Computer programs

2.1.3.1 IRS recognised any finite element computation program may be used to assess the stress and deflection of the hull structure, on condition that the combined effects of bending, shear, axial and torsional deformations are taken into account.

2.1.3.2 As required by Section 4/4 the computer program employed for the assessment of panel buckling proficiency is to consider the collective interaction of bi-axial compressive stresses, shear stress and lateral pressure loads.

2.1.3.3 A computer program that has been confirmed to produce reliable results to the satisfaction IRS is considered as a recognised program. For getting approval, it is mandatory to submit the full particulars of the computer program, including calculation output which is used are not supplied or recognised by IRS. It is suggested that the designers refer to the IRS on the suitability of the computer programs projected to be employed prior to the starting of any analysis work.

2.2. Cargo Tank Structural Strength Analysis

2.2.1. Objective and scope

2.2.2.1. The enquiry is to cover at least the assessment of:

a) Longitudinal hull girder structural members, primary supporting structural members and transverse bulkheads in the midship cargo tank region, and

b) Longitudinal hull girder shear structural members in way of transverse bulkheads against hull girder vertical shear loads within the cargo area. As defined in Chapter 1 Section 4/Table 1.4.1, these structural members include side shell, inner hull longitudinal bulkheads containing upper sloped plate where fixed, hopper, longitudinal bulkheads and double bottom girders. The essential strengthening of transverse bulkhead located in the forward, midship or aft cargo region shall be based on the maximum hull girder shear force. On the other hand assessment may be done in order to define the strengthening requirement of individual transverse bulkhead position. In Chapter 4 Section 2/1.1.1 the details are provided.

2.2.2.2. The essential strengthening of transverse bulkhead located in the forward, midship or aft cargo region shall be based on the maximum hull girder shear force. In order to define the strengthening requirement in way of individual transverse bulkhead position,conversely assessment may be done. In Chapter 4 Section 2/1.1.1 the details are provided.

2.2.2.3. It is required that the analysis is confirming that the following are within the acceptance principles under the applied static and dynamic loads:

a) Stress level in the plating of longitudinal hull girder structural members, primary support structural members and transverse bulkheads, face plate of primary support members modelled by plate or rod elements.
b) Buckling capability of plates and stiffened panels.

2.2.2. Structural modeling

2.2.2.1. As described in Chapter 1 Section 6/3.3.6.1 and Chapter 4 Section 2/2.2.1.5, the modelling scantlings of the cargo tank finite element model shall be based on net scantlings.

2.2.2.2. Cargo tank finite element model's length shall cover three cargo tank lengths. The middle tank of the finite element model is to represent the cargo tank of the greatest length where the tanks in the midship cargo region are of different lengths. In the finite element model, all main longitudinal and transverse structural elements are to be represented. These comprise of inner and outer shell, double bottom floor and girder system, transverse and vertical web frames, stringers, transverse and longitudinal bulkhead structures. It is required that all plating and stiffeners, as well as web stiffeners on these structural elements are to be modelled.

2.2.2.3. As far as practical the mesh of the finite element model is to follow the stiffening system of the structure and the actual plate panels between stiffeners is to be represented.

2.2.2.4. As given in Chapter 4 Section 2/2.2., the structure modelling is to be compliant with the requirements.

2.2.3. Loads and loading conditions

2.2.3.1. In the structural analysis it is required to verify the combinations of the ship static and dynamic loads which are likely to enforce the most difficult load regimes on the hull structure.

2.2.3.2. In Chapter 4 Section 2/2.3.1 the standard load cases which are going to be used in the structural analysis are provided.Seagoing conditions (design load combination S + D) and harbour/tank testing conditions (designload combination S) are covered in these load cases.

2.2.3.3. These additional loading conditions are to be verified where the loading conditions mentioned by the designer and are not covered by the standard load cases; see also Chapter 4 Section 2/2.3.1.

2.2.4. Load applications and boundary conditions

2.2.4.1. As given in Chapter 4 Sections 2/2.4 and 2/2.5, the application of local and hull girder loads to the finite element model is to be according to the requirements. All hull girder and local loads acting simultaneously are to be applied to the model.

2.2.4.2. In Chapter 4 Section 2/2.6, the boundary conditions to be which are applied are provided.

2.2.5. Acceptance criteria

2.2.5.1. In accordance with Chapter 4 Section 2/2.7, verification of results against the acceptance criteria shall be done.

2.2.5.2. Validation of results against the acceptance criteria is to be performed for all structural members within the longitudinal extent of the middle tanks of the three tank FE model, and the regions forward and aft of the middle tanks up to the extent of the transverse bulkhead stringer and buttress structure. For the calculation of shear strength in way of transverse bulkheads against hull girder shear loads, stress level and buckling capability of inner hull longitudinal bulkheads as well as upper sloped plate where fitted, side shell, longitudinal bulkheads, hopper and bottom longitudinal girders are to be tested against the acceptance criteria. See also Chapter 4 Section 2/2.7.1.

2.2.5.3. In order to demonstrate the structural analysis in which the permissible von Mises stress criteria and utilisation factor against buckling for plate and stiffened panels are specified shall not exceed Tables 2.3.2 and 2.3.3

2.2.5.4. As described in Chapter 1 Section 6/3.3.6.2 and Chapter 4 Section 2/2.7.3 capacity models used for the assessment of local buckling capability of plate and stiffened panels are to be based on deduction of full corrosion addition thickness from the plate and stiffeners.

2.2.5.5. As given in Tables 2.3.2 and 2.3.3, wherever a lower stool is not fixed to a transverse or longitudinal corrugated bulkhead, reduction of the maximum allowable stresses and buckling utilisation factors by 10% are required for the corrugation and below supporting structure within the extent which can be defined as follows:

a) Full height of the corrugation
b) Supporting structure for a transverse corrugated bulkhead − longitudinally within half a web frame space forward and aft of the bulkhead
c) Supporting structure for a longitudinal corrugated bulkhead – transversely within three longitudinal stiffener spacings from each side of the bulkhead.

Table 2.3.2 Maximum Permissible Stresses

Structural component	*Yield utilisation factor*
Internal structure in tanks	
Plating of all non-tight structural members including transverse web framestructure, wash bulkheads, internal web, horizontal stringers, floors and girders. Face plate of primary support members modeled using plate or rod elements	$\lambda_y \leq 1.0$ (load combination S+D)$\lambda_y \leq 0.8$(load combination S)
Structure on tank boundaries	
Plating of deck, sides, inner sides, hopper plate, bilge plate, plane and corrugatedcargo tank longitudinal bulkheads. Tight floors, girders and webs	$\lambda_y \leq 0.9$(load combination S + D) $\lambda_y \leq 0.72$(load combination S)
Plating of inner bottom, bottom, plane transverse bulkheads and corrugatedbulkheads.	$\lambda_y \leq 0.8$(load combination S + D) $\lambda_y \leq 0.64$(load combination S)

where:

$\lambda_y$yield utilisation factor

$= \frac{\sigma_{vm}}{\sigma_{yd}}$for plate elements in general

$= \frac{\sigma_{rod}}{\sigma_{yd}}$for rod elements in general

σ_{vm}Von Mises stress calculated based on membrane stresses at element's centroid, in N/mm^2

σ_{rod}axial stress in rod element, in N/mm^2

σ_{yd}specified minimum yield stress of the material, in N/mm^2, but not to be taken as greater than 315 N/mm^{2}for load combination S + D in areas of stress concentration (2)

Note

1) Structural items given in the table are for guidance only. Stresses for all parts of the FE model specified in 2.2.5.2 are to be verified against the permissible stress criteria. See also Chapter 4 Section B/2.7.1
2) Areas of stress concentration are corners of openings, knuckle joints, toes and heels of primary supporting structural members and stiffeners
3) Where a lower stool is not fitted to a transverse or longitudinal corrugated bulkhead, the maximum permissible stresses are to bereduced by 10% in accordance with 2.2.5.5.
4) The yield utilisation factor for plane and corrugated longitudinal bulkheads between cargo tanks may be taken as for non-tight structural members for FE load cases where either both sides of the bulkhead are empty or both sides are loaded. The water-tightbottom girder under the longitudinal bulkhead is to be treated as a tight structural member.

Table 2.3.3 Maximum Permissible Utilisation Factor Against Buckling

Structural component	*Buckling utilisation factor*
Plate and stiffened panels (3)	$\eta \leq 1.0$ (load combination S + D) $\eta \leq 0.8$ (load combination S)
Web plate in way of openings	$\eta \leq 1.0$ (load combination S + D) $\eta \leq 0.8$ (load combination S)
Pillar buckling of cross tie structure	$\eta \leq 0.75$(load combination S + D) $\eta \leq 0.65$ (load combination S)
Corrugated bulkheads — flange buckling — column buckling	$\eta \leq 0.9$ (load combination S + D) $\eta \leq 0.72$(load combination S)

where:

η utilisation factor against buckling calculated in accordance with Chapter 4 Sections 4/5 and 2/2.7.3. Also see Section 4/3.4.1 for web plate in way of openings and Section 4/3.5.1 for cross tie structure

Note

1) Buckling capability of curved panels (e.g. bilge plate), face plate and tripping bracket of primary supporting members are notassessed based on finite element stress result
2) Where a lower stool is not fitted to a transverse or longitudinal corrugated bulkhead, the maximum permissible bucklingutilisation factors are to be reduced by 10% in accordance with 2.2.5.5
3) Permissible buckling utilisation factors specified in this table are applicable for the reference advanced buckling method givenin Chapter 4 Section 4/1.1.2. If alternative buckling procedures are used the permissible utilisation factors are to be assessed and ifrequired adjusted to meet acceptance criteria for equivalence specified in Chapter 4 Section 4/1.1.2.

2.3. Local Fine Mesh Structural Strength Analysis

2.3.1. Objective and scope

2.3.1.1. The following areas in the midship cargo region are to be verified for tankers of conventional arrangements, as a minimum requirement:

a) Main bracket toes and openings at critical places and upper hopper knuckle joint of a typical transverse web frame located in the midship tank. Main bracket toes and openings at critical locations of transverse and vertical webs shall be located where a wash bulkhead is fixed.
b) Main bracket toes and openings at critical locations on a typical transverse web frame adjacent to a transverse bulkhead in way of the transverse bulkhead horizontal stringers
c) Main bracket toes, heels and openings at critical locations of horizontal stringers, connection of transverse bulkhead to double bottom girder or buttress of a typical transverse bulkhead
d) Connections of transverse and longitudinal corrugated bulkheads to bottom stool or inner bottom anddouble bottom supporting structure where a lower stool is not fitted. If a gusset plate is fitted the connection between the corrugation and the upper corners of the gusset are to be assessed
e) End brackets and attached web stiffeners of typical longitudinal stiffeners of double bottom and deck, andadjoining vertical stiffener of transverse bulkhead.

2.3.1.2. In accordance with Chapter 4 Section 2/3.1, the selection of critical locations on the structural members is described in 2.3.1.1 to perform fine mesh analysis.

2.3.1.3. A fine mesh analysis is to be done in order to demonstrate satisfactory scantlings where the stress level in areas of stress concentration on structural members are not specified in 2.3.1.1 and does not exceed the acceptance criteria of the cargo tank analysis.

2.3.1.4. A fine mesh analysis may be done to demonstrate satisfactory scantlings where the geometry cannot be satisfactorily represented in the cargo tank finite element model. In cases where fine mesh analysis is done, the average stress within an area equal to that specified in the cargo tank analysis (typically s by s) is to fulfill the requirements given in Table 9.2.1. See also Note 1 of Table 9.2.3.

2.3.2. Structural modeling

2.3.2.1. As given in Chapter 4 Section 2/ 3.2, the fine mesh structural models are to be in accordance with the requirements.

2.3.2.2. The fine mesh analysis may be done by means of a separate local finite element model with fine mesh zones, in combination with the boundary conditions attained from the cargo tank model, or by integrating fine mesh zones into the cargo tank model.

2.3.2.3. The calculated stresses at the areas of interest are not significantly affected by the imposed boundary conditions and application of loads in finite element models. In Chapter 4 Section 2/3.2 requirements on the extension of local finite element models are given.

2.3.2.4. The localised area of high stress shall be represented by the fine mesh zone.The finite element mesh size not greater than 50mm x 50mm within the fine mesh zones is to be considered.not greater than 50mm x 50mm. The extent of the fine mesh zone is to be according to Chapter 4 Section 2/3.2.

2.3.2.5. In accordance with Chapter 1 Section 6/3.3.6.3 and Chapter 4 Section 2/3.2 the fine mesh models are to be based on the net scantlings.

2.3.3. Loads and loading conditions

2.3.3.1. As required by 2.2.3, for the standard load cases, and any other specifically specified load cases, fine mesh detailed stress analysis is to be conducted.

2.3.4. Load applications and boundary conditions

2.3.4.1. Asgiven in Chapter 4 Section 2/3.4, the application of loads and boundary conditions to the finite element model is to be in accordance with the requirements.

2.3.5. Acceptance criteria

2.3.5.1. In accordance with Chapter 4 Section 2/3.5, confirmation of stress results against the acceptance criteria is to be obtained.

2.3.5.2. The structural assessment is requiredto establish that the von Mises stresses attained from the fine mesh finite element analysis do not exceed the maximum allowable stress criteria as specified in Table 9.2.3.

Table 2.3.3 Maximum Permissible Membrane Stresses for Fine Mesh Analysis

Element stress	*Yield utilisation factor*
Element not adjacent to weld	$\lambda y \le 1.7$ (load combination S + D) $\lambda y \le 1.36$ (load combination S)
Element adjacent to weld	$\lambda y \le 1.5$ (load combination S + D) $\lambda y \le 1.2$ (load combination S)

where:
λ_y yield utilisation factor
$= \frac{k\sigma vm}{235}$ for plate element
$= \frac{K\sigma rod}{235}$ for rod or beam element
σ_{vm} von Mises stress calculated based on membrane stress at element's centroid, in N/mm^2
σ_{rod}axial stress in rod element, in N/mm^2
k higher strength steel factor, as defined in Chapter 1 Section 6/1.1.4 but not to be taken as less than 0.78 for loadcombination S + D

Note

1) Where the von Mises stress of the elements in the cargo tank FE model in way of the area under investigation by fine meshexceeds its permissible value specified in Table 9.2.1, average von Mises stress, obtained from the fine mesh analysis, calculatedover an area equivalent to the mesh size of the cargo tank finite element model is to be less than the permissible value specifiedin Table 9.2.1

2) The maximum permissible stresses are based on the mesh size of 50mm x 50mm. Where a smaller mesh size is used, an averagevon Mises stress calculated in accordance with Chapter 4 Section 2/3.5.1 over an area equal to the specified mesh size may be used tocompare with the permissible stresses.

3) Average von Mises stress is to be calculated based on weighted average against element areas:

$$\sigma_{vm-a} = \frac{\sum_1^n A_i\, \sigma_{vm-i}}{\sum_1^n A_i}$$

where
$\sigma_{vm-av}$is the average von Mises stress
σ_{vm-I} is the von Mises stress of the ith plate element within the area considered
$A_i$is the area of the ith plate element within the area considered
n is the number of elements within the area considered

4) Stress averaging is not to be carried across structural discontinuities and abutting structure

5) Where a lower stool is not fitted to a transverse or longitudinal corrugated bulkhead, the maximum permissible stresses are to bereduced by 10% for the areas under investigation by fine mesh analysis.

2.4. Application of Scantlings in Cargo Tank Region

2.4.1. General

2.4.1.1. In this sub-section, compliant with the given requirements, the application of the scantlings fulfills the requirements of the finite element strength assessment, to the structure within the cargo tank region.

2.4.1.2. The application given in this sub-section accepts the material having same yield strength of the structure is sustained throughout the cargo tank region. The essential scantlings are to be assessed where steel having dissimilar yield strength is applied.

2.4.1.3. The scaling process given in this sub-section is based on scantlings that gratified the requirements given in Section 3/2 and Chapter 4 Section 2.

2.4.1.4. According to the specification in Chapter 1 Section 6/Table 1.6.1,, the net thickness and sectional properties for plating and local support members which are described in this sub-section are based on deduction of full corrosion addition from the gross scantlings. The gross thickness of plating, web and face plate of local support members are to be attained by addition of the full corrosion added to the net thickness.

2.4.2. Application of scantlings to deck

2.4.2.1. Within 0.4L amidships, the scantlings of deck plating and deck longitudinal stiffeners are to be sustained longitudinally. The scantlings of deck plating and deck longitudinal stiffeners at defined transverse location within 0.4L amidships are not to be taken as less than the maximum of that required for the corresponding transverse location along the length of the middle tanks of the cargo tank finite element model required by Chapter 4 Section 2/1.1.1.5.

2.4.2.2. The scantlings of the deck plating and deck longitudinal stiffeners may be narrowing to that required by Section 2 at the ends of the cargo tank region outside 0.4L amidships.

2.4.3. Application of scantlings to inner bottom

2.4.3.1. The thickness of inner bottom plating may differ along the length and breadth of a tank.

2.4.3.2. The scantlings of the inner bottom plating and longitudinal stiffeners of midship cargo tanks are not to be less than that required for the corresponding location of the middle tanks of the cargo tank finite element model required by Chapter 4 Section 2/1.1.1.5. Other than the fore-most and aft-most cargo tanks, the scantlings are to be sustained for all tanks within the cargo region,.

2.4.3.3. Provided that the spacing of primary support members are not reduced in the forward and/or aft cargo tank, the scantlings of the inner bottom longitudinal stiffeners are not to be less than the scantling requirements for the midship cargo tanks for the fore-most and aft-most cargo tanks. The minimum net thickness of the inner bottom plate, $t_{ib\text{-}net}$, is given by:
$t_{btm-net}$, is to obtained as follows :

$$t_{ib-n} = t_{ib-net-mid}\left[\frac{l_{bdg}}{l_{bdg-m}}\right]^{0.25}\frac{s_{ib}}{s_{ib-mid}} \text{ mm}$$

where

$t_{ib-net-mid}$ required net thickness of the inner bottom plating for the corresponding location in the midship tank, in mm

l_{bdg} effective bending span, of floor at location under consideration,in accordance with Figure 1.4.10, in m

l_{bdg-m} effective bending span, of floor at corresponding location in midship tank, defined in accordance with Figure 1.4.10, in m

S_{ib} spacing between longitudinal stiffeners at location under consideration, in mm

S_{ib-mid} spacing between longitudinal stiffeners at corresponding location in midship tank, in mm

2.4.4. Application of scantlings to bottom

2.4.4.1. Within 0.4L amidships, the scantlings of bottom longitudinal stiffeners are to be maintained longitudinally. The scantlings of the bottom longitudinal stiffener at a given transverse location within 0.4L amidships are not to be less than the maximum of that required for the corresponding transverse location along the length of the middle tanks of the cargo tank finite element model required by Chapter 4 Section 2/1.1.1.5.

2.4.4.2. The scantlings of the bottom longitudinal stiffeners may be tapered to that required by Section 2 at the ends of the cargo region, outside 0.4L amidships.

2.4.4.3. The thickness of the bottom plating may differ along the length and breadth of a tank. According to the requirement of Chapter 4 Section 2/1.1.1.5, the bottom platethicknesses of midship tanks are not to be less than that necessary for the corresponding location of the middletanks of the cargo tank finite element model. Other than the fore-most and aft-most cargo tanks, these thicknesses are to bekept for all tanks within the cargo region.

2.4.4.4. For the fore-most and aft-most cargo tanks, the required minimum net thickness of the bottom plating, $t_{btm-net}$, is to obtained as follows :

$$t_{btm-net} = t_{btm-net-mid}\left[\frac{l_{bdg}}{l_{bdg-mid}}\right]^{0.25}\frac{s_{btm}}{s_{btm-mid}} \text{ mm}$$

where

$t_{btm-net-mid}$ required net thickness of the bottom plating for the corresponding location in the midship tank, in mm

l_{bdg} effective bending span, of floor at location under consideration, in accordance with Figure 1.4.10, in m

$l_{bdg-mid}$ effective bending span, of floor at corresponding location in midship tank, defined inaccordance with Figure 1.4.10, in m

S_{btm} spacing between longitudinal stiffeners at location under consideration, in mm

$S_{btm-mid}$ spacing between longitudinal stiffeners at corresponding location in midship tank, in mm

2.4.5. **Application of scantlings to side shell, longitudinal bulkheads and inner hull longitudinal bulkheads**

2.4.5.1. Within 0.4L amidships, the scantlings of plating and longitudinal stiffeners of side shell, longitudinal bulkheads and inner longitudinal bulkheads within 0.15D from the deck are to be sustainedlongitudinally.

As required by Chapter 4 Section 2/1.1.1.5, the scantlings of plating and longitudinal stiffener at a given height are not to be less than the maximum of that required for the corresponding vertical location along the length of the middle tanks of the cargo tank finite element model.The scantlings of the plating and stiffeners within 0.15D from the deck may be taperedto that required by Section 2 at the ends of the cargo tank region, outside 0.4L amidships.

2.4.5.2. Outside 0.15D from the deck, the plate thickness of side shell, longitudinal bulkheads and inner hull longitudinal bulkheads, as well as hopper plating, may differ along the length and height of a tank. Away from the transverse bulkheads, the plate thickness is not to be less than that required for the corresponding location of the middle tanks of the cargo tank finite element model required by Chapter 4 Section 2/1.1.1.5. Except for the fore-most and aft-most cargo tanks, these scantlings are to be conserved for all tanks within the cargo region.

The minimum net thickness of the side shell, longitudinal bulkheads or inner hull longitudinal bulkheads (including hopper plating) plating outside 0.15D from the deck for the fore-most and aft-most cargo tanks is given by:

$$t_{net} = t_{net-m} \frac{S}{S_{mid}} \text{ mm}$$

Where

t_{net-m} required net thickness for corresponding location in the midship tank, in mm

Sspacing between longitudinal stiffeners at location under consideration, in mm

S_{mid}spacing between longitudinal stiffeners at corresponding location in midship tank, in mm

2.4.5.3. The plate thickness of side shell, longitudinal bulkheads and inner hull longitudinal bulkheads, together with hopper plating, in way of transverse bulkheads required for strengthening against hull girder shear loads is not to be less than that required by Chapter 4 Sections 2/1.1.1.6, 2/1.1.1.7 and 2/1.1.1.8. Within 0.15 D from the deck, the plate thicknesses in way of transverse bulkheads are not to be taken as less than that required by 2.4.5.1.The plate thicknesses in way of transverse bulkheads are not to be taken as less than that required by 2.4.5.2, outside 0.15D from the deck.

2.4.5.4. Outside 0.15D from the deck, the scantlings of longitudinal stiffeners of side shell, longitudinal bulkheads, inner longitudinal bulkheads and hopper plate at a given height, are not to be less than that essential for the corresponding vertical location of the middle tanks of the cargo tank finite element model as required by Chapter 4 Sections 2/1.1.1.5. These scantlings are to be sustained for all tanks within the cargo region.

2.4.6. Application of scantlings to transverse bulkheads

2.4.6.1. Along the height and breadth of the bulkhead the scantlings of transverse bulkhead plating, stiffeners and horizontal stringers may differ. The scantlings at a given location are not to be less than the maximum necessary at the corresponding location of both middle tank end transverse bulkheads of the cargo tank finite element model as required by Chapter 4 Sections 2/1.1.1.5.

2.4.7. Application of scantlings to primary structural support members

2.4.7.1. For primary structural support members the web thickness may differ along the length, breadth and height of a tank. The scantlings of the primary structural support members are not to be less than that essential for the corresponding location of the middle tanks of the cargo tank finite element model required by Chapter 4 Sections 2/1.1.1.5. Except the fore-most and aft-most cargo tanks, These scantlings are to be sustained for all tanks within the cargo region.

2.4.7.2. In accordance with Section 2/2.6.9, scantling requirements for primary support members in the fore-most and aft-most cargo tanks can be find out by scaling the scantlings of the corresponding structural members in the midship tanks.

2.4.8. Structural details and openings

2.4.8.1. Within the cargo tank region, arrangement and scantlings of openings and structural details of primary structural members, fulfilling the requirements of Chapter 4 Sections 2/3, are to be applied to the corresponding structural members in all tanks.

3. Fatigue Strength

3.1. Fatigue Evaluation

3.1.1. General

3.1.1.1. This Sub-Section, together with Chapter 4 Sections 3, deals with the minimum Rule requirements for design against fatigue failure for the structural details specified in these Rules. Structural details at other locations that are considered to be critical may need calculation using a procedure constant with that restricted in these Rules.

3.1.1.2. The fatigue criteria, relevant to a broad range of structural details and arrangements, are to be used for the calculation of fatigue strength using numerical techniques.

3.1.1.3. As specified in 3.4, the fatigue analysis is to be executed using either a ‘nominal stress approach’ or a ‘hot spot stress approach’ dependent on the structural details. The procedure is shown in Figure 2.3.2.

3.1.1.4. In a minimal stress approach, based on the applied loads and the structural properties of the component, stresses in a structural component are assessed by using either analytical methods (e.g. a beam model) or using numerical methods (e.g. a coarse finite element mesh).

3.1.1.5. In a hot spot stress approach, local stresses at a critical location (hot spot) where fatigue cracks may start are assessed by numerical methods (e.g. a fine mesh finite element analysis). The analysis considers the influence of structural discontinuities caused by the geometry connection but ignores the effects of welds.

3.2. Fatigue Criteria

3.2.1. Corrosion model

3.2.1.1. In accordance with Chapter 1 Section 6/3.3.7 net thicknesses are to be used in the fatigue assessment.

3.2.2. Loads

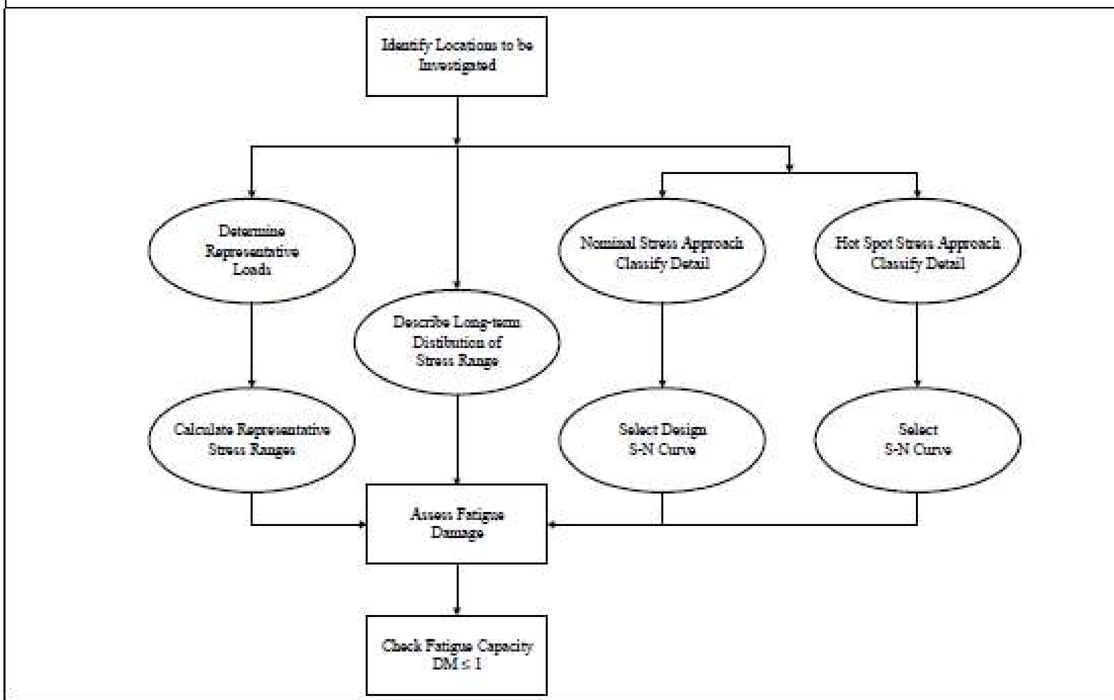
3.2.2.1. In Section 1/3, the mentioned loads which are based on the North Atlantic wave environment, are to be used for the fatigue assessment. Additional secondary cyclic loading, such as slamming, low cycle, or vibration induced fatigue, which may result in important levels of stress range over the anticipated lifetime of the vessel, even though not within the scope of these Rules, may need to be particularly considered.

3.2.2.2. For the purposes of load application and fatigue strength assessment these Rules take up a 10^{-4} probability level of exceedance.

3.2.3. Acceptance criteria

3.2.3.1. In this sub-section and Chapter 4 Sections 3, the stated 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, see Chapter 4 Sections 3/1.4.1.1.. The calculated fatigue damage, DM, is to be less than or equal to 1 for the design life of the ship, which is not to be taken as less than 25 years.

Figure 2.3.2 Schematic of Fatigue Assessment Process (For Each Location or Structural Detail)



3.3. Locations to Apply

3.3.1. Longitudinal structure

3.3.1.1. A fatigue strength calculation is to be carried out and submitted for the end connections oflongitudinal stiffeners to transverse bulkheads, as well as wash bulkheads and web frames within the cargo tank region, placed on the bottom shell, inner bottom, side shell, inner hull longitudinal bulkheads, longitudinal bulkheads and strength deck.

3.3.1.2. A fatigue strength calculation is to cover for scallops in way of block joints on the strengthdeck within the cargo tank region.

3.3.2. Transverse structure

3.3.2.1. Assessment of fatigue strength shall be done and submitted for the knuckle between inner bottom and hopper plate for at least one transverse frame close to amidships. The total stress range for fatigue assessment is to be determined from a fine mesh finite element analysis.

3.4. Fatigue Assessment Methods

3.4.1. Nominal stress approach

3.4.1.1. As described in Chapter 4 Sections 3/1, the nominal stress approach, is to be used for the fatigue evaluation of the following items:

a) Longitudinal stiffener end connections to the transverse bulkheads, including wash bulkheads, and web frames on the bottom, inner bottom, side shell, inner hull longitudinal bulkheads, longitudinal bulkhead and strength deck.
b) Scallops in way of block joints on the strength deck as described in Chapter 4 Sections 3/1.6.

3.4.2. Hot spot stress approach

3.4.2.1. As described in Chapter 4 Sections 3/2 , the hot spot stress approach, is to be used for the fatigue evaluation of the following item:

- knuckle between inner bottom and hopper plate

3.4.3. Alternative direct calculation approach

3.4.3.1. Fatigue assessment is to be based on IRS procedures where it is considered essential to do it using an alternative direct calculation approach, not applying the loads specified in Section 1/3. Nevertheless, in no case the scantlings are to be lower than those which would be required by 3.4.1 and 3.4.2.

SECTION 4 BUCKLING AND ULTIMATE STRENGTH

Contents

1. General 361
2. Stiffness and Proportions 361
3. Prescriptive Buckling Requirements 367
4. Advanced Buckling Analyses 382

1. General

1.1. Strength Criteria

1.1.1. Scope

1.1.1.1. This Section comprises of the strength criteria for buckling and ultimate strength of primary support members, local support members and other structuresviz. pillars, corrugated bulkheads and brackets.These criteria are to be applied as stated in Section 2 for determining the initial structural scantlings and also Section 3 for the design verification.

1.1.1.2. All structural elements are to conform to the proportionsand stiffness requirements stated in Sub- Section 2.

1.1.1.3. For every single structural member, the characteristic buckling strength is to be taken as the most unfavorable/critical buckling mode.

1.1.1.4. With respect to buckling and ultimate strength control in design, strength criteria are to be based on the following assumptions and limitations:

a) the buckling strength of stiffeners is to be greater than the plate panels they support
b) the primary support members supporting stiffeners are to have adequate inertia to prevent out of plane buckling of the primary member, refer to 2.3.2.3
c) all stiffeners with their associated effective plate are to have moments of inertia to provide adequate lateral stability, refer to 2.2.2
d) the proportions of primary support members and local support members are to be such that local instability is prevented
e) tripping of primary support members (for e.g. torsional instability) is to be prevented by fitment of tripping brackets or equivalents, refer2.3.3
f) the web plate of primary support members is to be such that elastic buckling of the plate between web stiffeners is prevented
g) for plates with openings, the buckling strength of the areas which surrounds the opening or cut out and any edge reinforcements are adequate, see 3.4.2 and 2.4.3.

2. Stiffness and Proportions

2.1. Structural Elements

2.1.1. General

2.1.1.1. All structural elements are to conform to the applicable slenderness or proportional ratio requirements as stated in2.2 to 2.3.

2.1.1.2. The requirements below are based on net scantlings, also refer Chapter 1 Section 6/3.

2.1.1.3. For definitions and structural idealisation,refer Chapter 1 Section 4/2.

2.2. Plates and Local Support Members

2.2.1.Proportions of plate panels and local support members

2.2.1.1. The net thickness of plate panels and stiffeners is to meet the criteria given below:

a) plate panels

$$t_{net} = \frac{s}{C}\sqrt{\frac{\boldsymbol{\sigma}_{yd}}{235}}$$

b) stiffener web plate

$$t_{w-ne} = \frac{d_w}{C_w}\sqrt{\frac{\sigma_{yd}}{235}}$$

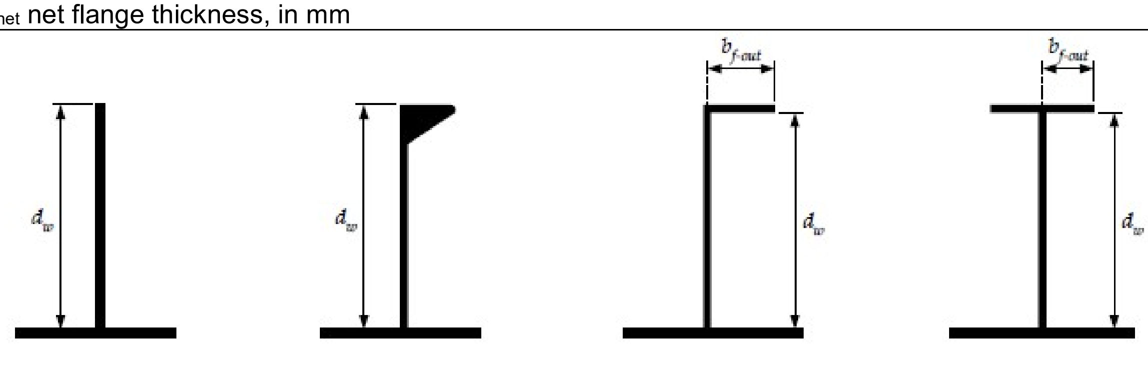
c) flange/face plate

$$t_{f-net} = \frac{b_{f-out}}{C_f}\sqrt{\frac{\sigma_{yd}}{235}}$$

where:
s plate breadth, in mm, taken as the spacing between the stiffeners, as defined in Chapter 1 Section 4/2.2.1
t_{net} net thickness of plate, in mm
d_w depth of stiffener web, in mm, as given in Table 2.4.1
t_{w-net} net web thickness, in mm
b_{f-out} breadth of flange outstands, in mm, as given in Table 2.4.1
t_{f-net} net flange thickness, in mm
C, C_w, C_f slenderness coefficients, as given in Table 2.4.1
σ_{yd} specified minimum yield stress of the material, in N/mm^2

Table 2.4.1: Slenderness Coefficients

Item		*Coefficient*
plate panel, C	hull envelope and tankboundaries	100
	other structure	125
stiffener web plate, C_w	angle and T profiles	75
	bulb profiles	41
	flat bars	22
flange/face plate(1), C_f	angle and T profiles	12
Note The total flange breadth, b_f, for angle and T profiles is not to be less than: $b_f = 0.25 d_w$ Measurements of breadth and depth are based on gross scantlings.		
where: t_{net} net thickness of plate, in mm d_w depth of web plate, in mm t_{w-net} net web thickness, in mm b_{f-out} breadth of flange outstands, in mm t_{f-net} net flange thickness, in mm		



Flat bars Bulb flats Angles T bars

2.2.2.Stiffness of stiffeners

2.2.2.1. The minimum net moment of inertia about the neutral axis parallel to the attached plate, I_{net}, of each stiffener with effective breadth of plate equal to 80% of the stiffener spacing s, is given by:

$$I_{net} = C l_{stf}^2 A_{net} \frac{\sigma_{yd}}{235} cm^4$$

where:

l_{stf} length of stiffener between effective supports, in m

A_{net} net sectional area of stiffener including attached plate assuming effective breadth of 80% of stiffener spacing s, in cm^2

s stiffener spacing, in mm, as defined in Chapter 1 Section 4/2.2.1

σ_{yd} specified minimum yield stress of the material of the attached plate, in N/mm^2

C slenderness coefficient:

= 1.43 for longitudinals subject to hull girder stresses

= 0.72 for other stiffeners

2.3. Primary Support Members

2.3.1. Proportions of web plate and flange/face plate

2.3.1.1. The net thicknesses of the web plates and face plates of primary support members are to meet the criteria given below:

a) web plate

$$t_{w-net} \geq \frac{S_w}{C_w}\sqrt{\frac{\sigma_{yd}}{235}}$$

b) flange/face plate

$$t_{f-net} \geq \frac{b_{f-out}}{C_f}\sqrt{\frac{\sigma_{yd}}{235}}$$

where:

s_w plate breadth, in mm, taken as the spacing between the web stiffeners. For web plates with stiffening parallel to the attached plate the spacing may be corrected as per Chapter 4 Sections 4/Fig. 5.6.

t_{w-net} net web thickness, in mm

b_{f-out} breadth of flange outstand, in mm

t_{f-net} net flange thickness, in mm

C_w slenderness coefficient for the web plate

= 100

C_f slenderness coefficient for the flange/face plate

= 12

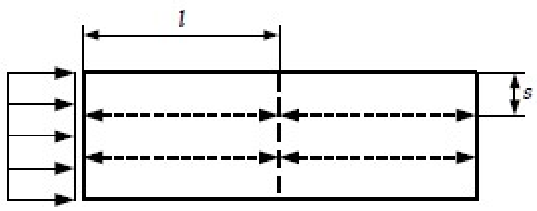
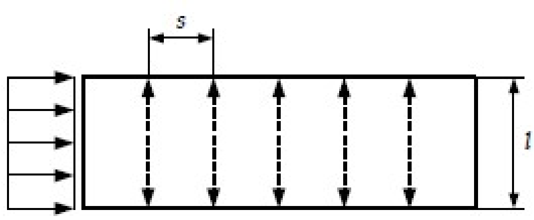
σ_{yd} specified minimum yield stress of the material,in N/mm^2

2.3.2. Stiffness requirements

2.3.2.1. The web and flange net thicknesses of web stiffeners are not to be less than mentioned in 2.2.1.

2.3.2.2. The net moment of inertia of each web stiffener, I_{net}, with effective breadth of plate equal to 80% of stiffener spacing s, is not to be less than as defined in Table 2.4.2.

Table 2.4.2: Stiffness Criteria for Web Stiffening

Mode	*Inertia requirements, cm⁴*
(a) web stiffeners parallel to the flanges of the primary support member 	$I_{net} = Cl^2 A_{net} \frac{\sigma_{yd}}{235} cm^4$
(b) web stiffeners normal to flanges of the primary support member 	$I_{net} = 1.14\text{x}\ 10^{-5} l\, s^2 t_{w-net} (2.5 \frac{1000l}{s} - 2 \frac{s}{1000l}) \frac{\sigma_{yd}}{235}$

where:
C = 1.43 for longitudinal stiffeners in cargo tank region
= 0.72 for other stiffeners
l length of web stiffener, in m.
For web stiffeners welded to local support members (LSM), the length is to be measured between the flanges
of the local support members.
For sniped web stiffeners the length is to be measured between the lateral supports e.g. the total distance between the flanges of the primary support member as shown for Mode (b).
A_{net} net section area of web stiffener including attached plate assuming effective breadth of 80% of stiffener spacing s, in cm^2
s spacing of stiffeners, in mm, as defined in Chapter 1 Section 4/2.2.1

t_{w-net} net web thickness of the primary support member, in mm
σ_{yd}specified minimum yield stress of the material of the web plate of the primary support member, in N/mm^2

2.3.2.3. The net moment of inertia for primary support members, $I_{prm-net50}$, supporting stiffeners subject to axial compressive stresses, including effective plate width at mid span, is not to be less than:

$$I_{psm-net50} = 300\ \frac{l_{bdg}^4}{S^3 s} I_{net} cm^4$$

where:
l_{bdg} bending span of primary support member, in m
S distance between primary support members, in m
s spacing of stiffeners, in mm, as defined in Chapter 1 Section 4/2.2.1
I_{net} maximum required moment of inertia, as given in 2.2.2.1, for stiffeners within the central half of the bending span, in cm^4

2.3.3. Spacing between flange supports or tripping brackets

2.3.3.1. The torsional buckling mode of primary support members is to be controlled by flange supports or tripping brackets. The unsupported flange length of the primary support member, i.e. the distance between tripping brackets, s_{bkt}, is not to be greater than:

$$S_{bkt} = b_f C \sqrt{\frac{A_{f-net50}}{\left(A_{f-n} \quad + \frac{A_{w-net}}{3}\right)}\left(\frac{235}{\sigma_{yd}}\right)}$$

but need not be less than $s_{bkt-min}$

where:
b_f breadth of flange, in mm
C slenderness coefficient:
= 0.022 for symmetrical flanges
= 0.033 for one sided flanges
$A_{f-net50}$ net cross-sectional area of flange, in cm^2
$A_{w-net50}$ net cross-sectional area of the web plate, in cm^2
σ_{yd} specified minimum yield stress of the material, in N/mm^2
$s_{bkt-min}$ = 3.0 m for primary support members in the cargo tank region, on tank boundaries or on the hull envelope including external decks
= 4.0 m for primary support members in other areas

2.4. Other Structure

2.4.1. Proportions of pillars

2.4.1.1. For I-sections the thickness of the web plate and the flange thickness is to conform to2.2.1.1.

2.4.1.2. The thickness of thin walled box sections is to conform to2.2.1.1(b). The radius of circular tube sections is to be less than 50 times the pillar's net thickness.

2.4.2. Proportions of brackets

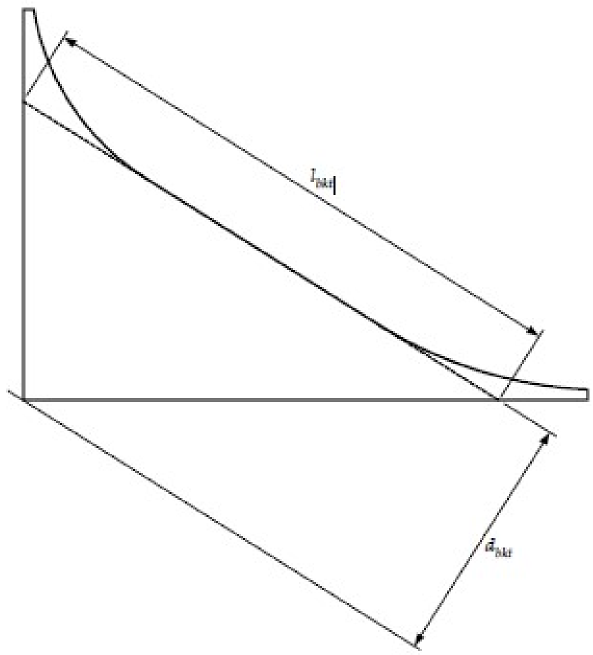
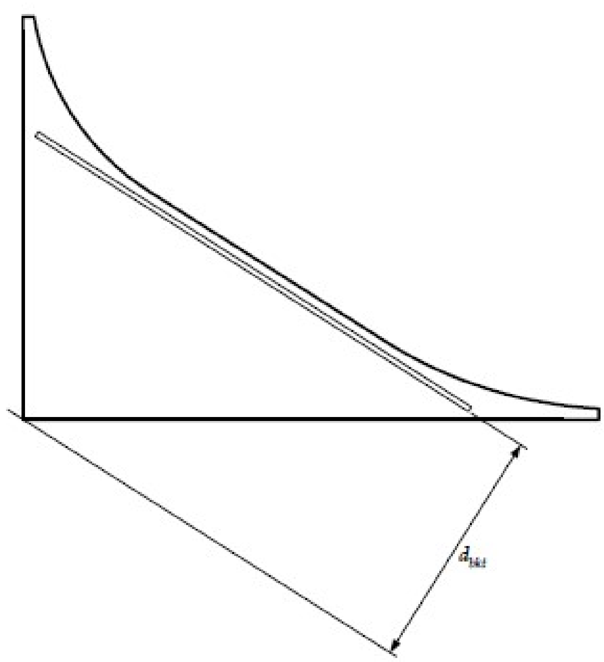
2.4.2.1. The net thickness of end brackets, $t_{bkt-net}$, except as specified in 2.4.2.2 isnot to be less than:

$$t_{bkt-net} = \frac{d_{bkt}}{C}\sqrt{\frac{\sigma_{yd}}{235}}$$

where:
d_{bkt} depth of brackets, in mm. See **Table 2.4.3**
C slenderness coefficient as defined in **Table 2.4.3**
σ_{yd} specified minimum yield stress of the material, in N/mm^2

2.4.2.2. Where it can be demonstrated that bracket is only subjected to tensile stresses, e.g. in way of internal brackets in a tank surrounded by void space, requirements in 2.4.2.1 need not be fulfilled.

Table 2.4.3: Buckling Coefficient, C, for Proportions of Brackets

Mode	*C*
(a) Brackets without edge stiffener 	$C = 20\left(\frac{d_{bkt}}{l_{bkt}}\right) + 16$ **where** $0.25 \le \frac{d_{bkt}}{l_{bkt}} \le 1.0$
(b) Brackets with edge stiffener 	**C=70**
where: l_{bkt} effective length of edge of bracket, in mm	

2.4.2.3. Tripping brackets on primary support members are to be stiffened by edge stiffener or flange, if the effective length of the edge, l_{bkt}, is greater than:

$$l_{bkt} = 75 t_{bkt-net} mm$$

where:
$t_{bkt-net}$ bracket thickness, in mm

2.4.3. Requirements to edge reinforcements in way of openings and bracket edges

2.4.3.1. The depth of stiffener web, d_w, of edge stiffeners in way of bracket edges and openings is not to be less than:

$$d_w = Cl\sqrt{\frac{\sigma_{yd}}{235}}$$ mm, or 50 mm, whichever is greater

where:

l length of edge stiffener, in m

σ_{yd} specified minimum yield stress of the material, in N/mm^2

C slenderness coefficient
- 75 for end brackets
- 50 for tripping brackets
- 50 for edge reinforcements in way of openings

2.4.3.2. The net thickness of flange of the edge stiffener and the web plate is not to be less than required in 2.2.1.

3. Prescriptive Buckling Requirements

3.1. General

3.1.1. Scope

3.1.1.1. This Sub-Section containsmethods for determination of buckling capacity, definitions ofbuckling utilisation factors and other measures vital to control buckling of stiffeners, plate panels and primary support members.

3.1.1.2. The buckling utilisation factor, η, is to meet the criteria given below:

$$\eta \leq \eta_{allow}$$

where:

η_{allow} allowable buckling utilisation factor, as defined in Section 2 and Section 3

η buckling utilisation factor, as defined in 3.2.1.1, 3.3.2.2, 3.3.3.1, 3.4.1.1 and 3.5.1.1.

3.1.1.3. For definitions and structural idealisation, see Chapter 1 Section 4/2also. As specified by the relevant Rule requirements, thickness and section properties of plates and stiffeners are to be taken.

3.2. Buckling of Plates

3.2.1. Uni-axial buckling of plates

3.2.1.1. The buckling utilisation factor, η, for uni-axial stress is to be taken as:

$$\eta = \frac{\sigma_x}{\sigma_{xcr}}$$ for compressive stresses in x-direction

$\eta = \frac{\sigma_y}{\sigma_{ycr}}$ for compressive stresses in y-direction

$\eta = \frac{\tau}{\tau_{cr}}$ for shear stress

where:

σ_x, σ_y actual compressive stresses, in N/mm^2

τ actual shear stress, in N/mm^2

σ_{xcr}, σ_{ycr} critical compressive stress, in N/mm^2, as defined in 3.2.1.3

τ_{cr} critical shear stress, in N/mm^2, as defined in 3.2.1.3

3.2.1.2. Reference degree of slenderness, to be taken as:

$$\lambda = \sqrt{\frac{\sigma_{yd}}{K\sigma_E}}$$

where:

K buckling factor, see Table 2.4.4

σ_E reference stress, in N/mm^2

$= 0.9E\left(\frac{t_{net}}{l_a}\right)^2$

E modulus of elasticity, 206 000 N/mm^2

t_{net} net thickness of plate panel, in mm

l_a length of the side of the plate panel as defined in Table 2.4.4, in mm

σ_{yd} specified minimum yield stress of the material, in N/mm^2

3.2.1.3. The critical stresses, σ_{xcr}, σ_{ycr} or τ_{cr}, of plate panels subject to compression or shear, respectively, is to be taken as:

$\sigma_{xcr} = C_x\sigma_{yd}$

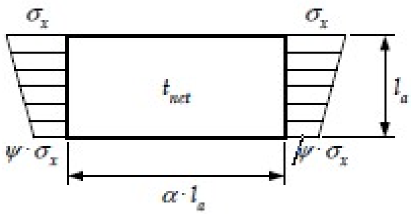
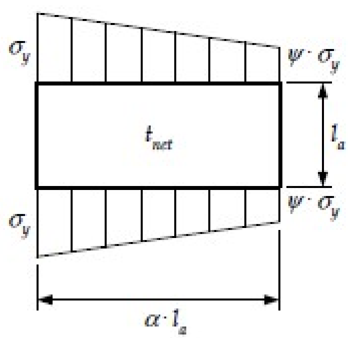
$\sigma_{ycr} = C_y\sigma_{yd}$

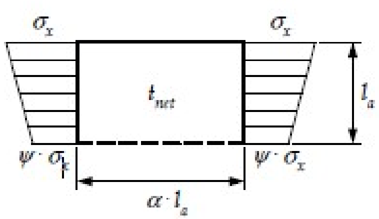
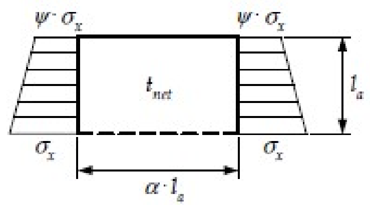
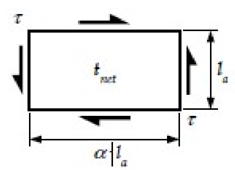
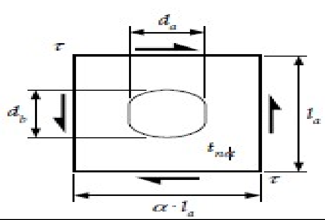
$\tau_{cr} = C_\tau\frac{\sigma_{yd}}{\sqrt{3}}$

where:

C_x, C_y, C_τ reduction factors, as given in Table 2.4.4.

Table 2.4.4: Buckling Factor and Reduction Factor for Plane Plate Panels

Case	*Stress ratio* Ψ	*Aspect ratio* α	*Buckling factor K*	*Reduction factor C*
1 	1≥Ψ≥0		$K = \frac{8.4}{\psi + 1.1}$	$C_x = 1$ *for* $\lambda \le \lambda_c$ $C_x = c\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)\ for\ \lambda > \lambda_c$ *Where:* *c= (1.25 -0.12Ψ)≤1.25* $\lambda_c = \frac{c}{2}\left(1 + \sqrt{1 - \frac{0.88}{c}}\right)$
	0>Ψ>-1	*α>1*	$K = 7.63 - \psi\,(6.26 - 10\,\psi)$	
	Ψ≤-1		$K = 5.975\,(1 - \psi)^2$	
2 	1≥Ψ≥0	*α ≥ 1*	$K = \left(1 + \frac{1}{\alpha^2}\right)\frac{2.1}{(\psi + 1.1)}$	$C_y = c\left(\frac{1}{\lambda} - \frac{R + F^2(H - R)}{\lambda^2}\right)$ *Where* *c =(1.25-0.12Ψ) ≤ 1.25* *R= λ (1-λ/c) for λ<λc* *R=0.22 for λ≥ λc* $\lambda_c = 0.5c\,(1 + \sqrt{1 - 0.88/c})$ $F = \left(1 - \left(\frac{K}{0.91} - 1\right)/\lambda_P^2\right)c_1 \ge 0$ $\lambda_P^2 = \lambda^2 - 0.5\ and\ 1 \le \lambda_P^2 \le 3$ $c_1 = 1\ for\ \sigma_y due\ to\ direct\ loads\ (3)$ $c_1 = (1 - 1/a) \ge 0\ for\ \sigma_y due\ to\ bending\ (in\ general)\ (2)$ $c_1 = 0$ for σ_y due to bending in extreme load cases (e.g. w/t. bhds.) $H = \lambda - \frac{2\lambda}{c\,(T + \sqrt{T^2 - 4}} \ge R$ $T = \lambda + \frac{14}{15\lambda} + \frac{1}{3}$
	0>Ψ>-1	*1≤ α ≤ 1.5*	$K = \left[1 + \frac{1}{\alpha^2}\right]^2 \frac{2.1\,(1 + \psi)}{1.1} - \frac{\psi}{\alpha^2}(13.9 - 10\psi)$	
		α>1.5	$K = \left[1 + \frac{1}{\alpha^2}\right]^2 \frac{2.1\,(1 + \psi)}{1.1} - \frac{\psi}{\alpha^2}(5.87 + 1.87\alpha^2 + \frac{8.6}{\alpha^2} - 10\psi)$	
	Ψ≤-1	$1 \le \alpha \le \frac{3\,(1 - \psi)}{4}$	$K = \left(\frac{1 - \psi}{\alpha}\right)^2 5.975$	
		$\alpha > \frac{3\,(1 - \psi)}{4}$	$K = \left(\frac{1 - \psi}{\alpha}\right)^2 3.9675 + 0.5375\left(\frac{1 - \psi}{\alpha}\right)^4 + 1.87$	

3 	1≥Ψ≥0	α>0	$K = \frac{4\,(0.425 + 1/\alpha^2)}{3\psi + 1}$	
	0>Ψ>-1		$K = 4\,(0.425 + 1/\alpha^2)(1+\Psi) - 5\Psi(1-3.42\Psi)$	
4 	0>Ψ>-1			$C_x = 1\ for\ \lambda \leq 0.07$ $C_x = \frac{1}{\lambda^2 + 0.51}\ for\ \lambda > 0.7$
5 				$C_r = 1\ for\ \lambda \leq 0.084$ $C_r = \frac{0.84}{\lambda}\ for\ \lambda > 0.84$
6 				

Where:
Ψ the ratio between smallest and largest compressive stress as shown for Case 1-4
$l_a$length in mm, of the shorter side of the plate panel for Cases 1 and 2
$l_a$length in mm, of the side of the plate panel as defined for Cases 3, 4, 5 and 6
α aspect ratio of the plate panel

Edge boundary conditions:

Notes
1) Cases listed are general cases. Each stress component (σ_x, σ_y) is to be understood in local coordinates.
2) c_1 due to bending (in general) corresponds to straight edges (uniform displacement) of a plate panel integrated in a large structure. This value is to be applied for hull girder buckling and buckling of web plate of primary support members in way of openings.
3) c_1 for direct loads corresponds to a plate panel with edges not restrained from pull-in which may result in non-straight edges

3.3. Buckling of Stiffeners

3.3.1. Critical compressive stress

3.3.1.1. The buckling utilisation factor of stiffeners is to be taken as torsional buckling mode and the maximum of the column as stated in3.3.2 and 3.3.3.

3.3.2. Column buckling mode

i) Stiffeners are to be verified against the column buckling mode as stated in3.3.2.2 with the allowable buckling utilisation factor, η_{allow}, refer to3.1.1.2. Stiffeners not subjected to lateral pressure and that have a net moment of inertia, I_{net}, conforming to3.3.2.4,have acceptable column buckling strength and does not requireverification against 3.3.2.2.

ii) The buckling utilisation factor for column buckling of stiffeners is to be taken as:

$$\eta = \frac{\sigma_x + \sigma_b}{\sigma_{yd}}$$

where:
σ_x compressive axial stress in the stiffener, in N/mm^2, in way of the midspan of the stiffener. See Chapter 1 Section 3/5.2.3.1
σ_b bending stress at the midspan of the stiffener as per 3.3.2.3, in N/mm^2
σ_{yd} specified minimum yield stress of the material, in N/mm^2

iii) The bending stress, σ_b, in N/mm^2, in the stiffener is equal to:

$$\sigma_b = \frac{M_0 + M_1}{1000\, Z_{net}}$$

where:

Z_{net} net section modulus of stiffener, in cm^3, including effective breadth of plating as per 3.3.4.1

a) if upon stiffner, lateral pressure is applied:

Z_{net} is the section modulus calculated at flange, if the lateral pressure is applied on the same side as the stiffener.

Z_{net} is the section modulus calculated at attached plate, if the lateral pressure is applied on the side opposite to the stiffener.

b) if no lateral pressure is applied on the stiffener:

Z_{net} is the minimum section modulus among those calculated at flange and attached plate.

M_1 bending moment, in Nmm, due to the lateral load P

$$= \frac{Ps\, l_{stf}^2}{24} 10^3$$

P lateral load, in kN/m^2

s stiffener spacing as defined in Chapter 1 Section 4/2.2.1, in mm

l_{stf} span of stiffener, in m, equal to spacing between primary support members

M_0 bending moment, in Nmm, due to the lateral deformation w of stiffener

$$= F_E\left(\frac{P_Z w}{c_f - P_z}\right) \; when \; (c_f - P_z) > 0$$

F_E ideal elastic buckling force of the stiffener, in N

$$= \left(\frac{\pi^2}{l_{stf}{}^2}\right) E I_{net} 10^{-2}$$

E modulus of elasticity, 206 000 N/mm^2

I_{net} moment of inertia, in cm^4, of the stiffener including effective width of attached plating according to 3.3.4.1. $I_{net}$is to conforming to the requirement below:

$$I_{net} \geq \frac{s t_{net}{}^3}{12} 10^{-4}$$

t_{net} net thickness of plate flange, to be taken as the mean thickness of the two attached plate panels, in mm

P_z nominal lateral load, in N/mm^2, acting on the stiffener due to membrane stresses, σ_x, σ_y and τ_1, in the attached plate in way of the stiffener midspan:

$$= \frac{t_{net}}{s}\left(\sigma_{xl}\left(\frac{\pi s}{1000\, l_{stf}}\right)^2 + 2\, c_y \sigma_y + \sqrt{2}\tau_1\right)$$

σ_{xl}

$$= \sigma_x\left(1 + \frac{A_{net}}{s\, t_{net}}\right) Nmm^2$$

τ_1

$$= \left[\tau - t_{net}\sqrt{\sigma_{yd} E\left(\frac{m_1}{(1000\, l_{stf})^2}\right)}\right] \geq 0$$

with m_1 and m_2 taken equal to

$m_1 = 1.47 m_2 = 0.49$ for $\frac{1000\, l_{stf}}{s} \geq 2.0$

$m_1 = 1.96 \; m_2 = 0.37$ for $\frac{1000\, l_{stf}}{s} \geq 2.0$

σ_x compressive axial stress in the stiffener, in N/mm^2, in way of the midspan of the stiffener. Refer Chapter 1 Section 3/5.2.3.1

A_{net} net sectional area of the stiffener without attached plating, in mm^2

c_y factor taking into account the membrane stresses in the attached plating acting normal to the stiffener's axis

$$= 0.5\,(1 + \psi) \; for \; 0 \leq \psi \leq 1$$

$$\frac{0.5}{1-\psi}\ for\ \psi < 0$$

ψ edge stress ratio for Case 2 as per Table 2.4.4

σ_y membrane compressive stress in the attached plating acting normal to the stiffener's axis, in N/m²

τ shear membrane stress in the attached plating, in N/mm²

σ_{yd} specified minimum yield stress of the material, in N/mm²

w deformation of stiffener, in mm

$$= w_0 + w_1$$

w_0 assumed imperfection, in mm.

$$= \min\left[\frac{1000 l_{stf}}{250}, \frac{s}{250}, 10\right]$$

For stiffeners sniped at both ends, w_0 is not to be taken less than the distance from the midpoint of attached plating to the neutral axis of the stiffener calculated with the effective width of the attached plating as per 3.3.4.1

w_1 deformation of stiffener at midpoint of stiffener span due to lateral load P, in mm. In case of uniformly distributed load, the w_1 is to be taken as:

$$= \frac{P\ s\ {l_{stf}}^4}{384.E\mathrm{I}_{net}} 10^5$$

c_f elastic support provided by the stiffener, in N/mm²

$$= F_E \frac{\tau^2}{{l_{stf}}^2}\left(1 + c_p\right)10^{-6}$$

$$c_p = \frac{1}{1+\frac{0.91}{c_a}\left(\frac{12\ I_{net}10^4}{s{t_{net}}^3}-1\right)}$$

$$c_a = \left[\frac{1000 l_{stf}}{2s} + \frac{2s}{1000 l_{stf}}\right]^2\ for\ l_{stf} \geq \frac{2s}{1000}$$

$$c_a = \left[1 + \left(\frac{1000 l_{stf}}{2s}\right)^2\right]^2\ for\ l_{stf} \geq \frac{2s}{1000}$$

Stiffeners not subjected to lateral pressure are considered as fulfilling the requirements of 3.3.2.2, when their net moments of inertia, in cm, meet requirement below:

$$I_{net} \geq 100\ \frac{P_z\, {l_{stf}}^2}{\pi^2}\left[\frac{w_0\left(e_f - 0.5\, t_{f-net}\right)}{\eta allow\ \sigma_{yd} - \sigma_x} + \frac{{l_{stf}}^2}{E\pi^2}10^6\right]$$

where:

e_f distance from connection to plate (C as shown in Figure 2.4.1) to centre of flange, in mm

$$= \left(d_w - 0.5\, t_{f-net}\right) for\ bulb\ flats$$

$$= \left(d_w + 0.5\, t_{f-net}\right) for\ angles\ and\ T\ bars$$

d_w depth of web plate, in mm, as shown in Figure 2.4.1.

t_{f-net} net flange thickness, in mm

η_{allow} allowable buckling utilisation factor as defined in Section 2 and Section 3

Note:

Other parameters are as defined in 3.3.2.3

3.3.3. Torsional buckling mode

3.3.3.1. The torsional buckling mode is to be verified against the allowable buckling utilisation factor, η_{allow}, see 3.1.1.2. The buckling utilisation factor for torsional buckling of stiffeners is to be taken as:

$$\eta = \frac{\sigma_x}{C_T \sigma_{yd}}$$

where:

σ_x compressive axial stress in the stiffener, in N/mm^2, in way of the midspan of the stiffener. See Chapter 1 Section 3/5.2.3.1

C_T torsional buckling coefficient

$$= 1.0\ for\ \lambda_T \le 0.2$$

$$= \frac{1}{\phi + \sqrt{\phi^2 - \lambda_T^2}}\ for\ \lambda_T > 0.2$$

$$\phi = 0.5\left(1 + 0.21(\lambda_T - 0.2) + \lambda_T^2\right)$$

reference degree of slenderness for torsional buckling

$$= \sqrt{\frac{\sigma_{yd}}{\sigma_{ET}}}$$

reference stress for torsional buckling, in N/mm^2

$$= \frac{E}{I_{p-net}}\left(\frac{\varepsilon \pi^2 I_{\omega-net} 10^{-4}}{l_t^2} + 0.385\, I_{T-net}\right)$$

σ_{yd} specified minimum yield stress of the material, in N/mm^2

E modulus of elasticity, 206 000 N/mm^2

I_{P-net} polar moment of inertia of the stiffener about point C, in cm^4, as given in Figure2.4.1 and Table 2.4.5

I_{T-net} St. Venant's moment of inertia of the stiffener, in cm^4, as given in Table 2.4.5.

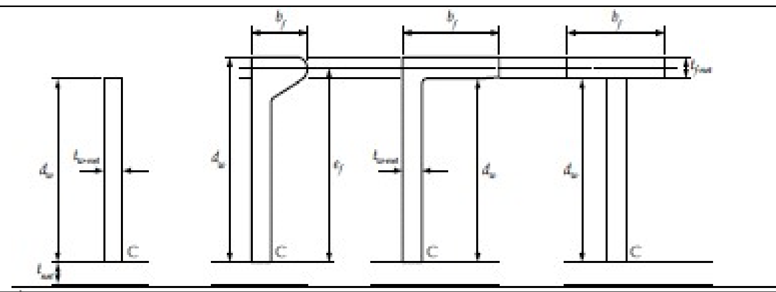
I_{w-net} sectorial moment of inertia of the stiffener about point C, in cm^6, as given in Figure 2.4.1and Table 2.4.5

εdegree of fixation

$$= 1 + 1000\sqrt{\frac{l_t^4}{\frac{3}{4}\pi^4 I_{\omega-net}\left(\frac{s}{t_{net}^3} + \frac{4\left(e_f - 0.5t_{f-net}\right)}{3t_{w-net}^3}\right)}}$$

l_t torsional buckling length to be taken equal the distance between tripping supports, in m

$d_w$depth of web plate, in mm
t_{w-net} web thickness, in mm
$b_f$flange breadth, in mm
t_{f-net} flange thickness, in mm
e_f distance from connection to plate (C in Figure 2.4.1) to centre of flange, in mm
$= (d_w - 0.5\ t_{f-net})\ for\ bulb\ flats$
$= \left(d_w + 0.5\ t_{f-net}\right)\ for\ angles\ and\ T\ bars$
A_{w-net} net web area, in mm^2
$= \ (e_f - 0.5\ t_{f-net})t_{w-net}$
A_{f-net} net flange area, in mm^2
$= b_f t_{f-net}$
s stiffener spacing as defined in Chapter 1 Section 4/2.2.1, in mm



Note:
1) Measurements of breadth and depth are based on gross scantlings as described in Chapter 1 Section 4/2.4.1.2.
2) Characteristic flange data for bulb profiles are given in Chapter 4 Section 3 /Table 4.3.2

Figure 2.4.1: Stiffener cross sections

Table 2.4.5: Moments of Inertia

Section property	*Flat bars*	*Bulb flats, angles and T bars*
$I_{P\text{-}net}$	$\frac{d_\omega^3 t_{\omega-net}}{3\times10^4}$	$\left(\frac{A_{\omega-net}\,(e_f-0.5t_{f-net})^2}{3}+A_{f-net}e_f^2\right)10^{-4}$
$I_{T\text{-}net}$	$\frac{d_\omega^3 t_{\omega-net}^3}{3\times10^4}\left(1-0.63\frac{t_{\omega-net}}{d_\omega}\right)$	$\frac{(e_f-0.5\,t_{f-net})t_{w-net}^3}{3\times10^4}\left(1-0.63\frac{t_{\omega-net}}{e_f-0.5t_{f-net}}\right)$ + $\frac{b_f t_{f-net}^3}{3\times10^4}\left(1-0.63\frac{t_{f-net}}{b_f}\right)$
$I_{\omega\text{-}net}$	$\frac{d_\omega^3 t_{\omega-net}^3}{36\times10^6}$	**for bulb flats and angles:** $\frac{A_{f-net}\,e_f^2 b_f^2}{12\times10^6}\left(\frac{A_{f-net}+2.6A_{\omega-net}}{A_{f-net}+\ A_{\omega-net}}\right)$ **for T bars:** $\frac{b_f^3 t_{f-net}e_f^2}{12\times10^6}$

3.3.4. Effective breadth of attached plating

3.3.4.1. The effective breadth of attached plating of ordinary stiffeners is to be taken as:

$$b_{eff}=\min(C_x s,\chi_s s)$$

where:

$$\chi_s=0.0035\left(\frac{1000l_{eff}}{s}\right)^3-0.0673\left(\frac{1000l_{eff}}{s}\right)^2+0.4422\left(\frac{1000l_{eff}}{s}\right)-0.0056\ \le 1.0$$

s stiffener spacing as defined in Chapter 1 Section 4/2.2.1, in mm
C_x average reduction factor for buckling of the two attached plate panels, as per Case 1 in Table 2.4.4
l_{stf} span of stiffener, in m, equal to spacing between primary support members
l_{eff} Effective span of stiffeners in m

$l_{eff}=l_{stf}$ when simply supported at both ends
$l_{eff}=0.6l_{stf}$ when fixed at both ends

3.4. Primary Support Members

3.4.1. Buckling of web plate of primary support members in way of openings

3.4.1.1. The web plate of primary support members with openings is to be assessed for buckling based on the combined axial compressive and shear stresses. The web plate adjacent to the opening (on both sides) is to be considered as individual unstiffened plate panels as given in Table 2.4.6. The buckling utilisation factor, η, is to be taken as:

$$\eta=\left(\frac{|\sigma_{av}|}{C\sigma_{yd}}\right)^{e}+\left(\frac{|\tau_{av}|\sqrt{3}}{C\sigma_{yd}}\right)^{e_\tau}$$

where:

σ_{av} average compressive stress in the area of web plate being considered as per case: 1, 2 or 3 in Table 2.4.4, in N/mm^2

τ_{av} average shear stress in the area of web plate being considered according to case 5 or 6 in Table 2.4.4, in N/mm^2

σ_{yd} specified minimum yield stress of the material, in N/mm^2

$e = 1 + C^4$ exponent for compressive stress

$e_\tau = 1 + CC_\tau^2$ exponent for shear stress

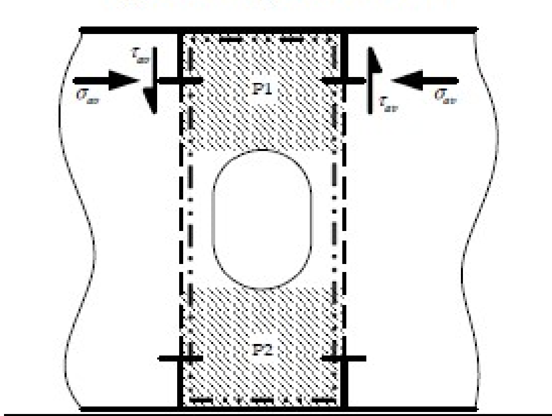
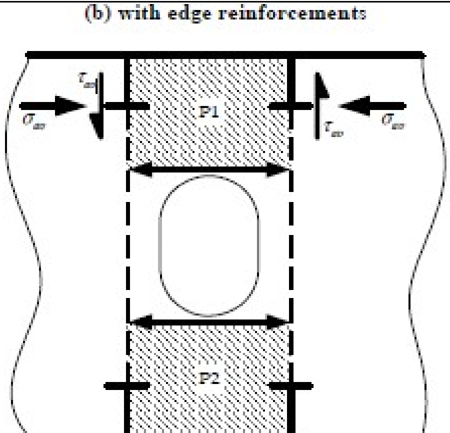
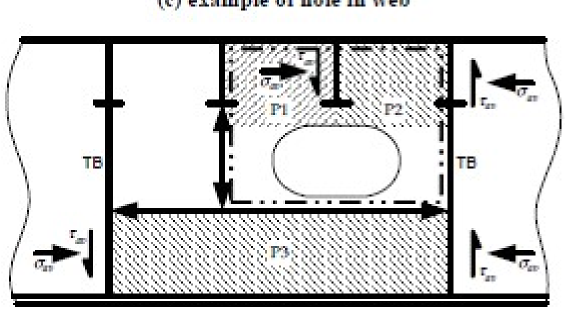
$C = C_x$ reduction factor as per Case 1 or 3, Table 2.4.4

$C = C_y$ reduction factor as per Case 2, Table 2.4.4

C_τ reduction factor as per Case 5 or 6, Table 2.4.4

The reduction factors, C_x or C_y in combination with C_t, of the plate panel(s) of the web adjacent to the opening is to be taken as given in Table 2.4.6.

Table 2.4.6: Reduction Factors

Mode	C_x C_y	C_t
(a) without edge reinforcements 	Separate reduction factors are to be applied to areas P1 and P2 using Case 3, Table 2.4.4, with edge stress ratio: Ψ□□□1.0	A common reduction factor is to be applied to areas P1 and P2 using Case 6, Table 2.4.4 for area marked: 
(b) with edge reinforcements 	Separate reduction factors are to be applied for areas P1 and P2 using: Cx for Case 1 or Cy, for Case 2, see Table 2.4.4 with stress ratio: Ψ□□□1.0	Separate reduction factors are to be applied for areas P1 and P2 using Case 5, Table 2.4.4
(c) example of hole in web 	Panels P1 and P2 are to be evaluated in accordance with (a). Panel P3 is to be evaluated in accordance with (b)	

Note
1) Web panels to be considered for buckling in way of openings are shown shaded and numbered P1, P2, etc.

3.5. Other Structures

3.5.1. Struts, pillars and cross ties

3.5.1.1. The critical buckling stress for axially compressed struts, cross ties and pillars is to be taken as the lesser of the column and torsional critical buckling stresses. The buckling utilisation factor, η, is to be taken as:

$$\eta = \frac{\sigma_{av}}{\sigma_{cr}}$$

where:
σ_{av} average axial compressive stress in the member, in N/mm^2
σ_{cr} minimum critical buckling stress according to 3.5.1.2, in N/mm^2

3.5.1.2. The critical buckling stress in compression, σ_{cr}, for each mode is to be taken as:

$$\sigma_{cr} = \sigma_E \, for \sigma_E \leq 0.5\sigma_{yd}$$

$$\sigma_{cr} = \left(1 - \frac{\sigma_{yd}}{4\sigma_E}\right)\sigma_{yd} \, for \; \sigma_E > 0.5 \; \sigma_{yd}$$

where:
σ_E elastic compressive buckling stress, in N/mm², given for each buckling mode, see 3.5.1.3 to 3.5.1.5
σ_{yd} specified minimum yield stress of the material, in N/mm²

3.5.1.3. The elastic compressive column buckling stress, σ_E, of pillars subject to axial compression is to be taken as:

$$\sigma_E = 0.001 E f_{end} \frac{I_{net50}}{A_{pill-net5} \;\; {l_{pill}}^2} \; Nmm^2$$

I_{net50} net moment of inertia about the weakest axis of the cross-section, in cm⁴
$A_{pill-net50}$ net cross-sectional area of the pillar, in cm²f_{end} end constraint factor:

- 1.0 where both ends are pinned
- 2.0 where one end is pinned and the other end is fixed
- 4.0 where both ends are fixed

A pillar end may be considered fixed when effective brackets are fitted. These brackets are to be supported by structural members with greater bending stiffness than the pillar.
Column buckling capacity for cross tie shall be calculated using f_{end} equal to 2.0 and span as defined in 2/2.6.8.1
E modulus of elasticity, 206 000, in N/mm²
l_{pill} unsupported length of the pillar, in m

3.5.1.4. The elastic torsional buckling stress, σ_{ET}, with respect to axial compression of pillars is to be taken as:

$$\sigma_{ET} = \frac{G I_{sv-net50}}{I_{pol-net50}} + \frac{0.001 f_{end} E c_{warp}}{I_{pol-net50} {l_{pill}}^2} Nmm^2$$

where:

G shear modulus $= \frac{E}{2(1+v)}$

E modulus of elasticity, 206 000, in N/mm²
v Poisson's ratio, 0.3
$I_{sv-net50}$ net St. Venants moment of inertia, in cm⁴,see Table 2.4.7

$I_{pol-net50}$ net polar moment of inertia about the shear centre of cross section, in cm⁴
f_{end} end constraint factor:

- 1.0 where both ends are pinned
- 2.0 where one end is pinned and the other end is fixed
- 4.0 where both ends are fixed

Elastic torsional buckling capacity for cross tie shall be calculated using f_{end}equal to 2.0 and span as defined in 2/2.6.8.1
c_{warp} warping constant, in cm⁶, see Table 2.4.7
l_{pill} unsupported length of the pillar, in m

y_0 position of shear centre relative to the cross-sectional centroid, in cm, see Table 2.4.7
z_0 position of shear centre relative to the cross-sectional centroid, in cm, see Table 2.4.7
$I_{y\text{-}net50}$ net moment of inertia about y-axis, in cm^4
A_{net50} net cross-sectional area, in cm^2
$I_{z\text{-}net50}$ net moment of inertia about z-axis, in cm^4

3.5.1.5. At cross-sections, where centroid and the shear centre do not coincide, interaction between the torsional and column buckling mode is to be examined. The elastic torsional/column buckling stress, σ_{ETF}, with respect to axial compression is to be taken as:

$$\sigma_{ETF} = \frac{1}{2\zeta}\left[(\sigma_E + \sigma_{ET}) - \sqrt{(\sigma_E + \sigma_{ET})^2 - 4\zeta\sigma_E\sigma_{ET}}\right]$$

where:

$$\zeta = 1 - \frac{({\gamma_0}^2 + {z_0}^2)A_{net50}}{I_{pol-net50}}$$

y_0 position of shear centre relative to the cross-sectional centroid, in cm, see Table 2.4.7:

z_0 position of shear centre relative to the cross-sectional centroid, in cm, see Table 2.4.7

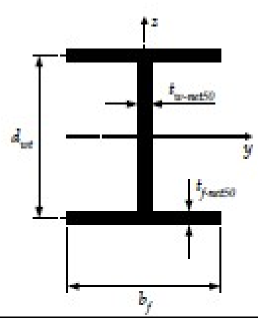
$I_{pol\text{-}net50}$ net polar moment of inertia about the shear centre of cross section, as defined in 3.5.1.4

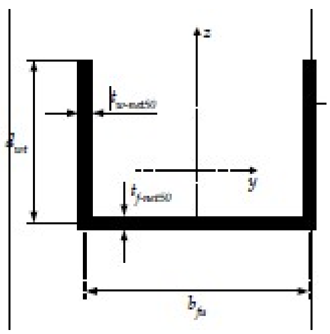
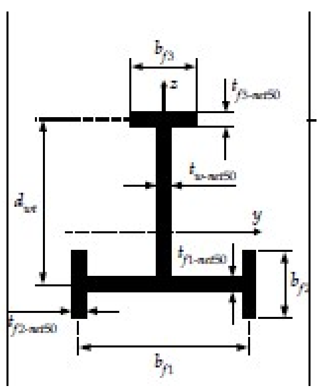
A_{net50} net cross-sectional area, in cm^2

σ_{ET} elastic torsional buckling stress, as defined in 3.5.1.4

σ_E elastic column compressive buckling stress, as defined in 3.5.1.3

Table 2.4.7: Cross Sectional Properties

<table>
<tr><td colspan="2">Double symmetrical sections</td></tr>
<tr><td rowspan="2"></td><td>$I_{sv-net50} = \frac{1}{3}\left(2b_f t_{f-net50}^3 + d_{wt} t_{w-net50}^3\right)10^{-4} cm^4$</td></tr>
<tr><td>$C_{warp} = \frac{d_{wt}^2 b_f^3 t_{f-net50}}{24} 10^{-6}\ cm^6$</td></tr>
<tr><td></td><td>$I_{sv-net50} = \frac{1}{3}\left(b_f t_{f-net50}^3 + d_{wt} t_{w-net50}^3\right)10^{-4} cm^4$</td></tr>
</table>

	$y_0 = 0\ cm$ $z_0 = \frac{0.5 d_{wt}^2 t_{w-net50}}{d_w t_{w-net} + b_f t_{f-net50}} 10^{-1}$ $C_{warp} = \frac{b_f^3 t_{f-net50}^3 + 4 d_{wt}^3 t_{w-net50}^3}{144} 10^{-6} cm^6$
	$I_{sv-net50} = \frac{1}{3}\left(b_{fu} t_{f-net50}^3 + 2 d_{wt} t_{w-net50}^3\right) 10^{-4} cm^4$ $y_0 = 0\ cm$ $z_0 = -\frac{d_{wt}^2 t_{w-net50} 10^{-1}}{2 d_{wt} t_{w-net} + b_f t_{f-net}} - \frac{0.5 d_{wt}^2 t_{w-net50} 10^{-1}}{d_{wt} t_{w-net} + b_{fu} t_{f-net} /6} cm$ $C_{warp} = \frac{b_{fu}^2 d_{wt}^3 t_{w-net50}\left(3 d_{wt} t_{w-net50} + 2 b_{fu} t_{f-net50}\right)}{12\left(6 d_{wt} t_{w-net} + b_{fu} t_{f-net}\right)} 10^{-6} cm^6$
	$\boldsymbol{I_{sv-net50} = \frac{1}{3}\left(b_{f1} t_{f1-net50}^3 + 2 b_{f2} t_{f2-net50}^3 + b_{f3} t_{f3-net50}^3 + d_{wt} t_{w-net50}^3\right) 10^{-4}}$ $y_0 = 0\ cm$ $z_0 = z_s = \frac{\left(b_{f3} d_{wt} t_{f3-net50} + 0.5 d_{wt}^2 t_{w-net}\right)10^{-1}}{d_{wt} t_{w-net} + b_{f1} t_{f1-net50} + 2 b_{f2-net50} + b_{f3} t_{f3-net50}} cm$ $C_{warp} = I_{f1} z_s^2 + \frac{I_{f2} b_{f1}^2}{200} + I_{f3}\left(\frac{d_{wt}}{10} - z_s\right)^2 cm^6$ $I_{f1} = \left(\frac{\left(b_{f1} - t_{f2-net50}\right)^3 t_{f1-net50}}{12} + \frac{b_{f2} t_{f2-net50} b_{f1}^2}{2}\right) 10^{-4}\ cm^4$ $I_{f2} = \frac{b_{f2}^3 t_{f2-net50}}{12} 10^{-4} cm^4$ $I_{f3} = \frac{b_{f3}^3 t_{f3-net50}}{12} 10^{-4} cm^4$ $Z_s = \frac{I_{f3} d_{wt}}{I_{f1} + I_{f3}} 10^{-1}\ cm$
Note 1) All dimensions of thickness, breadth and depth are in mm 2) Cross sectional properties not covered by this table are to be obtained by direct calculation.	

3.5.2. Corrugated bulkheads

3.5.2.1. Local buckling of a unit flange of corrugated bulkheads is to be controlled as per 3.2.1.1, for Case 1, as shown in Table 2.4.4, applying stress ratio $\psi = 1.0$.

3.5.2.2. The overall buckling failure mode of corrugated bulkheads subjected to axial compression is to be checked for column buckling as per 3.5.1 (e.g. horizontally corrugated longitudinal bulkheads, vertically corrugated bulkheads subject to localised vertical forces). End constraint factor corresponding to pinned ends is to be applied except for fixed end support to be used in way of stool with width exceeding twice the depth of corrugation.

4. Advanced Buckling Analyses

4.1. General

4.1.1. Assessment

4.1.1.1. For stiffened panels and plates subjected to combined stress fields, the advanced buckling assessment method is to be followed.

4.1.1.2. The advanced buckling assessment method considers following effects in deriving buckling capacity:

a) non-linear geometrical behavior
b) inelastic material behaviour
c) initial imperfections (geometrical out-of flatness of plate and stiffeners)
d) welding residual stresses
e) interactions between structural elements; plates, stiffeners, girders etc.
f) simultaneous acting loads; bi-axial compression/tension, shear and lateral pressure
g) boundary conditions

4.1.1.3. All effects are to be modelled to represent a lower bound of structural strength. The amplitude of geometrical imperfections and modelling shape is to be such that the most critical failure modes are triggered.

4.1.1.4. The buckling strength is to be derived as per the method described in Chapter 4 Section 4.

4.1.1.5. If they give comparable results with the bench mark results attained after implementing advanced buckling methodology described in Chapter 4 Section 4., alternative advanced buckling analysis tools may be used.

4.1.1.6. For review and acceptance, theoretical background, models, verifications, assumptions, calibrations, etc., for alternative advanced buckling analysis are to be submitted.

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SECTION 1 GENERAL REQUIREMENTS

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1. Hull Openings and Closing Arrangements

1.1. Shell and Deck Openings

1.1.1. General

1.1.1.1. For closing appliances for openings in superstructures, deck house sides and ends, see 1.4. For discharges and inlets and overflows and vents, see 1.5.

1.1.1.2. See Sub-Section 5 fortesting requirements.

1.1.2. Cargo tank hatches – materials

1.1.2.1. Covers for access hatches, tank cleaning and other openings for cargo tanks and adjacent spaces are to be manufactured using the following material:

a) normal strength steel as per Chapter 1 Section 6/1
b) non-ferrous material such as bronze or brass may be considered; however, aluminium alloy is not to be used for covers of any opening to cargo tanks and spaces adjacent thereto
c) Synthetic materials may also be considered, taking into account their fire resistance and physical, chemical properties in relation to the intended operating conditions. All the details of the properties of the material, design of the cover and the manufacturing method are to be submitted for approval.

1.1.2.2. There has to be compatibility between hatch cover packing material and the cargoes that are intended to be carried and that is to be effectively held in place.

1.1.3. Cargo tank access coamings

1.1.3.1. The hatch coaming height above the upper surface of the freeboard deck is not to be less than 600mm. The Flag Administration may permit the lower heights. The top of the hatch coaming is also not to be lower than the highest point of the tank over which it is fitted and is to be of adequate height for the damage stability purpose.

1.1.3.2. The gross thickness of coaming plate is not to be less than 10mm. Where the coaming height, as fitted, exceeds 600mm, the thickness may be increased or edge stiffening fitted. If an area of 1.2m^2 or more is enclosed by and/or scantlings of coaming plates of tank access coamings are not configured with a well rounded shape, those may be subject to additional requirements.

1.1.4. Cargo tank access hatch covers

1.1.4.1. Not less than 12.5mm shall be the gross thickness of unstiffened plate covers with an area less than 1.2m^2. The gross thickness of covers of a larger area is required to be increased or the cover will require stiffening.

1.1.4.2. Fastenings with a spacing of not more than 600mm shall be used to secure flat and unstiffened covers on circular hatchways.

1.1.4.3. Generally, on rectangular hatchways, the spacing of fastenings is not to be greater than 450mm and the distance between hatch corners, and adjacent fastenings, is not to be greater than 230mm.

1.1.4.4. To dished or covers of other specially approved design, requirements of 1.1.4.1 to 1.1.4.3 do not apply.

1.1.4.5. Where the cover is hinged, there has to be adequate provision of stiffening of the coaming and cover in way of the hinge. In general, hinges are not to be considered securing devices for the cover and should be so designed that the over tightening of gasket is prevented.

1.1.5. Machinery access openings – protection

1.1.5.1. Generally, machinery casings are to be protected by an enclosed bridge or poop; or by a deck house structures that conform to the strength requirements stated in 1.4.

1.1.5.2. Where vessel is intended to operate at the freeboard allowed by the International Convention onLoad Lines for Type-A freeboard vessels, such structure's height is not to be less than 2.3m. The scantlings at least equivalent to those required for bridgefront bulkheads shall be there for bulkheads at the forward ends of these structures, see 1.4.9 and 1.4.13.

1.1.6. Small hatches on the exposed fore deck

1.1.6.1. Openings to forward spaces as defined in 1.1.6.2 are to conform to the requirements given from 1.1.6.3 to 1.1.6.14.

1.1.6.2. These requirements are applicable to small hatches (generally for openings of 2.5m^2 or less) on the exposed deck within 0.25L from the F.P. and at a height less than 22m or 0.1L, whichever is less, from the summer load water line at the hatch location.

1.1.6.3. Hatches designed especially for emergency escape need not conform to 1.1.6.9(a), 1.1.6.9(b), 1.1.6.13 and 1.6.14.

1.1.6.4. For small rectangular steel hatch covers, the stiffener arrangement, plate thickness and scantlings are to be as given in Table 3.1.1 and Figure 3.1.1.

1.1.6.5. Stiffeners, where fitted, are to be aligned with the metal to metal contact points as required by 1.1.6.10 and 1.1.6.11. Also, see Figure 3.1.1 Continuous primary stiffeners are to be there. All stiffeners are to be welded to the inner edge stiffener. Refer to Figure 3.1.2

1.1.6.6. The upper edge of the hatchway coaming is to be reinforced by a horizontal member adequately, normally not more than 190mm from the coaming's upper edge.

1.1.6.7. For small hatch covers that have circular or similar shape, the cover plate thickness and reinforcement shall provide strength and stiffness equivalent to the requirements for small rectangular hatches.

1.1.6.8. For small hatch covers made of materials other than normal strength steel, required scantlings shall give equivalent strength and stiffness.

1.1.6.9. The primary securing devices are to be such that the hatch cover can be secured in place and be made weathertight employing a closing mechanism that uses one of the following methods:

a) butterfly nuts tightening onto forks (clamps)
b) quick acting cleats, or
c) a central locking device.

However, dogs (twist tightening handles) with wedges are unacceptable.

1.1.6.10. A gasket of elastic material is to be fitted on the hatch cover. This is to be designed to allow metal to metal contact at designed compression and prevent over compression of the gasket by green sea forces that may loosenor dislodge the securing device.

1.1.6.11. The metal to metal contacts are to be arranged close to each securing device as illustrated in Figure 3.1.1, and capableof with standing the bearing force.

1.1.6.12. The primary securing method is to be designed and manufactured in a manner that designed compression pressure can be achieved by a person alone without any tools.

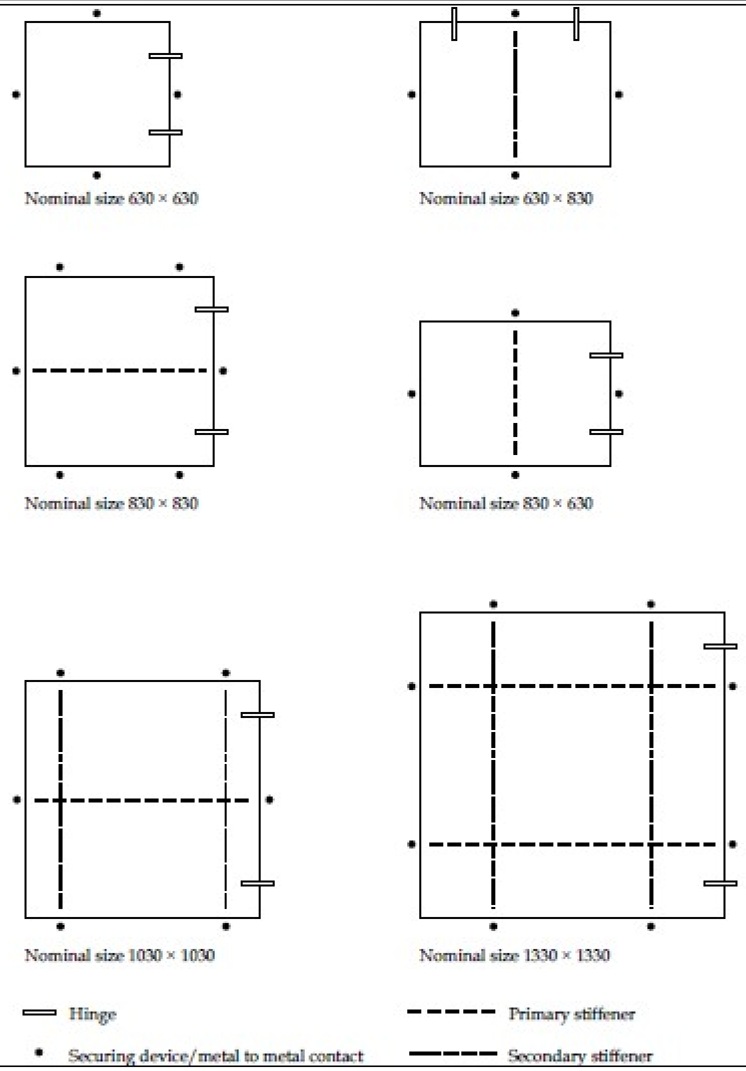
1.1.6.13. For a primary securing method that employs butterfly nuts, the forks (clamps) are to be of robust design. They are to be designed so as to minimize the risk of butterfly nuts being dislodged while in use, using curving the forks upward and raising the surface on the free end, or a similar method. Of unstiffened steel forks, gross plate thickness is not to be less than 16mm. Figure 3.1.2 shows an example arrangement.

1.1.6.14. Small hatches on the exposed fore deck are to be fitted with an independent secondary securingdevice, for e.g. using a sliding bolt, a hasp or a backing bar of slack fit, i.e. capable of keeping the hatch cover in place, as and when, the primary securing device becomes loosened or dislodged. Itsfitting is to be done on the side opposite to the hatch cover hinges.

1.1.6.15. For small hatch covers located on the exposed deck within the forward 0.25L from the F.P., hinges are to be so fitted that prominent direction of green sea will cause the cover to close, which implies that normally hinges are to be located on the fore edge.

Table 3.1.1: Scantlings for Small Steel Hatch Covers on the Fore Deck

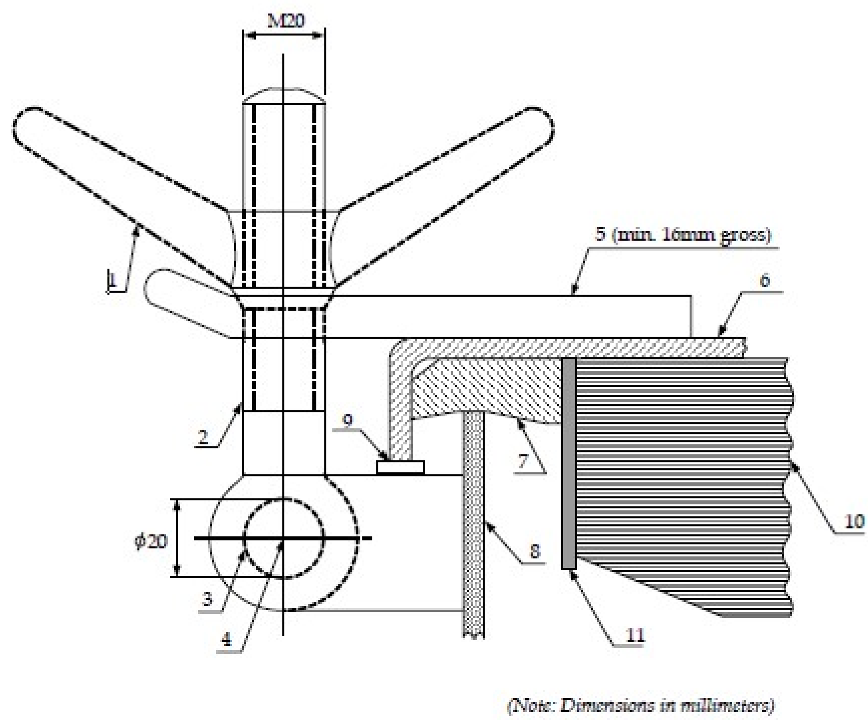
Nominal Size (mm xmm)	*Cover Plate Gross Thickness (mm)*	*Primary Stiffeners*	*Secondary Stiffeners*
		Gross Flat Bar Scantlings (mm×mm); number	
630×630	8	---	---
630×830	8	100x8; 1	---
830×630	8	100x8; 1	---
830×830	8	100x10; 1	---
1030×1030	8	120x12; 1	80x8; 2
1330×1330	8	150x12; 2	100x10; 2



Note

1) Size dimensions are in millimetres

Figure 3.1.1: Arrangement of Stiffeners



1: butterfly nut
2: bolt
3: pin
4: center of pin
5: fork (clamp) plate
6: hatch cover
7: gasket
8: hatch coaming
9: bearing pad welded on the bracket of a toggle bolt for metal to metal contact
10: stiffener
11: inner edge stiffener

Figure 3.1.2: Example of a Primary Securing Method

1.1.7. Manholes and flush deck scuttles

1.1.7.1. Manholes and flush deck scuttles in Position 1 or 2, as defined in Section 4/1.2, or within superstructures, other than enclosed superstructures, are to be closed by considerable covers capable of being made watertight.

1.1.7.2. The strength of watertight manholes shall be equivalent to that of the deck.

1.1.7.3. Unless secured by closely spaced bolts, covers are to be attached permanently.

1.1.8. Other openings

1.1.8.1. Any openings in freeboard decks other than hatchways, machinery space openings, flush scuttles and manholes are to be protected by an enclosed superstructure, or by a deck house or companionway of equivalent strength and weathertightness. Any such opening in an exposed superstructure deck, or in the top of a deck house on the freeboard deck, which gives access to a space below the freeboard deck or a space within an enclosed superstructure, is to be protected by a competent deck house or companionway, as defined in 1.4.

1.1.9. Escape openings

1.1.9.1. The easy operability of closing appliances of escape openings from each side is required.

1.1.10. Rope hatches

1.1.10.1. Rope hatches may be accepted with reduced coaming height, but generally not less than 380mm, provided that they are well secured and can be opened at Master's discretion only. The gross thickness of the coaming is not to be less than the Rule minimum gross thickness for hull envelope plating for that position, or 11mm, whichever is less.

1.1.11. Portable plates

1.1.11.1. Where portable plates are required in decks or casings, for unshipping machinery or other suchreasons, they may be accepted provided that they are of equivalent strength to the un-pierced deck or bulkhead.

Portable plates may be fitted with flush covers and they are to be secured by gaskets and closely spaced bolts at a distance not greater than five (5) bolt diameters.

1.1.11.2. The sill heights of access openings and the deck opening’s coaming heights, closed by covers whichare kept permanently closed at sea will be considered especially.

1.1.12. Tank cleaning and ullage openings

1.1.12.1. Tank cleaning and ullage openings are to be fitted with watertight covers or equivalent. Flush covers may be accepted for tank cleaning and allege openings where they conform to the applicable requirements of 1.1.11.

Table 3.1.2: 900mm High Ventilator Thickness and Bracket Standards

Nominal pipe Size	*Minimum fitted gross thickness, in mm*	*Maximum projected area of head, in cm²*	*Height of brackets, in mm*
80A	6.3	-	460
100A	7.0	-	380
150A	8.5	-	300
200A	8.5	550	-
250A	8.5	880	-
300A	8.5	1200	-
350A	8.5	2000	-
400A	8.5	2700	-
450A	8.5	3300	-
500A	8.5	4000	-

1.2. Ventilators

1.2.1. General

1.2.1.1. Ventilators are to conform to the requirements of 1.2.2 through 1.2.6 and are also to be as per any relevant requirements for machinery of the individual Classification Societies.

1.2.2. Details, arrangements and scantlings for ventilators

1.2.2.1. For standard ventilators of 900mm in height, closed by heads of not more than tabulated projected area, the minimum pipe thickness and bracket heights are to be as specified in Table 3.1.2

1.2.2.2. For ventilators of height greater than 900mm, provision for brackets or alternative means of support is to be there. Where fitted, brackets are to be of appropriate thickness and length just as their height.

1.2.2.3. Ventilators shall have coamings constructed of steel or other equivalent material and meet the requirements specified in Table 3.1.3.

1.2.2.4. All component parts and connections of ventilators are to withstand the loads defined in 1.2.3.

1.2.2.5. Rotating type mushroom ventilator heads are not to be applied or used in the areas stated in1.2.3.1.

1.2.2.6. Ventilators which pass through superstructures, other than enclosed ones, are to have adequately constructed coamings of steel or other equivalent material at the freeboard deck. Ventilators of deep tanks or tunnels passing through tween decks are to be watertight with scantlings to withstand the expected pressure.

Table 3.1.3: Coamings for Ventilators

Feature	*Requirement*
Height(4)	h_{coam}= 900 at Position 1 h_{coam}= 760 at Position 2(1)
Thickness(2), (3)	$d_{coam} \leq 130$ $t_{coam-grs} = 7.5$ $165 < d_{coam} < 320$ $d_{coam} \geq 470$ $t_{coam-grs} = 8.5$ $t_{coam-grs} = 10.0$ Intermediate values are to be obtained by linear interpolations
Support(3)	Where h_{coam}exceeds 900 the coaming is to be specially supported
where: h_{coam} height of coaming, in mm d_{coam} external diameter of coaming, in mm $t_{coam-grs}$ gross thickness of coaming, in mm	
Note: 1) The coaming height may need to be increased to satisfy any applicable subdivision and damage stability requirements. 2) Where the height of the ventilator exceeds that given, the gross thickness given above may be gradually reduced, above that height, to a minimum of 6.5mm. 3) See also 1.2.3 and for 1.2.4 ventilators in the forward part of the ship. 4) Heights are measured above sheathing, if fitted.	

1.2.3. Applied loading on ventilators

1.2.3.1. Ventilators on an exposed deck within the forward 0.25L, and where the height of the exposed deck at the ventilator is less than 0.1L or 22m, whichever is less, from the summer load waterline are to conform tothe requirements of 1.2.3.2 through 1.2.3.3 and 1.2.4.1.

1.2.3.2. The following formulae gives the pressures acting on ventilators, P_{vent}, and their closing devices:

$$P_{vent} = 0.5\, \rho_{sw} v_{sea}{}^{2} C_1 C_2 C_3 \; kN/m^2$$

Where:

ρ_{sw} density of sea water, 1.025 tonnes/m^3

v_{sea} velocity of water over the fore deck, 13.5 m/sec

C_1 shape coefficient:
- 0.5 for pipes
- 1.3 for pipe or ventilator heads, in general
- 0.8 for pipe or ventilator heads of cylindrical form with its axis in the vertical direction

C_2 slamming coefficient, 3.2

C_3 protection coefficient:
- 0.7 for pipes and ventilator heads located immediately behind a breakwater or forecastle
- 1.0 elsewhere, including immediately behind a bulwark

1.2.3.3. Using the pressure derived above, forces acting in the horizontal direction on the ventilator and its closing device may be calculated, considering largest projected area of each component.

1.2.4. Strength requirements for ventilators and their closing devices

1.2.4.1. Stresses and bending moments in ventilators are to be calculated at critical positions, as given below:

a) at penetration pieces
b) at weld or flange connections
c) at toes of supporting brackets. Bending stresses in the net section are not to exceed 0.8 σ_{yd} , where σ_{yd} is the specified minimum yield stress or 0.2% proof stress of the steel at room temperature. Then, irrespective of corrosion protection, a corrosion addition to the net section of 2 mm is to be applied.

1.2.5. Closing appliances

1.2.5.1. Except as specified otherwise in this paragraph, ventilator openings are to be provided with competent, permanently attached, closing appliances. Ventilators in Position 1, the coamings of which extend to more than 4.5m above the deck, and in Position 2, the coamings of which extend to more than 2.3m above the deck, need not be fitted with closing arrangements unless uncommon features of the design make it mandatory. Chapter 1 Section 4/1.2 defines Position 1 and Position 2.

1.2.6. Fire dampers

1.2.6.1. Where a fire damper is there within a ventilation coaming, an inspection port or opening at least 150mm in diameter is to be provided in the coaming to aid survey of the damper without disassembling the coaming or the ventilator. The closure provided for the inspection port or opening is to maintain the weathertight integrity of the coaming and, if appropriate, fire integrity of the coaming as well.

1.3. Air Pipes

1.3.1. General

1.3.1.1. Air pipes are to conform to the requirements of 1.3.2 through 1.3.6 and are also to be in line with any of the relevant requirements for machinery of the individual Classification Societies.

1.3.2. Height

1.3.2.1. The minimum height for air pipes on decks exposed to weather is given as:

a) 760 mm for those on the freeboard deck; and
b) 450 mm for those on the superstructure deck.

The measurement of height is to be done from top of the sheathing, if fitted, to the point where water may have accessbelow.

1.3.2.2. Where these heights may disturb or impede working of the vessel, a lower height may be accepted,subject to the fitting of an approved closing appliance at open end of the vent.

1.3.2.3. The height may be increased to satisfy any applicable subdivision and damage stability requirements.

1.3.2.4. Where air pipes are led through side of superstructures, height of their opening is to be at least 2.3m above the summer load waterline. Provision of automatic vent heads of approved design is to be there.

1.3.3. Details, arrangement and scantlings for air pipes

1.3.3.1. The wall thicknesses of air pipes are not to be taken less than that given in Table 3.1.4, where air pipes are exposed to weather.

Table 3.1.4: Minimum wall Thickness for Air Pipes

External diameter, in mm	*Gross minimum wall thickness, in mm*
$d_{air} \leq 80$	6.0
$d_{air} \geq 165$	8.5
where: d_{air} external diameter of pipe, in mm	
Note 1) Intermediate values are to be obtained by linear interpolations. 2) See also 1.3.4 and 1.3.5 for ventilators in forward part of the ship.	

1.3.3.2. For standard air pipes of 760mm in height, closed by heads of not more than the tabulated projected area, the minimum pipe thickness and bracket heights are to be as specified in Table 3.1.5. Three or more radial brackets are to be fitted, where brackets are required. Besides, the relevant requirements of 1.3.4 are to be applied.

1.3.3.3. Brackets are to have a minimum length of 100mm, gross thickness of 8mm or more, and height as specified in Table 3.1.5, but need not extend over the joint flange for the head. Bracket toes at the deck are to be supported. In addition, loads as per1.3.4 are to be applied.Where brackets are fitted, they are to be of adequate thickness and length in accordance with their height.

1.3.3.4. Gross pipe thickness is to be in line with the relevant requirements for machinery of individual Classification Societies.

1.3.4. Applied loading on air pipes

1.3.4.1. Air pipes on an exposed deck within the forward 0.25L and where the height of the exposed deck at the air pipe is less than 22m or 0.1L, whichever is less, from the summer load waterline are to conform to the requirements of 1.3.4.2 through 1.3.4.3 and 1.3.5.1.

Table 3.1.5: Thickness and Bracket Standards for 760 mm High Air Pipes

Nominal pipe size	*Minimum fitted gross thickness, in mm*	*Maximum projected area of head, in cm^2*	*Height [(1)] of brackets, in mm*
65A	6.0	-	480
80A	6.3	-	460
100A	7.0	-	380
125A	7.8	-	300
150A	8.5	-	300
175A	8.5	-	300
200A	8.5[(2)]	1900	300 [(2)]
250A	8.5[(2)]	2500	300 [(2)]
300A	8.5[(2)]	3200	300 [(2)]
350A	8.5[(2)]	3800	300 [(2)]
400A	8.5[(2)]	4500	300 [(2)]

Note
1) Brackets (see 1.3.3.2) need not extend over the joint flange for the head.
2) Brackets are required where the gross thickness of the pipe section is less than 10.5 mm, or where the tabulated projected head area is exceeded.

1.3.4.2. The following formulae gives the pressures P_{pipe}, acting on air pipes and their closing devices:

$$P_{pipe} = 0.5\,\rho_{sw} v_{sea}{}^2 C_1 C_2 C_3 \; kN/m^2$$

where:
ρ_{sw} density of sea water, 1.025 tonnes/m^3
v_{sea} velocity of water over the fore deck, 13.5 m/sec
C_1 shape coefficient:
0.5 for pipes
1.3 for pipe or ventilator heads in general
0.8 for pipe or ventilator heads of cylindrical form with its axis in the vertical direction
C_2 slamming coefficient, 3.2
C_3 protection coefficient:
0.7 for pipes and ventilator heads located immediately behind a breakwater or forecastle
1.0 elsewhere, including immediately behind a bulwark

1.3.4.3. From the pressure derived above,forces acting in the horizontal direction on the pipe and its closing device may be calculated using the largest projected area of each component.

1.3.5. Strength requirements for air pipes and their closing devices

1.3.5.1. Bending moments and stresses in air pipes are to be calculated at critical positions such as:

a) penetration pieces
b) weld or flange connections
c) toes of supporting brackets.

Bending stresses in the net section are not to exceed 0.8 σ_{yd} , where σ_{yd} is the specified minimum yield stress or 0.2% proof stress of the steel at room temperature. Then, irrespective of corrosion protection, a corrosion addition to the 2mm net section is to be applied.

1.3.6. Closing appliances for air pipes

1.3.6.1. All air pipes that terminate on the weather deck are to be fitted with return bends (gooseneck), or some other equivalent arrangement to prevent passing of water inboard.

1.3.6.2. A permanent and weathertight means of closure is to be provided for the outlet. The closing device is to be of automatic type, i.e. it shall close automatically upon submergence (e.g. ball float or equivalent) for any of the following cases:

a) the outlet is submerged, with the ship at its summer load water line at 40 degrees angle, or the angle of down flooding, if this is less than 40 degrees
b) to conform to damage stability requirements.

1.3.6.3. Valves that may impair the venting function are not to be fitted in the air pipes.

1.4. Deck Houses and Companionways

1.4.1. Applicability

1.4.1.1. To the steel deck houses and companionways, as defined in 1.4.3.1 and 1.4.3.2, requirements of this section are applicable.

1.4.1.2. Scantling requirements depend on the item's vertical location relative to the waterline which is categorized in terms of "tiers".

1.4.2. Materials

1.4.2.1. The scantlings in 1.4 are applicable to structures made of hull structural steel, as per the requirements of Chapter 1 Section 6/1. IRS considers scantlings of aluminium alloy deck houses, supported by submission of a specification of the proposed alloys.

1.4.3. Definitions

1.4.3.1. A deck house may be defined as decked structure that is above the strength deck, with the side plating being inboard of the shell plating by more than 4% of the ship's breadth, B.

1.4.3.2. A companionway may be defined as a weathertight deck structure; that protects an access opening leadingbelow the freeboard deck, or into a space within an enclosed superstructure.

1.4.3.3. A tier may be defined as a measure of the extent of a deck house. A deck house tier is made up of deck and external bulkheads. In general, the first tier is the tier located on the freeboard deck.

1.4.4. Structural continuity

1.4.4.1. In deck houses aft, front bulkhead is to be in line with a transverse bulkhead in the hull below or is to be supported by a combination of partial girders, transverse bulkheads and pillars.

1.4.4.2. Effective support for aft end bulkhead is to be provided.

1.4.4.3. At corners of the deck house attachment at the strength deck, attention to the connection of the deck house to the deck and the arrangements to transmit load into the under-deck supporting structure is to be given.

1.4.4.4. As much as feasible, exposed sides and main longitudinal and transverse bulkheads are to be located above bulkheads and/or deep girder frames in the hull structure, and are to be in line with the various accommodation tiers. Other effective support is to be provided where such structural arrangement in line is not possible.

1.4.4.5. Arrangements to minimize the effect of discontinuities in erections are to be made. All openings cut in the sides are to be substantially framed and have well-rounded corners. Continuous coamings or girders are to be fitted below and above doors and at similar openings.

1.4.5. Deck plating

1.4.5.1. The gross thickness of the plating, $t_{dk\text{-}grs}$, is not to be less than:

$$t_{dk-g} = 7.5\sqrt{\frac{ks}{s_{std}}}\text{mm, on first tier deck houses}$$

$$t_{dk-grs} = 7.0\sqrt{\frac{ks}{s_{std}}}\text{mm, on second tier deck houses}$$

$$t_{dk-grs} = 6.5\sqrt{\frac{ks}{s_{std}}}\text{mm, on third tier and above deck house}$$

Where:

s spacing of stiffeners, in m

k higher strength steel factor, as defined in Chapter 1 Section 6/1.1.4

σ_{yd} specified minimum yield stress of the material, in N/mm^2

s_{std} standard reference spacing of longitudinals or beams, in m:

$$= 0.470 + 0.00167L_1$$

L_1 rule length, as defined in Chapter 1 Section 4/1.1.1.1, but is not to be taken greater than 250m

1.4.5.2. The plating thickness inside deck houses may be reduced by 10%, provided that the reduced gross thickness, $t_{dh\text{-}grs}$, is not less than:

$$t_{dk-g} = (5.8s + 1)\sqrt{k}$$

where:
s spacing of stiffeners, in m
k higher strength steel factor, as defined in Section 6/1.1.4
σ_{yd} specified minimum yield stress of the material, in N/mm^2

1.4.6. Deck longitudinals and beams

1.4.6.1. For each longitudinal or beam, allied with the plating to which it is attached, the gross section modulus, $Z_{lng\text{-}grs}$, is not to be less than:

$$Z_{\mathrm{lng-grs}} = 4.563 s {l_{bdg}}^{2} h_{tier} k\ cm^{3}$$

where:

s spacing of stiffeners, in m

l_{bdg} effective bending span, as defined in Chapter 1 Section 4/2.1.1, in m

B as defined in Chapter 1 Section 4/1.1.3.1

h_{tier} load head in relation to the deck house tier, in m:
1.68 for poop and first tier above freeboard deck
1.30 for second tier above freeboard deck
0.91 for third and higher tiers above freeboard deck

For decks with position second tier or higher above the freeboard deck, generally used only as weather covering, the value of h_{tier} may be reduced, but in no case,it is to be less than 0.46 k higher strength steel factor, as defined in Chapter 1 Section 6/1.1.4

σ_{yd} specified minimum yield stress of the material, in N/mm^2

1.4.7. Deck girders and transverses

1.4.7.1. Deck girders and transverses are to be arranged to support deck longitudinals or beams. Where theirarrangements is such that these members act as a grillage structure, additional analysis may be done to consider grillage effects and justify that scantlings are equivalent to those required by 1.4.7.2 and 1.4.7.3. In this analysis, gross scantlings are to be used and basic geometry parameters are to be as stated in1.4.7.2, the load is to be taken as the head required by1.4.7.2 with a unit density of 0.715tonnes/m^3 and the permissible bending stress is to be taken as 0.67σ_{yd}. For the determination of equivalent scantlings as required by 1.4.7.3, equivalency is to be based on the deflection at girder/transverse intersection points and at midspan of the members, and the permissible deflection is to be taken as the deflections calculated for a simple beam that meet the requirements of 1.4.7.2 and with depth d_{grd}as required by 1.4.7.3.

1.4.7.2. For each deck girder or transverse web, gross section modulus, $Z_{t\text{-}grs}$, is not to be less than:

$$Z_{\mathrm{t-grs}} = 4.74 b_{dk} {l_{bdg}}^{2} h_{tier} k\ cm^{3}$$

Where:

b_{dk} mean breadth of the area of deck supported, in m

l_{bdg} effective bending span, to be taken as the distance between centres of supporting pillars, or between pillars, tranverse members, girders and/or bulkheads supporting them, in m. Where an effective bracket is fitted at the bulkhead, the length *l*bdg may be modified, see Chapter 1 Section 4/2.1.4

h_{tier} load head in relation to the deck house tier, in m:

1.68 for poop and first tier above freeboard deck
1.30 for second tier above freeboard deck
0.91 for third and higher tiers above freeboard deck
For decks with position second tier or higher above the freeboard deck, generally used only as weather covering, the value of h_{tier} may be reduced, but in no case is it to be less than 0.46

k higher strength steel factor, as defined in Chapter 1 Section 6/1.1.4
σ_{yd} specified minimum yield stress of the material, in N/mm^2

1.4.7.3. The depth of girders and transverse webs, d_{grd}, is not to be less than:

$$d_{grd} = 0.0583 l_{bdg} \quad m$$

where:
l_{bdg} effective bending span, to be taken as the distance between centres of supporting pillars, or between transverse members, pillars, girders and/or bulkheads supporting them, in m. Where an effective bracket is fitted at the bulkhead, the length l_{bdg} may be altered, refer Chapter 1 Section 4/2.1.4.

Where the girders and transverse webs intersect, it may be considered to accept a lesser depth for the longer member, where the shorter member gives full support to the longer member.

1.4.7.4. The gross thickness of girders or transverse webs is not to be taken less than 1mm per 100mm of depth, plus an additional 4mm. Where web shear strength and buckling capacity are demonstrated to be satisfactory, lesser thicknesses may be accepted. For shear strength analysis, gross scantlings are to be used, basic geometry parameters are to be as stated in1.4.7.2, load is to be taken as the head required by 1.4.7.2 with a unit density of 0.715 tonnes/m^3 and permissible shear stress is to be taken as 0.39σ_{yd}.

It is demonstrated that bucking capacity is satisfactory when the depth to gross thickness ratio of the web is less than 75.

1.4.8. Pillars

1.4.8.1. The gross scantlings of pillars are to be such that the permissible load, determined as per1.4.8.2, is greater than the design load, determined as per1.4.8.3,andconsidering the requirements given in 1.4.8.4.

1.4.8.2. The permissible loading on a pillar, W_{perm}, is given by:

$$W_{perm} = \left(f_{s1} - h_{pill} f_{s2} / r_{gyr-grs}\right) A_{pill-grs} \ kN$$

where:
f_{s1} steel factor:
12.09 normal strength steel
13.59 HT27 strength steel

16.11 HT32 strength steel
17.12 HT34 strength steel
18.12 HT36 strength steel
20.14 HT40 strength steel

h_{pill} distance between the top of the pillar supporting deck or other structure to the underside of the supported beam or girder, in m
f_{s2} steel factor:
4.44 normal strength steel
5.57 HT27 strength steel
7.47 HT32 strength steel
8.24 HT34 strength steel
9.00 HT36 strength steel
10.52 HT40 strength steel
$r_{gyr-grs}$ radius of gyration for gross pillar section, in cm
$A_{pill-grs}$ gross cross sectional area of pillar, in cm^2

1.4.8.3. The design load for a specific pillar, W_{des}, is given by:

$$W_{des} = 7.04\ b_{dk} h_{tier} l_{dk}\ kN$$

where:
b_{dk} mean breadth of the area of deck supported, in m
h_{tier} load head in relation to the deck house tier, in m:
1.68 for poop and first tier above freeboard deck
1.30 for second tier above freeboard deck
0.91 for third and higher tiers above freeboard deck
For decks with position second tier or higher above the freeboard deck, and generally used only as weather covering, the value of h_{tier} may be reduced, but in no case, it is to be less than 0.46
l_{dk} mean length of the area of deck supported, in m

1.4.8.4. Where pillars are arranged in a vertical line, at each level, design load on the pillar is to be calculated by summing the design load for the deck directly above the pillar and ½ of the design load for each pillar above.

1.4.9. Exposed bulkheads

1.4.9.1. The scantlings of the exposed bulkheads of deck houses and companionways are to be as per 1.4.10 to 1.4.13. There may be requirement ofincreased scantlings where the structure supports loads from deck equipment, fittings, etc.

1.4.9.2. The bulkhead scantlings of deck houses which do not protect openings in the freeboard deck, superstructure deck or in the top of a lowest tier deck house may be specially considered alongside the bulkhead scantlings of deck houses which do not protect machinery casings, provided they do not contain accommodation or do not protect equipment vital to the vessel's operation.

1.4.9.3. Long deck houses may require additional support to provide resistance to racking, refer 1.4.13.

1.4.10. Exposed bulkhead plating

1.4.10.1. The gross thickness of plating, $t_{blk-grs}$, is not to be less than that calculated from 1.4.10.2 and that given by:

$$t_{blk-grs} = 3s\sqrt{kh_{des}}\ \text{mm}$$

Where:
s spacing of stiffeners, in m
h_{des} design head, in m:
k higher strength steel factor, as defined in Chapter 1 Section 6/1.1.4
σ_{yd} specified minimum yield stress of the material, in N/mm^2

$$C_4[(C_5 f) - z]c$$

but is not to be taken less than given below for a specified location:
$2.5 + L_1/10$unprotected front bulkheads on the lowest tier

$1.25 + L_2/200$ elsewhere
L_1 rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but is not to be taken greater than 250m
L_2 rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but is not to be taken greater than 300m
C_4 coefficient as given in Table 3.1.6
C_5 coefficient:
$1.0 + \left[\frac{(x/L)-0.45}{C_{b1}+0.2}\right]^2$ where x/L ≤ 0.45
$1.0 + 1.5\left[\frac{(x/L)-0.45}{C_{b1}+0.2}\right]^2$ where x/L ≤ 0.45
C_{b1} block coefficient as defined in Chapter 1 Section 4/1.1.9.1, but is not to be taken as less than 0.60 or greater than0.80. For aft end bulkheads forward of amidships, C_{b1} may be taken as 0.80
x distance between the A.P. and the bulkhead being considered, in m. Deck house side bulkheads are to be divided into equal parts not exceeding 0.15L in length, and x is to be measured from the A.P. to the centre of each part considered
f as defined in Table 3.1.7
L rule length, as defined in Chapter 1 Section 4/1.1.1.1
z vertical distance from the summer load waterline measured to the middle of the plate, in m but is not to be taken as less than 1.0 for exposed machinery casing bulkheads and in no case is $b_{dh}/B_1$to be taken as less than 0.25
b_{dh} breadth of deck house at the position being considered, in m
B_1 actual breadth of the vessel at the freeboard deck at the position being considered, in m

Table 3.1.6: Values of 'C_4'

Bulkhead location	*Value of 'C_4'*
Unprotected front, lowest tier	2.0 + L_2/120
Unprotected front, 2nd tier	1.0 + L_2/120
Unprotected front, 3rd tier	0.5 + L_2/150
Protected front, all tiers	0.5 + L_2/150
Sides, all tiers	0.5 + L_2/150
Aft ends, aft of amidships, all tiers	0.7 + (L_2/1000) - 0.8x/L
Aft ends, forward of amidships, all tiers	0.5 + (L_2/1000) - 0.4x/L

Table 3.1.7: Values of 'f'

L, in m	*f, in m*
90	6.00
100	6.61
120	7.68
140	8.65
160	9.39
180	9.88
200	10.27
220	10.57
240	10.78
260	10.93
280	11.01
≥ 300	11.03
Note 1) This Table is based on the equations given in Table 3.1.8	

Table 3.1.8: Origin of 'f' Values

L, in m	*f, in m*
L ≤ 150	$(L/10)\ (e^{-L/300}) – [1-(L/150)^2]$
150 < L < 300	$(L/10)\ (e^{-L/300})$
L ≥ 300	11.03

1.4.10.2. The gross thickness for the lowest tier bulkheads, $t_{blk-tier-grs}$, is not to be less than:

$$t_{blk-tier-grs} = 5.0 + L_1/100$$

For other tiers, the gross thickness of bulkheads is not to be less than:

$t_{blk-tier-grs} = 4.0 + L_1/100$mm, or 5.0 mm, whichever is greater

Where:

L_1 rule length, L, as defined in Chapter 1 Section 4/1.1.1.1, but is not to be taken greater than 250m.

1.4.11. Exposed bulkhead stiffeners

1.4.11.1. Each stiffener, associated with the plating to which it is attached, is to have a gross section modulus, $Z_{blk-grs}$, not less than:

$$Z_{blk-grs} = 3.5 s h_{tween}{}^2 h_{des} k\ cm^3$$

where:

s spacing of stiffeners, in m
h_{tween} 'tween deck height, in m
h_{des} design head, as defined in 1.4.10.1, with z taken as the vertical distance from the summer load waterline to midpoint of the stiffener span, in m
k higher strength steel factor, as defined in Chapter 1 Section 6/1.1.4
σ_{yd} specified minimum yield stress of the material, in N/mm^2

1.4.12. Stiffener end attachments for stiffeners on exposed bulkheads

1.4.12.1. Both the ends of webs of lowest tier bulkhead stiffeners are to be properly attached. Special consideration is given to the scantlings of stiffeners having other types of end connection.

1.4.13. Web arrangements for webs on exposed bulkheads

1.4.13.1. In long deck houses with multiple tiers, partial bulkheads or web frames are to be fitted within the first tier, with maximum spacing of approximately 9m and arranged, where practicable, in line with watertight bulkheads below.

1.4.13.2. Similarly, webs are also to be arranged in way of large openings, boats davits and other points of high loading.

1.4.14. Closing arrangements for openings in deck houses and companionways

1.4.14.1. All openings in the bulkheads of deck houses and companionways, which give direct access toenclosed superstructures or to spaces below the freeboard, are to have efficient means of closing so that in any sea condition, water does not penetrate inside the vessel.

1.4.14.2. Doors of such openings are to be made up of steel or other equivalent material, permanently and strongly attached to the bulkhead. The gaskets and clamping devices or other equivalent arrangements shall be provided in doors, which are to be permanently attached to the bulkhead or to the doors themselves. The doors are to be so arranged that they can be operated from both sides of the bulkhead. Doors conforming to a recognized National or International standard will generally be accepted.

1.4.14.3. Access openings are to be so framed and stiffened such that the whole structure is equivalent to the unpiercedbulkhead, when closed.

1.4.14.4. Except as permitted by 1.4.14.5, air inlets, access doors and openings to accommodation spaces, control stations and machinery spaces, are not to face the cargo tank region. They are to be situated on the transverse bulkhead or on the side of the deck house at a distance of at least 0.04L and not less than 3m from the end of the deck house facing the cargo tank region. This distance need not go beyond 5m.

1.4.14.5. Access doors in boundary bulkheads facing the cargo tank region, or within the 5m limits as specified in 1.4.14.4,and leading to the main cargo control stations and service spaces used as provision rooms, store rooms and lockers, may be allowed, provided they do not give access directly or indirectly to any other space containing or providing for control stations, accommodation, or service spaces such as pantries, galley or work shops, or similar spaces containing source of vapour ignition. The boundary of such a space is to be insulated to “A-60” class standard, exceptthat facing the cargo tank region.

1.4.15. Sills of access openings

1.4.15.1. The sills of access openings, in the bulkheads of deck houses and companionways, which give direct access to enclosed superstructures or to spaces below the freeboard deck, is to have a height of minimum

600mm in Position 1 and 380mm in Position 2, as specified in Chapter 1 Section 4/1.2.

1.4.16. Access openings in machinery casings on Type ‘A’ freeboard tankers

1.4.16.1. In general, there are to be no openings that give direct access from the freeboard deck to the machinery space in exposed machinery casings.

1.4.16.2. A door conforming to the requirements of 1.4.14.1 to 1.4.14.3 may be allowed 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 conforming tothe requirements of 1.4.14.1 to 1.4.14.3. The sill of the exterior door is not to be taken less than 600mm and of the second door is not to be taken less than 230mm.

1.4.17. Windows and side scuttles

1.4.17.1. Side scuttles, in the external bulkheads of deck houses and weathertight doors, are to be of substantial construction as per a recognised National or International standard.

1.4.17.2. Windows and side scuttles, fitted in deck houses boundaries protecting direct access into superstructures, or to spaces below the freeboard deck, are to be fitted with competent hinged inside deadlights.

1.4.17.3. Windows and portlights facing the cargo tank region, and on the side of the superstructures or deck houses within the limits specified in 1.4.14.4 and 1.4.14.5, shall be of a fixed (non-opening) type except those in wheelhouse windows, which shall be constructed to “A-60” class standard.

1.5. Scuppers, Inlets and Discharges

1.5.1. Drains – enclosed spaces

1.5.1.1. Scuppers and discharges which drain spaces below the freeboard deck, or spaces within intact superstructures or deck houses on the freeboard deck, fitted with doors conforming to the requirements of the International Convention on Load Lines, Regulation 12, may be led to the bilges in the case of scuppers, or to appropriate sanitary tanks in the case of sanitary discharges. Alternatively, they may be led overboard, provided that:

a) the freeboard is such that deck edge is not immersed when the ship heels to five degrees either way, and
b) each drain has means to prevent water from passing inboard, as per 1.5.3.

1.5.2. Drains – open spaces

1.5.2.1. Drains leading from deck houses or superstructures which are not fitted with doors conforming to the requirements of International Convention on Load Lines, Regulation 12 are to be led overboard.

1.5.3. Prevention of water passing inboard

1.5.3.1. Drains either from spaces below the freeboard deck or from within superstructures and deck houses on the freeboard deck, where allowed to be led overboard, refer 1.5.1.1(a), are to be fitted with competent and accessible means that prevents water from passing inboard, as per 1.5.3.2 to 1.5.3.7.

1.5.3.2. For drains which remain open during normal operation of the ship, like sanitary discharges and means for preventing water passing inboard are to be as per those given below for the area described.h_{disc} is the height from the summer load line to the inboard end of the discharge, in m:

a) $h_{disc} \leq$ 0.01LL:
- one automatic non-return valve with a positive means of closing it from a position above the freeboard deck
- alternatively, one automatic non-return valve and one positive closing valve controlled from above the freeboard deck may be accepted.

b) $0.01L_L < h_{disc} \leq 0.02L_L$:
- two automatic non-return valves, without positive means of closing, provided that the inboard valve is always accessible for examination under service conditions
- the inboard valve is to be located above the deepest salt water load line
- if this is not practicable, additional locally controlled positive closing may be provided outboard, or theoutboard non-return valve may be provided with a locally controlled positive closing feature, in which case the inboard valve need not be located above the deepest salt water load line.

c) $h_{disc} > 0.02L_L$:
- one single automatic non-return valve without positive means of closing.

1.5.3.3. A locally operated positive closing valve at shell together with a non-return valve inboard, may be accepted in lieu of those required by 1.5.3.2for overboard discharges in way of machinery spaces,.

1.5.3.4. For acceptable arrangements of discharges and scuppers, see Figure 3.1.3.

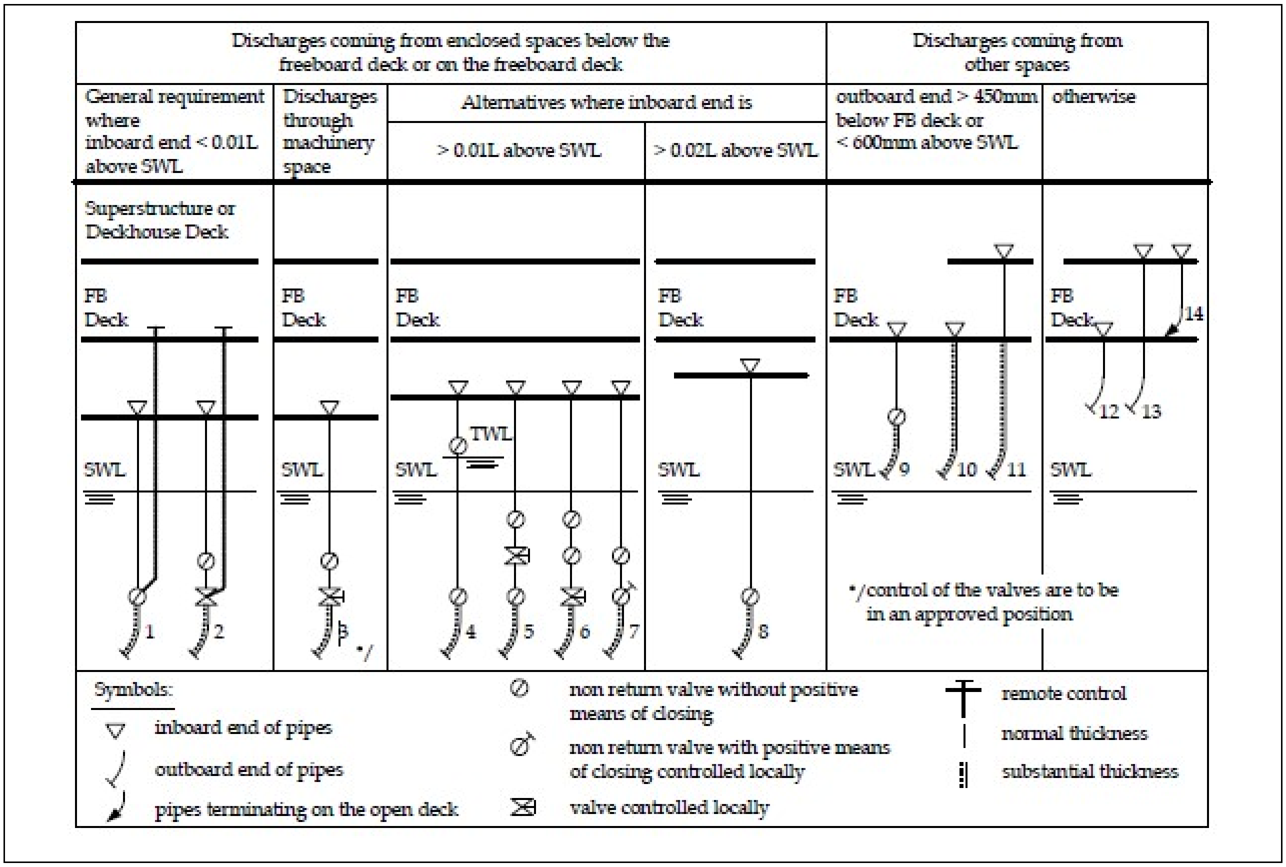


Figure 3.1.3: Diagrammatic Arrangement of Discharge and Scupper Systems

1.5.3.5. A single screw down valve operated from the deck may be accepted for drains which close at sea, such as gravity drains from topside ballast tanks.

1.5.3.6. There has to be ready access to means for operating the positive closing valve and those are to be provided with an indicator as well to show whether the valve is open or closed.

1.5.3.7. Drain pipes originating at any level and penetrating the shell either more than 450mm below the freeboard deck or less than 600mm above the summer load waterline are to have a non-return valve at the shell. This valve, unless required from1.5.3.2 through 1.5.3.4, may be omitted, if the pipe is of considerable thickness, as per1.5.7.3.

1.5.4. Sea inlets

1.5.4.1. In manned machinery spaces, main and auxiliary sea inlets and discharges with respect to the operation of machinery may be controlled locally. There has to be ready access to control that is also provided with indicators to show whether the valves are open or closed.

1.5.5. Shell valves and fittings

1.5.5.1. For installations; mounting of the shell valves are to be on the shell (or sea chest). However, where this is not feasible, a distance piece, of considerable thickness as per 1.5.7.3, may be fitted. Shell outlets are to be located so as to prevent any discharge falling onto a lowered survival craft.

1.5.5.2. For material; all required shell valves and fittings are to be of steel, bronze or other approved ductile material as ordinary cast iron or similar material are unacceptable.

1.5.5.3. Material readily rendered ineffective by heat is not to be used for shell connection as their failure in case of fire would give increase risk of flooding.

1.5.6. Unattended machinery space

1.5.6.1. For unattended machinery space; control of any valve serving a sea inlet, a bilge injection system or a discharge below the waterline is to be situated so as to allow personnel to reach it in time and operate the control, in case of ingress of water to the space with the ship is in the fully loaded condition.

1.5.6.2. For application of 1.5.6.1 in an unattended machinery space; where it can be demonstrated by calculation that the damaged water line will not be above the tank top floor level after 10 minutes from initiation of the uppermost bilge level alarm, valve control may be from the tank top floor.

Various Flag Administrations have interpretations of this requirement. Where the ship is flagged by an Administration having an interpretation of this requirement, the interpretation of the Flag Administration shall take precedence or the requirements of 1.5.6.2.

1.5.7. Pipes

1.5.7.1. All pipes from shell to the first valve are to be made of steel or other equivalent material.

1.5.7.2. The gross wall thickness of steel piping inboard of the valve is not to be less than that given in Table 3.1.9, unless considerable thickness is required.

Table 3.1.9: Thickness of Normal Steel Piping

External diameter, in mm	*Gross wall thickness, in mm*
≤155	4.5
≥230	6.0
Note 1) Intermediate values are to be obtained by linear interpolation.	

1.5.7.3. The gross wall thickness of steel piping, where required to be of substantial thickness, refer1.5.3.7 and 1.5.5.1, is not to be less than given in Table 3.1.10.

Table 3.1.10: Thickness of Substantial Steel Piping

External diameter, in mm	*Gross wall thickness, in mm*
≤80	7.0
180	10.0
≥ 220	12.5
Note 1) Intermediate values are to be obtained by linear interpolation.	

1.5.8. Rubbish chutes, offal and similar discharges

1.5.8.1. Rubbish chutes, offal, and similar discharges are to be constructed of mild steel piping or plating equal to the shell thickness. Special consideration to other materials will be given.

1.5.8.2. Openings are to be kept clear of the areas of high stress concentration and sheer strake.

1.5.8.3. Rubbish chute hoppers are to be provided a hinged weathertight cover at the inboard end with an interlock so that the discharge flap and hopper cover don't open simultaneously.

1.5.8.4. When not in use, the hopper cover is to be secured closed and a suitable notice is to be displayed at its control position.

1.5.8.5. Where the inboard end of the hopper is less than 0.01LL, a positive closing valve is to be provided along with the cover and flap, in a readily accessible position above the deepest salt water load line.

1.5.8.6. The controlling position of the valve is to lie adjacent to the hopper and provided with an open/shutindicator. It is to be kept closed when not in use, and a notice to that effect is to be displayed at thevalve operating position.

2. Crew Protection

2.1. Bulwarks and Guardrails

2.1.1. General

2.1.1.1. Bulwarks or guard rails are to be provided at the boundaries of exposed freeboard and superstructure decks and first tier deck houses and at ends of superstructures.

2.1.1.2. Bulwarks, or guard rails, are to be of a minimum 1.0m height, measured above sheathing, and are to be constructed as required in 2.1.2. Where this height disturbs the normal operation of the vessel, a lesser height may be approved. Where approval of a lower height is requested, submission of justifying information is to be done.

2.1.1.3. Within 0.6L amidships, bulwarks are to be so arranged thatit is ascertained that they are free from hull girder stresses.

2.1.1.4. Guard rails, life lines, gangways, under deck passages or an equivalent are to be provided for the protection of crew during passage from their quarters, the machinery space, and all other locations vital to crewing of the ship, refer 2.3.1.1.

2.1.2. Construction of bulwarks

2.1.2.1. The gross thickness of bulwark plating at the boundaries of exposed freeboard and superstructure decks, is not to be less than that specified inTable 3.1.11.

2.1.2.2. Plate bulwarks are to be stiffened by a top rail. Plate bulwarks on the freeboard deck and forecastle deck are to be supported by stays with a spacing not greater than 2.0m.

2.1.2.3. There has to be stiffening of free edge of the stay.

2.1.2.4. The $Z_{stay-grs}$ i.e. gross section modulus of stays is not to be less than that given below. In section modulus calculation, the material connected to the deck is to be included only. The bulb or flange of the staymay be taken into account where connected to the deck. Where, at the ends of the ship, the bulwark plating isconnected to the sheer strake, a width of attached plating, not exceeding 600mm, may also be included.

$$Z_{stay-grs} = 77{h_{blwk}}^2 s_{stay} cm^3$$

where:

h_{blwk} height of bulwark from the top of the deck plating to the top of the rail, in m

s_{stay} spacing of the stays, in m

2.1.2.5. Where mooring fittings subject the bulwark to large forces, strength of the stays is to be appropriately upgraded.

2.1.2.6. Bulwark stays are to be supported by, or are to be in line with, apt under deck stiffening. Thestiffening is to be connected by double continuous fillet welds in way of bulwark stay connections.

2.1.2.7. Where bulwarks are cut to form a gangway or other opening, stays of increased strength are to be fitted at opening ends.

2.1.2.8. Bulwarks are to be strengthened sufficiently and increased in thickness in way of mooring pipes.

2.1.2.9. The cuts in bulwarks for gangways or other openings are to be kept clear of breaks of superstructures.

2.1.2.10. Where bulwarks are fitted, freeing ports are to be provided as required in 2.1.5. The freeing ports are to conform to the requirements of Part 3.

Table 3.1.11: Thickness of Bulwark Plates

Height of Bulwark	*Gross Thickness*
1.8m or more	As required for superstructure in the same position
1.0m	6.5mm
Intermediate height	To be determined by linear interpolation

2.1.3. Construction of guard rails

2.1.3.1. Stanchions of guard rails required by 2.1.1.1 are to conform to the requirements below:

a) fixed, removable or hinged stanchions are to be fitted approx. 1.5m apart
b) at least every 3rdstanchion is to be supported by a bracket or stay
c) removable or hinged stanchions are to be capable of being locked in upright position
d) in the case of ships with rounded gunwales, stanchions are to be placed on the flat of the deck

e) for ships with sheer strake, stanchions are not to be attached to the sheer strake, upstand or a continuous gutter bar.

2.1.3.2. The opening's size, below the lowest course of rails and the deck or upstand, is to be maximum 230mm. The distance between other courses is not to be greater than 380mm.

2.1.3.3. In lieu of guard rails, only in special circumstances and in limited lengths, wire ropes may be accepted. In such cases, they are to be made taut using turnbuckles.

2.1.3.4. In lieu of guard rails, chains may be accepted, only where they are fitted between two fixed stanchions and/or bulwarks.

2.1.4. Additional requirements for bulwarks and guard rails related to spill containment

2.1.4.1. Generally, open guard rails are to be fitted on the upper deck. Plate bulwarks, with a 230mm high continuous opening, at the lower edge, may be accepted, provided arrangement allows for the acceptable handling of spillage on deck and minimizesrisk of accumulation of volatile gas.

2.1.4.2. Deck spills are to be prevented from spreading to the accommodation and service areas and from discharging into the sea by a permanent continuous coaming with a minimum height of 100mm surrounding the cargo deck. Along the sides at the aft end of the cargo deck, coaming is to have a minimum height of 200mm extending a minimum of 4.5m forward from each corner. At aft end of the cargo deck, coaming is to have a minimum height of 300mm and shall extend from ship-side to ship-side.

2.1.4.3. Where a continuous gutter bar deck coaming is fitted, it is to be constructed of similar material strength and grade as the deck plating to which it is attached.

2.1.4.4. Scupper plugs of mechanical type and means of draining or removing oil or oily water within the coaming are to be provided.

2.1.5. Additional requirements for deeper loading

2.1.5.1. Ships with Type A or B-100 Freeboard (i.e. a freeboard less than that based on Type B-60) are to have open rails fitted for a minimum of ½ the length of the exposed parts of the weather deck. Alternatively, if a continuous bulwark is fitted, minimum freeing area is to be at least 33% of the total area of the bulwark and is to be located in the lower part of the bulwark.

2.1.5.2. Where superstructures are connected by trunks, open rails are to be fitted along the whole length of the exposed parts of freeboard deck.

2.1.5.3. Ships with Type B-60 Freeboard (i.e. a freeboard less than that based on Type B but not less than Type B-60) are to have a minimum freeing area of at least 25% of the total area of the bulwark located in the lower part of the bulwark.

2.2. Tank Access

2.2.1. Access to tanks in the cargo tank region

2.2.1.1. Access to tanks in the cargo tank region is to be as specified in Chapter 1 Section 5/5.

2.3. Bow Access

2.3.1. General

2.3.1.1. Means to give safe access to the bow even in severe weather conditions are to be provided in the ship for the crew, see Table 3.1.12.

Table 3.1.12: Acceptable Arrangements for Access

<table>
<tr><th rowspan="2">Locations of Access</th><th rowspan="2">Assigned Summer Freeboard</th><th colspan="4">Acceptable Arrangements According to Type of Freeboard Assigned (6)(7)(8)</th></tr>
<tr><th>Type A</th><th>Type B-100</th><th>Type B-60</th><th>Type B & B+</th></tr>
<tr><td rowspan="2">Access to Bow
Between poop and bow, or
Between a deck house containing living accommodation or navigation equipment,
or both, and bow, or
In the case of a flush deck vessel, between
Crew accommodation and the forward end of vessel.</td><td>≤ (hFB + hss)</td><td colspan="4">ae
f(1)
f(5)</td></tr>
<tr><td>> (hFB + hss)</td><td colspan="4">ae
f(1
)f(2)</td></tr>
<tr><td rowspan="2">Access to Aft End
In the case of a flush deck vessel, between
crew accommodation and the aft end of vessel.</td><td>≤3000mm</td><td>ab
c(1)
e
f(1)</td><td>ab
c(1)
c(2)
e
f(1)
f(2)</td><td>ab
c(1)
c(2)
e
f(1)
f(2)</td><td rowspan="2">ab
c(1)
c(2)
c(4)
d(1)
d(2)
d(3)
e
f(1)
f(2)
f(4)</td></tr>
<tr><td>> 3000mm</td><td>ab
c(1)
d(1)
e
f(1)</td><td>ab
c(1)
c(2)
d(1)
d(2)
e
f(1)
f(2)</td><td>ab
c(1)
c(2)
c(4)
d(1)
d(2)
d(3)
e
f(1)
f(2)
f(4)</td></tr>
<tr><td colspan="6">where:
h_{ss} the standard height of a superstructure as defined in ICLL Regulation 33
h_{FB} freeboard from the summer load waterline amidships, in m, calculated as a Type A ship, regardless of the type of freeboard actually assigned</td></tr>
<tr><td colspan="6">a. a well lit and ventilated under deck passageway with a clear opening with a minimum width of 0.8m, and a minimum height of 2.0m, providing access to the locations under consideration and located as close as practicable to the freeboard deck</td></tr>
<tr><td colspan="6">b. a permanently constructed gangway fitted at or above the level of the superstructure deck, on or as near as practicable to the centreline of the vessel, providing a continuous platform of a non-slip surface at least 0.6m in width, with a foot-stop and guard rails extending on each side along its length. Guard rails are to be as required in 2.1.3, except that stanchions</td></tr>
</table>

	are to be fitted with a maximum spacing of 1.5m
c.	a permanent walkway with a minimum width of 0.6m, fitted at the freeboard deck level, consisting of two rows of guard rails, the stanchions of which, are to have a maximum spacing of 3m. The number of courses of rails and their spacing are to be as given in 2.1.3. On Type B freeboard ships, hatchway coamings with a height equal to or greater than 0.6m may be regarded as forming one side of the walkway provided that two rows of guard rails are fitted between the hatchways
d.	a rope lifeline with a minimum diameter of 10mm, supported by stanchions approximately 10m apart, or a single hand rail or wire rope attached to the hatch coamings, continued and adequately supported between hatchways
e.	a permanently constructed gangway fitted at or above the level of the superstructure deck on, or as near as practicable, to the centreline of the vessel: i. located so as not to hinder easy access across the working areas of the deck ii. providing a continuous platform with a minimum width of 1.0m iii. constructed of fire resistant and non-slip material iv. fitted with guard rails extending on each side throughout its length. Guard rails are to be as required in 2.1.3, except that stanchions are to be fitted with a maximum spacing of 1.5m v. provided with a foot stop on each side vi. having openings, with ladders to and from the deck, where appropriate. Openings are to be spaced a maximum of 40m apart vii. having shelters of substantial construction set in way of the gangway at intervals not exceeding 45m, if the length of the exposed deck to be traversed is greater than 70m. Every such shelter is to be capable of accommodating at least one person and be so constructed as to afford weather protection on the forward, port and starboard sides
f.	a permanent and efficiently constructed walkway fitted at the freeboard deck level on, or as near as practicable, to the centreline of the vessel, having the same specifications as those defined for a permanent gangway in ‘e’ above, except for foot-stops. On Type B freeboard ships the hatch coamings may be accepted as forming one side of the walkway, provided that the combined height of the hatch coaming and hatch cover, in the closed condition, is not less than 1m, and that two rows of guard rails are fitted between the hatchways
Note	
1) At or near the centreline of the vessel, or fitted on hatchways at or near the centreline of the vessel	
2) Fitted on each side of the vessel	
3) Fitted on one side of the vessel, provision being made for fitting on either side	
4) Fitted on one side only	
5) Fitted on each side of the hatchways as near to the centreline as far as practicable	
6) In all cases where wire ropes are fitted, adequate devices are to be provided to enable the maintaining of their tautness	
7) A means of passage over obstructions, if any, such as pipes or other fittings of a permanent nature is to be provided	
8) Generally, the width of the gangway or walkway is not to go beyond 1.5m.	
Note: Deviations from some or all of these requirements may be allowed, subject to agreement on a case-by-case basis with the relevant Flag Administration.	

3. Support Structure and Structural Appendages

3.1. Support Structure for Deck Equipment

3.1.1. General

3.1.1.1. For approval, information pertaining to the support structure of deck equipment and fittings, as listed in 3.1.2 to3.1.7, is to be submitted.

3.1.1.2. This sub-section gives the scantling requirements for the support structure and foundations of the pieces of equipment and fittings given below:

a) anchor windlasses

b) anchoring chain stoppers
c) mooring winches
d) deck cranes, derricks and lifting masts
e) emergency towing arrangements
f) bollards and bitts, fairleads, stand rollers, chocks and capstans
g) other deck equipment and fittings which are subject to specific approval
h) miscellaneous deck fittings which are not subject to specific approval.

3.1.1.3. Where deck equipment is subject to multiple load cases, like, an operational load and a green seas load, thoseare be applied independently for evaluation of strength of foundations and support structure.

3.1.2. Supporting structures for anchoring windlass and chain stopper

3.1.2.1. The windlass is to be efficiently bedded and secured to the deck. There has to be compatibility between deck thickness in way of the windlass and chain stopper and the deck attachment design.

3.1.2.2. Besidesconforming to the requirements of 3.1.2.6, shipbuilder and the windlass manufacturer are to satisfy themselves that the foundation is suitable for safe operation and maintenance of the windlass equipment.

3.1.2.3. Breaking Strength is defined as the minimum breaking strength of the chain.

3.1.2.4. For approval, following plans and information are to be submitted:
a) details of the supporting structure for the anchor windlass
b) details of the windlass foundation design, including material specifications for holding down bolts and the connection of the foundation to the deck.
c) details of the chain stopper foundation design, including material specification and the connection of the foundation to the deck.

3.1.2.5. Submission of the following supporting information is also required:
a) general arrangement drawing of anchoring equipment.
b) design loads as specified in 3.1.2.8 and 3.1.2.9 and associated reaction forces applied to the foundation and supporting structure.

3.1.2.6. The scantlings of the support structure are to be dimensioned to ascertain that for each load scenarios specified in 3.1.2.8 and 3.1.2.9, calculated stresses in the support structure does not exceed the permissible stress levels given in 3.1.2.15 to 3.1.2.18.

3.1.2.7. Theassessment of these requirements is doneemploying a simplified engineering analysis based on elastic beamtheory, two-dimensional grillage or finite-element analysis using gross scantlings.

3.1.2.8. The load cases given below are to be examined for the anchoring operation, or as appropriate:
- windlass where chain stopper is provided: 45% of Breaking Strength
- windlass where chain stopper is not provided: 80% of Breaking Strength
- chain stopper: 80% of Breaking Strength

Breaking Strength is defined in 3.1.2.3 above.

3.1.2.9. The forces below are to be applied separately in the load cases that will be examined for the design loads due to green seas in the forward 0.25L, see Figure 3.1.4:

$P_x = 200A_x$kN, acting normal to the shaft axis
$P_y = 150A_y f$ kN, acting parallel to the shaft axis (inboard and outboard directions to be examined separately)
Where:
A_x projected frontal area, in m^2
A_y projected side area, in m^2
$f = 1 + \frac{B_W}{H}$but not to be taken greater than 2.5
H overall height of windlass, in m, see Figure 3.1.4
B_W breadth of windlass measured parallel to the shaft axis, in m. See Figure 3.1.4

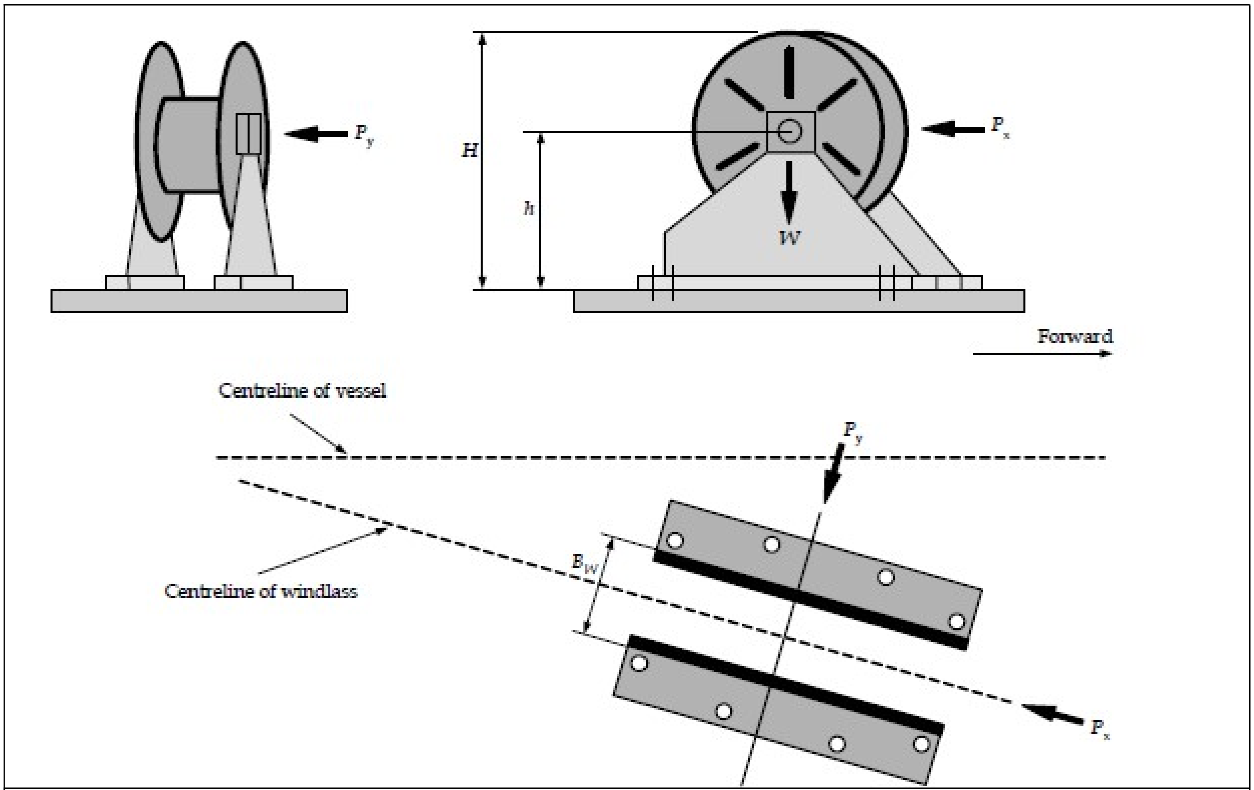


Figure 3.1.4:Direction of Forces and Weight

3.1.2.10. Calculation of forces resulting from green sea design loads in the bolts, chocks and stoppers securing the windlass to the deck are to be done. The windlass is supported by a number of bolt groups, N, each having one or more bolts. See Figure 3.1.5.

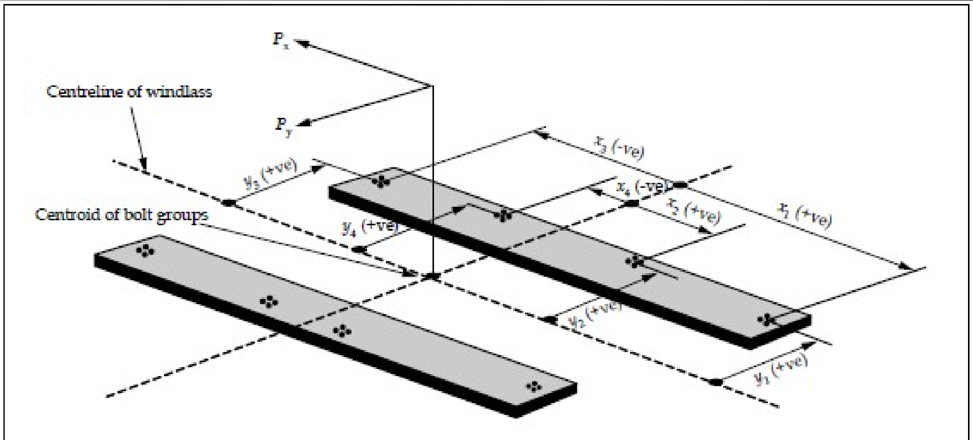


Figure 3.1.5: Bolting Arrangements and Sign Conventions

3.1.2.11. The axial forces, R_{xi} and R_{yi}, in bolt group (or bolt) i, positive in tension, are given by following:

$$R_{xi} = P_x h x_i A_i / I_x$$
$$R_{yi} = P_y h y_i A_i / I_y$$
$$R_i = R_{xi} + R_{yi} - R_{si}$$

Where:
P_x force acting normal to the shaft axis, in kN
P_y force acting parallel to the shaft axis, either inboard or outboard, whichever gives the greater force in bolt group i, in kN
x_i, y_i x and y coordinates of bolt group i from the centroid of all N bolt groups, in cm. Positive in the direction opposite to that of the applied force
h shaft centre height above the windlass mounting, in cm, see Figure 3.1.4
A_i cross sectional area of all bolts in group i, in cm^2
$I_x = \sum A_i x_i^2$ for N bolt groups, in cm^4
$I_y = \sum A_i y_i^2$for N bolt groups, in cm^4
R_{si} static reaction at bolt group i, due to the weight of windlass, in kN

i) The shear forces, F_{xi} and F_{yi}, applied to the bolt group i, and the resultant combined force F_i, are given by:

$$F_{xi} = (P_x - C_1 g m)/N$$

$$F_{yi} = \left(P_y - C_1 g m\right)/N$$

$$F_i = \sqrt{{F_{xi}}^2 + {F_{yi}}^2}$$

Where:
C_1 coefficient of friction, 0.5
m mass of windlass, in tonnes
g acceleration due to gravity, 9.81m/s^2
N number of bolt groups

ii) The resultant forces from the application of the loads specified in 3.1.2.8 and 3.1.2.9 are to be considered while designing the supporting structure.

iii) Where a separate foundation is provided for the windlass brake, distribution of resultant forces is to be calculated assuming that the brake is applied for load cases (a) and (b) defined in 3.1.2.8.

iv) The stresses resulting from anchoring design loads induced in the supporting structure are not to be greater than the permissible values given below, on basis of gross thickness of the structure:
Normal stress 1.00 σ_{yd}
Shear stress 0.58 σ_{yd}

Where:

σ_{yd} specified minimum yield stress of the material, in N/mm^2

Normal stress is the sum of axial stress and bending stress along with the corresponding shearing stress acting at 90 degress to the normal stress.

v) The tensile axial stresses resulting from green sea design loads in the individual bolts in each bolt group i are not to exceed 50% of the bolt proof strength under the above forces. The load is to be applied in the direction of chain. Where fitted bolts are designed to support these shear forces in one or both directions, the von Mises equivalent stresses are not to exceed 50% of the bolt proof strength.

vi) The horizontal forces resulting from the green sea design loads F_{xi} and F_{yi}may be reacted by shear chocks. Where pourable resins are incorporated in the holding down arrangements, its due account is taken in the calculation.

vii) The stresses resulting from green sea design loads induced in the supporting structure are not to be greater than permissible values given below, based on the gross thickness of the structure:
Normal stress 1.00 σ_{yd}
Shear stress 0.58 σ_{yd}
where:
σ_{yd} specified minimum yield stress of the material, in N/mm^2

Normal stress is the sum of axial stress and bending stress along with the corresponding shearing stress actingat 90 degress to the normal stress.

3.1.3. Supporting structure for mooring winches

3.1.3.1. Mooring winches are to be efficiently bedded and secured to the deck. There has to be compatibility between deck thickness in way of mooring winches and the deck attachment design.

3.1.3.2. Besides conforming to the requirements of 3.1.3.6, shipbuilder and mooring winch manufacturer are to satisfy themselves that the foundation is suitable for the safe operation and maintenance of the its equipment.

3.1.3.3. Rated Pull is defined as the maximum load which the mooring winch is designed to exert during operation and that is to be stated on the mooring winch foundation/support plan.

3.1.3.4. Holding Load is defined as the maximum load which the mooring winch is designed to resist during operation and is to be taken as the design brake holding load or equivalent and is to be stated on the mooring winch foundation/support plan.

3.1.3.5. For approval, following plans and information are to be submitted:

a) details of the supporting structure for mooring winches
b) details of the mooring winch foundation design, including material specifications for hold down bolts and the connection of the foundation to the deck

c) design loads as specified in 3.1.3.8 and 3.1.3.9 and associated reaction forces applied to the foundation and supporting structure.

3.1.3.6. The scantlings of the support structure are to be dimensioned to ascertain that, for each of the load cases specified in 3.1.3.8 and 3.1.3.9, calculated stresses in the support structure do not exceed the permissible stress levels specified in 3.1.3.13 and 3.1.3.14, respectively.

3.1.3.7. The assessment of these requirements are to be done employing a simplified engineering analysis based on elastic beam theory, two-dimensional grillage or finite-element analysis using net scantlings.

3.1.3.8. Following load cases are to be examined for design loads due to mooring operation:

a) mooring winch at maximum pull: 100% of the rated pull
b) mooring winch with brake effective: 100% of the holding load
c) line strength: 125% of the breaking strength of the mooring line (hawser) required by Table 3.1.15 for the ship's corresponding equipment number

Rated pull and holding load are defined in 3.1.3.3 and 3.1.3.4. The design load is to be applied through themooring line as per the arrangement shown on the mooring arrangement plan.

3.1.3.9. For mooring winches situated within the forward 0.25L, load cases for green seas are to be applied as specified in 3.1.2.9.

3.1.3.10. For mooring winches situated within the forward 0.25L, the resultant forces in the bolts obtained from green sea design loads are to be calculated as per 3.1.2.10 to 3.1.2.12.

3.1.3.11. The resultant forces from the application of the loads specified in 3.1.3.8 and 3.1.3.9 are to beconsidered while designing supporting structure.

3.1.3.12. Where a separate foundation is provided for the mooring winch brake, distribution of resultant forces is to take into account different load path. The brake is only to be considered in relation to the forces in 3.1.3.8, load case (b).

3.1.3.13. The stresses resulting from mooring operation design loads, induced in the supporting structure, are not to exceed those given in 3.1.2.15.

3.1.3.14. For mooring winches situated within the forward 0.25L, the stresses resulting from green sea design loads, induced in the bolts and supporting structure, are not to exceed values specified in 3.1.2.16 through 3.1.2.18.

3.1.4. Supporting structure for cranes, derricks and lifting masts

3.1.4.1. Support structures of cranes, derricks and lifting masts with a Safe Working Load greater than 30kN, or a maximum overturning moment to the supporting structure greater than 100kNm, are to conform to the following requirements.

3.1.4.2. These requirements are applicable to the connections to the deck and the supporting structure of cranes, derricks and lifting masts. Where these are to be certified by IRS, additional requirements may be applied by the IRS.

3.1.4.3. These requirements do not cover the following:
   a) supports of lifting appliances for personnel or passengers, see 3.1.7.5.
   b) the structure of the lifting appliance pedestals or post above the area of the deck connection
   c) Holding down bolts and their arrangement, which are considered part of the lifting appliance.

3.1.4.4. Lifting Appliance is a crane, derrick or lifting mast.

3.1.4.5. Safe Working Load is defined as the maximum load which the lifting appliance is certified to lift at any specified outreach.

3.1.4.6. Self Weight is the calculated gross self weight of the lifting appliance, including the weight of any lifting gear.

3.1.4.7. Overturning Moment is the maximum bending moment, calculated at the connection of the lifting appliance to the ship structure, due to the lifting appliance operating at Safe Working Load, taking into account outreach and self weight.

3.1.4.8. Crane Pedestal and Derrick Mast are defined in Figure 3.1.6.

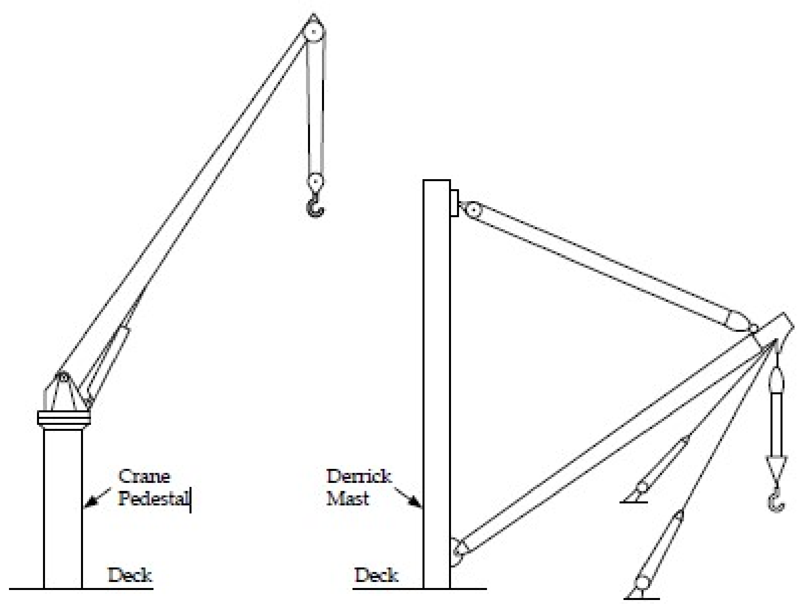


Figure 3.1.6: Crane Pedestal and Derrick Mast

3.1.4.9. For approval, following plans and information are to be submitted:
   a) details of the supporting structure of the lifting appliance, including its connection of the deck
   b) details of the Safe Working Load, self weight, vertical reaction forces and the maximum overturning moment in the supporting structure of the lifting appliance
   c) for offshore operation, maximum sea state in which the lifting appliance is to be used.

3.1.4.10. Following supporting information is to be submitted:

a) a general arrangement drawing of the crane/derrick/lifting mast.

3.1.4.11. Deck plating and under deck structure is to provide adequate support for derrick masts against the calculated vertical loads and maximum overturning moment. Where deck is penetrated, deck plating is to be adequately strengthened.

3.1.4.12. Under deck structure and deck plating is to provide adequate support for crane pedestals against the maximum overturning moment and calculated vertical loads.

3.1.4.13. In general, maintenance of the structural continuity of the deck structure and deep under-deck members to support the crane pedestal are to be provided.

3.1.4.14. On the basis of the arrangement of the deck connection in way of crane pedestals, following additional requirements are to be fulfilled:

a) adequate under deck structure directly in line with the crane pedestal is to be provided, where the pedestal is directly connected to the deck, without above deck brackets. Where the crane pedestal is attached to the deck without bracketing or where crane pedestal is not continuous through the deck, welding to the deck of the crane pedestal and its under deck support structure is to be made by appropriate full penetration welding. This could include a deep penetration welding procedure with a maximum root face of 3mm,provided these results in full penetration consequently enables ultrasonic lamination testing afterwelding is complete. The weld connection design is to be adequate for the calculated stressin the welded connection, as per 3.1.4.21

b) where the pedestal is directly connected to the deck with brackets, under deck support structure is to be fitted to ascertain a satisfactory load transmission, and to avoid structural hard spots. Above deck brackets may be fitted inside or outside of the pedestal and are to be aligned with deck girders and webs.The design is to avoid stress concentrations caused by a sudden change of section. Brackets and other direct load carrying structure and under deck support structure are to be welded to the deck by suitable full penetration welding. This could include a deep penetration welding procedure with a maximum root face of 3mm provided this results in full penetration and consequently enables ultrasonic lamination testing after welding is complete. The design of the connection is to be adequate for the calculated stress, as per 3.1.4.21.

3.1.4.15. There has to be compatibility between deck plates thickness and material strength with the crane pedestal. Where required, a thicker insert plate is to be fitted. Doublers are not to be used in any casewhere structures are subject to tension.

3.1.4.16. The scantlings of the support structure are to be dimensioned to ascertain that for the load cases specified in 3.1.4.18 and 3.1.4.19, calculated stresses in the support structure do not exceed those given in 3.1.4.21.

3.1.4.17. The assessment of these requirements are to be doneemploying a simplified engineering analysis based on elastic beam theory, two-dimensional grillage or beam element finite-element analysis using gross scantlings.

3.1.4.18. For lifting appliances which are used only in harbour, following load scenario is to be examined:

a) 130% of the Safe Working Load added to the lifting appliances self weight.

3.1.4.19. The following is to be submitted for approval purposes for lifting appliances which may be used for offshore operations:

a) maximum sea state in which lifting appliance is to be used
b) worst case vertical and horizontal accelerations
c) worst case wind loadings for the specified design sea state and wind environment.

The load scenario to be examined is to take into account these environmental loads. Following load scenario is to be examined, as a minimum:

a) 150% of the Safe Working Load added to the lifting appliances self weight.

The load scenario is to be specially considered when a crane cab is fitted above the slewing ring.

3.1.4.20. The vertical reaction force and maximum overturning moment, corresponding to the design loads specified in 3.1.4.18 and 3.1.4.19, are to be calculated and used in structural assessment.

3.1.4.21. The stresses induced in the supporting structure are not to exceed the following permissible values, based on gross thickness of the structure:

Normal stress 1.00 σ_{yd}

Shear stress 0.58 σ_{yd}

where:

σ_{yd} specified minimum yield stress of the material, in N/mm^2 considered in the design of the supporting structure.

Normal stress is the sum of axial stress and bending stress with the corresponding shearing stress acting at 90^0 to the normal stress.

3.1.4.22. It is to be assured that supporting structure has the capability to resist buckling failure.

3.1.5. Supporting structures for components used in emergency towing arrangements on tankers

3.1.5.1. Tankers with a deadweight of greater than or equal to 20 000tonnes,at both ends, are to be fitted with emergency towing arrangement, conforming to Maritime Safety Committee Resolution MSC 35(63).

3.1.5.2. The Safe Working Load of emergency towing arrangements is as specified in IMO Resolution MSC 35(63), as given below:

a) 1000kN for vessels having a deadweight greater than or equal to 20000tonnes, but less than 50 000tonnes
b) 2000kN for vessels having a deadweight greater than or equal to 50000tonnes.

3.1.5.3. For approval, following plans are to be submitted:

a) supporting structure details of the emergency towing arrangement, including the connection to the deck.

3.1.5.4. Also, following supporting information is to be submitted:

a) details of the emergency towing arrangement showing adequate detail to enable the position and direction of load actions to be ascertained.

3.1.5.5. The deck in way of fairleads and strong-points is to have a minimum gross thickness of 15mm.

3.1.5.6. Provision for continuity of strength is to be facilitated by structural arrangement.

3.1.5.7. The structural arrangement of the ship's structure in way of the emergency towing equipment is to be such that, sudden changes of shape or section are to be avoided to minimise stress concentrations. Sharp corners and notches are to be avoided, especially in high stress areas.

3.1.5.8. The scantlings of the support structure are to be dimensioned to ascertain that for the load cases specified in 3.1.5.10 and 3.1.5.11, the calculated stresses in the support structure do not exceed the permissible stress levels specified in 3.1.5.12.

3.1.5.9. The assessment of these requirements are to be done employing a simplified engineering analysis based on elastic beam theory, two-dimensional grillage or finite-element analysis using gross scantlings.

3.1.5.10. The design load for the connection of the strong-point and fittings to the deck and its supporting structure is to be taken as two times the Safe Working Load.

3.1.5.11. The assessment of the structure is to consider lines of action of the applied design load, taking into account proposed particular arrangements. See IMO MSC 35(63).

3.1.5.12. For the design load given in 3.1.5.10 and 3.1.5.11,the stresses induced in the supporting structure and welds, in way of strong-points and fairleads, are not to exceed permissible values given below based on the gross thickness of the structure:

Normal stress 1.00 σ_{yd}
Shear stress 0.58 σ_{yd}
where:
σ_{yd} specified minimum yield stress of the material, in N/mm^2 considered in the supporting structure design.
Normal stress is the sum of axial stress and bending stress with the corresponding shearing stress acting perpendicular to the normal stress.

3.1.5.13. It is to be assured that the structure has the capability to resist buckling failure.

3.1.6. Supporting structure for bollards and bitts, fairleads, stand rollers, chocks and capstans

3.1.6.1. In general, shipboard fittings (fairleads, bollards and bitts, stand rollers and chocks) and capstans used for mooring and towing (other than as specified in 3.1.5) of the vessel are to be fitted to the deck or bulwark structures using a purpose designed base or attachment.

3.1.6.2. The attachment of shipboard fittings to sheer strakes or sheer strake upstands is to be avoided, as required by Chapter 2 Section 2/2.2.5.2 and Chapter 2 Section 2/2.2.5.3.

3.1.6.3. Where fairleads are fitted in bulwarks and the imposed loads from mooring or towing lines are high, thickness of bulwarks may be increased. Also refer to 2.1.2.

3.1.6.4. For approval, following plans are to be submitted:

a) supporting structure details for the shipboard fitting and capstan arrangements, including connection of shipboard fittings and their seats to the deck.

3.1.6.5. Submission of the following supporting information is also required:

a) shipboard fittings and capstans details including the Safe Working Load of shipboard fittings and arrangements showing adequate detail to enable the position and direction of load actions to be ascertained.

3.1.6.6. Provision for continuity of strength is to be facilitated by structural arrangement.

3.1.6.7. The structural arrangement of the ship’s structure in way of the shipboard fittings and their seats and in way of capstans is to be such that, sudden changes of shape or section are to be avoided to minimize stress concentrations. Notches and sharp corners are to be avoided, especially in high stress areas.

3.1.6.8. The scantlings of the support structure are to be dimensioned to ascertainedthat for the loads specified in3.1.6.10, 3.1.6.11 and 3.1.6.12, the calculated stresses in the support structure do not exceed the permissible stress levels specified in 3.1.6.13.

3.1.6.9. The assessment of these requirements is to be done employing a simplified engineering analysis based on elastic beam theory, two-dimensional grillage or finite-element analysis using net scantlings. The required gross thickness is attained by adding relevant full corrosion addition specified in Chapter 1 Section 6/3 to the required net thickness.

3.1.6.10. The design load for the connection of shipboard fittings and their seats to the deck and its supporting structure is to be based on the line load as greater of the following requirements, as applicable for the particular fitting and its intended use:

a) for normal towing in harbour or manoeuvring operations, 125% of the maximum towline load as indicated on the towing and mooring arrangement plan, or
b) for towing service other than that experienced in harbour or manoeuvring operations, such asescort service, the nominal breaking strength of towline as per Table 3.1.15 for the ship’scorresponding equipment number, or
c) for mooring operations 125% of the nominal breaking strength of the mooring line (hawser) or towline as per Table 3.1.15 for the ship’s corresponding equipment number.

3.1.6.11. The design load for the supporting structure for capstans is to be based the:

a) 125% of the maximum hauling in force

3.1.6.12. The assessment of the structure is to consider lines of action of the applied design load, taking into account the particular arrangements proposed. However, the total load applied for towing and mooring scenarios described in 3.1.6.10 need not be more than two times the design load on the mooring line or towline. The force acting point on the shipboard fittings is to be taken as the attachment point of the mooring line or towline, or at a change in its direction.

3.1.6.13. For the design load specified in 3.1.6.10, 3.1.6.11 and 3.1.6.12,the stresses induced in the supporting structure and welds are not to exceed the permissible values given below based on the net thickness of the structure. The required gross thickness is attained by adding the relevant full corrosion addition specified in Chapter 1 Section 6/3 to the required net thickness.

where:

Normal stress 1.00 σ_{yd}

Shear stress 0.58 σ_{yd}

σ_{yd} specified minimum yield stress of the material, in N/mm^2 considered in the design of the supporting structure.

Normal stress is the sum of axial stress and bending stress with the corresponding shearing stress acting at 90 degrees to the normal stress.

3.1.6.14. It is to be assured that the structure has the capability to resist buckling failure.

3.1.6.15. The requirements on Safe Working Load apply to a single post basis (no more than one turn of one cable) are given below.

a) Safe Working Load used for normal towing operations (e.g., harbour/manoeuvring) is not to exceed 80% of the design load per 3.1.6.10.(a) and the Safe Working Load used for other towing operations (e.g., escort) is not to exceed the design load per 3.1.6.10.(b). For deck fittings used for both normal and other towing operations, the greater of the design loads of 3.1.6.10.(a) and 3.1.6.10.(b) is to be used.
b) Safe Working Load for mooring operations is not to exceed 80% of the design load per 3.1.6.10.(c).
c) Safe Working Load of each deck fitting is to be marked (by weld bead or equivalent) on the deck fittings used for towing and/or mooring.
d) The towing and mooring arrangements plan described in 3.1.6.16 is to define the method of use of towinglines and/or mooring lines.

3.1.6.16. The Safe Working Load for the intended use for each deck fitting is to be noted in the towing andmooring arrangements plan available on board for the guidance of the Master. Following information is to be provided on the plan for each deck fitting:

a) Location on the ship;
b) Fitting type;
c) SWL;
d) Purpose (mooring/harbor towing/escort towing); and

e) Manner of applying towing or mooring line load including limiting fleet angles.

This information is to be incorporated into the pilot card to provide pilot proper information on harbour/escorting operations.

3.1.7. Supporting structures for other deck equipment or fittings which are subject to specific approval

3.1.7.1. These requirements relate to other items of deck equipment which are not covered by 3.1.2 to 3.1.6. The scantlings and arrangements of support structure for such items are to be in line with the following requirements and the additional requirements of IRS.

3.1.7.2. The support structure of items not given in this sub-section will be independently considered by IRS.

3.1.7.3. Following details are to be submitted for approval. They may be indicated separately or may be included in the main structural drawings:

a) plans showing the supporting structure for deck equipment/fittings
b) details of the loads imposed on the structure by the deck equipment/fittings.

3.1.7.4. The support structure is to be arranged to resist both in-plane and out-of-plane loads acting on the deck structure.

3.1.7.5. Support for lifting appliances for personnel is to be provided as below:

a) in general, lifesaving appliances (lifeboats, life-rafts and rescue boats) are to be stowed on a purpose built cradle, seat or deployment appliance. The design load imposed on the ship structure is to be established by the supplier of the lifesaving appliance
b) the support structure is to be adequate for the design loads. Local stiffening and a local increase in plating thickness is to be provided. Deep support members may be required. Additional National and International Regulations are to be applied, where applicable
c) support structure for crew lifts is to be provided in way of the anchor points of lift operating equipment
d) support structure for boarding (accommodation) ladders is to be provided in way of the anchor points of accommodation ladders.

3.1.7.6. Support for mast structures fitted with navigation aids is to be provided as given below:

a) adequate primary support members for the mast are to be arranged in the form of deep beams or girders or bulkheads. Such members are to be arranged below or close to the mast structure
b) to transmit the loads from the mast structure to the primary support members, under-deck stiffening members are to be arranged below the mast structure forming the attachment of the mast to the deck
c) the deck thickness may be increased to provide an adequate thickness for the weld attachments.

3.1.7.7. Supporting structure for breakwaters is designed to withstand the same design load as the breakwater itself. It is suitable for transmitting loads from the breakwater into the primary support members of the ship. Competent under-deck stiffening is to be provided in way of the breakwater structure that forms the deck connection.

3.1.8. Support and attachment of miscellaneous deck fittings which are not subject to specificapproval

3.1.8.1. These general requirements are to be considered while designing the support and attachment of miscellaneous fittings which impose relatively small loads on the ship's structure and are not subject to specific approval. The arrangements of such details do not require the approval of plans by IRS.

3.1.8.2. Support positions are to be arranged so that attachment to the ship structure is clear of deck openings and stress concentrations, such as toes of end brackets. Design of supports is to be such that the attachment to deck minimizes creation of hard points.

3.1.8.3. A cargo manifold support is a self-contained, fabricated assembly designed to support the main pipework used for loading and unloading the ship. The design of the cargo manifold support is to be such that it distributes the loads imposed on the pipework during loading and unloading into the ship structure. To attain this, connection of the cargo manifold support to the deck is normally to be arranged to align with stiffening members of the main hull structure. Where this is not feasible, additional stiffening is to be fitted to avoid creation of hard points. Attention is to be paid to the detail design of the structure forming the deck attachment to minimize the effects of change of section.

3.2.Docking

3.2.1. Docking arrangements

3.2.1.1. The drydocking arrangement is not explicitly covered in these Rules.

3.2.1.2. The bottom girders structure is to be stiffened adequately to withstand the forces imposed by drydocking the ship.

3.2.1.3. For ships of unusual form, or where the Owner of the vessel has specific docking strength requirements, builder may do some additional calculations. Though such calculations are outside of the scope of Classification, they may be reviewed upon request.

3.2.2. Docking plan

3.2.2.1. It is recommended to provide a docking plan for a vessel that indicate any and all assumptions made during the design, including but not limited to, the arrangement of docking blocks, the maximum permissible loading during docking and the corresponding load at each block.

3.2.2.2. The approval of the docking plan is not required by IRS as a condition of Classification.

1) It is recommended that bottom plugs are not fitted in way of the keel plate.

3.3.Bilge Keels

3.3.1. Construction and materials

3.3.1.1. The bilge keel is to be of the similar material tensile properties as the bilge strake to which it is attached.

3.3.1.2. Special consideration will be given to bilge keels of a different design, than shown in Figure 3.1.7.

3.3.1.3. For the approval of the material strength and grades, welded connections and detail design, plan of all bilge keels is to be submitted.

3.3.1.4. The single web bilge keels design is to ascertain that failure to the web occurs prior to failure of the ground bar. In general, this may be achieved by ensuring that the web thickness of the bilge keel does not exceed that of the ground bar.

3.3.2. Ground bars

3.3.2.1. Where fitted, bilge keels are to be attached to the shell by a ground bar, or doubler, as shown in Figures 3.1.7 and 3.1.8. In general, ground bar is to be continuous.

3.3.2.2. The gross thickness of the ground bar is not to be less than that of the bilge strake or 14mm, whichever is the less.

3.3.2.3. The ground bar is to be of the same material strength as the bilge strake to which it is attached and made up of the steel grade given in Chapter 1 Section 6/1.2, Tables 1.6.2 and 1.6.3 for bilge strakes.

3.3.3. End details

3.3.3.1. The ends of the bilge keel are to be suitably tapered and are to terminate on an internal stiffening member. Typical arrangements conforming to the requirements of this sub-section are shown in Figure 3.1.8. If considered equivalent, alternative end arrangements will be accepted.

3.3.3.2. The bilge keel ends and ground bar are to be tapered or rounded. Where the ends are tapered, tapers are to be gradual with a minimum ratio of 3:1. See Figures 3.1.8 (a), 3.1.8 (b), 3.1.8 (d) and 3.1.8 (e). Where the ends are rounded, details are to be as shown in Figure 3.1.8 (c). Cut outs on the bilge keel web, within zone ‘A’, see Figures 3.1.8 (b) and 3.1.8 (e) are not allowed.

3.3.3.3. The end of the bilge keel web is not to be less than 50mm and not greater than 100mm from the end of the ground bar. See Figures 3.1.8 (a) and 3.1.8 d).

3.3.3.4. An internal transverse support member is to be situated between the end of the bilge keel web and the halfway point between the end of the bilge keel web and the end of the ground bar. See Figures 3.1.8 (a), 3.1.8 (b) and 3.1.8(c).

3.3.3.5. Where an internal longitudinal stiffener is fitted in line with the bilge keel web, longitudinal stiffener is to extend to at least the nearest transverse member forward and aft of zone ‘A’. See Figures 3.1.8 (b) and 3.1.8 (e). In this case, requirements in 3.3.3.4 relating to the internal transverse support do not hold applicable.

3.3.4. Welding

3.3.4.1. The ground bar is to be connected to the shell with a continuous fillet weld, and the bilge keel to the ground bar with a light continuous fillet weld, as per Table 3.1.13

3.3.4.2. Butt welds, in the bilge keel and ground bar, are to be clear of each other and of butts in the shellplating. In general, shell butts are to be flush in way of the ground bar and ground bar butts are to flush inway of the bilge keel. Direct connection between ground bar butt welds and shell plating and bilge keel butt welds and ground bar is to be avoided.

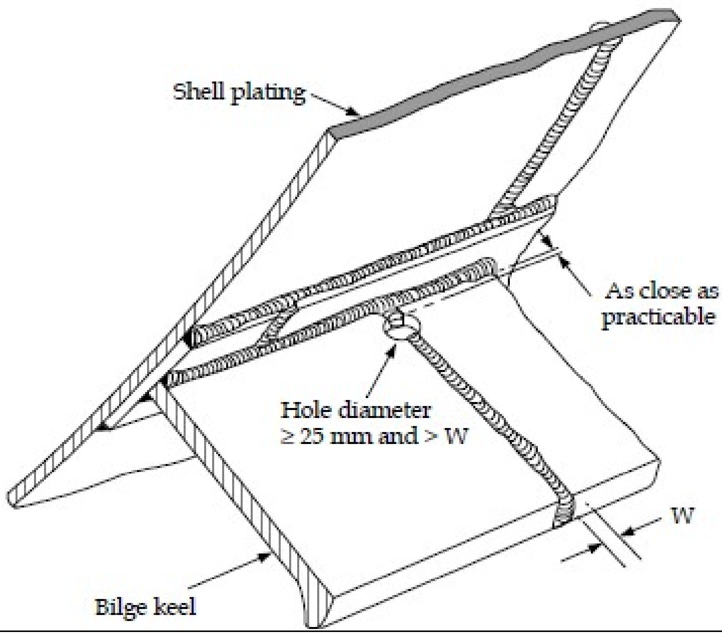


Figure 3.1.7: Bilge Keel Construction

3.3.4.3. In general, scallops and cut-outs are not to be used. Crack arresting holes are to be drilled in the bilge keel butt welds to the ground bar, as closely as possible. The hole diameter is to be greater than width of the butt weld and is to be a minimum of 25mm, as illustrated in Figure 3.1.7. Where butt weld has been subjected to non-destructive examination, crack arresting hole may be omitted.

3.3.4.4. Welds at the end of the ground bar, shell plating, and the bilge keel web and ground bar connection, within Zone ‘B’, referFigures 3.1.8(a) and 3.1.8(d) are to have a throat thickness as specified inTable 3.1.13 for “At ends”. The toes of these welds are to be ground to properly blend them with the base materials.

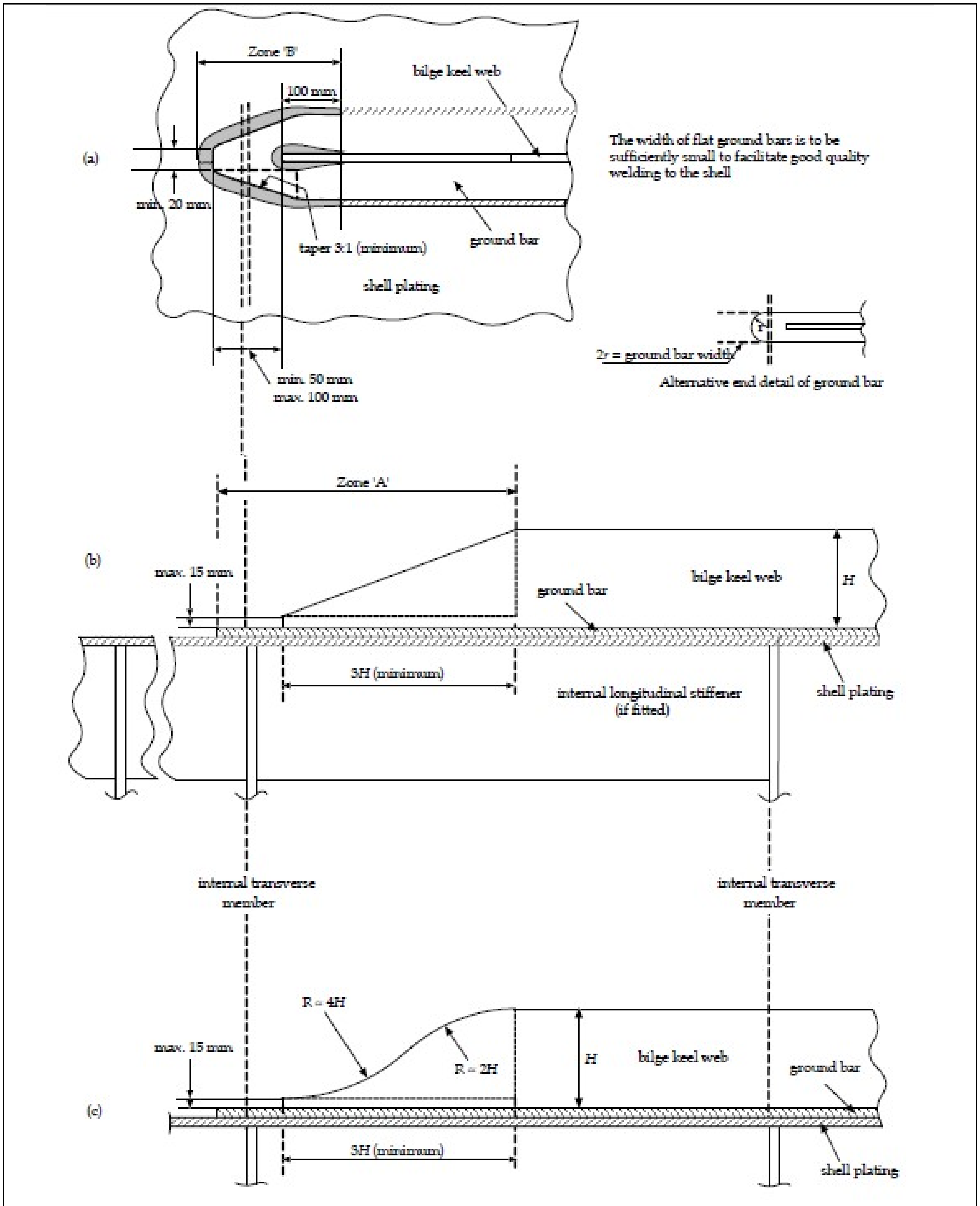


Figure 3.1.8 (a) – (c) Bilge Keel End Design

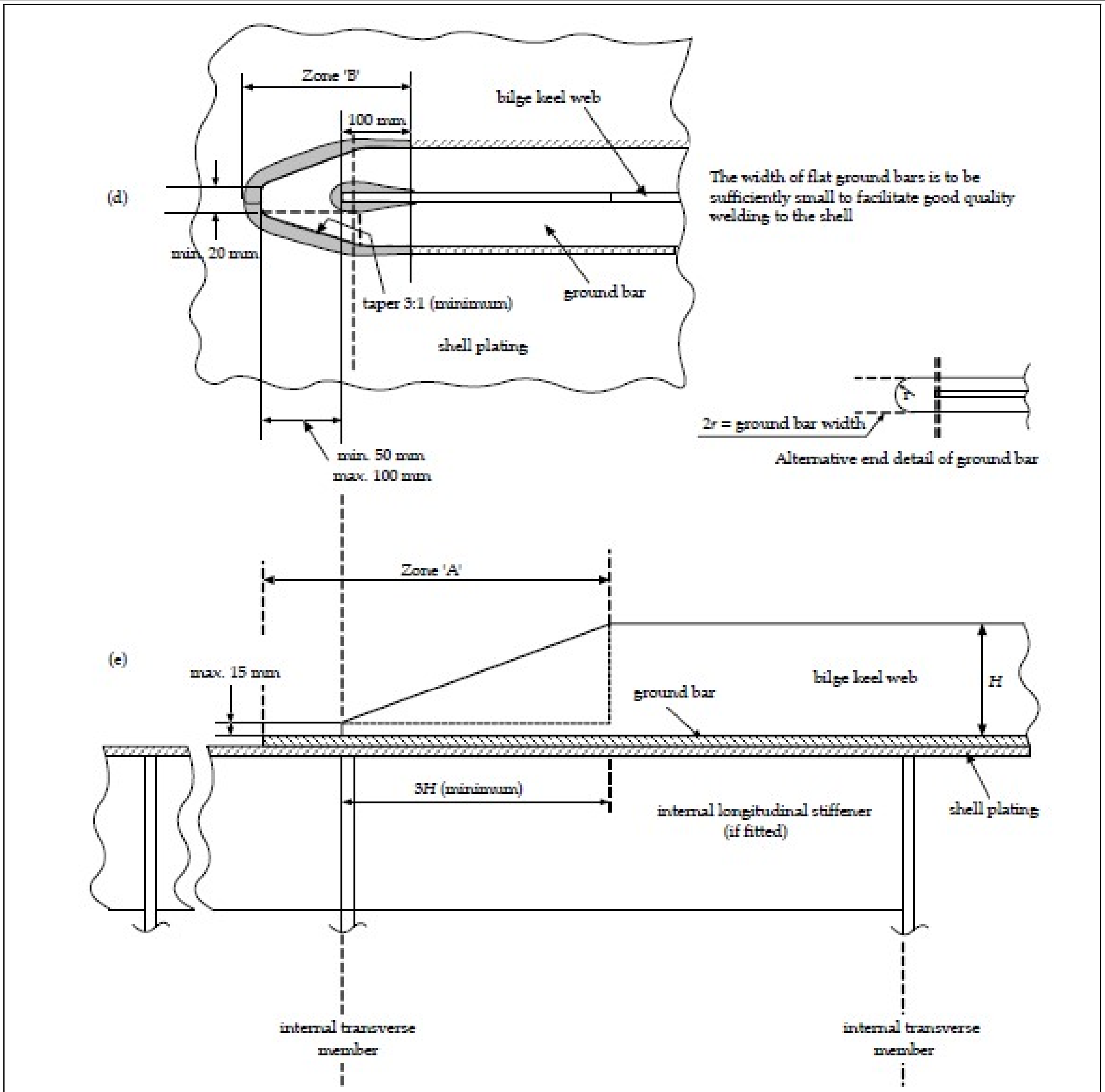


Figure 3.1.8 (d) – (e) Bilge Keel End Design

Table 3.1.13: Welding Requirements for End Connections of Bilge

Structural items being joined	*Throat thickness, in mm*	
	At ends	*Elsewhere*
Ground bar to shell	0.44 t_{grs}	0.34 t_{grs}
Bilge keel web to ground bar	0.34 t_{grs}	0.21 t_{grs}
Where: t_{grs} gross thickness of the item being attached, in mm		

4. Equipment

4.1. Equipment Number Calculation

4.1.1. Requirements

4.1.1.1. Chains and anchors are to be as specified inTable 3.1.14 and the quantity, mass and sizes of these are to be determined by the equipment number (EN), given by following formulae:

$$EN = \Delta^{2/3} + 2Bh_{dk} + 0.1A$$

Where:

Δ moulded displacement, in tonnes, as defined in Chapter 1 Section 4/1.1.7.1

B moulded breadth, in m, as defined in Chapter 1 Section 4/1.1.3.1

h_{dk} $h_{FB} + h_1 + h_2 + h_3 + \ldots$, as shown in Figure 3.1.9. In the calculation of h, sheer, camber and trim may be neglected

h_{FB} freeboard from the summer load waterline amidships, in m

h_1, h_2, h_3 … h_n height on the centreline of each tier of houses having a breadth greater than B/4, in m

A profile area of the hull, superstructure and houses above the summer load waterline which are within the length L, in m^2. Superstructures or deck houses having a breadth equal to or less than B/4 at any point may be excluded. While determining A, when a screen or bulwark is more than 1.5m high, the area shown in Figure 3.1.10 as A_2needs to be included in A

L rule length, as defined in Chapter 1 Section 4/1.1.1.1

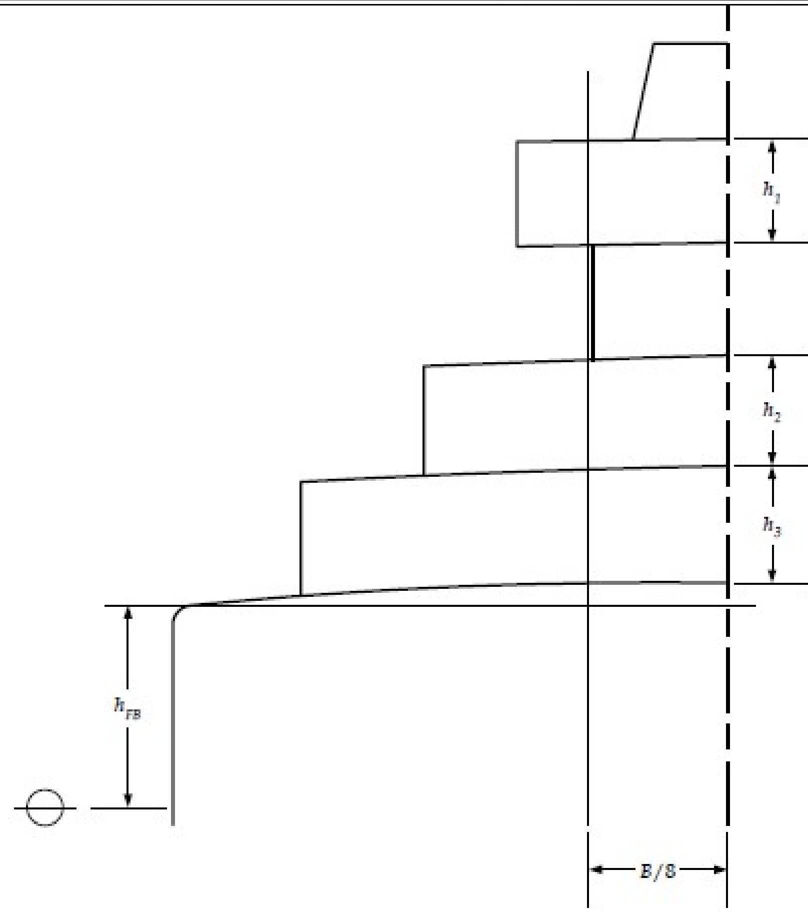


Figure 3.1.9: Effective Heights of Deck Houses

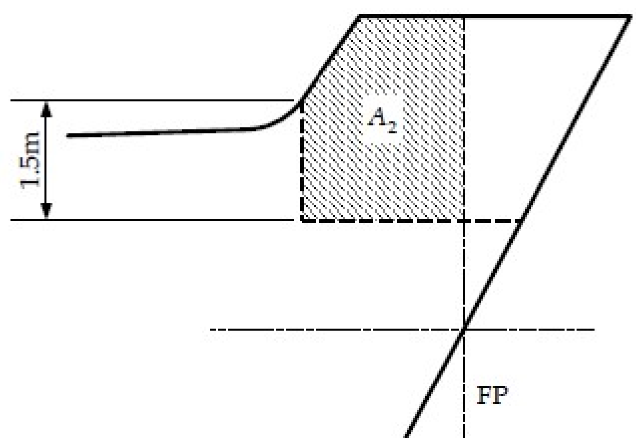


Figure 3.1.10: Profile Areas of Screens and Bulwarks

4.2. Anchors and Mooring Equipment

4.2.1. General

4.2.1.1. The anchoring equipment specification is intended for temporary mooring of a vessel within a harbour or sheltered area when the vessel is expecting berth, tide, etc.

4.2.2. Limitations

4.2.2.1. The specified equipment is not intended to be adequate to hold a ship off fully exposed coasts in roughweather or to stop a ship i.e. moving or drifting. In such a condition, loads on the anchoring equipment increase to an extent that its components may be damaged or lost.

4.2.2.2. The specified anchoring equipment is intended to hold a ship in good holding ground in conditions that prevent dragging of the anchor. If the holding ground is poor, the ability of anchors to hold the ship will be substantially reduced.

4.2.3. Assumptions

4.2.3.1. The Equipment Number (EN) formula for the required anchoring equipment assumescurrent speed of 2.5m/s, wind speed of 25m/s and a scope of chain cable between 6 and 10. The scope of chain cable is the ratio between the length of chain paid out and the waters depth.

4.2.3.2. Under normal circumstances, a ship is assumed to be using only one bow anchor and chain cable at a time.

4.2.4. Documentation

4.2.4.1. For approval, following plans and particulars are to be submitted:

a) equipment number calculations
b) equipment list that includes type, grade of anchor chain besides type and breaking load of steel and fibre ropes
c) anchor design, if it is different from standard or previously approved anchor types, including the material specification
d) windlass design; including material specifications for shafts, cable lifters, couplings and brakes
e) material specification and chain stopper design
f) emergency towing, towing and mooring arrangement plans and applicable Safe Working Load data, andother information related to such arrangements that will be available onboard the ship for the guidance of the Master.

4.2.5. Anchors

4.2.5.1. Chain cable is connected to two bower anchors and stowed in position that is ready for use.

4.2.5.2. It is recommended that a third anchor is provided as a spare bower anchor and that is to be listed for guidance only; it is not required as a condition of classification.

4.2.5.3. Anchors are to be of an approved design. The design of anchor heads is such that stress concentrations are minimized. Specifically, the radii, on all parts of cast anchor heads are to be as large as possible, especially where there is considerable change of section.

4.2.5.4. The mass per anchor of bower anchors as specified in Table 3.1.14 is for anchors of equal mass. The mass of individual anchors may vary 7% above or below the tabulated value, provided that combined mass of all anchors is not less than that required for anchors of equal mass.

4.2.6. Ordinary anchors

4.2.6.1. Anchors are to be of the stockless type. The mass of the head of a stockless anchor, including fittings and pins, is not to be less than 60% of anchor's total mass.

4.2.7. High holding power anchors

4.2.7.1. Wherever Owner agrees, use of special types of anchors will be considered. Where these are of a proven increased holding ability, consideration may also be given to reduction in the basic requirement of anchor mass, up to a maximum of 25% from the mass specified in Table 3.1.14.

4.2.7.2. Anchor for which approval is sought as a high holding power (HHP) anchor, that is to be tested at seato demonstrate that it has a holding power twice of that approved for a standard stockless anchor of the same mass.

4.2.7.3. If approval is sought for a range of sizes, then at least two are to be tested. The smaller of the two anchors is to have a mass not less than 1/10thof the larger anchor. The larger of the two anchors tested is to have a mass not less than 1/10thof that of the largest anchor for which approval is sought.

4.2.7.4. Each test is to make a comparison between at least two anchors, one ordinary stockless bower anchor and one HHP anchor. The anchor masses are to be equal approximately.

4.2.7.5. The tests are to be conducted on at least three different types of bottom, which may be sand or gravel, soft mud or silt and hard clay or similarly compacted material.

4.2.7.6. Generally, the tests are to be carried by means of a tug. Adynamometer measures the pull or it is otherwise determined from recently verified data of the tug's bollard pull as a function of propeller rpm.

4.2.7.7. The diameter of the chain cables connected with anchors is to be as required by relevant Equipment Number. During the test, length of the chain cable on each anchor is to be adequate to obtain horizontal pull on the anchor. Generally, a horizontal distance between tug and anchor equal to 10 times the water depth will be adequate.

4.2.7.8. High holding power anchors are to be of such design that ensures that these will take effective hold of the sea bed without any delay and also remain stable, for holding forces up to those required by 4.2.7.2, irrespective of the angle or position at which they first settle on the sea bed when dropped from a normal type of hawse pipe. These abilities of anchors are required to be demonstrated.

4.2.7.9. The design approval of high holding power anchors may be given as a general/type approval, and listed in a published document by IRS.

4.2.8. Chain cables

4.2.8.1. The total length of chain that is to be carried onboard, as given inTable 3.1.14, is to be approximately equally divided between the two bower anchors.

4.2.8.2. Where Owner needs equipment for anchoring at depths greater than 82.5m, it is hisresponsibility to specify the appropriate total length of the chain cable required. In such a case, dividing the chain cable into two unequal lengths may also be considered.

4.2.8.3. Those chain cables which are intended to form part of the equipment are not to be used as check chains when the vessel is launched.

4.2.9. Chain lockers

4.2.9.1. The capacity and form of chain locker is be adequate and suitable to provide for the proper stowage of the chain cable and allowing an easy direct lead for the cable into the chain pipes when the cable is fully stowed. There shall be separate spaces for port and starboard cables.

4.2.9.2. The chain locker boundaries and access openings are to be watertight. Provisions to minimize the probability of the chain locker being flooded in bad weather are to be made. Adequate drainage facilities for the chain locker are to be provided.

4.2.9.3. Chain or spurling pipes are to be of appropriate size and shall be provided with chafing lips.

4.2.9.4. Chain lockers fitted aft the collision bulkhead are to be watertight and the space is to be drained properly.

4.2.10. Securing and emergency release of chain cable

4.2.10.1. Provisions are to be made for securing the inboard ends of the chain to the structure. This attachment shall withstand a force of not less than 15% or more than 30% of the minimum breaking strength ofthe as fitted chain cable. The structure to which it is attached is to be adequate for this load.

4.2.10.2. The fastening of the chain to the ship is to be arranged in a manner that during an emergency, when the anchor and chain have to be sacrificed, chain can be readily released from an accessible position outside the chain locker. The proposed arrangement for slipping the chain cable must be made watertight, as much as possible.

4.2.11. Chain stoppers

4.2.11.1. Means to secure each chain cable once it is paid out are to be provided and that is normally achieved with the help of chain stoppers.

4.2.11.2. Securing arrangements of chain stoppers shall be such that they are able to withstand a load equal to 80% of the breaking load of the chain cable as required by 4.2.8, without going through permanent deformation.

4.2.12. Tests

4.2.12.1. The testing of all anchors and chain cables are to be carried out at establishments and on machines recognised by IRS, under the supervision of Surveyors or other Representatives of IRS and as per the relevant requirements for materials of IRS.

4.2.12.2. Test certificates containing the particulars of weights of anchors, or size and weight of cable and of the test loads applied are to be available. The Surveyor examines the certificates when the anchors and cables are placed onboard the ship.

4.2.12.3. Fibre ropes and steel wires are to be tested as per the relevant requirements for materials of IRS.

4.2.13. Mooring lines and towlines

4.2.13.1. Except as discussed in 4.3, mooring lines and towlines are not required as a condition of Classification.

The hawsers and towlines listed in Table 3.1.15 are intended as a guide. Where the tabular breaking strength is greater than 490kN, the breaking strength and the number of individual hawsers given in the Table may be modified, provided that their product is not less than the breaking strength and number of hawsers given in the Table.

4.2.14. Increased number or strength of mooring lines

4.2.14.1. For a ship that frequently uses exposed berths, it is recommended that total strength of mooring lines is two times that indicated in 4.2.13.1.

4.2.14.2. Attention is also drawn to the Oil Companies International Marine Forum document, Mooring Equipment Guidelines, for guidance on mooring of tankers at exposed locations.

4.2.15. Alternative mooring arrangement

4.2.15.1. For ease of handling, diameter of fibre ropes should not be less than 20mm.

4.2.15.2. All ropes with breaking strengths greater than 736kN and used in normal mooring operations should be handled by, and stored on, appropriately designed winches. Alternative methods of storing are given due consideration to fight the difficulties experienced in manually handling ropes with breaking strengths in excess of 490kN. In such cases, breaking strength and number of individual hawsers specified in Table 3.1.15 may be modified, but their product is not to be less than that of the breaking strength and the number of hawsers given in the Table. Moreover, number of mooring lines is not to be less than six (6), and no line should have a breaking strength less than 490kN.

4.2.16. Securing mooring lines

4.2.16.1. Means to enable mooring lines to be adequately secured onboard ship shall be provided. It is recommended that total number of suitably placed bollards on either side of the ship and/or the total brake holding power of mooring winches is to be capable of holding not less than 1.5 times the sum of the maximum breaking strengths of the mooring lines.

4.2.17. Bollards and bitts, fairleads, stand rollers and chocks

4.2.17.1. The strength of shipboard fittings used for normal and/or emergency operations at bow, sides and stern are to conform to the requirements of

4.2.17.2 and 4.2.17.3. 3.1.6 specifies the requirements for the support structure of these shipboard fittings.

4.2.17.2. Shipboard fittings are to be designed and constructed in accordance with recognized standards (e.g. ISO3913 Shipbuilding Welded Steel Bollards). The design load that is used to assess shipboard fittings and their attachments to the hull are to be as specified in 3.1.6.

4.2.17.3. The requirements on Safe Working Load (SWL) apply to shipboard fittings used for mooring and/or emergency towing, as given below:

a) the SWL is not to exceed 80% of the design load specified in 3.1.6.10(a)and 3.1.6.10(c) or 100% of the design load specified in 3.1.6.10(b), as applicable
b) the SWL of each fitting is to be marked by weld bead or equivalent
c) the SWL with its intended use, i.e., mooring, towing or emergency towing operations or some combination thereof, for each fitting is to be indicated in the towing/emergency towing and mooring arrangement plans available onboard the ship for the guidance of the Master. The arrangement plans or information is to include information on each fitting detailing location on the ship, fitting type, Safe Working Load, purpose, method of applying load and limiting fleet angle, and it is to explicitly prohibit the use of mooring and/or towing lines outside of their intended function and/or different characteristics
d) the requirements of this paragraph apply for a single post basis (no more than one turn of one cable).

4.2.18. Mooring winches

4.2.18.1. Mooring winch design and capacity are not subject to approval by the IRS as a condition of Classification. Mooring winch plans and information are to be submitted for approval of the supporting structure in way of the winch and for the connection of the mooring winch to its foundation and the connection of the foundation to the deck, as required by 3.1.3.

Mooring winches should be fitted with drum brakes, the strength of which is to be adequate to prevent unreeling of the mooring line when the rope tension is equal to 80% of that for a rope with breaking strength equal to the greater of the maximum breaking strength of the rope specified on the mooring arrangement plan or as perTable 3.1.15 for the ship’s corresponding equipment number, as fitted on the first layer on the winch drum.

4.2.19. Windlass

4.2.19.1. A windlass of adequate power and suitable for size of the chain is to be fitted to the ship as per the requirements of IRS. Where Owner requires equipment significantly in excess of Rule requirements, it is also Owner’s responsibility to specify increased windlass power.

4.2.19.2. The windlass is to be capable of heaving in either cable.

4.2.19.3. The design of the windlass is to be such that access to the chain pipe is adequate to permit the fitting of a cover or seal of sufficient strength over the sperling pipe.Special consideration will be given to the acceptance of equivalent arrangements that minimize the probability of the chain locker or forecastle being flooded in bad weather.

4.2.20. Anchor windlass trial

4.2.20.1. Each windlass that is tested under working conditions after installation onboardis required to demonstrate satisfactory operability. Independent testing of each of the following unit is to be done for:

a) braking
b) clutch functioning
c) lowering and hoisting of anchor and chain cable
d) proper riding of the chain over the chain lifter
e) proper transit of the chain through the hawse and the chain pipe
f) effecting proper stowage of the chain and anchor.

4.2.20.2. During onboard ship trials, windlass is to be shown to:

a) for all specified design anchorage depths, anchor is raised from a depth of 82.5m to 27.5m at mean speed of 9m/min
b) for specified design anchorage depths greater than 82.5m, in addition to (a), anchor is raised from the specified design anchorage depth to a depth of 82.5m at mean speed of 3m/min.

Where depth of the water in the trial area is insufficient, alternatively, suitable equivalent simulating conditions will be considered.

4.2.21. Stowage and deployment arrangements for anchors

4.2.21.1. Arrangements to ensure simple deployment, recovery and stowage of anchors are to be provided. Generally, these consist of a hawse pipe and anchor housing which may be in the form of a fabricated pocket or anchor box.

4.2.21.2. Alternative arrangements will be specially considered, where hawse pipes are not fitted.

4.2.22. Dimensions and scantlings of hawse pipes and anchor pockets

4.2.22.1. Hawse pipes are to be of apt size and configuration for ensuring adequate clearance and easylead of the chain cable from the chain stopper through ship's side.

4.2.22.2. The strength of the hawse pipes shall beadequate.

4.2.22.3. Anchor pockets are to be of considerable thickness and suitable size and form so as to house the anchors efficiently, preventing, as much as feasible, cable slackening or anchor movements, caused by wave action.

4.2.22.4. Anchor pockets and hawse pipes are to have full-rounded flanges or rubbing bars to minimize nip on the cables and the probability of cable links being subjected to high bending stresses.

The radius of curvature is to be such that at least three links of chain simultaneously bear on the rounded parts of the lower and upper ends of the hawse pipes in those areas when the vessel is at anchor and where the chain cable is supported during paying out and hoisting.

4.2.23. Hull reinforcement

4.2.23.1. Using continuous welds, hawse pipes are to be securely attached to thick, doubling or insert plates.

4.2.23.2. To ascertain rigid fastening of the hull, framing in way of anchor pockets or hawse pipes is to be reinforced, or as necessary.

4.2.23.3. In case of ships provided with a bulbous bow, but where obtaining a suitable clearance between shell plating and the anchors during anchor handling wasn't possible, provision for local reinforcements of the bulbous bow are to be there in the form of increased shell plate thickness.

4.2.24. Testing

4.2.24.1. The anchors are to be shipped and unshipped so that the Surveyor is satisfied that there is no such risk as the jamming ofthe anchor in the hawse pipe.

4.2.24.2. During windlass trials at sea, Surveyor is required to be sure that upon release of the brake, anchor immediately starts falling by its own weight.

4.2.24.3. When in position, anchor pockets and hawse pipes are required to be thoroughly tested for watertightness via a hose in which the water pressure is as per the requirements of Sub-section 5.

Table 3.1.14: Equipment – Bower Anchors and Chain Cables

		Stockless bower anchors		Chain cable stud link bower chain diameter			
Equipment Number		Number of anchors	Mass per anchor, in kg	Length, in m	Normal strength steel (Grade 1), in mm	Higher strength steel (Grade 2), in mm	Extra higher strength steel (Grade 3),in mm
greater than in mm or equal to	less than						
150	175	2	480	275	22	19	
175	205	2	570	302.5	24	20.5	
205	240	2	660	302.5	26	22	20.5
240	280	2	780	330	28	24	22
280	320	2	900	357.5	30	26	24
320	360	2	1020	357.5	32	28	24
360	400	2	1140	385	34	30	26
400	450	2	1290	385	36	32	28
450	500	2	1440	412.5	38	34	30
500	550	2	1590	412.5	40	34	30
550	600	2	1740	440	42	36	32
600	660	2	1920	440	44	38	34
660	720	2	2100	440	46	40	36
720	780	2	2280	467.5	48	42	36
780	840	2	2460	467.5	50	44	38
840	910	2	2640	467.5	52	46	40
910	980	2	2850	495	54	48	42
980	1060	2	3060	495	56	50	44
1060	1140	2	3300	495	58	50	46
1140	1220	2	3540	522.5	60	52	46
1220	1300	2	3780	522.5	62	54	48
1300	1390	2	4050	522.5	64	56	50
1390	1480	2	4320	550	66	58	50
1480	1570	2	4590	550	68	60	52
1570	1670	2	4890	550	70	62	54
1670	1790	2	5250	577.5	73	64	56
1790	1930	2	5610	577.5	76	66	58
1930	2080	2	6000	577.5	78	68	60
2080	2230	2	6450	605	81	70	62
2230	2380	2	6900	605	84	73	64
2380	2530	2	7350	605	87	76	66
2530	2700	2	7800	632.5	90	78	68
2700	2870	2	8300	632.5	92	81	70
2870	3040	2	8700	632.5	95	84	73
3040	3210	2	9300	660	97	84	76
3210	3400	2	9900	660	100	87	78
3400	3600	2	10500	660	102	90	78
3600	3800	2	11100	687.5	105	92	81
3800	4000	2	11700	687.5	107	95	84
4000	4200	2	12300	687.5	111	97	87

Table 3.1.14: Equipment – Bower Anchors and Chain Cables (Continued)

		Stockless bower anchors		*Chain cable stud link bower chain diameter*			
Equipment Number		*Number of anchors*	*Mass per anchor, in kg*	*Length, in m*	*Normal strength steel (Grade 1), in mm*	*Higher strength steel (Grade 2), in mm*	*Extra higher strength steel (Grade 3),in mm*
greater than in mm or equal to	*less than*						
4200	4400	2	12900	715	114	100	87
4400	4600	2	13500	715	117	102	90
4600	4800	2	14100	715	120	105	92
4800	5000	2	14700	742.5	122	107	95
5000	5200	2	15400	742.5	124	111	97
5200	5500	2	16100	742.5	127	111	97
5500	5800	2	16900	742.5	130	114	100
5800	6100	2	17800	742.5	132	117	102
6100	6500	2	18800	742.5	*	120	107
6500	6900	2	20000	770	*	124	111
6900	7400	2	21500	770	*	127	114
7400	7900	2	23000	770	*	132	117
7900	8400	2	24500	770	*	137	122
8400	8900	2	26000	770	*	142	127
8900	9400	2	27500	770	*	147	132
9400	10000	2	29000	770	*	152	132
10000	10700	2	31000	770	*	*	137
10700	11500	2	33000	770	*	*	142
11500	12400	2	35500	770	*	*	147
12400	13400	2	38500	770	*	*	152
13400	14600	2	42000	770	*	*	157
14600	16000	2	46000	770	*	*	162

Note
1) Spare anchors are not included in the number of required anchors.
2) ‘*’ chain grade not to be used at this diameter.

Table 3.1.15: Equipment - Towline and Hawsers

Equipment Number		*Towline wire or rope*		*Hawsers*		
greater than or equal to	less than	*Length, in m*	*Breaking strength, in kN*	*Number*	*Length of each, in m*	*Breaking strength, in kN*
150	175	180	98.0	3	120	54.0
175	205	180	112.0	3	120	59.0
205	240	180	129.0	4	120	64.0
240	280	180	150.0	4	120	69.0
280	320	180	174.0	4	140	74.0
320	360	180	207.0	4	140	78.0
360	400	180	224.0	4	140	88.0
400	450	180	250.0	4	140	98.0
450	500	180	277.0	4	140	108.0
500	550	190	306.0	4	160	123.0
550	600	190	338.0	4	160	132.0
600	660	190	371.0	4	160	147.0
660	720	190	406.0	4	160	157.0
720	780	190	441.0	4	170	172.0

Table 3.1.15: Equipment - Towline and Hawsers (Continued)

Equipment Number		*Towline wire or rope*		*Hawsers*		
greater than or equal to	less than	*Length, in m*	*Breaking strength, in kN*	*Number*	*Length of each, in m*	*Breaking strength, in kN*
780	840	190	480.0	10	170	186.0
840	910	190	518.0	11	170	201.0
910	980	190	559.0	11	170	216.0
980	1060	200	603.0	12	180	230.0
1060	1140	200	647.0	13	180	250.0
1140	1220	200	691.0	14	180	270.0
1220	1300	200	738.0	15	180	284.0
1300	1390	200	786.0	16	180	309.0
1390	1480	200	836.0	17	180	324.0
1480	1570	220	888.0	18	190	324.0
1570	1670	220	941.0	19	190	333.0
1670	1790	220	1024.0	21	190	353.0
1790	1930	220	1109.0	10	190	378.0
1930	2080	220	1168.0	11	190	402.0
2080	2230	240	1259.0	11	200	422.0
2230	2380	240	1356.0	12	200	451.0
2380	2530	240	1453.0	13	200	480.0
2530	2700	260	1471.0	14	200	480.0
2700	2870	260	1471.0	15	200	490.0
2870	3040	260	1471.0	16	200	500.0
3040	3210	280	1471.0	17	200	520.0
3210	3400	280	1471.0	18	200	554.0
3400	3600	280	1471.0	19	200	588.0
3600	3800	300	1471.0	21	200	618.0
3800	4000	300	1471.0	10	200	647.0
4000	4200	300	1471.0	11	200	647.0
4200	4400	300	1471.0	11	200	657.0
4400	4600	300	1471.0	12	200	667.0
4600	4800	300	1471.0	13	200	677.0
4800	5000	300	1471.0	14	200	686.0
5000	5200	300	1471.0	15	200	686.0
5200	5500	300	1471.0	16	200	696.0
5500	5800	300	1471.0	17	200	706.0
5800	6100	300	1471.0	18	200	706.0
6100	6500	300	1471.0	19	200	716.0
6500	6900	300	1471.0	21	200	726.0
6900	7400	300	1471.0	10	200	726.0
7400	7900	300	1471.0	11	200	726.0
7900	8400	300	1471.0	11	200	735.0
8400	8900	300	1471.0	12	200	735.0
8900	9400	300	1471.0	13	200	735.0
9400	10000	300	1471.0	14	200	735.0
10000	10700	-	-	15	200	735.0
10700	11500	-	-	16	200	735.0
11500	12400	-	-	17	200	735.0
12400	13400	-	-	18	200	735.0
13400	14600	-	-	19	200	735.0
14600	16000	-	-	21	200	735.0

4.3. Emergency Towing

4.3.1. General requirements

4.3.1.1. Every tanker with deadweight of 20000 tonnes or more shall have emergency towing arrangements fitted at both, bow and stern, as required by the International Convention for the Safety of Life at Sea, 1974, as amended (Regulation II-1/3-4).

4.3.1.2. The construction and design of towing arrangements is to be approved by the applicable Flag Administration, based on IMO MSC.35(63), Guidelines for Emergency Towing Arrangements on Tankers. Also refer 3.1.5 for requirements related to support structure of emergency towing equipment.

5. Testing Procedures

5.1. Tank Testing

5.1.1. Application

5.1.1.1. The tanks and boundaries given below are to be tested as perthe requirements given in 5.1.3 to 5.1.9:

a) gravity tanks, excluding independent tanks of less than 5m^3 capacity, for their tightness and structural adequacy
b) watertight boundaries, other than tank boundaries, for watertightness
c) weathertight boundaries for weathertightness.

5.1.2. Definitions

5.1.2.1. It is implied by watertight thatit is capable of preventing the passage of water through the structure under head of water for which the surrounding structure is designed.

5.1.2.2. It is implied by weathertight that in any sea condition, water will not penetrate into the ship.

5.1.2.3. Structural Testing is a hydrostatic test that demonstrates structural adequacy of the design. Where it is not feasible due to severe practical limitations, hydropneumatic testing may be done in its place.

5.1.2.4. Leak Testing is an air or other medium test that is carried out to establish tightness of the structure.

5.1.2.5. Hose Testing is done using a jet of water to demonstrate tightness of the structure items which are not subjected to hydrostatic or leak testing, and to other components which contribute to the watertight or weathertight integrity of the hull.

5.1.2.6. Hydropneumatic Testing is a combination of hydrostatic and air testing, undertaken by filling the tank with water and applying an additional air pressure. It is done to demonstrate the tightness of the tanks and the structural adequacy of the design as an alternative to a hydrostatic test.

5.1.2.7. Hydrostatic Testing verify the structural adequacy of the design and the tightness of the tank's structure with help of water pressure, generated by filling water to the level given in Table 3.1.16.

5.1.2.8. Hydrostatic testing is normal means for structural testing except where severe practical limitations prevent it or where air testing is permitted.

5.1.2.9. Shop Primer is a thin coating applied after surface preparation and before fabrication as a protection against corrosion during fabrication.

5.1.2.10. Protective Coating is the coating system applied to protect the structure from corrosion. This excludes the shop primer.

5.1.3. Test procedures

5.1.3.1. All the test procedures are to be carried out in the presence of, and to the satisfaction of the Surveyor. The construction shall have reached close to completion stage, and after all attachments, outfittings or penetrations, which may affect the strength or tightness of the structure, have been completed and before any ceiling and cement work is applied over joints, such that these are not subsequently impaired.

5.1.3.2. Table 3.1.16 gives specific test requirements.

5.1.3.3. For coating application timing in relation to testing, refer to5.1.8.

5.1.4. Structural testing

5.1.4.1. Where structural testing is specified as inTable 3.1.16, hydrostatic testing will be acceptable, except where practical restrictions prevent it or where leak testing is allowed by Note 1 to Table 3.1.16. In lieu of hydrostatic testing, hydropneumatic testing may be approved.

5.1.4.2. Hydrostatic testing is to comprise of a head of water to the level as specified in Table 3.1.16.

5.1.4.3. Where approved, hydropneumatic testing, is to simulate the actual loading, as far as practicable, in relation to the combined water level and air pressure. The recommendations and requirements given in 5.1.5 with respect to air pressure will also be applicable.

5.1.4.4. Structural testing may be done afloat where testing using water is undesirable on the building berth or in dry dock. It is to be performed by filling each tank and cofferdam separately to the test head specified inTable 3.1.16.

5.1.4.5. With half the number of tanks full, bottom and lower side shell in the empty tanks is to be examined and remainder of the lower side shell is to be examined when the water has been transferred to the rest of the tanks.

5.1.4.6. Tank boundaries are to be tested from at least one side. Tanks to be tested for structural adequacy (see Note 1 to Table 3.1.16) are to be so selected that all representative structural members are tested for the expected compression and tension.

5.1.5. Leak testing

5.1.5.1. All erection joints, boundary welds and penetrations including pipe connections are to be examined as per the approved procedure and under a pressure of at least 0.15bar with a leak indicating solution (e.g. soapy water solution). Pressures greater than 0.20bar are not recommended.

5.1.5.2. It is recommended that air pressure in the tank be raised to and maintained at 0.20bar for approx.1 hour, with minimum number of personnel around, before being lowered to the test pressure.

5.1.5.3. A U-tube filled with water up to a height corresponding to the required test pressure is to be fitted for verification and avoid over pressure. The cross sectional area of the U-tube is not to be less than that of the air supplying pipe. Besides U-tube, a master gauge or other approved means is to be provided for pressure verification.

5.1.5.4. Other effective leak testing methods, including vacuum testing or compressed air fillet weld testing may be considered upon submission of full particulars.

5.1.6. Hose testing

5.1.6.1. Hose testing is done for structures not subjected to air or structural testing but that need to be watertight or weathertight as perTable 3.1.16.

5.1.6.2. Hose testing is to be conducted with a hose pressure of at least 2.0 bar for the test duration. The nozzle is to have minimum inside diameter of 12mm and is to be directed at the joint being tested from a distance not exceeding 1.5 m.

5.1.6.3. In lieu of hose testing, leak or structural testing may be accepted.

5.1.7. Other methods of testing

5.1.7.1. After submission of the full particulars, other methods of testing may be considered.

5.1.8. Application of coating – protective coating

5.1.8.1. Final coating may be applied before hydrostatic testing, provided that leak testing is executed prior to the application of the final coating.

5.1.8.2. The cause of any disturbance or discolouration of the coating is to be ensured, and any deficiencies repaired.

5.1.8.3. For all semi-automatic or manual erection welds, and all fillet weld tank boundary connections, including penetrations, final coating is to be applied after leak testing has taken place. For other welds, final coating may be applied before leak testing, provided the Surveyor, after carefully examining the coating i.e. to be applied, is satisfied with the weld. The Surveyor may also carry out leak testing prior to final coating of automatic erection welds and manual or automatic pre-erection welds, taking in account the quality control procedure of the shipyard.

5.1.8.4. Final coating is to be applied after all required hose testing is done.

5.1.9. Temporary coating

5.1.9.1. Temporary coatings which may conceal defects or leaks are to be applied as specified for protective coating, refer to 5.1.8. This requirement is not applicable to shop primer applied prior to fabrication.

5.1.9.2. Prior to leak testing, silicate based shop primer may be applied to welds. While normally the layer of the primer is to be applied with a maximum thickness of 50 microns, if other primers of uncertain chemical composition are applied, their maximum thickness is to be 30 microns.

Table 3.1.16: Testing Requirements for Tanks and Boundaries

	Structures to be tested	***Type of testing***	***Hydrostatic testing head or pressure***	***Remarks***
1	Double Bottom Tanks	Structural(1)	The greater of • to the top of overflow, or • to the bulkheaddeck	Tank boundaries tested from at least one side
2	Double Side Tanks	Structural(1)	The greater of • to the top of overflow, or • to 2.4m above top of tank(2)	Tank boundaries tested from at least one side
3	Cargo Tanks Fuel Oil Bunkers	Structural(1)	The greatest of • to the top of overflow, • to 2.4m above top of tank(2), or • to the top of tank(2) plus setting of any pressure relief valve	Tank boundaries tested from at least one side
4	Cofferdams	Structural	The greater of • to the top of overflow, or • to 2.4m above top of cofferdam	
5a	Peak Tanks	Structural(3)	The greater of • to the top of overflow, or • to 2.4m above top of tank(2)	Aft peak tank test to be carried out after installation of stern tube.
5b	Fore Peak not used as a tank	Structural		
5c	Aft Peak not used as atank	Refer to		
6	Watertight Bulkheads in way of dry space	SOLAS II.1		Including steps and recesses
7	Watertight Doors below freeboard or bulkhead deck	Reg.14		For testing before installation(5)
8	(void)	Leak		
9	Watertight hatch covers of tanks on combination carriers	Hose(4)	The greater of: • to 2.4m above the top of hatch cover, or • setting pressure of the Pressure relief valve	At least every second hatch cover is to be tested
10	Weathertight HatchCovers, Doors and other Closing	Hose		

	Appliances			
11	Shell plating in way of pump room	Visual examination		To be carefully examined with the vessel afloat
12	Chain Locker (aft Collision Bulkhead)	Structural	To the top of chain locker spurling pipe	
13	Independent Tanks	Structural	The greater of — to the top of overflow, or — to 0.9 m above top of tank	
14	Ballast Ducts	Structural	Ballast pump maximum pressure or setting of any relief valve for the ballast duct if that is less	
15	Hawse Pipes	Hose		

Note

1) Leak or hydropneumatic testing may be accepted under the conditions specified in 5.1.5, provided that at least one tank for each type is structurally tested, and selected in connection with the approval of the design. In general, the structural testing need not be repeated for subsequent vessels of a series of identical new buildings unless the Surveyor deems the repetition necessary. The structural testing of cargo space boundaries and tanks for segregated cargoes or pollutants on subsequent vessels of a series of identical new buildings are to be in accordance with the requirements of IRS.

2) Top of tank is defined as the deck forming the top of the tank excluding hatchways.

3) Leak testing in accordance with 5.1.5 may be accepted, except that hydropneumatic testing may be required in consideration of the construction techniques and welding procedures employed.

4) Where hose testing is impractical due to the stage of outfitting (machinery, cables, switchboard, insulation etc.), it may be replaced at IRS's discretion, by a careful visual examination of all the crossings and welded joints. A dye penetrant test, leak test or ultrasonic leak test may be required.

5) Before installation (i.e. normally at manufacture) the watertight access doors or hatches are to be hydrostatically tested with a head of water equivalent to the bulkhead deck at centre, from the side which is most prone to leakage. The acceptance criteria are as follows:

- no leakage for doors or hatches with gaskets
- a maximum water leakage of one litre per minute for doors or hatches with metallic sealing.

6) If leak or hydropneumatic testing is carried out, arrangements are to be made to ensure that no pressure in excess of 0.30 bar is applied.

SECTION 2 SHIP IN OPERATION RENEWAL CRITERIA

Contents

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1. Allowable Thickness Diminution for Hull Structure

1.1. General

1.1.1. Applicability

1.4.2.1. This Section deals with the criteria for the allowable thickness shrinking of the ships' hull structure.

1.4.2.2. It is applied only to ships which are designed and built in accordance with these Rules.

1.4.2.3. In order to evaluate the ships' structure against the identified renewal criteria, Thickness measurements are generally used.

1.1.2. Wastage allowance concept

1.1.2.1. Wastage allowance is contained of two aspects; local wastage allowance and overall hull girder wastage allowance. In 1.4, local wastage allowance is defined and in 1.5 the overall hull girder wastage allowance is specified.

1.1.2.2. During the operational life of the vessel, assessment against both local and overall hull girder wastage criteria is essential.

1.1.2.3. If either the local or overall hull girder wastage allowance is exceeded, steel renewal is required.

1.1.2.4. The new building requirements within these Rules combine corrosion additions, see Chapter 1 Section 6/3, and consider all applicable loads and failure modes (e.g. yielding, buckling, and fatigue). No further assessment of the scantlings against the requirements within these Rules is needed during the operational life of the ship on condition that that the thickness of any structural member remains greater than the renewal thickness stated herein.

1.1.3. Requirements for documentation

1.1.3.1. As defined in 1.4.2, the plans to be supplied onboard the ship, (see Chapter 1 Section 3/2.2.3) are to comprise both the as-built and renewal thickness. Any owner's extra thickness is also to be clearly shown on the drawings.

1.1.3.2. As defined in 1.5, the "as-built" Midship Section plan given by the builder and carried on board the ship is to consist of a table showing the minimum allowable hull girder sectional properties, for the mid-tank transverse section in all cargo tanks.

1.2. Assessment of Thickness Measurements

1.2.1. General

1.4.2.1. In accordance with requirements of Part 1*, the* minimum survey requirements for the maintenance of class of double hull oil tankers are well-defined.

1.4.2.2. In accordance with the requirements of Part 1*,* thickness measurements are to be conducted.

1.2.2. Assessment of local wastage

1.2.2.1. As defined in 1.4.2 and 1.6 respectively, thickness measurements are considered to check that the measured thickness is not less than the renewal thickness for general corrosion and local pitting/edge corrosion, See also 1.3.

1.2.2.2. According the Surveyor's discretion, when a survey identifies that steel renewal is essential or presence of structural defects which will damage the ships' fitness for continuous service; counteractive measures are to be executed before the ship continues in service.

1.2.2.3. At Annual and Intermediate Surveys, the re-examination and added thickness measurements are necessary where the measured thickness, t_m, is less than the permissible thickness at annual survey, t_{annual}, defined as:

$t_{annual} = t_{as-built} - t_{own} - t_{was}$ mm

Where:

$t_{as-built}$ as built thickness, in mm

t_{was} wastage allowance, as defined in 1.4.2.2

t_{own} owner/builder specified additional wastage allowance, if applicable, in mm

1.2.2.4. In accordance with Table 3.2.1 and requirement of 1.2.2.3, in order to determine the full extent of the corrosion pattern, re-examination and additional thickness measurements are to be done.

Table 3.2.1 **Additional Thickness Measurement in way of Structure Identified with $t_m < t_{annual}$**

Structural member	*Extent of measurement*	*Pattern of measurement*
Plating	Suspect areas and adjacent plates	5 point pattern over 1m^2
Stiffeners	Suspect areas	3 measurements in line across web 3 measurements in line across flange

1.2.2.5. At each Special Survey as considered essential by the surveyor, thickness measurements are to be taken in way of critical areas. Critical areas are to comprise of locations throughout the ship with corrosion levels that are likely to contravene 1.2.2.3 and/or are considered prone to rapid wastage.

1.2.3. Assessment of overall hull girder wastage

1.2.3.1. The hull girder sectional properties of the ship are to be assessed for the cross-sections, based on the thicknesses given by the thickness measurements, to confirm that the resulting hull girder sectional properties are not less than the minimum standard defined in 1.5.2..

1.3. Categories of Corrosion

1.3.1. General corrosion

1.3.1.1. General corrosion is defined as areas where general uniform reduction of material thickness is found over a far-reaching area.

1.3.1.2. Renewal criteria for general corrosion are given in 1.4.

1.3.2. Pitting corrosion

1.3.2.1. Pitting corrosion is defined as scattered corrosion spots/areas with local material reductions which are greater than the general corrosion in the adjoining area.

1.3.2.2. The pitting intensity is defined in Figure 3.2.1.

1.3.2.3. Renewal criteria for pitting corrosion are given in 1.6.2.

1.3.3. Edge corrosion

1.3.3.1. Edge corrosion is well-defined as local corrosion at the free edges of plates, stiffeners, primary support members and around openings. An instance of edge corrosion is shown in Figure 3.2.2.

1.3.3.2. In 1.6.3 Renewal criteria for edge corrosion are mentioned.

1.3.4. Groove corrosion

1.3.4.1. Groove corrosion is normally known as local material loss adjacent to weld joints along abutting stiffeners and at stiffener or plate butts or seams. An instance of groove corrosion is shown in Figure 3.2.3.

1.3.4.2. Renewal criteria for groove corrosion are given in 1.6.4.

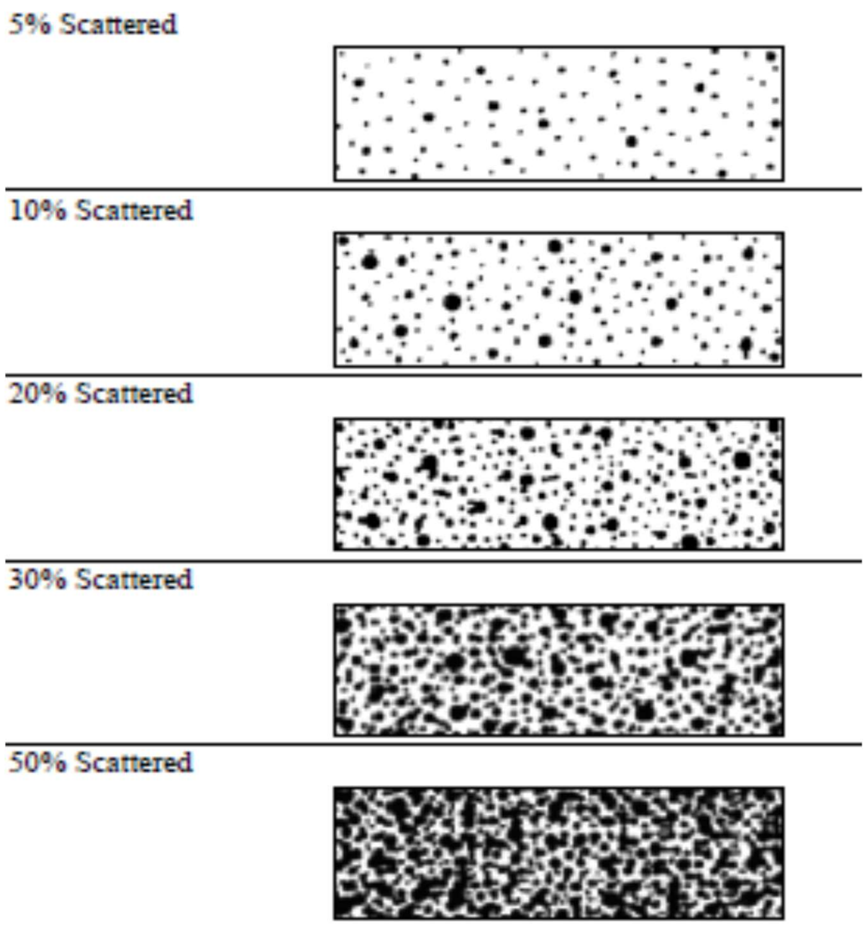

Figure 3.2.1 Pitting Intensity Diagrams

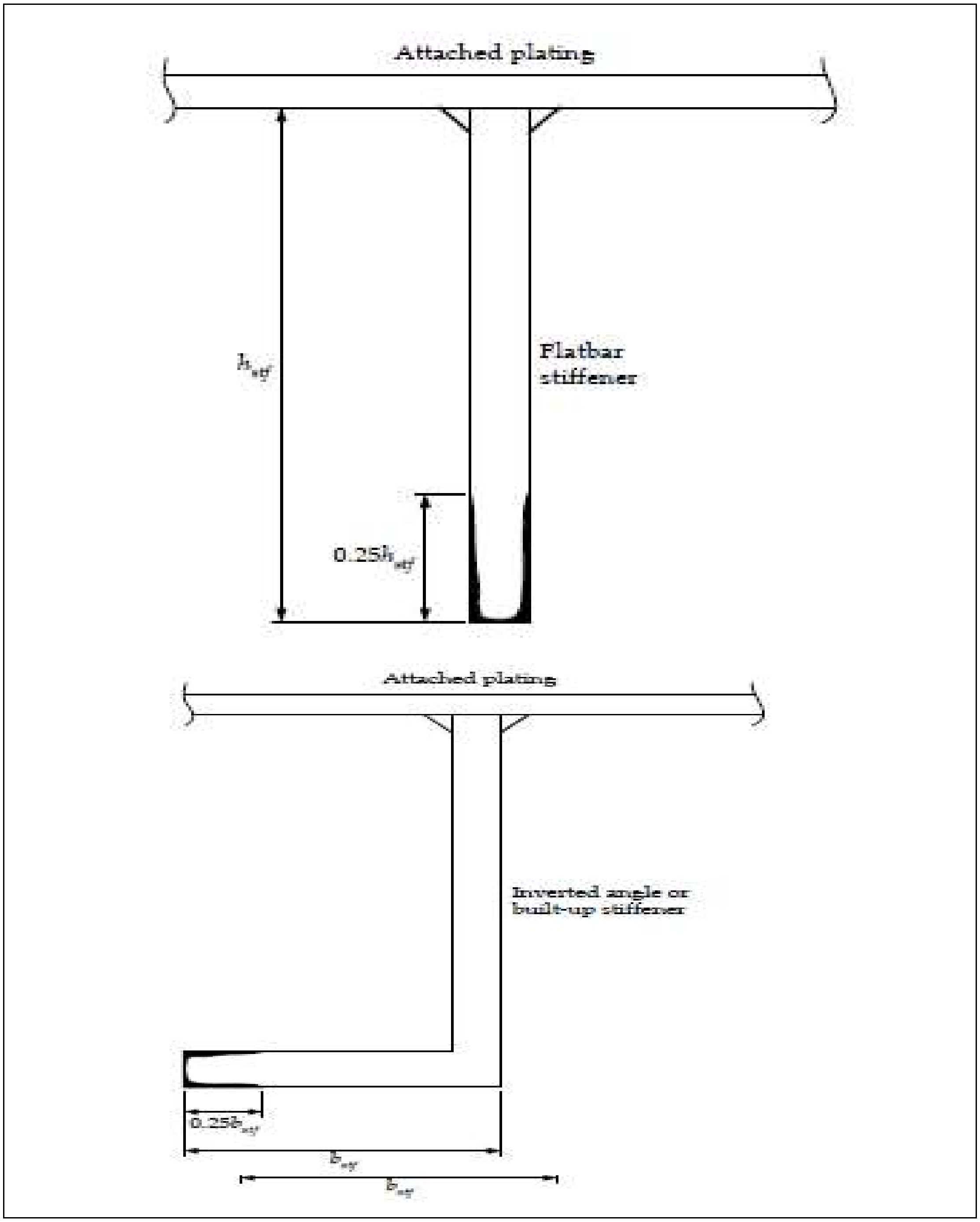

Figure 3.2.2 Edge Corrosion

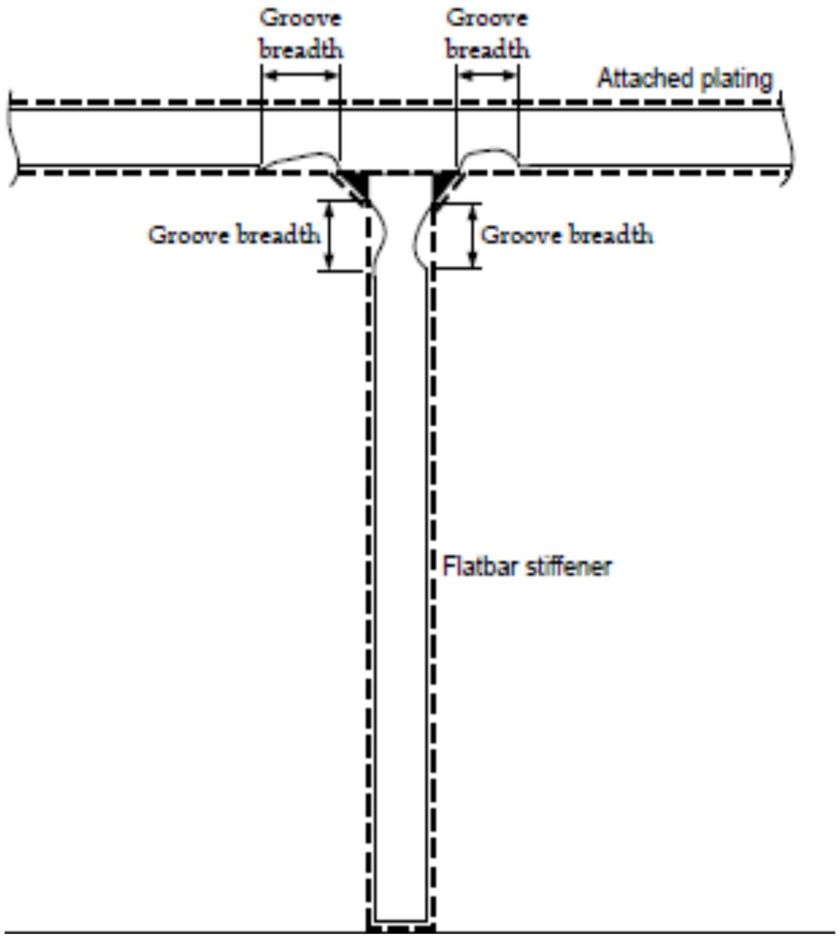

Figure 3.2.3 Groove Corrosion

1.4. Renewal Criteria of Local Structure for General Corrosion

1.4.1. Application

1.4.1.1. Generally the renewal criteria in 1.4.2 apply to areas of structural members with general corrosion.

1.4.2. Renewal criteria

1.4.2.1. If the measured thickness, t_{tm}, is less than the renewal thickness steel renewal is essential, t_{ren}, defined as:

$$t_{ren} = t_{as-built} - t_{was} - t_{own} - t_{corr-2.5} \ mm$$

Where:

$t_{as-built}$ as built thickness, in mm

t_{was} wastage allowance, as defined in 1.4.2.2

t_{own} owner/builder specified additional wastage allowance, if applicable, in mm

$t_{corr-2.5}$ 0.5 mm, wastage allowance in reserve for corrosion occurring in the two and a half years between Intermediate and special surveys

1.4.2.2. The wastage allowance, t_{was} , is given by:

$t_{was} = t_{was-1} + t_{was-2}$ $mm$and rounded up to the nearest 0.5mm

t_{was} total wastage allowance of the considered structural member, in mm

t_{was-1} wastage allowance for side one of the structural member considering the contents of thecompartment to which it is exposed, in mm, as given Table 3.2.2

t_{was-2} wastage allowance for side two of the structural member considering the contents of thecompartment to which it is exposed, in mm, as given Table 3.2.2

1.4.2.3. In no case is the wastage allowance, t_{was}, to be less than 1.5mm, except in way of internals of dry spaces and pump room where 1.0 mm is applicable.

1.4.2.4. Wastage allowances for compartments not listed in Table 3.2.2 will be subject to special consideration.

1.4.2.5. On the basis of the renewal criteria in 1.4.2.1, areas which need to be renewed are generally, to be repaired with inserted material which is to have the same or greater grade/strength as the original and to have a thickness, repair, not less than:

$$t_{repair} = t_{as-built} - t_{own} \quad \text{mm}$$

Where:

$t_{as-built}$ as built thickness, in mm

t_{own} owner/builder specified additional wastage allowance, if applicable, in mm

Table 3.2.2 Local Wastage Allowance for One Side of Structural Elements

Compartment Type	*Structural Member*		*Ship in Operation Component Wastage Allowance, t_{was-1} or t_{was-2}(mm)*
Ballast water tank and chain locker	Face plate of PSM	Within 3m below top of tank (1)	2.0
		Elsewhere	1.5
	Other members(3)	Within 3m below top of tank (1)	1.7
		Elsewhere	1.2
Cargo oil tank	Face plate of PSM	Within 3m below top of tank (1)	1.7
		Elsewhere	1.4
	Inner-bottom plating/bottom of tank		2.1
	Other members	Within 3m below top of tank (1)	1.7
		Elsewhere	1.0
Exposed to atmosphere	Weather deck plating		1.7
	Other members		1.0
Exposed to sea water	Shell plating(2)		1.0
Fuel and lube oil tank (4)	Top of tank and attached internal stiffeners		1.0
	Elsewhere		0.7
Fresh water tank	Top of tank and attached internal stiffeners		1.0
	Elsewhere		0.7
Void spaces	Spaces not normally accessed, e.g. access only via bolted manhole openings, pipe tunnels, etc.		0.7
Dry spaces	Internals of deckhouses, machinery spaces, pump room, store rooms, steering gear space, etc.		0.5

Notes
1) Only applicable to cargo and ballast tanks with weather deck as the tank top.
2) 0.5mm to be added for side plating in the quay contact region as defined in Section 8/Figure 8.2.2.
3) 0.5mm to be added to the plate surface exposed to ballast for plate boundary between water ballast and heated cargo oil tanks. 0.3mm to be added to each surface of the web and face plate of a stiffener in a ballast tank and attached to the boundary between water ballast and heated cargo oil tanks. Heated cargo oil tanks are defined as tank arranged with any form of heating capability (most common type is heating coils).
4) 0.7mm to be added for plate boundary between water ballast and heated fuel oil tanks.

1.5. Renewal Criteria of Hull Girder Sectional Properties for General Corrosion

1.5.1. General

1.5.1.1. It is needed to check the following actual hull girder sectional properties, see 1.5.2-3:

a) Vertical hull girder moment of inertia, about the horizontal axis, I_v
b) Hull girder section modulus about the horizontal axis - at deck-at-side, Z_v- dk
c) Hull girder section modulus about the horizontal axis - at keel, Z_v- kl
d) Hull girder section modulus about the vertical axis - at side, Z_h- side
e) Hull girder vertical shear area, A_v- shr

1.5.2. Renewal criteria

1.5.2.1. Steel renewal is essential if the actual hull girder sectional properties, $I_{v\text{-}tm}$, $Z_{v\text{-}tm\text{-}dk}$, $Z_{v\text{-}tm\text{-}kl}$, $Z_{h\text{-}tmside}$, $A_{v\text{-}tm\text{-}shr}$, is assessed using the actual thickness measurements which are less than the minimum allowable hull girder sectional properties, as defined in accordance with 1.5.3.

1.5.2.2. In accordance with Chapter 1 Section 4/2.6, the actual hull girder sectional properties listed in 1.5.2.1 are to be assessed, using the measured thicknesses.

1.5.2.3. Due to reduced hull girder sectional properties, if steel renewal is needed, it should be done byreplacing local corroded structural elements. Any combination of structural elements may be substituted on condition that the resulting hull girder sectional properties satisfy 1.5.2.1. Local structural elements being renewed are to be replaced according to the requirements of 1.4.2.3.

1.5.3. Calculation of the minimum allowable hull girder sectional properties

1.5.3.1. In accordance with Chapter 1 Section 4/2.6, the minimum allowable hull girder sectional properties listed in 1.5.1.1 are to be assessed using the thicknesses defined in 1.5.3.2.

1.5.3.2. The minimum allowable hull girder sectional properties in the corroded condition are assessed using the same corrosion thickness reductions that are used during the newbuilding stage, thus linking thenewbuilding and ship in operation criteria. Thus, the calculation of the minimum allowable hull girder sectional properties is to be done on basis of a member thickness, t, given by:

$$\mathrm{t} = \mathrm{t}_{\mathrm{as-built}} - 0.5\mathrm{t}_{\mathrm{corr}} - \mathrm{t}_{\mathrm{own}} \quad \mathrm{mm}$$

Where
$\mathrm{t}_{\mathrm{as-built}}$ as built thickness, in mm

$0.5t_{corr}$ corrosion addition, as defined in Chapter 1 Section 6/3.2
t_{own} owner/builder specified additional wastage allowance, if applicable, in mm

1.6. Allowable Material Diminution for Pitting, Grooving and Edge Corrosion

1.6.1. General

1.6.1.1. If the measured thickness is less than the criteria defined in 1.6.2, 1.6.3 and 1.6.4 respectively, steel renewal for pitting, grooving and edge corrosion is needed.

1.6.2. Pitting

1.6.2.1. For plates with pitting intensity less than 20%, see Figure 3.2.1, the measured thickness, t_{tm}, of any individual measurement is to meet the lesser of the following criteria:

$$t_{tm} \geq 0.7(t_{as-built} - t_{own}) \text{ mm}$$
$$t_m \geq t_{ren} - 1\ mm$$

$t_{as-built}$ as built thickness of the member
t_{own} owner/builder specified additional wastage allowance, if applicable, in mm
t_{ren} renewal criteria for general corrosion as defined in 1.4.2.1

1.6.2.2. As given in 1.4.2.1, the average thickness across any cross section in the plating is not to be less than the renewal criteria for general corrosion.

1.6.3. Edge corrosion

1.6.3.1. Provided that the overall corroded height of the edge corrosion of the flange, or web in the case of flat bar stiffeners, is less than 25%, see Figure 3.2.2, of the stiffener flange breadth or web height, as applicable, the measured thickness, ttm, is to meet the lesser of the following criteria:

$$t_{tm} \geq 0.7(t_{as-built} - t_{own}) \text{ mm}$$
$$t_m \geq t_{ren} - 1\ mm$$

$t_{as-built}$ as built thickness of the member, in mm
t_{own} owner/builder specified additional wastage allowance, if applicable, in mm
t_{ren} renewal criteria for general corrosion as defined in 1.4.2.1

1.6.3.2. The average measured thickness across the breadth or height of the stiffener is not to be less than that defined in 1.4.2.

1.6.3.3. Plate edges at openings for manholes, lightening holes etc. may be below the minimum thickness given in 1.4.2 provided that:

a) The maximum extent of the reduced plate thickness, below the minimum as given in 1.4.2, from the opening edge is not more than 20% of the smallest dimension of the opening and does not go beyond 100mm
b) Rough or uneven edges may be cropped-back on condition that the maximum dimension of the opening is not increased by more than 10%.

1.6.4. Grooving

1.6.4.1. The measured thickness, t_{tm}, in the grooved area is to meet the lesser of the following criteria where the groove breadth is a maximum of 15% of the web height, but not more than 30mm, see Figure 3.2.3:

$t_{tm} \geq 0.75(t_{as-built} - t_{own})\ mm$

$t_{tm} \geq t_{ren} - 0.5\ mm$

But is not to be less than

t_m =6 mm

Where,

$t_{as-built}$ as built thickness of the member, in mm

t_{own} owner/builder specified additional wastage allowance, if applicable, in mm

t_{ren} renewal criteria for general corrosion as defined in 1.4.2.1

1.6.4.2. Based on the criteria for general corrosion as defined in 1.4.2, members with areas of grooving greater than those in 1.6.4.1 are to be evaluated using the average measured thickness across the plating/stiffener.

2. In service survey plan.

2.1. The critical areas, high stress with fatigue considerations, structural prone failure areas and any other areas will be surveyed according to Part 1, Ch 4, sec 3,[3.1]

CHAPTER 4 STRENGTH ASSESSMENT

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SECTION 1 HULL GIRDER ULTIMATE STRENGTH

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1. General

1.1. Definitions

1.1.1. Hull girder bending moment capacity

1.1.1.1. The hull girder ultimate bending moment capacity, M_u, is defined as the maximum bending capacity of the hull girder beyond which the hull will collapse. Hull girder failure is controlled by buckling, ultimate strength and yielding of longitudinal structural elements.

1.1.1.2. The sagging hull girder ultimate capacity of a hull girder section, is defined as the maximum value on the static non-linear bending moment-curvature relationship, M_κ, as shown in Figure 4.1.1. The curve represents the progressive collapse behaviour of hull girder under vertical bending.

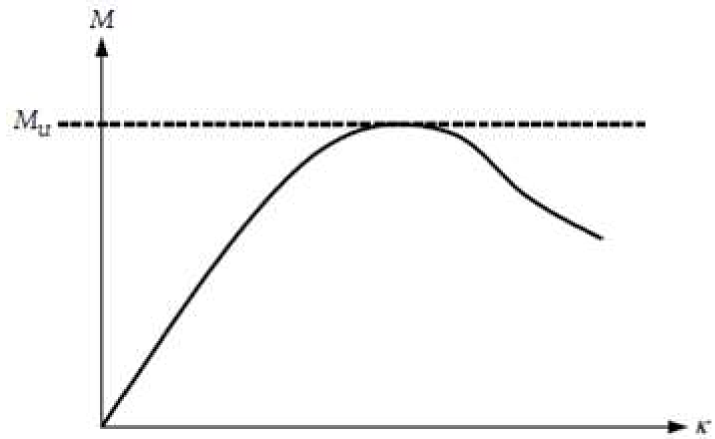

Figure 4.1.1: Bending Moment Curvature Curve M-κ

1.1.1.3. The curvature of the critical inter-frame section, κ, is defined as:

$$\kappa = \frac{\theta}{l}$$

Where:

θ the relative angle rotation of the two neighbouring cross-sections at transverse frame positions

l the transverse frame spacing, i.e. span of longitudinals

1.2. Application

1.2.1. General

1.2.1.1. The sagging hull girder ultimate bending capacity is required to be assessed by the single step method in 2.1 or the incremental-iterative method in 2.2. This is only applicable to longitudinally framed double hull tankers in the sagging bending condition.

1.2.1.2. In Chapter 2 Section 3/1.4, the magnitudes of the partial safety factors have been calibrated for this single step method in 2.1 and are also appropriate for the incremental iterative method in 2.2.

1.3. Assumptions

1.3.1. General

1.3.1.1. The method for calculating the ultimate hull girder capacity is to identify the critical failure modes of all main longitudinal structural elements. For tankers, in sagging, the critical mode is generally inter-frame buckling of deck structures, as illustrated in Figure 4.1.2.

1.3.1.2. The structures which are compressed beyond their buckling limit have reduced load carrying capacity. In order to identify the weakest inter-frame failure mode, all relevant failure modes for individual structural elements, such as: plate buckling, torsional stiffener buckling, stiffener web buckling, lateral or global stiffener buckling; and their interactions, are to be considered.

1.3.1.3. Only vertical bending is considered for tankers in the sagging condition. The effects of shear force, torsional loading, horizontal bending moment and lateral pressure are neglected.

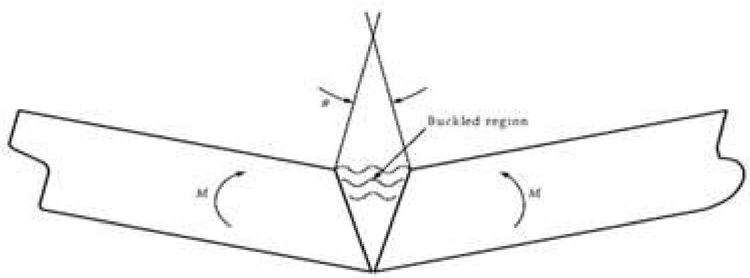

Figure 4.1.2: Ship in Extreme Sagging Inter-Frame Buckling Failure

1.4. Alternative Methods

1.4.1. General

1.4.1.1. In Sub-Section 3, principles for alternative methods for the calculation of the hull girder ultimate bending capacity; e.g. incremental-iterative procedure that may differ from the one defined in 2.2, and non-linear finite element analysis, are stated.

1.4.1.2. The application of alternative methods is to be agreed with IRS prior to commencement. Documentation of the analysis methodology and detailed comparison of its results along with IRS procedures are to be submitted for review and acceptance. In Chapter 2 Section 3/1.4, the use of such methods may require the partial safety factors to be re-calibrated.

2. Calculation of Hull Girder Ultimate Capacity

2.1. Single Step Ultimate Capacity Method

2.1.1. Procedure

2.1.1.1. The single step procedure for calculation of the sagging hull girder ultimate bending capacity is a simplified method based on a reduced hull girder bending stiffness accounting for buckling of the deck, as shown in Figure 4.1.3. The hull girder ultimate bending moment capacity, M_u, is to be taken as:

$$M_u = Z_{red}\sigma_{yd}.10^3 \quad kNm$$

where:

Z_{red}reduced section modulus of deck (to the mean deck height)

$$= \frac{I_{red}}{z_{dk-mean} - z_{NA-red}} m^3$$

I_{red} reduced hull girder moment of inertia, inm^4. The inertia is to be calculated in accordance with Chapter 1 Section 4/2.6.1.1, using:

— A hull girder net thickness of $t_{net50}$for all longitudinally effective members

— The effective net area after buckling of each stiffened panel of the deck, A_{eff}

A_{eff}effective net area after buckling of the stiffened deck panel. The effective area is the proportion of stiffened deck panel that is effectively able to be stressed to yield:

$$= \frac{\sigma_u}{\sigma_{yd}} A_{net50} m^3$$

Note

The effective area of deck girders is to be taken as the net area of the girders using a thickness oft_{net50}.

A_{net50} net area of the stiffened deck panel, in m^2

σ_u buckling capacity of stiffened deck panel, in N/mm^2. To be calculated for each stiffened panel using:

— the advanced buckling analysis method, see Chapter 2 Secction 4/4 and Chapter 4 Section 4

— the net thickness $t_{net50}\sigma_{yd}$ specified minimum yield stress of the material, in N/mm^2, that is used to determine the hull girder section modulus. In the case of the stiffener and plate having different specified minimum yield stress, σ_{yd}, is to be taken as the lesser of the two.

z_{dk-me} vertical distance to the mean deck height, taken as the mean of the deck at side and the deck at centre line, measured from the baseline, in m

z_{NA-r} vertical distance to the neutral axis of the reduced section measured from the baseline, in m

2.1.1.2. For the bottom shell plating, it is to be indicated that the ultimate bending moment capacity,M_u, does not give stresses beyond the specified minimum yield stress of material, σ_{yd},

Hence, the ultimate bending moment capacity,M_u, should be limited to:

$$M_u = \sigma_{yd} \frac{I_{red}}{z_{NA-}}.10^3 \quad kNm$$

Where:

σ_{yd}specified yield stress of material, in N/mm^2

I_{red}reduced hull girder moment of inertia, as defined in 2.1.1.1

z_{NA-r} vertical distance to the neutral axis of the reduced section measured from the baseline, in m

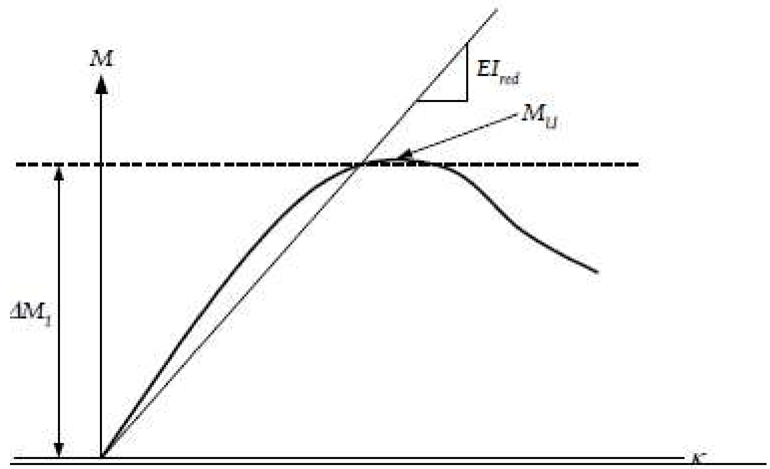

Figure 4.1.3: Moment –Curvature of Hull Girder Single Step Procedure

2.1.2. Assumption

2.1.2.1. The ultimate sagging capacity of tankers is the point at which the ultimate capacity of the stiffened deck panels is reached is the assumption behind this procedure. An alternative method is used to derive the ultimate capacity, if the assumption of the structural configuration is not valid.

2.2. Simplified Method Based on an Incremental-iterative Approach

2.2.1. Procedure

2.2.1.1. In this section, ultimate hull girder bending moment capacity M_u is defined as the peak value of the curve with vertical bending moment M versus the curvature κ of the ship cross section as illustrated in Figure 4.1.1.

2.2.1.2. The curve $M_{-\kappa}$ is obtained by means of an incremental-iterative approach; the steps involved in the procedure are given in 2.2.1.7 and illustrated in the flow chart given in Figure 4.1.4.

2.2.1.3. For each step of the incremental procedure, the bending moment M_i which acts on the hull girder transverse section due to the imposed curvatureκ_i is calculated. This imposed curvature corresponds to an angle of rotation of the hull girder transverse section about its effective horizontal neutral axis, which induces an axial strain ε in each hull structural element. In sagging condition, the structural elements below the neutral axis are lengthened, while elements above the neutral axis are shortened.

2.2.1.4. The stress σ induced in each structural element by the strain ε is obtained from the stress-strain curve $\sigma - \epsilon$ of the element, which takes into account the behaviour of the structural element in the non-linear elasto-plastic domain.

2.2.1.5. The force in each structural element is obtained from its area times the stress and these force are summated to derive the total axial force on the transverse section. It is to be noted that the element area is taken as the total net area of the structural element. This total force may not be zero as the effective neutral axis may have moved due to the nonlinear response. Therefore, it is necessary to adjust the neutral axis position, recalculate the element strains, forces and total sectional force and iterate until the total force is zero.

2.2.1.6. The correct stress distribution in the structural elements is obtained as soon as the position of the new neutral axis is known. Due to the imposed curvature, κ_i, the bending moment M_i about the new neutral axis is then obtained by summating the moment contribution given by the force in each structural element.

2.2.1.7. The main steps of the incremental-iterative approach are summarized as follows (as shown in Figure 4.1.4):

- Step 1 The hull girder transverse section is divided into structural elements, ie longitudinal stiffened panels (one stiffener per element), hard corners and transversely stiffened panels, see 2.2.2.2.
- Step 2 The stress-strain curves (or so called load-end shortening curves) is to be derived for all structural elements, as shown in 2.3.
- Step 3 Derive the expected maximum required curvature, κ_F, see 2.2.1.8. The curvature step size $\Delta\,\kappa$ isto be taken as $\kappa_F/300$. The curvature for the first step,κ_1, is to be taken as$\Delta\,\kappa$. Derive the neutral axis z_{NA-i} for the first incremental step (i =1) with the value of the elastic hull girder section modulus, $z_{v-net50}$, see Chapter 1 Section 4/2.6.1
- Step 4 For each element (index j), calculate the strain $\varepsilon_{ij} = \kappa_i\left(z_j - z_{NA-i}\right)$ corresponding to κ_i□i, the corresponding stress σ_j , see 2.2.1.9, and hence the force in the element $\sigma_j A_j$.
- Step 5 Determine the new neutral axis position z_{NA-i} by checking the longitudinal force equilibrium over the whole transverse section. Hence adjust z_{NA-i} until $F_i = 0.1\sum A_j\,\sigma_j \quad kN = 0$
  Note σ_j is positive for elements under compression and negative for elements under tension. Repeat from step 4 until equilibrium is satisfied. Equilibrium is satisfied when the change inneutral axis position is less than 0.0001m.
- Step 6 Calculate the corresponding moment by summating the force contributions of all elements as follows:
  $$M_i = 0.1\sum\left|\sigma_j A_j\left(z_j - z_{NA-i}\right)\right| \quad kNm$$
- Step 7 Increase the curvature by $\Delta\kappa$, use the current neutral axis position as the initial value for the next curvature increment and repeat from step 4 until the maximum required curvature is reached. The ultimate capacity is the peak value M_u from the $M_{-\kappa}$□curve. If the peak does not occur in the curve, then κ_F is to be increased until the peak is reached.

2.2.1.8. The expected maximum required curvature,κ_F, in m^{-1}, for the sagging condition is to be taken as:

$$\kappa_F = 3\frac{M_{yd}}{EI_{v-net50}}10^{-3}m^{-1}$$

Where:

M_{yd}vertical bending moment given by a linear elastic bending stress of yield in the Deck or keel. To be taken as the greater of :

$$Z_{v-net50-dk}\sigma_{yd}10^3 \quad kNm$$
$$Z_{v-net50-kl}\sigma_{yd}10^3 \quad kNm$$

$Z_{v-net50-dk} Z_{v-net-kl}$	section modulus at deck or bottom, in m3, see Chapter 2 section 2/1.2.2.3 and 1.2.2.4,
E	modulus of elasticity, 2.06 x 105 N/mm^2
σ_{yd}	specified minimum yield stress of the material, in N/mm^2
$I_{v-net50}$	hull girder moment of inertia, in m^4 , see Chapter 2 section 2/1.2.1.1

2.2.1.9. For each structural element, the stress σ_j corresponding to the element strain ε_{ij} is to be taken as the minimum stress value from all applicable stress-strain curves $\sigma - \varepsilon$ for that element

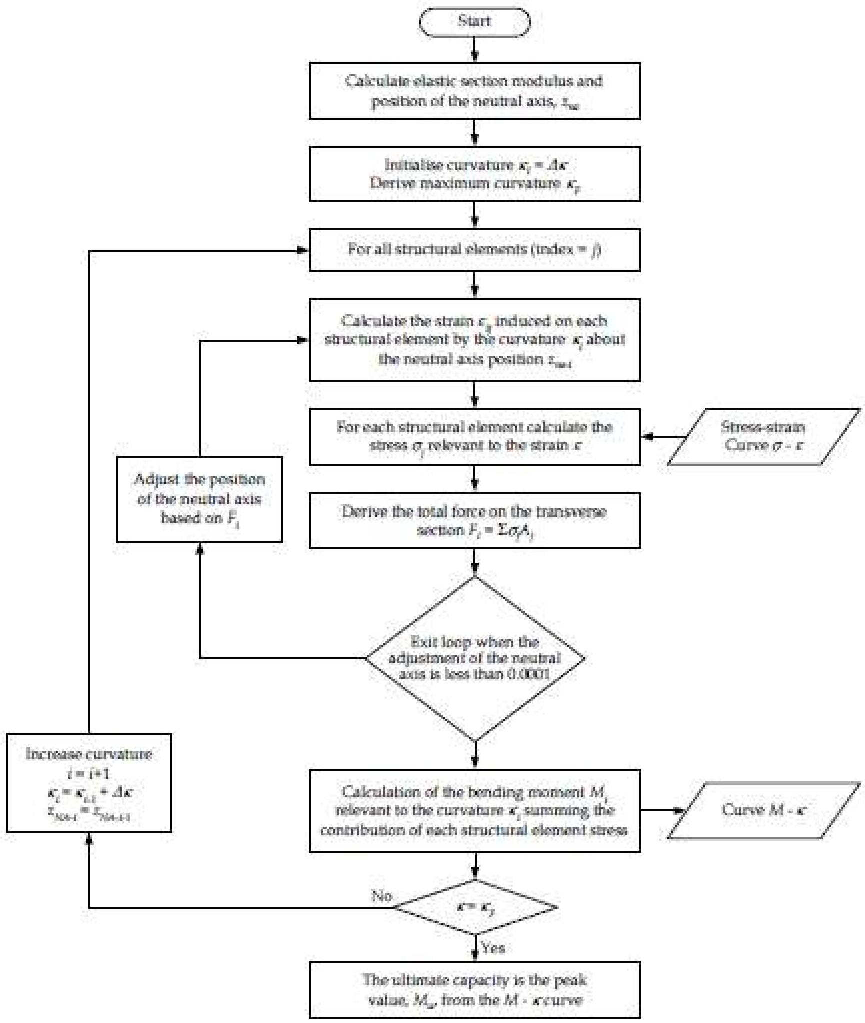

Figure 4.1.4 :Flow Chart of the Procedure for the Evaluation of the Curve $M - \chi$

2.2.2. Assumptions and modelling of the hull girder cross-section

2.2.2.1. In applying the procedure described in 2.2.1, the following assumptions are to be made:

a) The ultimate strength is calculated at a hull girder transverse section between two adjacent transverse webs.

b) During each curvature increment the hull girder transverse section remains plane.

c) The material properties of steel are assumed to be elastic, perfectly plastic.

d) The hull girder transverse section can be divided into a set of elements which act independently of each other.

2.2.2.2. The elements making up the hull girder transverse section are:

a) Longitudinal stiffeners with attached plating, the structural behaviour is given in 2.3.1

b) Transversely stiffened plate panels, the structural behaviour is given in 2.3.1

c) Hard corners, as defined in 2.2.2.3, the structural behaviour is given in 2.3.2

2.2.2.3. The following structural areas are to be defined as hard corners:

a) The plating area adjacent to intersecting plates

b) The plating area adjacent to knuckles in the plating with an angle greater than 30 degrees.

c) Plating comprising rounded gunwales

An illustration of hard corner definition for girders on longitudinal bulkheads is given in Figure 4.1.5.

The hard corner size is defined in 2.2.2.4.

2.2.2.4. The size and modelling of hard corner elements are as follows:

a) It is to be assumed that the hard corner extends up to s/2 from the plate intersection for longitudinally stiffened plate, where s is the stiffener spacing

b) It is to be assumed that the hard corner extends up to $20t_{grs}$ from the plate intersection for transversely stiffened plates, where t_{grs} is the gross plate thickness.

Note:

For transversely stiffened plate, the effective breadth of plate for the load shortening portion of the stress-strain curve is to be taken as the full plate breadth, i.e. to the intersection of other plates – not from the end of the hard corner, if any. The area on which the value of σ_{CR} defined in 2.3.8.1 applies is to be taken as the breadth between the hard corners, i.e. excluding the end of the hard corner, if any.

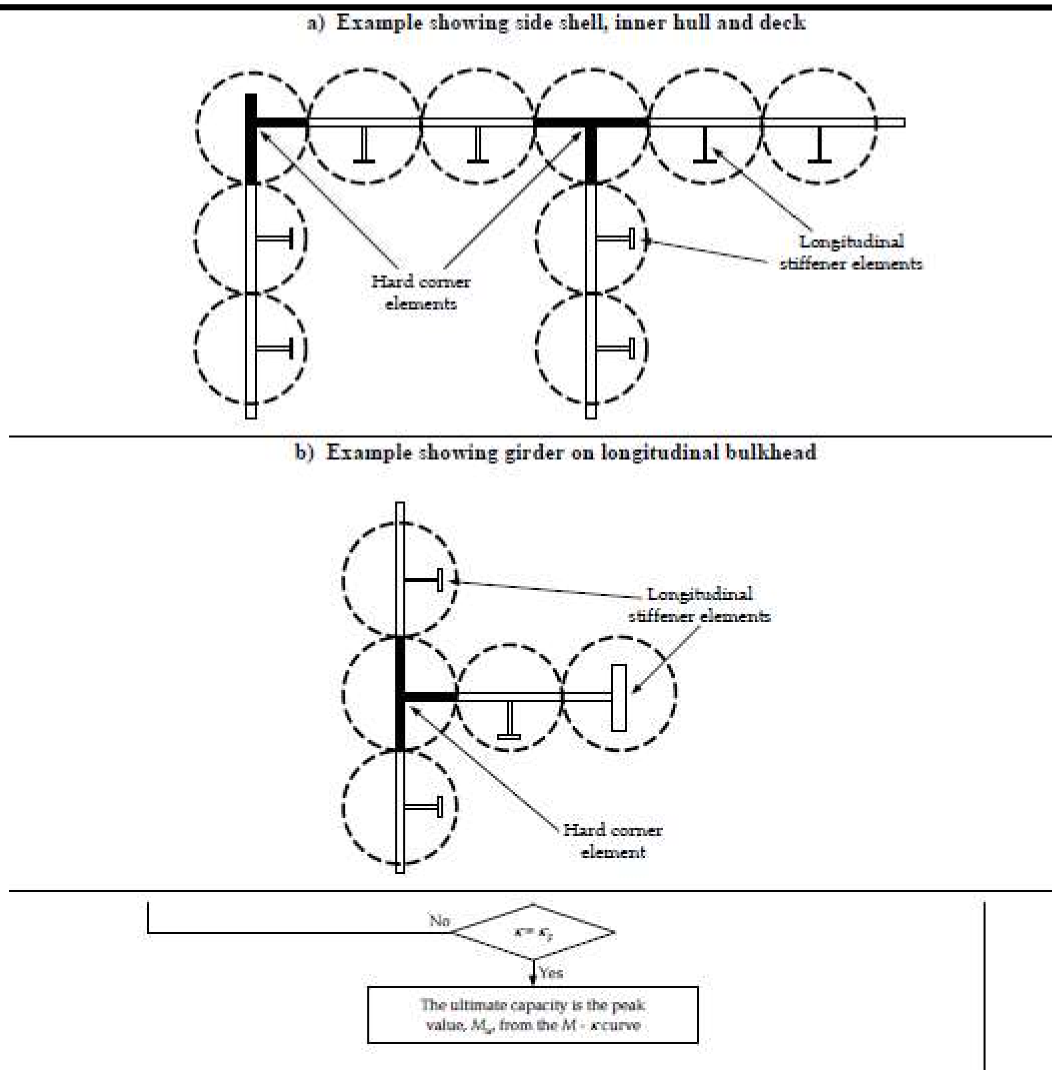

Figure 4.1.5 : Example of Defining Structural Elements

2.3. Stress-strain Curves $\sigma - \varepsilon$(or Load-end Shortening Curves)

2.3.1. Plate panels and stiffeners

2.3.1.1. As specified in Table 4.1.3, plate panels and stiffeners are assumed to fail according to one of the modes of failure. According to Table 4.1.3, the relevant stress-strain curve $\sigma - \varepsilon$ is to be obtained for lengthening and shortening strains.

2.3.2. Hard corners

2.3.2.1. Hard corners are sturdier elements which are assumed to buckle and fail in an elastic, perfectly plastic manner. According to 2.3.3, the relevant stress strain curve $\sigma - \varepsilon$ is to be obtained for lengthened and shortened hard corners.

Table 4.1.3: Modes of failure of Plate Panels and Stiffeners

Element	Mode of failure	Stress-strain curve $\boldsymbol{\sigma}-\boldsymbol{\varepsilon}$ defined in
Lengthened transversely framed plate panels or stiffeners	Elastic, perfectly plastic failure	See 2.3.3
Shortened stiffeners	Beam column buckling Torsional buckling Web local buckling of flanged profiles Web local buckling of flat bars	See 2.3.4 See 2.3.5 See 2.3.6 See 2.3.7
Shortened transversely framed plate panels	Plate buckling	See 2.3.8

2.3.3. Elasto-plastic failure of structural elements

2.3.3.1. The equation describing the stress-strain curve $\boldsymbol{\sigma}-\boldsymbol{\varepsilon}$ or the elasto-plastic failure of structural elements is to be obtained from the following formula, valid for both positive (compression or shortening) of hard corners and negative (tension or lengthening) strains of all elements (shown in Figure 4.1.6):

$$\sigma = \Phi\sigma_{yd}$$

Where:

Φ edge function:

$$\Phi = -1 \text{ for } \varepsilon < -1$$
$$\Phi = \varepsilon \text{ for } -1 < \varepsilon < 1$$
$$\Phi = 1 \text{ for } \varepsilon > 1$$

ε relative stain:

$$\varepsilon = \frac{\varepsilon_E}{\varepsilon_{yd}}$$

ε_E element strain

ε_{yd} strain corresponding to yield stress in the element:

$$\varepsilon_{yd} = \frac{\sigma_{yd}}{E}$$

σ_{yd}specified minimum yield stress of the material, in N/mm^2

Note:
The signs of the stresses and strains in this Section are opposite to those in the rest of the Rules.

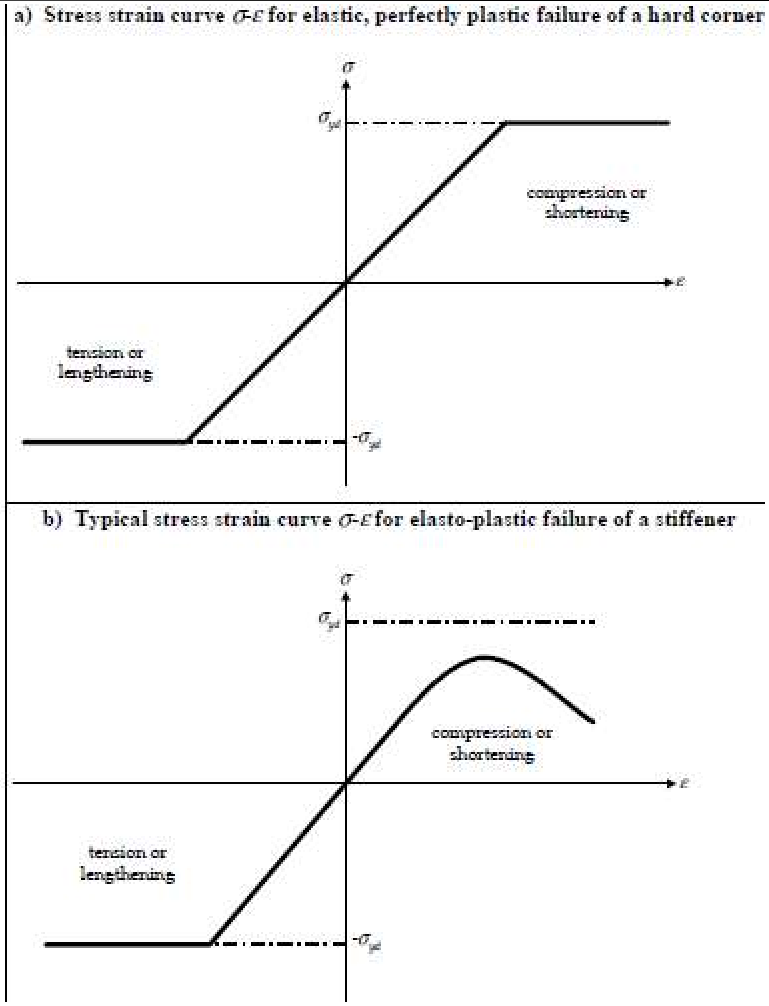

Figure 4.1.6:Example of Stress-strain Curves $\sigma - \varepsilon$

2.3.4. Beam column buckling

2.3.4.1. According to the formula, the equation describing the shortening portion of the stress strain curve $\sigma_{CR1} - \varepsilon$ for the beam column buckling of stiffeners is to be obtained:

$$\sigma_{CR1} = \Phi\sigma_{C1}\left(\frac{A_{s-net50} + 10^{-2} b_{eff-p} t_{net50}}{A_{s-net50} + 10^{-2}{}_{st_{net50}}}\right) \quad N/mm^2$$

Where:

Φ edge function defined in 2.3.3.1

$A_{s-net50}$ net area of the stiffener, in cm^2, without attached plating

σ_{C1} critical stress, in N/mm^2:

$$\sigma_{C1} = \frac{\sigma_{E1}}{\varepsilon} \qquad for\ \sigma_{E1} \le \frac{\sigma_{yd}}{2}\epsilon$$

$$\sigma_{C1} = \sigma_{yd}\left[1 - \frac{\sigma_{yd}\varepsilon}{4\sigma_{E1}}\right] \qquad for\ \sigma_{E1} > \frac{\sigma_{yd}}{2}\epsilon$$

ϵ relative strain defined in 2.3.3.1

σ_{E1} Euler column buckling stress, in N/mm^2:

$$\sigma_{E1} = \pi^2 E \frac{I_{E-net50}}{A_{E-net50} l_{stf}^2} 10^{-4}$$

E modulus of elasticity, 2.06 x 105 N/mm^2

$I_{E-n\ 50}$ net moment of inertia of stiffeners, in cm^4, with attached plating of width b_{eff-s}

b_{eff-s} effective width, in mm, of the attached plating for the stiffener:

$$b_{eff} = \frac{s}{\beta_p} \qquad for\ \beta_p > 1.0$$

$$b_{eff-s} = s \qquad for\ \beta_p \leq 1.0$$

$$\beta_p = \frac{s}{t_{net50}} \sqrt{\frac{\varepsilon \sigma_{yd}}{E}}$$

s plate breadth, in mm, taken as the spacing between the stiffeners, as defined in Chapter 1 Section 4/2.2.1

t_{net50} net thickness of attached plating, in mm

$A_{E-net50}$ net area, in cm^2, of stiffeners with attached plating of width b_{eff-p}

l_{stf} span of stiffener, in m, equal to spacing between primary support members

b_{eff-p} effective width, in mm, of the plating:

$$b_{eff-p} = \left(\frac{2.25}{\beta_p} - \frac{1.25}{\beta_p^2}\right) s \qquad for\ \beta_p > 1.25$$

$$b_{eff-p} = s \qquad for\ \beta_p \leq 1.25$$

2.3.5. Torsional buckling of stiffeners

2.3.5.1. According to the following formula, the equation describing the shortening portion of the stress-strain curve $\sigma_{CR2} - \varepsilon$ for the lateral-flexural buckling of stiffeners is required to be obtained:

$$\sigma_{CR2} = \Phi \frac{A_{s-net50}\sigma_{C2} + 10^{-2} s t_{net50} \sigma_{CP}}{A_{s-net50} + 10^{-2} s t_{net50}} \qquad N/mm^2$$

Where:

Φ edge function defined in 2.3.3.1

$A_{s-net50}$ net area of the stiffener, in cm^2, without attached plating

σ_{C2} critical stress, in N/mm^2:

$$\sigma_{C2} = \frac{\sigma_{E2}}{\varepsilon} \qquad \text{for } \sigma_{E2} \leq \frac{\sigma_{yd}}{2} \varepsilon$$

$$\sigma_{C2} = \sigma_{E2}\left(1 - \frac{\sigma_{yd}\varepsilon}{4\sigma_{E2}}\right) \qquad \text{for} \sigma_{E2} > \frac{\sigma_{yd}}{2} \varepsilon$$

σ_{E2} Euler torsional buckling stress, in N/mm^2

$$\sigma_{E2} = \sigma_{ET}$$

σ_{ET} reference stress for torsional buckling, in N/mm^2, defined in Chapter 2 Section 4/3.3.3.1, calculated based on gross thickness minus the corrosion addition 0.5tcorr.

ε relative strain defined in 2.3.3.1

s plate breadth, in mm, taken as the spacing between the stiffeners, as defined in Chapter 1 Section 4/2.2.1

t_{net50} net thickness of attached plating, in mm

σ_{CP} ultimate strength of the attached plating for the stiffener, in N/mm^2:

$$\sigma_{CP} = \left(\frac{2.25}{\beta_p} - \frac{1.25}{\beta_p^2}\right)\sigma_{yd} \qquad \text{for } \beta_p > 1.25$$

$$\sigma_{CP} = \sigma_{yd} \qquad \text{for } \beta_p \leq 1.25$$

β_p coefficient defined in 2.3.4

2.3.6. Web local buckling of stiffeners with flanged profiles

2.3.6.1. According to the following formula, the equation describing the shortening portion of the stress strain curve $\sigma_{CR3} - \varepsilon$ for the web local buckling of flanged stiffeners is to be obtained:

$$\sigma_{CR3} = \Phi\sigma_{yd}\left(\frac{b_{eff-p}t_{net50} + d_{w-eff}t_{w-net50} + b_f t_{f-net50}}{st_{net50} + d_w t_{w-net50} + b_f t_{f-net50}}\right)\ \mathrm{N/mm^2}$$

Where:

Φ edge function defined in 2.3.3.1

b_{eff-p} effective width, in mm, of the plating, defined in 2.3.4

t_{net50} net thickness of plate, in mm

d_w depth of the web, in mm

$t_{w-net50}$ net thickness of web, in mm

b_f breadth of the flange, in mm

$t_{f-net50}$ net thickness of flange, in mm

S plate breadth, in mm, taken as the spacing between the stiffeners, as defined in Chapter 1 Section 4/2.2.1

d_{w-eff} effective depth of the web, in mm:

$$d_{w-eff} = \left(\frac{2.25}{\beta_w} - \frac{1.25}{\beta_w^2}\right)d_w \qquad \text{for } \beta_w > 1.25$$

$$d_{w-eff} = d_w \qquad \text{for } \beta_w \leq 1.25$$

$$\beta_w \frac{d_w}{t_{w-net50}}\sqrt{\frac{\varepsilon\sigma_{yd}}{E}}$$

ε relative strain defined in 2.3.3.1

E modulus of elasticity, 2.06 x 105 N/mm^2

2.3.7. Web local buckling of flat bar stiffeners

2.3.7.1. According to the formula, the equation describing the shortening portion of the stress-strain curve $\sigma_{CR4} - \varepsilon$ for the web local buckling of flat bar stiffeners is to be obtained:

$$\sigma_{CR4} = \Phi\left(\frac{st_{net50}\sigma_{CP} + 10^{-2}A_{s-net50}\sigma_{C4}}{st_{net50} + 10^{-2}A_{s-net50}}\right)$$

Where:

Φ edge function defined in 2.3.3.1

σ_{CP} ultimate strength of the attached plating, in N/mm2, defined in 2.3.5

σ_{C4} critical stress, in N/mm2:

$$\sigma_{C4} = \frac{\sigma_{E4}}{\varepsilon} \qquad \text{for } \sigma_{E4} \leq \frac{\sigma_{yd}}{2}\varepsilon$$

$$\sigma_{C4} = \sigma_{yd}\left(1 - \frac{\sigma_{yd}\varepsilon}{4\sigma_{E4}}\right) \qquad \text{for } \sigma_{E4} > \frac{\sigma_{yd}}{2}\varepsilon$$

σ_{E4} Euler buckling stress, in N/mm2:

$$\sigma_{E4} = 160000\left(\frac{t_{w-net50}}{d_w}\right)^2$$

ε relative strain defined in 2.3.3.1.

$A_{s-net50}$ net area of stiffener, in cm2, see 2.3.5.1

$t_{w-net50}$ net thickness of web, in mm

d_w depth of the web, in mm

s plate breadth, in mm, taken as the spacing between the stiffeners, as defined in Chapter 1 Section 4/2.2.1

t_{net50} net thickness of attached plating, in mm

2.3.8. Buckling of transversely stiffened plate panels

2.3.8.1. According to the formula, the equation describing the shortening portion of the stress-strain curve $\sigma_{CR5} - \varepsilon$ for the buckling of transversely stiffened panels is to be obtained:

2.3.9.

$$\sigma_{CR5} = \min \begin{cases} \Phi\sigma_{yd} \\ \sigma_{yd}\Phi \left[\frac{s}{1000 l_{stf}} \left(\frac{2.25}{\beta_p} - \frac{1.25}{{\beta_p}^2} \right) + 0.1 \left(1 - \frac{s}{1000 l_{stf}} \right) \left(1 + \frac{1}{{\beta_p}^2} \right)^2 \right] \end{cases} \text{N/mm2}$$

Where:

β_p coefficient defined in 2.3.4.1

Φ edge function defined in 2.3.3.1

s plate breadth, in mm, taken as the spacing between the stiffeners, as defined in Chapter 1 Section 4/ 2.2.1

l_{stf} stiffener span, in m, equal to spacing between primary support members

σ_{yd} specified minimum yield stress of the material, in N/mm²

3. Alternative Methods

3.1. General

3.1.1. Considerations for alternative models

3.1.1.1. By alternative methods, the bending moment-curvature relationship,M-κ, may be established. Such models are to consider all the relevant effects important to the non-linear response with due considerations of:

a) Non-linear geometrical behaviour
b) In-elastic material behaviour
c) Geometrical imperfections and residual stresses (geometrical out-of flatness of plate and stiffeners)
d) Simultaneously acting loads:
- bi-axial compression
- bi-axial tension
- shear and lateral pressure

e) boundary conditions
f) interactions between buckling modes
g) interactions between structural elements such as plates, stiffeners, girders etc.
h) post-buckling capacity.

3.2. Methods

3.2.1. Incremental-iterative procedure

3.2.1.1. The common method used to assess the hull girder ultimate moment capacity is to derive the non-linear moment-curvature relationship, M-κ, by gradually increasing the bending curvature, κ, of the hull section between two adjacent transverse frames and then identifying the maximum moment along this curve as the ultimate bending capacity, M_U.

3.2.1.2. The M-κ curve is required to be based on the axial non-linear P-ε (load/strain) load-shortening curves for individual structural component in the cross-section. The P-ε curves shall consider all relevant structural effects as given in 3.1.1.1.

3.2.2. Non-linear finite element analysis

3.2.2.1. For the assessment of the hull girder ultimate capacity, advanced non-linear finite element analyses models may be used. With due consideration of the items given in 3.1.1.1, such models are required to consider the relevant effects important to the non-linear responses.

It is required to give particular attention in order to model the shape and size of geometrical imperfections. The shape and size of geometrical imperfections should be ensured to trigger the most critical failure modes.

SECTION 2 RESIDUAL STRENGTH

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1. Introduction

This guide is intended to act as a guideline for designers. This guideline will detail the assumptions and procedures necessary to facilitate structural redundancy strength at an early design stage.

A set of hypothetical accidents are considered are first described and then a method to assess the hull girder strength and a minimum hull girder strength as prescribed later is to be achieved.

Ensuring a minimum residual strength will help minimize the risk of total collapse during post-accident scene or tow and rescue operations.

2. Types of accident

- The following types of accidents should be considered for examining the residual strength: grounding on rocky sea bed with considerable rupture of the double-bottom structures.
- Collision, when another ship strikes a tanker on one side, which results in extensive rupture of the double-side structure.

3. Location and extend of grounding

The damaged bottom structure is assumed to be in the most unfavorable location anywhere on the flat bottom within the fore part of the hull between 0.5L and 0.2L aft from F.P. At least one location should be examined.

Bottom structures are assumed to be damaged over a considerable length and the damaged members should be excluded from the hull-girder.

The following members are assumed to be damaged and excluded, completely or partially, from the hull girder section modulus calculation (see Fig. 1).

- Bottom shell plating for a width of 4 m or B/6, whichever is greater, where B is the ship breadth as defined in 3/1.3 of the Rules.
- Double-bottom girders attached to the damaged shell plating are assumed to be damaged and ineffective up to the following percentage of the girder’s height:
- 25% for girders situated within 1 meter marginal zones of the damaged plating as shown in Fig. 1.
- 75% for girders situated between the marginal zones.
- All of the bottom longitudinals within the damaged bottom shell and the longitudinal stiffeners within the damaged parts of girders.

4. Location and extent of damage due to collision

The damaged side structure is assumed to be in the most unfavorable location on the freeboard anywhere between 0.15L aft from F.R. and 0.21L forward from the A.P. At least two locations should be examined; one within the midship region and another at the region of high shear forces. The collision damage is assumed to be located at the upper part of the side shell, down from (and including) the stringer plate of the strength deck. The following members should be assumed to be damaged and excluded totally or partially, from the hull girder section modulus calculation (see Fig. 2).

- side shell plating for the vertical extent of 4 m or DA, (designated as "h" in Fig. 2), whichever is greater, down from the upper edge of the shear strake, where D is the ship depth as defined in 3/1.5 of the Rules.
- Strength of deck plating including the stringer plate extending from the side shell to the inner skin.
- Side stringers and platforms, within the damaged zone extending for 75% of the double-side width, 3/4b as shown in Fig. 2.
- All deck and side longitudinals and longitudinal stiffeners attached to the damaged plating.

5. Residual strength assessment

The assessment is to demonstrate that the appropriate residual longitudinal strength of the hull girder after an accident as specified in 2.0 is in compliance with the strength criteria given in 7.0 for a single trip from the site of accident to a repair yard under load conditions as specified in 6.0. The residual hull girder section modulus may be calculated using either a finite element model or a simplified method based on the assumed damage, as given in 3.0 or 4.0.

The residual bending strength should be analyzed both for collision and grounding situations. The residual shearing strength should be checked for collision, but need not be analyzed for grounding.

6. Load criteria

Residual strength of the damaged hull-girder should be assessed based on the total longitudinal bending moments, M_t, and shear forces, F_t , given as follows:

$M_t = K_{us} + M_s + K_{uw} + M_w$ (kN-m)
$F_t = K_{us}F_s + K_{uw}\,F_w$(kN)
M_s, F_s, = maximum still-water bending moment (hogging and/or sagging) and shear force (positive and/or negative), in intact condition.
M_w,F_w = wave-induced vertical longitudinal bending moments (hogging and sagging) and shear forces (positive and negative), calculated in accordance with 3/6.3.3 of the Rules.
K_{us} and K_{uw} are given in the following table.

		Grounding	Collision
Hogging	K_{us}	1.1	1.0
	K_{uw}	0.5	0.7
Sagging	K_{us}	0.9	1.0
	K_{uw}	0.5	0.7

Both hogging and sagging conditions are to be considered. Local loads for secondary and tertiary bending need not be taken into consideration.

7. Residual Bending Strength Criterion

The residual section moduli of the damaged hull-girder, calculated in accordance with 5/2A 4.2.1 of the Rules excluding the nominal design corrosion values and the damaged members as specified in 3.0 and 4.0, are not to be less than the nominal section modulus:

SM_t= 0.9 M_t/f_p cm^2 –m
M_t is the total longitudinal bending moment as specified in 6.0.
f_p is the nominal permissible bending stress as specified in
The shear stresses, f_{sr} in the side shell plating, after damage due to a collision, are not to be greater than that given by the formula:

$$f_{sr} = n_1 n_2\, F_t m_t/(t_t t_s) \leq 1.1 f_s$$

F_t = total shear force as specified in 6.0
t_s = thickness of side shell plating in cm (in.)
f_s -=- permissible shear stress specified in 5/2A4.2.3 of the Rules.
rn_r and i_r are the first moment, in cm^3(in ^{3}), and moment of inertia, in cm ^{4} (in^4), of the "net" hull-girder damaged due to a collision at the station being considered.

$$n_1 = A_{sr}/2(A_{sd} + A_b + 0.5)$$

n_2 = D/(D-h)
A_{sr}, = residual shell plating area of the damaged side, in cm^2 (in^2).
A_{sd} = total plating area of one side shell (outer skin), in cm ^{2} (in ^{2}).
A_b = total plating area of one outermost longitudinal bulkhead (inner skin), in cm ^{2} (in^2).

A_i = total plating area of all other longitudinal bulkheads between the inner skins, in cm ^{2} (in^2).
D and h are as defined in Fig. 2.

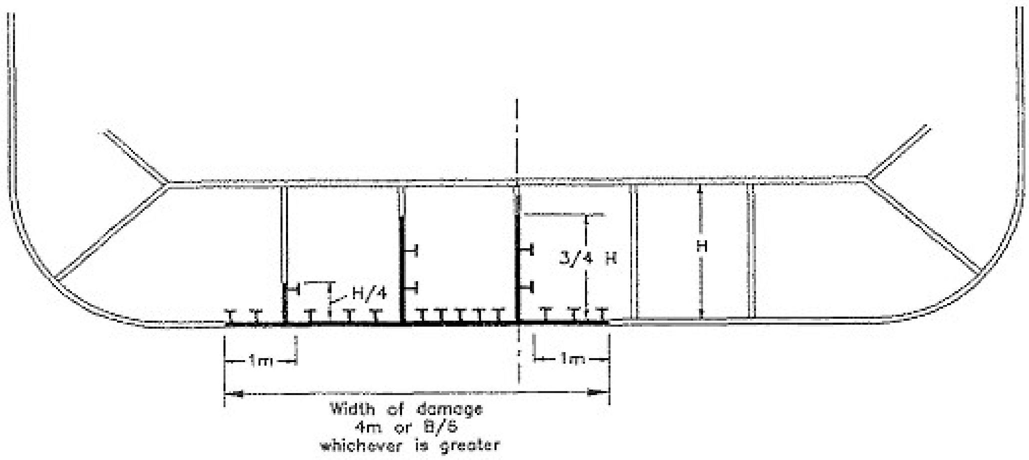

Figure 1

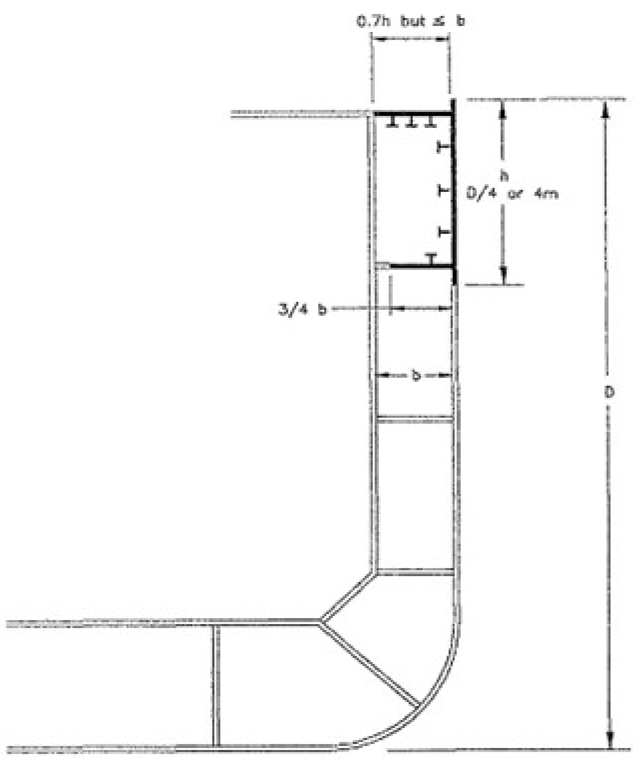

Figure 2

8. Structural redundancy

Structural redundancy is ensured via ensuring the above mentioned residual strength. Redundancy is the ability of a component or system to maintain or restore its function when one failure has occurred. Redundancy can be achieved for instance by installation of more units or elements to restrain the loads, or by alternative means for performing a function.

As the damage cases assumed to calculate residual strength takes into account the failure of members, the structure can be considered inherently redundant.

Load re-distribution or reserve capacity after first component failure may represent structural redundancy in the sense that the first failure does not necessarily causes an overall failure of the system. This redundancy may be utilised in the component design by reduced requirements to the reliability of the individual components.

Inspectability will also be aided by the provision of redundant structures. A redundant structure can be obtained by providing more than one number to serve the same function or to share the same load. By this measure, the probability of total failure due to the failure of a single element will be much reduced if not eliminated depending on the degree of redundancy provided. When more than one member exists to take up the same loading, then finding damage in one member will point out the need to carefully inspect other redundant members.

SECTION 3 STRUCTURAL STRENGTH ASSESSMENT

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1. General

1.1. Application

1.1.1. General

1.1.1.1. As per Chapter 2 Section 3/2.1, a finite element (FE) assessment is to be executed to verify strength of the hull structure.

1.1.1.2. The structural assessment is to be executedas per the requirements given in this Section. The structural assessment is to verify that acceptance criteria specified are conformed to.

1.1.1.3. The requirements in this Section are applicable to the assessment of longitudinal hull girder structural members, primary supporting structural members and transverse bulkheads of the tanks in the midship cargo region. Additionally, the assessment of strengthening of longitudinal hull girder shear structural members, as defined in Chapter 2 Section 3/2.2.1.1 and Chapter 2 Section 4/Table 4.1.1, in way of transverse bulkheads for hull girder vertical shear loads in the forward and aft cargo regions. The strength assessment of longitudinal hull girder shear structural members given in this Section is not applicable for engine room transverse bulkhead, forward transverse collision bulkhead and slop tank transverse bulkheads.

1.1.1.4. For purpose of the FE structural assessment, cargo tank regions are as defined in Figure 4.2.1.

1.1.1.5. Cargo tank structural strength analysis, as per Chapter 4 Section 2/2, for assessment ofscantlings of longitudinal hull girder structural members, primary supporting structural members and transverse bulkheads in tanks within the midship cargo region, is mandatory. The assessment is to be based on maximum permissible still water (load combination S) and combined permissible still water and wave hull girder vertical shear forces (load combination S+D) between and including the forward bulkhead of the aft most cargo tank and 0.65L from AP, but not including engine room and slop tank transverse bulkheads, see Figure 4.2.1(a).

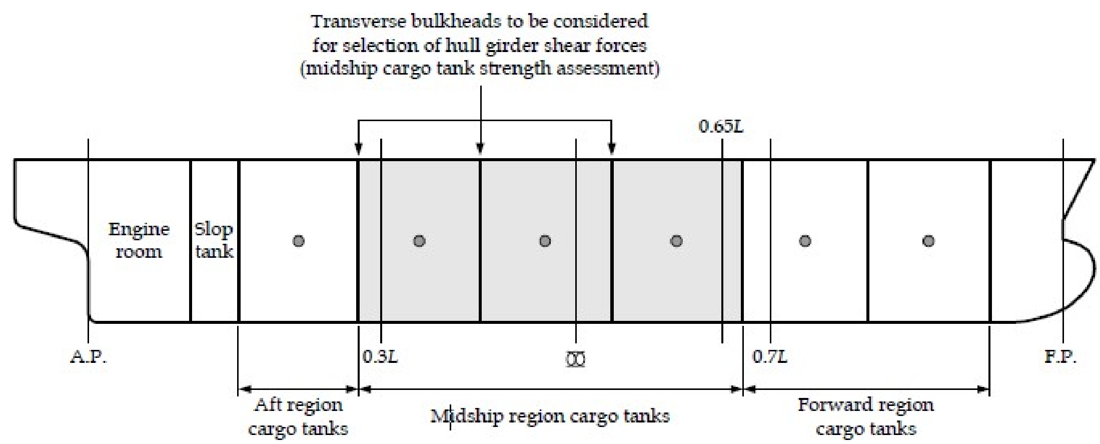
1.1.1.6. The assessment of longitudinal hull girder shear structural members in the forward cargo region, as per Chapter 4 Section 2/2, is mandatory. The strengthening of these structural members in way oftransverse bulkheads in the tanks of the forward cargo region may be based on the maximum permissible still water (load combination S) and combined permissible still water and wave hull girder vertical shear forces (load combination S+D) at the bulkhead positions forward of 0.65L from AP, but not including forward collision bulkhead, see Figure 4.2.1(b).

1.1.1.7. Strengthening of longitudinal hull girder shear structural members in way of transverse bulkheads ofthe tanks in the midship cargo region and the aft cargo region, as per Chapter 4 Section 2/2, may be based on the scantling result obtained from the midship cargo tank analysis as stated in 1.1.1.5.

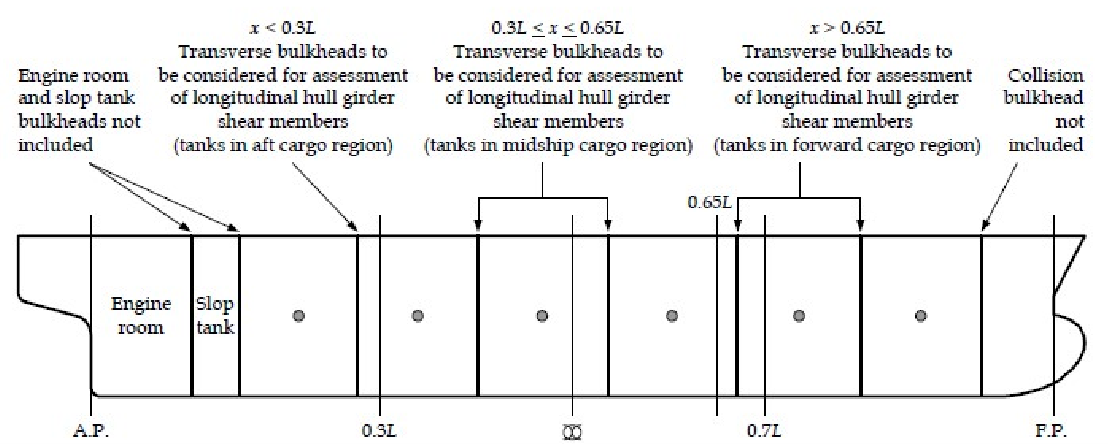
1.1.1.8. Alternatively, optional assessment may be executed to determine the strengthening requirement of longitudinal hull girder shear structural members in way of individual transverse bulkheads based on the permissible still water (load combination S) and combined permissible still water and wave hull girder vertical shear forces (load combination S+D) at the transverse bulkhead position under consideration, see Figure 4.2.1(b).

1.1.1.9. Fine mesh finite element analysis, as per Chapter 4 section 2/3, and the finite element based fatigue assessment of lower hopper knuckle joint, as per Chapter 4 section 2/4, are mandatory for the midship cargo region.

(a) Midship cargo tank strength assessment



(b) Assessment of longitudinal hull girder shear structural members



Note

1) Tanks in the forward cargo region are defined as tanks with their longitudinal centre of gravity position forward of 0.7L from A.P.
2) Tanks in the midship cargo region are defined as tanks with their longitudinal centre of gravity position at or forward of 0.3L from AP and at or aft of 0.7L from A.P.
3) Tanks in the aft cargo region are defined as tanks with their longitudinal centre of gravity position aft of 0.3L from A.P.

Figure 4.2.1: Definition of Cargo Tank Regions for FE Structural Assessment

1.2. Symbols, Units and Definitions

1.2.1. General

1.2.1.1. Those symbols and definitions which are applicable to this section and given in Chapter 1 Section 4/1, Chapter 2 section 1 are as follows:

a_t transverse acceleration, taken at centre of gravity of tank
a_v vertical acceleration, taken at centre of gravity of tank
a_{lng} longitudinal acceleration, taken at centre of gravity of tank
E Modulus of Elasticity of steel, 2.06x105 N/mm^2
M_h horizontal wave bending moment for a dynamic load case
M_{wv} vertical wave bending moment for a dynamic load case
M_{sw} vertical still water bending moment for a finite element loading pattern
Q_{sw} vertical still water shear force for a finite element loading pattern
Q_{wv} vertical wave shear force for a dynamic load case
T_{LC} draught at the loading condition being considered
T_{sc} scantling draught, as defined in Chapter 1 Section 4/1.1.5.5
T_{bal-em} emergency draught of ship
t_{grs} proposed new building gross thickness excluding Owner's extras, see Chapter 2 Section 2/6.3.4
t_{corr} corrosion addition, as defined in Chapter 1 Section 6/3.2
σ_{yd} specified minimum yield stress of the material, N/mm^2
σ_{vm} von Mises stress

$$= \sqrt{\sigma_x{}^2 + \sigma_y{}^2 - \sigma_x\sigma_y + 3\tau_{xy}{}^2}$$

σ_x axial stress in element x direction
σ_y axial stress in element y direction
τ_{xy} element shear stress in x-y plane
δ_x displacement in x direction, in compliance with the coordinate system defined in Chapter 1 Section 4/1.4
δ_z displacement in z direction, in compliance with the coordinate system defined in Chapter 1 Section 4/1.4
δ_y displacement in y direction, in compliance with the coordinate system defined in Chapter 1 Section 4/1.4
θ_x rotation about x axis, in compliance with the coordinate system defined in Chapter 1 Section 4/1.4
θ_y rotation about y axis, in compliance with the coordinate system defined in Chapter 1 Section 4/1.4

θ_z rotation about z axis, in compliance with the coordinate system defined in Chapter 1 Section 4/1.4

1.2.1.2. The Chapter 1 Section 4/1.5 defines the nomenclature of structural components.

1.2.1.3. Consistent co-ordinate and unit systems are to be used for all the parts of structural analysis. However, in calculations using Rule Formulae, the specified units and co-ordinate system are to be used.
Where derived output values from Rule formulae are in a different unit and/or co-ordinate system as used in the structural analysis, those are to be converted to appropriate unit and co-ordinate system.

1.2.2. Finite element types

1.2.2.1. The structural assessment is to be based on linear finite element analysis of three dimensional structural models. **Table 4.2.1** containsgeneral types of finite elements to be used in the finite element analysis**.**

1.2.2.2. Two node line elements and 3/4 node plate/shell elements are considered adequate for the hull structure representation. The mesh requirements given in this Section are based on assumption that these elements are used in the finite element models. However, higher order elements may also be used.

Table 4.2.1: Types of Finite Element

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

1.2.2.3. For cargo tank and fine mesh strength analyses as specified in this Section 2/2 and Section 2/3, assessment against stress acceptance criteria is to be based on membrane (or in-plane) stresses of plate elements. For the fatigue assessment as specified in this Section 2/4, calculation of dynamic stress range for the determination of fatigue life is to be based on surface stresses of plate elements.

2. Cargo Tank Structural Strength Analysis

2.1. Assessment

2.1.1. General

2.1.1.1. For tankers of conventional arrangements, finite element strength assessment of the hull girder and primary supporting structural members is to be in line with this section’s requirements.

2.2. Structural Modelling

2.2.1. General

2.2.1.1. The longitudinal extent of the midship cargo tank finite element (FE) model is to cover three cargo tank lengths about midships. Where the tanks in the midship cargo region are of different lengths, middle tank of the finite element model is to represent cargo tank of greatest length. The finite element model may be prismatic. The transverse bulkheads at the ends of the model are to be represented. Where corrugated transverse bulkheads are fitted, model is to include extent of the bulkhead stool structure forward and aft of the tanks at the model ends. The length of the model extending beyond the end transverse bulkheads is to be kept equal, at both ends. The web frames at the ends of the model are to be modelled. Typical finite element models representing the midship cargo tank region of different tanker configurations are illustrated in Figure 4.2.2.

2.2.1.2. The assessment of longitudinal hull girder shear structural members, as defined in Chapter 2 section 3/2.2.1.1 and Chapter 1 Section 4/Table 4.1.1, against hull girder vertical shear loads in the forward and aft cargo regions may be based on the midship cargo tank finite element model with modification of plate and stiffener properties, where appropriate. Where for the assessment of shear strength, separate cargo tank finite element model is used, the model is to cover three tank lengths.

2.2.1.3. Both starboard sides and port sides of the ship are to be modeled rather the full depth of the ship is to be modelled.

2.2.1.4. All main transverse and longitudinal structural elements are to be modeled and these shall include inner and outer shell, transverse and vertical web frames, double bottom floor and girder system, stringers and transverse and longitudinal bulkhead structures. All plates and stiffeners on the structure, including web stiffeners, are also to be modelled, refer 2.2.1.11.

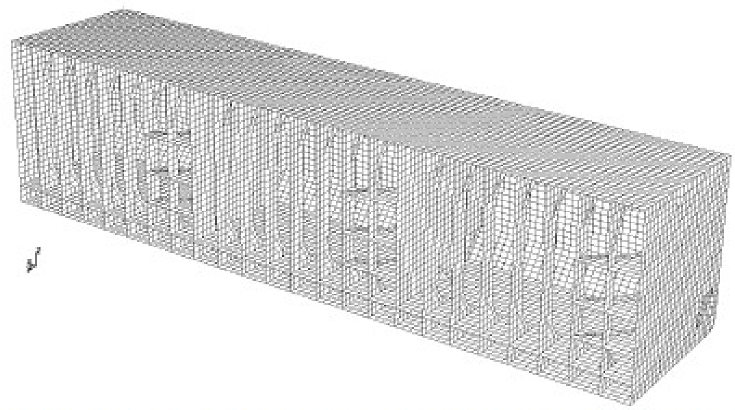
2.2.1.5. The reduced thickness used in the FE model of the cargo tanks i.e. applicable to stiffener's web and flanges and all plating is to be calculated as given below:

$$t_{FEM-net5} = t_{grs} - 0.5\, t_{corr}$$

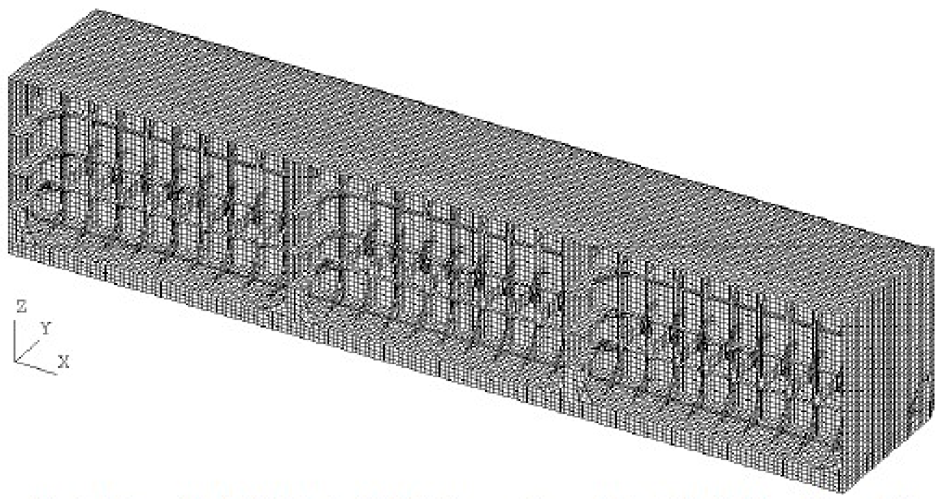
Where:

t_{grs} gross thickness, as defined in 1.2

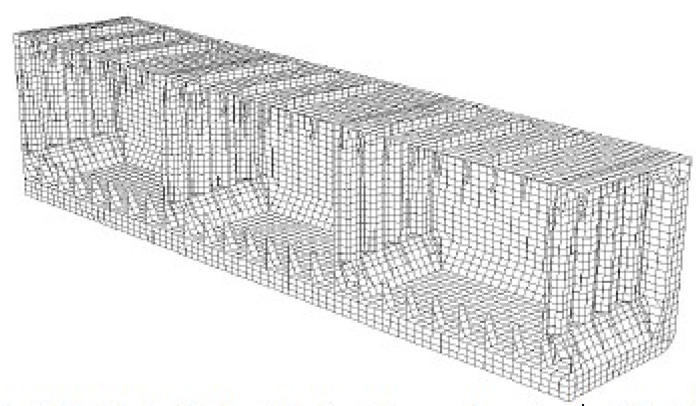
t_{corr} corrosion addition, as defined in Chapter 1 Section 6/3.2



Typical Cargo Tank Model of an AfraMax Oil Tanker (shows only starboard side of the full breadth model)



Typical Cargo Tank Model of a VLCC (shows only port side of the full breadth model)



Typical Cargo Tank Model of a Product Tanker (shows only port side of the full breadth model)

Figure 4.2.2: Typical 3-Tank FE Models Representing Midship Cargo Tank Region of Tankers

2.2.1.6. The plate element mesh is to follow the stiffening system, as much asfeasible, hence representing the actual plate panels between stiffeners. In general, the plate element mesh is to meetthe requirements below:

a) One element between every longitudinal stiffener, refer Figure 4.2.3. Longitudinally, the element length is not to be greater than 2 longitudinal spaces
b) One element between every vertical stiffener on transverse bulkheads, refer Figure 4.2.4
c) One element between every web stiffener on transverse and vertical web frames, cross ties and stringers, refer Figure 4.2.3 and Figure 4.2.5
d) Minimum three elements over the depth of double bottom girders and floors, transverse web frames, vertical web frames and horizontal stringers on transverse bulkheads. For cross ties, deck transverse and horizontal stringers on transverse wash bulkheads and longitudinal bulkheads with a smaller web depth, representation that uses two elements over the depth is acceptable provided that there is at least one elementbetween every web stiffener. The mesh size of adjacent structure is to be adjusted to suit
e) The mesh on the hopper tank web frame shall be fine enough to represent the shape of the web ring opening, refer Figure 4.2.3
f) The curvature of the free edge on large brackets of primary support members is to be modelled accurately to avert unrealistic high stress due to geometry discontinuities. In general, a mesh size equal to the stiffener spacing is acceptable. The bracket toe may be ceased at the nearest nodal point, provided themodelled length of the bracket arm does not exceed the actual bracket arm length. The bracket flange is not to be connected to the plating, refer to Figure 4.2.6. The modelling of the tapering part of the flange is to be as per2.2.1.14. An acceptable mesh is illustrated in Figure 4.2.6. A finer mesh is to be used for the determination of detailed stress at the bracket toe, refer Section 2/3.

2.2.1.7. Corrugated bulkheads and bulkhead stools are to be modelled using shell plate elements, refer to Figure 4.2.7. Diaphragms in the stools and internal longitudinal and vertical stiffeners on the stool plating are to be included in the model. Modelling is to be executed as given below:

a) In general, the shell element mesh on the flange and web of the corrugation is to follow the stiffener spacing inside the bulkhead stool
b) where in matching the mesh on the corrugations directly with the mesh on the stool, there is a difficulty, it is acceptable to adjust the mesh on the stools in way of the corrugations such that the corrugation bulkhead will retain its original geometrical shape. However, if the corrugation shape is adjusted tosimplify the modelling procedure, this effect is to be taken into account in evaluation of stresses as described in 2.7.2.6.
c) for a corrugated bulkhead without lower stool and/or an upper stool, it may be vital to adjust the geometry to simplify the modelling. The adjustment is to be made such that the position and shape of the corrugations and primary support members are retained. Hence, adjustment is to be made on stiffeners and plate seams, if required.

2.2.1.8. In general, the aspect ratio of the plate elements is not to exceed three. The use of triangular plate elements is to be kept to a minimum. Where feasible, 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.

2.2.1.9. Typical mesh arrangements of the cargo tank structure are as illustrated in Figure 4.2.8.

2.2.1.10. Shell elements, in alliance with beam elements, are to be used to represent stiffened panels in areas under lateral pressure. Shell elements are to be used to represent unstiffened panels in areas under lateralpressure. Rod and membrane elements may be used to represent non-tight structure under no pressure loads.

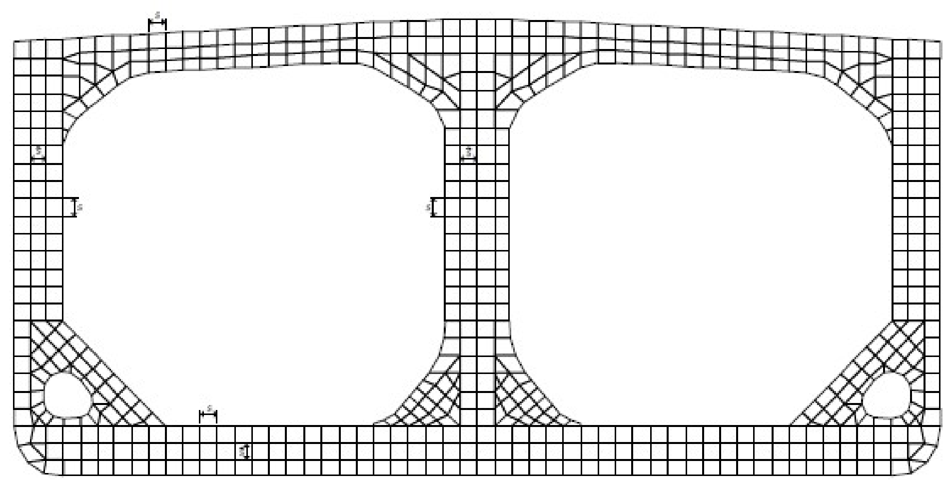


Figure 4.2.3: Typical Finite Element Mesh on Web Frame

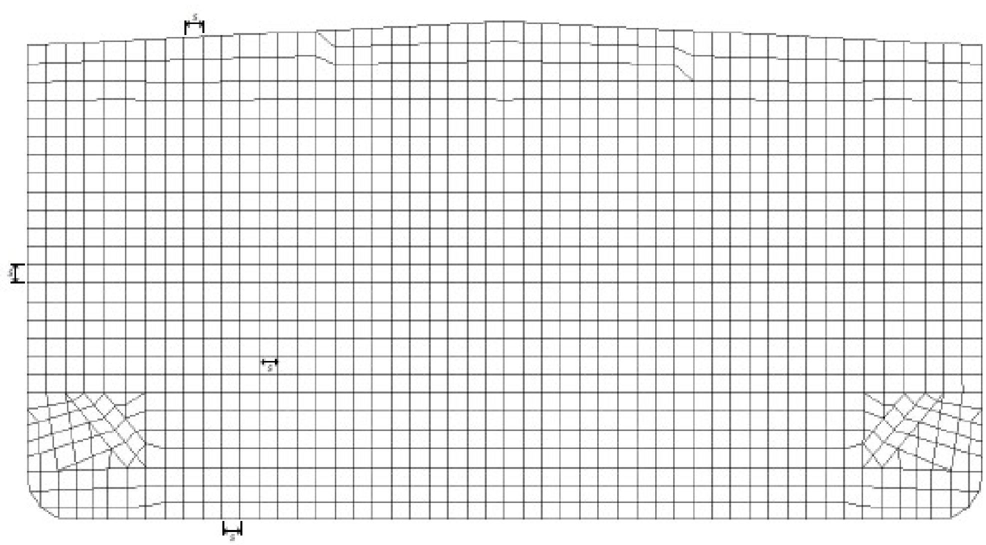


Figure 4.2.4: Typical Finite Element Mesh on Transverse Bulkhead

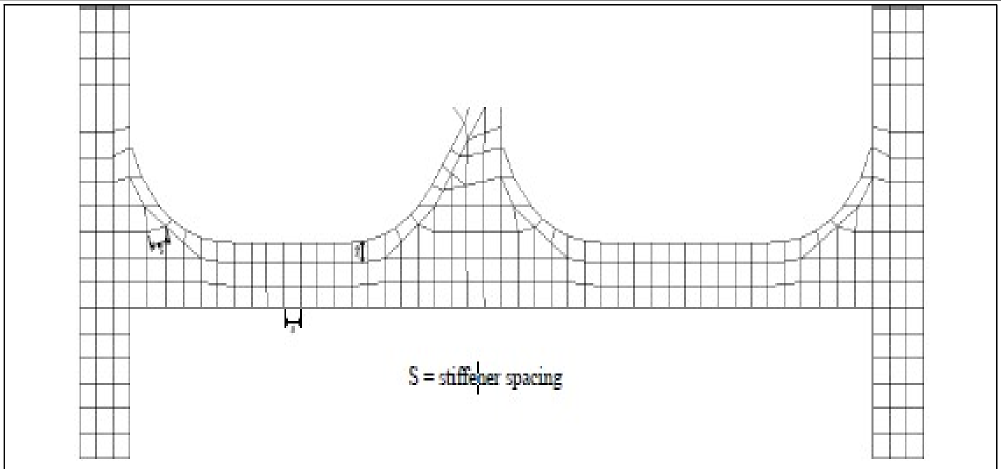


Figure 4.2.5: Typical Finite Element Mesh on Horizontal Transverse Stringer on Transverse Bulkhead

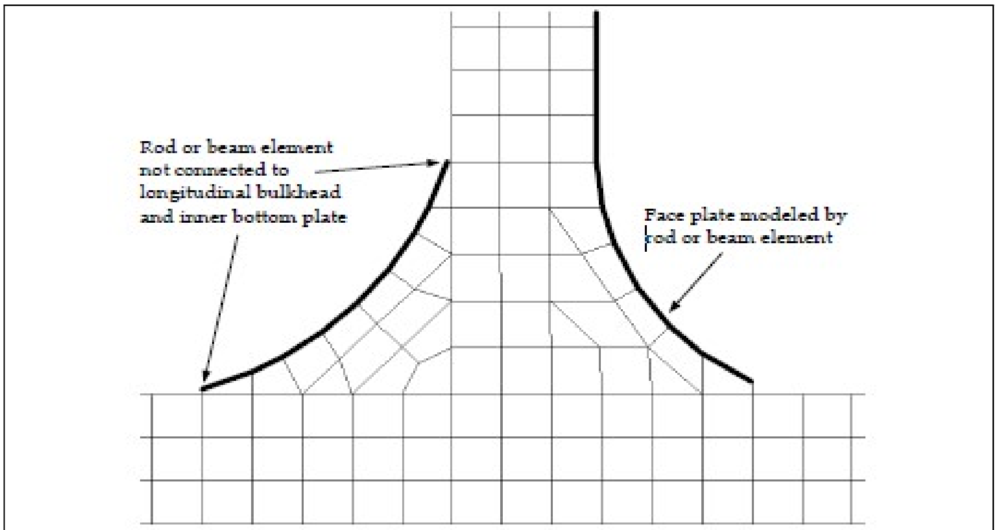


Figure 4.2.6: Typical Finite Element Mesh on Transverse Web Frame Main Bracket

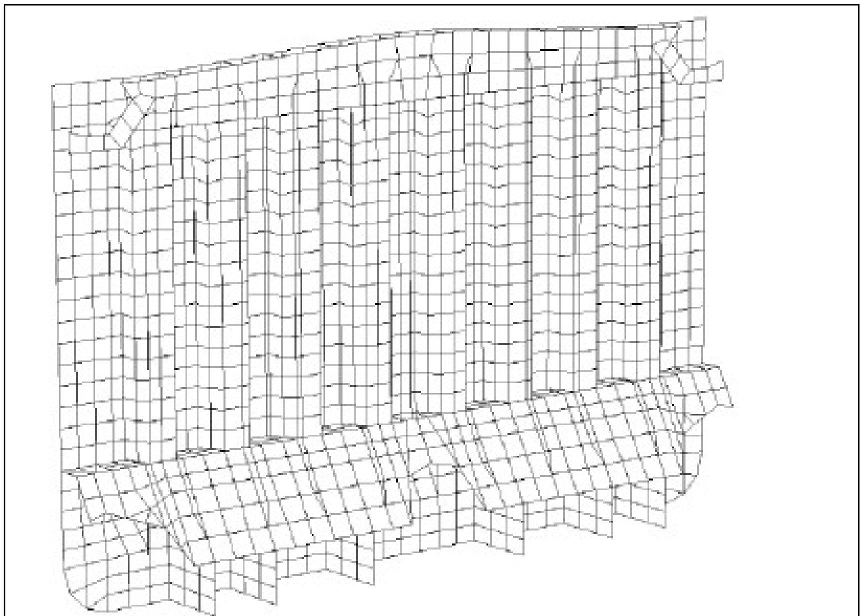
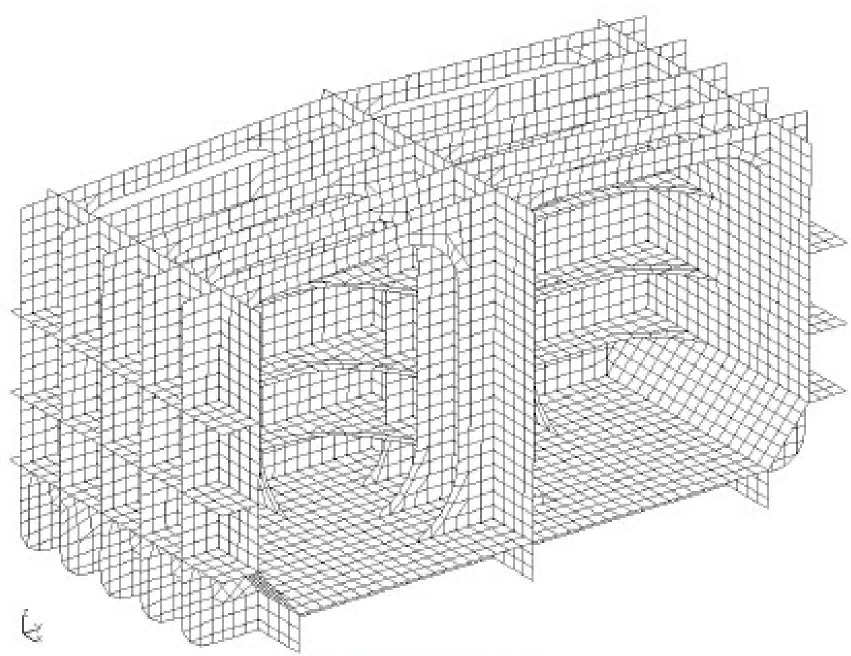
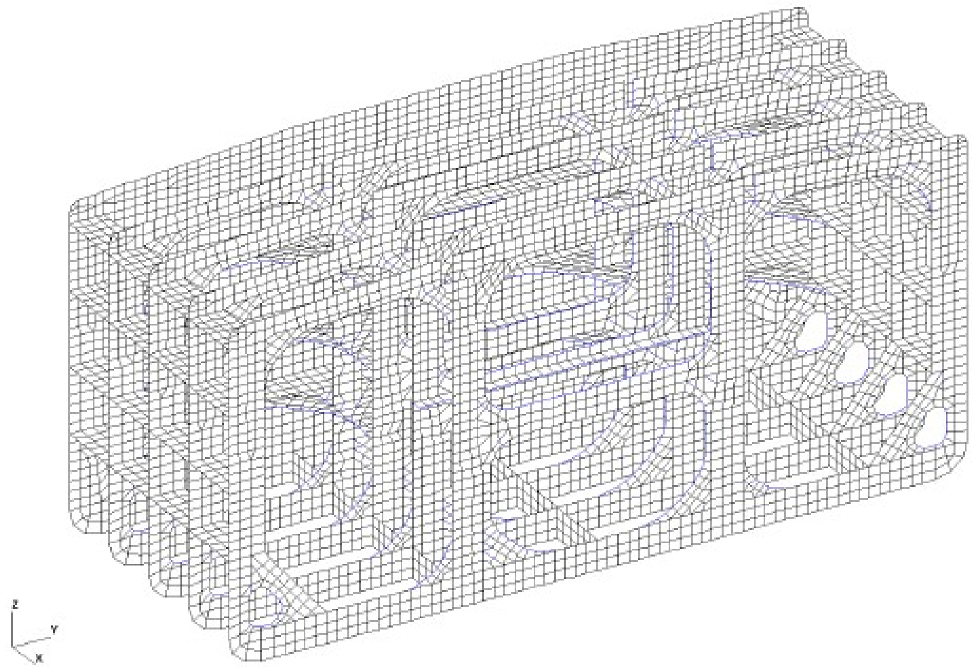


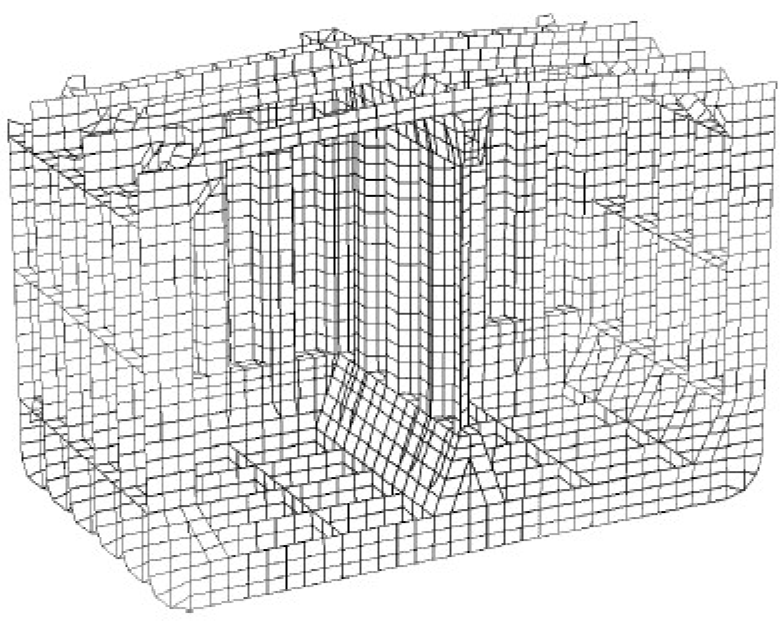
Figure 4.2.7: Typical Finite Element Mesh on Transverse Corrugated Bulkhead Structure



Aframax Oil Tanker



VLCC



Product tanker

Figure 4.2.8: Typical Finite Element Mesh Arrangements of Cargo Tank Structure

2.2.1.11. All local stiffeners are to be modelled. These stiffeners may be modelled using line elements positioned in the plane of the plating. Beam elements are to be used in areas under the action of lateral loads whilst rod (truss) elements may be used to represent local stiffeners on internal structural members under no lateral loads. The line elements are to have the properties given below:

a) for beam elements, out of plane bending properties are to represent the inertia of the combined plating and stiffener. The width of the attached plate is to be taken as ½ + ½ stiffener spacing on each side of the stiffener. The eccentricity of the neutral axis is not required to be modelled.
b) for rod and beam elements, other sectional properties are to be based on a cross sectional area representing the stiffener area, excluding the area of the attached plating.

2.2.1.12. The effective cross sectional area of non-continuous stiffeners is to be calculated as perTable 4.2.2.

Table 4.2.2: Effective Cross Sectional Area of Stiffener Line Elements

Structure represented by line element	*Effective area A_e*	
Stiffener within a distance $2d_w$from a sniped (non-continuous) end	All sections	$A_e = 25\% A_{net-50}$
Stiffener outside a distance $2d_w$from a sniped (non-continuous) end	All sections	$A_e = 100\% A_{net-50}$
Where: $A_{n\text{-}net50}$ average cross sectional area over length of line element d_w depth of stiffener web, excluding attached plate		

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

2.2.1.14. Face plates of primary support members and brackets may be modelled using rod elements. The effective cross sectional area at the curved part of the face plate is to be calculated as per Chapter 1 Section 4/2.3.4. The cross-sectional area of a rod element representing the tapering part of the face plate is to be based on the average cross sectional area of the face plate in way of element length.

2.2.1.15. Methods used for representing openings in webs of primary support members are to be in line with Table 4.2.3. Cut-outs for scallops, local stiffeners, drain and air holes need not be represented.

Table 4.2.3: Representation of Openings in Primary Support Member Webs

$h_o/h < 0.35$ and $g_o < 1.2$	Openings do not need to be modelled
$0.5 > h_o/h \geq 0.35$ and $g_o < 1.2$	The plate modelled with mean thickness $t_{1\text{-net}50}$
$h_o/h < 0.5$ and $2 > g_o \geq 1.2$	The plate modelled with mean thickness $t_{2\text{-net}50}$
$h_o/h \geq 0.5$ or $g_o \geq 2.0$	The geometry of the opening is to be modelled

Where:

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

$$t_{1-net50} = \frac{h-h_0}{h} t_{w-net}$$

$$t_{2-net50} = \frac{h-h_0}{hg_0} t_{w-net50}$$

$t_{w\text{-net}50}$ net web thickness

l_o length of opening parallel to primary support member web direction, see Figure 4.2.9

h_o height of opening parallel to depth of web, see Figure 4.2.9

h height of web of primary support member in way of opening, see Figure 4.2.9

t_{corr} corrosion addition, as defined in Chapter 1 Section 6/3.2

Note

1) For sequential openings where the distance, d_o, between openings is less than 0.25h, the length l_o is to be taken as the length across openings as shown in Figure 4.2.10.

2) The same unit is to be used for l_o, h_o and h.

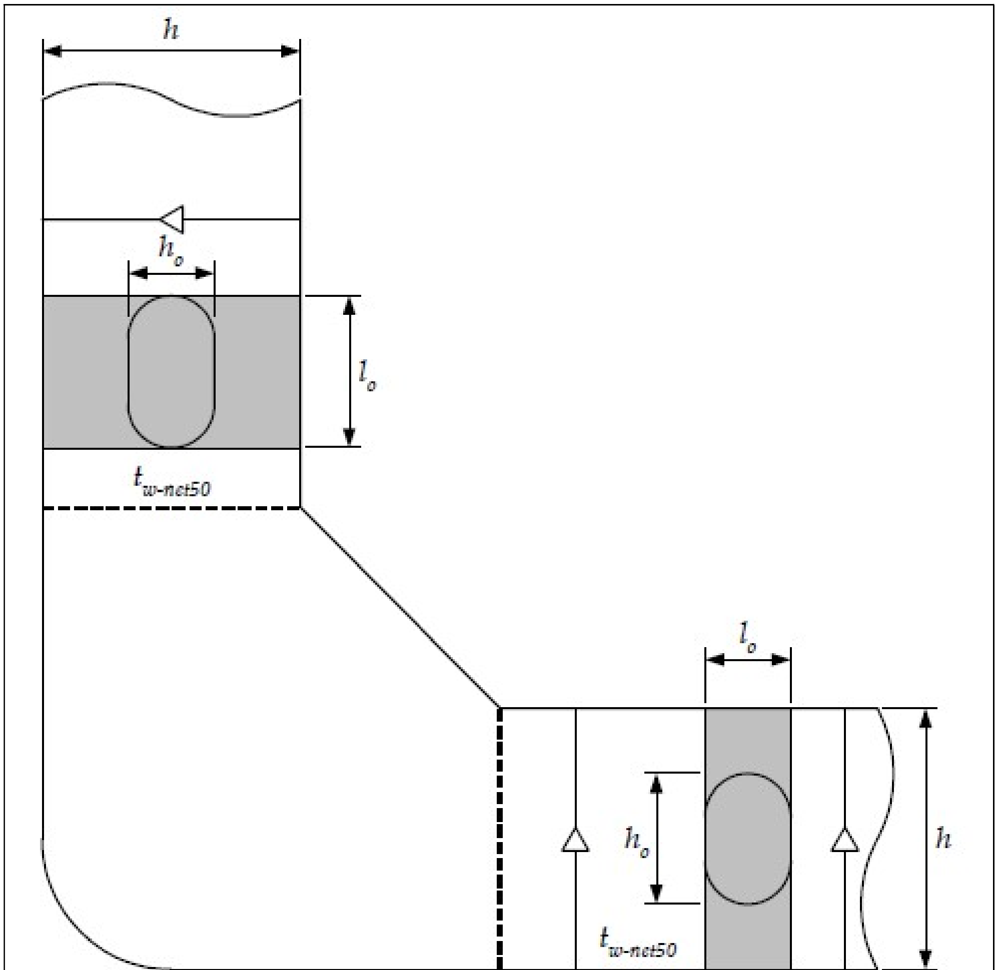


Figure 4.2.9: Openings in Web

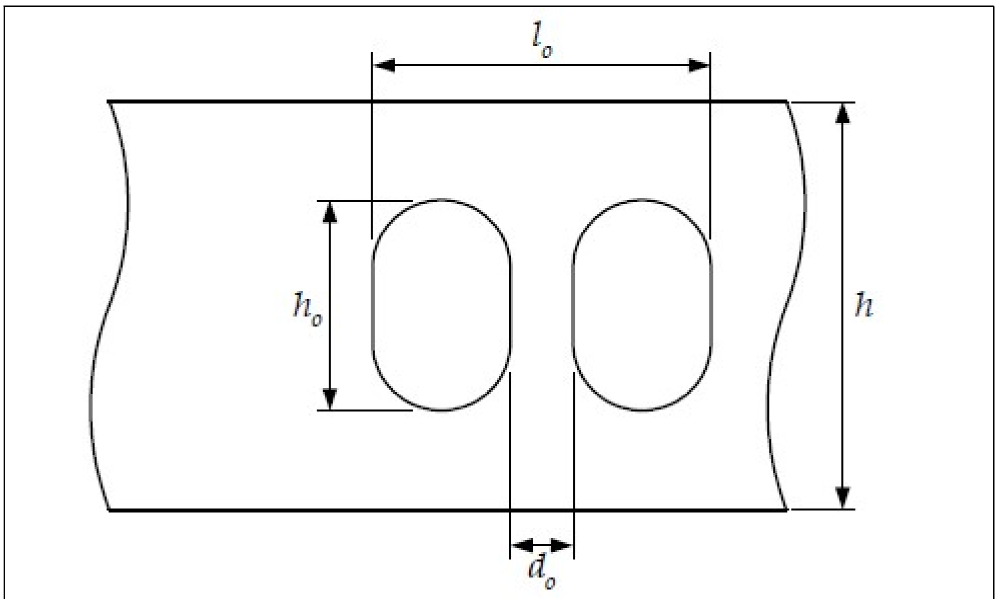


Figure 4.2.10: Length lo for Sequential Openings with d_o< h/4

2.3. Loading Conditions

2.3.1. Finite element load cases

2.3.1.1. For tankers with two oil-tight longitudinal bulkheads and one centreline oil-tight longitudinal bulkhead, standard design load combinations to be used in the structural analysis are given in Tables 4.2.4 and 4.2.5 respectively.

2.3.1.2. For S+D design load combinations (seagoing load cases) the number of dynamic load cases requiring investigation for each loading pattern is indicated by the dynamic load case numbers specified for each loading pattern in Tables 4.2.4 and 4.2.5. Each S+D design load combination has two parts:

a. static loads, as described by the loading pattern, ship draught, hull girder still water bending moment and shear force specified; and
b. dynamic loads defined in Chapter 2 Section 1/Table 2.1.2 for the dynamic load case number specified.

2.3.1.3. For tankers with two oil-tight longitudinal bulkheads and a cross tie arrangement in the centre cargo tanks, loading patterns A7 and A12 in Table 4.2.4 are to be examined for the possibility that unequal filling levels in transversely paired wing cargo tanks would result in a more onerous stress response. Loading pattern A7 are analysed only if such a non-symmetric seagoing loading condition is included in the ship loading manual. Loading patterns A7 and A12 need not be examined for tankers without a cross tie arrangement in the centre cargo tanks.

2.3.1.4. For tankers with two oil-tight longitudinal bulkheads, seagoing loading pattern A3 and harbor loading pattern A13, with all cargo tanks abreast empty, are to be analysed with a ship draught of $0.55T_{sc}$ and $0.65T_{sc}$ respectively. If conditions in the ship loading manual specify greater draughts for loading pattern A3 or A13, then maximum specified draught in the ship's loading manual for the loading pattern is to be used.

2.3.1.5. For tankers with two oil-tight longitudinal bulkheads, seagoing loading pattern A5 and harbor loading pattern A11, with all cargo tanks abreast fully loaded, are to be analysed with a ship draught of $0.8T_{sc}$ and $0.7T_{sc}$ respectively. If conditions in the ship loading manual specify lesser draughts for loading pattern A5 or A11, then minimum specified draught in the ship's loading manual for the loading pattern is to be used.

2.3.1.6. For loading patterns A1, A2, B1, B2 and B3, with cargo tank(s) empty, in analysis, a minimum ship draught of $0.9T_{sc}$ is to be used. If conditions in the ship loading manual specify greater draughts for loading patterns with empty cargo tank(s), then maximum specified draught for the actual condition is to be used.

2.3.1.7. Where a ballast condition is specified in the ship loading manual with ballast water filled in one or more cargo tanks, loading patterns A8 and B7 in Tables 4.2.4 and 4.2.5 are to be examined. If this loading is un-symmetrical, then additional strength assessment is to be done as per the requirements of IRS.

Table 4.2.4: FE Load Cases for Tankers with Two Oil tight Longitudinal Bulkheads

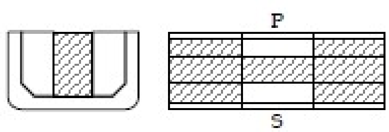
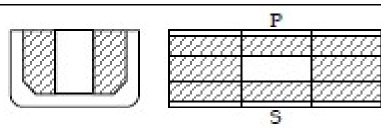
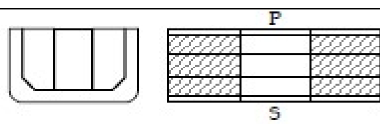
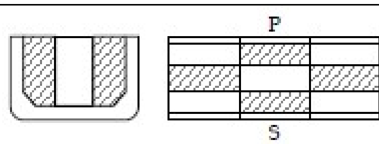
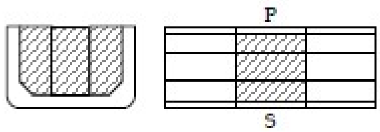
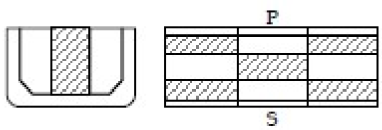
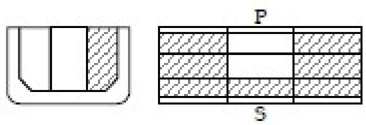
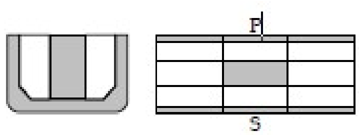
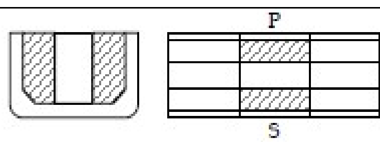
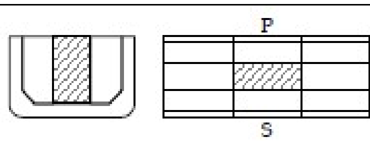
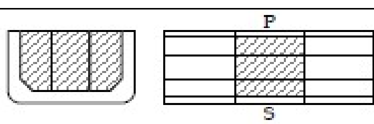
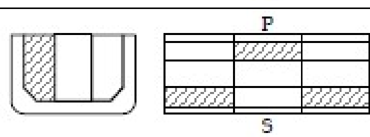
Loading Pattern	*Figure*	*Still Water Loads*			*Dynamic load cases*		
		Draught	*% of Perm. SWBM (2)*	*% of Perm. SWSF(2)*	*Strength assessment (1a)*	*Strength assessment against hull girder shear loads (1b)*	
					Midship region	*Forward region*	*Midship and aft regions*
Design load combination S + D (Sea-going load cases)							
A1		0.9 T_{sc}	100% (sag)	See note 3	1	\	\
			100% (hog)	100% (-ve fwd) See note 4	2, 5a	\	\
A2		0.9 T_{sc}	100% (sag)	See note 3	1	\	\
			100% (hog)	100% (-ve fwd) See note 4	2, 5a	\	\
A3		0.55 T_{sc} see note (6)	100% (hog)	100% (-ve fwd) See note 5	2	4	2
				100% (-ve fwd) See note 4	5a	\	\
A4		0.6 T_{sc}	100% (sag)	100% (+ve fwd) See note 4	1, 5a	\	\

Table 4.2.4: FE Load Cases for Tankers with Two Oil tight Longitudinal Bulkheads (Continued)

Loading Pattern	Figure	Still Water Loads			Dynamic load cases		
		Draught	% of Perm. SWBM (2)	% of Perm. SWSF(2)	Strength assessment (1a)	Strength assessment against hull girder shear loads (1b)	
					Midship region	Forward region	Midship and aft regions
A5		0.8 T_{sc} See note 7	100% (sag)	100% (+ve fwd) See note 5	1	3	1
				100% (+ve fwd) See note 4	5a	\	\
A6		0.6 T_{sc}	100% (hog)	100% (-ve fwd) See note 4	5a	\	\
A7(8)		T_{LC}	100% (hog)	100% (-ve fwd) See note 4	5a	\	\
A8(9)		$T_{bal\text{-}em}$	100% (sag)	100% (+ve fwd) See note 4	1	\	\
Design load combination S (Harbour and tank testing load cases)							
A9(13)		¼T_{sc}	100% (sag)	100% (+ve fwd) See note 4	Only applicable to strength assessment of midship region (see note 1(a))		
A10(13)		¼T_{sc}	100% (sag)	100% (+ve fwd) See note 4	Only applicable to strength assessment of midship region (see note 1(a))		
A11(12,13)		0.7 T_{sc}see note 12	100% (sag)	100% (+ve fwd) See note 5	Applicable to strength assessment of midship region (see 1(a)) and strength assessment against hull girder shear loads (see 1(b))		
A12(10,13)		1/3T_{sc}	See note 10	See note 10	Only applicable to strength assessment of midship region (see note 1(a))		

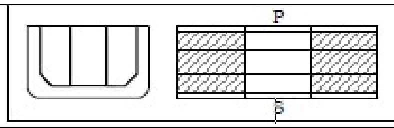
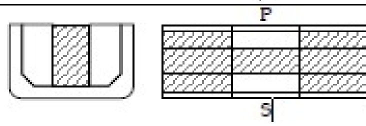
A13(11,13)		0.65 T_{sc}see note 11	100% (Hog)	100% (-ve fwd) See note 5	Applicable to strength assessment of midship region (see 1(a)) and strength assessment against hull girder shear loads (see 1(b))
A14(13)		T_{sc}	100% (Hog)	100% (-ve fwd) See note 4	Only applicable to strength assessment of midship region (see note 1(a))

Table 4.2.4: FE Load Cases for Tankers with Two Oil-tight Longitudinal Bulkheads (Continued)

Loading Pattern	*Figure*	*Still Water Loads*			*Dynamic load cases*		
		Draught	*% of Perm. SWBM (2)*	*% of Perm. SWSF(2)*	*Strength assessment (1a)*	*Strength assessment against hull girder shear loads (1b)*	
					Midship region	*Forward region*	*Midship and aft regions*

Note

1)

a) For the assessment of scantlings of longitudinal hull girder structural members, primary supporting structural members and transverse bulkheads within midship cargo region, see 1.1.1.5.

b) For the assessment of strengthening of longitudinal hull girder shear structural members in way of transverse bulkheads for hull girder vertical shear loads, see 1.1.1.6, 1.1.1.7 and 1.1.1.8.

2) The selection of permissible SWBM and SWSF for the assessment of different cargo regions of the ship is to be in accordance with Table 4.2.7. The percentage of the permissible SWBM and SWSF to be applied are to be in accordance with this table.

3) The actual shear force that results from the application of static and dynamic local loads to the FE model are to be used.

4) The actual shear force that results from the application of static and dynamic local loads to the FE model are to be used. Where this shear force exceeds the target SWSF (design load combination S) or target combined SWSF and VWSF, calculated in accordance with 2.4.5.2, (design load combination S+D) as specified in the table, correction vertical loads are to be applied to adjust the shear force down to the required value.

5) Correction vertical loads are to be applied to adjust the shear force to the required value specified.

6) For loading pattern A3, with all cargo tanks abreast empty in sea-going condition, a draught of 0.55Tsc is to be used in the analysis. Where such conditions are specified in the ship's loading manual with a draught greater than 0.55T_{sc}, the maximum specified draught for those loading conditions is to be used in the FE analysis.

7) For loading pattern A5, with all cargo tanks abreast fully loaded in sea-going condition, a draught of 0.8T_{sc} is to be used in the analysis. Where such conditions are specified in the ship's loading manual with a draught lesser than 0.8T_{sc}, the minimum specified draught for those loading conditions is to be used in the FE analysis.

8) Loading pattern A7 is only required to be analysed for tankers with a cross tie arrangement in the centre cargo tanks if the ship's loading manual includes a non-symmetrical loading condition with only one of the wing tanks filled. The actual draught from the loading manual for the condition is to be used in the analysis, see Table 4.2.6.

9) Ballast loading pattern A8 with ballast filled in one or more cargo tanks (i.e. gale ballast/emergency ballast conditions etc.) is only required to be analysed if the condition is specified in the ship's loading manual. The actual loading pattern and draught from the loading manual for the condition is to be used in the analysis, see Table 4.2.6.

10) Loading patterns A12 is only required for tankers with a cross tie arrangement in the centre cargo tanks. The actual shear force and bending moment that results from the application of local loads to the FE model are to be used. Adjusting vertical loads and bending moments are not applied.

11) For loading pattern A13, with all cargo tanks abreast empty in harbour condition, a draught of 0.65T_{sc} is to be used in the analysis. Where such conditions are specified in the ship's loading manual with a draught greater than 0.65T_{sc}, the maximum specified draught for those loading conditions is to be used in the FE analysis.

12) For loading pattern A11, with all cargo tanks abreast fully loaded in harbour condition, a draught of 0.7T_{sc} is to be used in the analysis. Where such conditions are specified in the ship's loading manual with a draught less than 0.7T_{sc}, the minimum specified draught for those loading conditions is to be used in the FE analysis.

13) No dynamic loads are to be applied to Design Load Combination S (harbour and tank testing load cases).

Table 4.2.5: Load Cases for Tankers with One Centreline Oil-tight Longitudinal Bulkhead

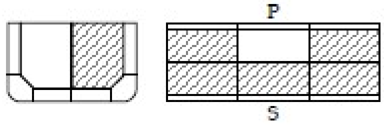
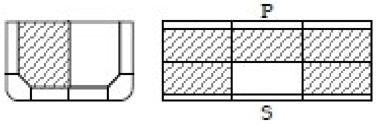
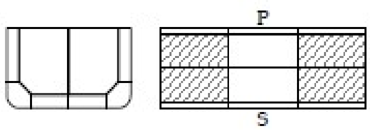
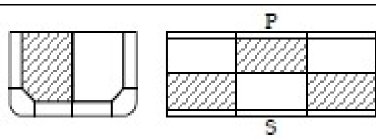
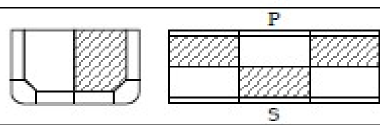
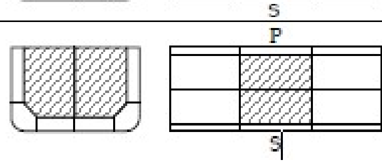
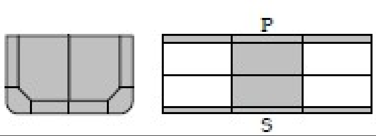
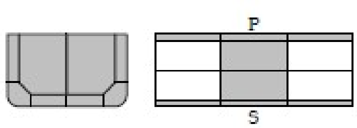
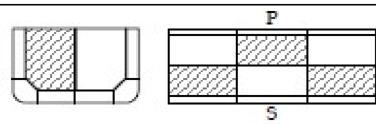
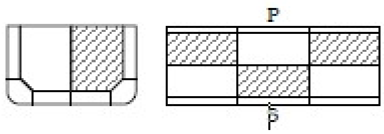
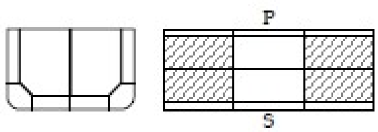
Loading Pattern	*Figure*	*Still Water Loads*			*Dynamic load cases*		
		Draught	*% of Perm. SWBM (2)*	*% of Perm. SWSF(2)*	*Strength assessment (1a)*	*Strength assessment against hull girder shear loads (1b)*	
					Midship region	*Forward region*	*Midship and aft regions*
Design load combination S + D (Sea-going load cases)							
B1		0.9 T_{sc}	100% (sag)	See note 3	1	\	\
			100% (hog)	100% (-ve fwd) See note 4	2,5a	\	\
B2 (6)		0.9 T_{sc}	100% (sag)	See note 3	1	\	\
			100% (hog)	100% (-ve fwd) See note 4	2,5b	\	\
B3		0.9 T_{sc}	100% (hog)	100% (-ve fwd) See note 5	2	4	2
				100% (-ve fwd) See note 4	5a, 5b, 6a, 6b	\	\
B4		0.6 T_{sc}	100% (sag)	75% (+ve fwd) See note 4	1, 5a	\	\
B5 (6)		0.6 T_{sc}	100% (sag)	75% (+ve fwd) See note 4	1, 5b	\	\
B6		0.6 T_{sc}	100% (sag)	100% (+ve fwd) See note 5	1	3	1
				100% (+ve fwd) See note 4	5a, 5b	\	\
B7(7)		T_{bal-em}	100% (sag)	100% (+ve fwd) See note 4	1	\	\
Design load combination S (Harbour and tank testing load cases)							
B8(8)		1/3T_{sc}	100% (sag)	100% (+ve fwd) See note 5	Applicable to strength assessment of midship region (see 1(a)) and strength assessment against hull girder shear loads (see 1(b))		

Table 4.2.5: Load Cases for Tankers with One Centreline Oil-tight Longitudinal Bulkhead (Continued)

Loading Pattern	Figure	Still Water Loads			Dynamic load cases		
		Draught	% of Perm. SWBM (2)	% of Perm. SWSF(2)	Strength assessment (1a)	Strength assessment against hull girder shear loads (1b)	
					Midship region	Forward region	Midship and aft regions
B9[8]		$1/3T_{sc}$	100% (sag)	75% (+ve fwd) See note 4	Only applicable to strength assessment of midship region (see note 1(a))		
B10[6,8]		$1/3T_{sc}$	100% (sag)	75% (+ve fwd) See note 4	Only applicable to strength assessment of midship region (see note 1(a))		
B11[8]		T_{sc}	100% (hag)	100% (-ve fwd) See note 5	Applicable to strength assessment of midship region (see 1(a)) and strength assessment against hull girder shear loads (see 1(b))		

Note

1)

a) For the assessment of scantlings of longitudinal hull girder structural members, primary supporting structural members and Transverse bulkheads within midship region, see 1.1.1.5.

b) For the assessment of strengthening of longitudinal hull girder shear structural members in way of transverse bulkheads for hull girder vertical shear loads, see 1.1.1.6, 1.1.1.7 and 1.1.1.8.

2) The selection of permissible SWBM and SWSF for the assessment of different cargo regions of the ship is to be in accordance with Table 4.2.7. The percentage of the permissible SWBM and SWSF to be applied are to be accordance with this table.

3) The actual shear force that results from the application of static and dynamic local loads to the FE model are to be used.

4) The actual shear force that results from the application of static and dynamic local loads are to be used. Where this shear force Exceeds the target SWSF (design load combination S) or target combined SWSF and VWSF, calculated in accordance with 2.4.5.2, (design load combination S+D) as specified in the table, correction vertical loads are to be applied to adjust the shear force down to the required value.

5) Correction vertical loads are to be applied to adjust the shear force to the required value specified.

6) Load cases B2, B5 and B10 are only required if the structure is not symmetrical about the ship's centreline.

7) Ballast loading pattern B7 with ballast filled in cargo tanks (i.e. gale ballast/emergency ballast conditions etc.) is only required to be analysed if the condition is specified in the ship's loading manual. The actual loading pattern and draught from the loading Manual for the condition is to be used in the analysis, see Table 4.2.6. If the actual loading pattern is different from load case B7 then:

(a) An operational restriction corresponding to the analysed condition is to be added in the Loading Manual.

(b) 100% of the permissible SWBM is to be applied when analyzing loading pattern with ballast in cargo tanks.

8) No dynamic loads are to be applied to Design Load Combination S (harbour and tank testing load cases).

2.3.2. Dynamic load cases

2.3.2.1. The dynamic load cases to be used for the finite element analysis are given in Chapter 2 Section 1/6.4.

2.4. Application of Loads

2.4.1. General

2.4.1.1. The application of loads to the finite element model is to be as per Chapter 2 Section 1/6 and the requirements as specified in Section 2/2.4.

2.4.1.2. The load parameters and locations to be used for the calculation of the applied loads and accelerations are to be as per Table 4.2.6 and Table 4.2.7.

2.4.1.3. Constant pressure load, evaluated at the element's centroid, may be applied to a finite plate element. Alternately, a linear pressure distribution between element's nodal points can be applied.

Table 4.2.6: Parameters for Calculation of Loads and Accelerations

Parameter	*Standard Conditions*			*Optional Conditions*	
	Draught T_{sc}	*Draught $0.9T_{sc}$*	*Draught $0.6T_{sc}$*	*Loaded conditions: A3 (draught > 0.6Tsc) and A7*	*Gale/emergency ballast conditions: A8 and B7*
L	Rule Length			Rule Length	
C_b	block coefficient, as defined in Chapter 1 Section 4/1.1.1.1			block coefficient, as defined in Chapter 1 Section 4/1.1.1.1	
Ship speed	0			0	
Roll Response					
GM	0.12B	0.12B	0.24B	Corrected GM in the ship's loading manual for the loaded or gale/emergency ballast pattern under consideration, see Note 1	
$r_{roll-gyr}$	0.35B	0.35B	0.4B	See Note 2	
Pitch response, longitudinal and transverse accelerations, horizontal wave bending moment and sea pressures					
Ship draught	*T_{sc}*	*$0.9T_{sc}$*	*$0.6T_{sc}$*	Maximum mean draught in the loading manual for the loading pattern under consideration	Minimum mean draught in the loading manual for the loading pattern under consideration

Note
1) Where GM for optional loaded or gale/emergency ballast conditions is not given in the ship's loading manual, GM is to be determined in accordance with Chapter 2 Section 1/3.1.3.2.
2) Where $r_{roll-gyr}$ for optional loaded or gale/emergency ballast conditions is not given in the ship's loading manual, $r_{roll-gyr}$ is to be determined in accordance with Chapter 2 Section 1/3.1.3.3.
3) A gale/emergency ballast condition is defined as a ballast condition with one or more cargo tanks filled with ballast.

Table 4.2.7: Locations for the Determination of Loads and Accelerations

	Strength assessment (1a)	*Strength assessment against hull girder shear loads (1b)*		
	Midship cargo region	*Forward cargo region*	*Midship cargo region*	*Aft cargo region*
Design load combinations S + D (Sea-going load cases)				
Dynamic wave pressure and green sea load	Transverse section at 0.5L from AP	Transverse section at 0.75L from AP	Transverse section at 0.5L from AP	Transverse section at 0.25L from AP

Acceleration av, at, alng	at CG position of midship tanks (i.e. 0.5L from AP is within the tank boundary)	at CG position of forward tanks (i.e. 0.75L from AP is within the tank boundary)	at CG position of midship tanks (i.e. 0.5L from AP is within the tank boundary)	at CG position of aft tanks (i.e. 0.25L from AP is within the tank boundary)
VWBM and SWBM (SWBM is to be based on sea-going permissible values, as defined in Chapter 2 Section 1/2.1.1 and 2.1.2)	at 0.5L from AP	at 0.75L from AP	at 0.5L from AP	at 0.25L from AP
HWBM	at 0.5L from AP	\	\	\
VWSF and SWSF (SWSF is to be based on sea-going permissible values, as defined in Chapter 2 Section 1/2.1.3 and 2.1.4)	at the transverse bulkhead with maximum combined seagoing permissible SWSF and VWSF in the region (see 1.1.1.5)	at the transverse bulkhead with maximum combined seagoing permissible SWSF and VWSF in the region (see 1.1.1.6) or at individual bulkhead position (see 1.1.1.8)	based on midship cargo tank strength assessment (see 1.1.1.7) or seagoing permissible SWSF and VWSF at individual transverse bulkhead position (see 1.1.1.8)	
Design load combination S (Harbour and tank testing load cases)				
SWBM (SWBM is to be based on harbour permissible values, as defined in Chapter 2 Section 1/2.1.1 and2.1.2)	at 0.5L from AP	at 0.75L from AP	at 0.5L from AP	at 0.25L from AP
SWSF (SWSF is to be based on harbour permissible values, as defined in Chapter 2 Section 1/2.1.3 and 2.1.4)	maximum harbour permissible SWSF in the region (see 1.1.1.5)	maximum harbour permissible SWSF in the region (see 1.1.1.6) or at individual bulkhead position (see 1.1.1.8)	based on midship cargo tank strength assessment (see 1.1.1.7) or harbour permissible SWSF at individual transverse bulkhead position (see 1.1.1.8)	

Note

1) The following assessments are to be carried out:
   a) for the assessment of scantlings of longitudinal hull girder structural members, primary supporting structural members and transverse bulkheads in tanks within midship cargo region, see 1.1.1.5
   b) for the assessment of strengthening of longitudinal hull girder shear structural members in way of individual transverse bulkheads for hull girder shear loads, see 1.1.1.6, 1.1.1.7 and 1.1.1.8.
2) For each FE load case, accelerations are to be calculated at the centre of gravity position of the ballast and/or cargo in accordance with this table. The acceleration calculated for each reference tank is to be applied to the 3 corresponding cargo or ballast tanks along the length of the FE model.
3) Longitudinal distances used in the calculation of loads refer to distance measured forward from the A.P., as defined in Chapter 1 Section 4/1.1.12
4) Dynamic wave pressure calculated at the specified section is to be applied to the full length of the FE model
5) Dynamic load combination factors applied to dynamic loads for design load combination S + D (sea-going load cases) as defined in Chapter 2 Section 1/6.4.
6) The SWBM and SWSF to be applied are to be in accordance with Tables 4.2.4 and 4.2.5.

2.4.2. Structural weight, cargo and ballast density

2.4.2.1. The design cargo density is to be taken as 1.025 tonnes/m^3, see 2.4.7.2.

2.4.2.2. The density of sea water is to be taken as 1.025 tonnes/m^3

2.4.2.3. The weight of the structure is to be included in the FE analysis. The density of steel is to be taken as 7.85 tonnes/m^3.

2.4.3. Static sea pressure

2.4.3.1. The static sea pressure applied to a plate element due to draught immersion is to be calculated in accordance with Chapter 2 Section 1/2.2.2.

2.4.3.2. The still water draught to be considered for each finite element load case is to be in accordance with Tables 4.2.4 and 4.2.5. A constant draught is to be applied over the full length of the cargo tank FE model.

2.4.3.3. The static sea pressure due to immersed draught for the ship in an upright condition is to be applied for all finite element load cases. The static sea pressure change due to rolling of the ship is included in the dynamic wave pressure formulation.

2.4.4. Dynamic wave pressure

2.4.4.1. The dynamic wave pressure distribution is to be determined at a transverse section of the hull at the longitudinal position as defined in Table 4.2.7. The dynamic wave pressure distribution is to be calculated in accordance with Chapter 2 Section 1/6.3.5. This pressure distribution is to be applied over the full length of the FE model.

2.4.4.2. The pressure distribution due to green sea load on the weather deck is to be calculated in accordance with Chapter 2 Section 1/6.3.6 at the longitudinal position as defined in Table 4.2.7. This pressure distribution is to be applied to the weather deck over the full length of the FE model.

2.4.5. Hull girder vertical bending moment and vertical shear force

2.4.5.1. The hull girder vertical bending moment is to reach the following required value, $M_{v\text{-}targ}$, at a section within the length of the middle tank of the three tanks FE model:

$$M_{v-trg} = M_{sw} + M_{wv}$$

where:

M_{wv} is the vertical wave bending moment

M_{sw} is the still water bending moment to be applied to the FE load case, as specified in Tables 4.2.4 and 4.2.5.

2.4.5.2. Hull girder vertical shear force is to reach the following required Q_{targ} value at the forward transverse bulkhead position of the middle tank:

$$Q_{targ} = Q_{sw} + Q_{wv}$$

Where:

Q_{wv} is the vertical wave shear force for the dynamic load case under consideration, calculated in accordance with Chapter 2 Section 1/6.3.4.

Q_{sw} is the vertical still water shear force to be applied to the FE load case, as specified in Tables 4.2.4 and 4.2.5.

2.4.5.3. The required hull girder vertical bending moment and shear force are to be accomplished in the same load case where required by Tables 4.2.4 and 4.2.5. The procedure to attain the required shear force and bending moment distributions is explained in 2.5.

2.4.6. Hull girder horizontal wave bending moment

2.4.6.1. 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 under consideration, calculated as per Chapter 2 Section 1/6.3.3.

2.4.6.2. The procedure to adjust the required hull girder horizontal bending moment is explained in 2.5.

2.4.7. Pressure in cargo and ballast tanks

2.4.7.1. The total tank pressure, P_{in}, to be applied at the boundary of a cargo or ballast tank in the finite element analysis is to include static and dynamic components given in Chapter 2 Section 1/Table 2.1.3 and Table 4.2.7.

2.4.7.2. For the seagoing load cases (design combination S + D) the cargo tank pressure is to be taken as:

$$P_{in} = f_{density}\left(P_{in-t} \; + P_{in-dyn}\right) kN/m^2$$

Where:

$f_{density}$ factor for joint probability of occurrence of cargo density and maximum sea state in 25 years design life

$= \rho_{maxLM} / \rho_{allowable}$

ρ_{maxLM}maximum cargo density associated with a full tank from any loading condition in the ship's loading manual.

$\rho_{maxLM}$is not to be taken as less than 0.9 tonnes/m^{3}for cargo loaded conditions and 1.025 tonnes/m^3 for the optional emergency ballast condition (i.e. A8 and B7 in Tables 4.2.4 and 4.2.5 respectively)

P_{in-tk} static tank pressure as given in Chapter 2 Section 1/2.2.3.1, in kN/m^2, and with density of fluid in tank equal to the design cargo density, $\rho_{allowable}$

$\rho_{allowable}$ design cargo density associated with a full tank to be taken as 1.025 tonnes/m^3 unless a higher density is specified by the builder, see Chapter 1 Section 2/3.1.8.1.

P_{in-dyn} simultaneously acting dynamic pressure given in Chapter 2 Section 1/6.3.7.1, in kN/m^2, with simplification given in 2.4.7.3 and with density of fluid in tank equal to the design cargo density, $\rho_{allowable}$

2.4.7.3. The envelope vertical acceleration, a_v, at the centre of gravity of tanks is calculated in accordance with Chapter 2 Section 1/3.3.3 with the following simplifications:

a. for head sea conditions, a_{roll-z} is taken as 0
b. for beam sea conditions, $a_{pitch-z}$ is taken as 0.

2.4.7.4. The vertical, transverse and longitudinal accelerations are to be calculated at the centre of gravity of the abreast tanks at the longitudinal position as specified in Table 4.2.7. These accelerations are to be applied to all corresponding tanks along length of the three-tank FE model.

2.4.7.5. The calculation of dynamic tank pressure is to be doneas per Chapter 2 Section 1/6.3.7.1, also see Table 4.2.7.

2.4.7.6. For ballast tanks which use ballast water exchange by flow-through method, following are tobe considered while calculating tank pressure for seagoing load cases (design combination S + D) as required by Chapter 2 Section 1/Table 2.1.3:

- Maximum vertical height of the air pipe or overflow pipe, i.e. hair as defined in Chapter 2 Section 1/2.2.3.2 and Figure 2.1.8, of all ballast tanks in the cargo region is to be used in the dynamic tank pressure calculation due to vertical acceleration (see Chapter 2 Section 1/6.3.7.1).
- Maximum value of hair and P_{drop}, as defined in Chapter 2 Section 1/2.2.3.3, of all ballast tanks in the cargo region are to be used for static tank pressure calculation.

2.4.7.7. Following are to be considered while calculating the static tank pressure in cargo tanks for harbour/tank testing load cases (design combination S) as required by Chapter 2 Section 1/Table 2.1.3:

- Maximum setting of pressure relief valve, P_{valve} as defined in Chapter 2 Section 1/2.2.3.5, of all cargo tanks and, where applicable, maximum hair, as defined in Chapter 2 Section 1/2.2.3.2 and Figure 2.1.8, of all cargo tanks in the cargo region are to be considered in the calculation of $P_{in-test}$, see Chapter 2 Section 1/2.2.3.5.

2.4.7.8. Where length of the model is extended beyond the end transverse bulkheads, see 2.2.1.1, tank pressure is to be applied to the complete tanks within the model length only.

2.5. Procedure to Adjust Hull Girder Shear Forces and Bending Moments

2.5.1. General

i) The procedure described in this section 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 values.

ii) Vertical distributed loads are applied to each frame position, together with a vertical bending moment applied to the model ends to produce the required value of vertical shear force at the forward bulkhead of the middle tank of the FE model, and the required value of vertical bending moment at a section within the length of the middle tank of the FE model. The required values are mentioned in 2.4.5.

iii) A horizontal bending moment is applied to the ends of the model to produce the required target valueof horizontal bending moment at a section within length of the middle tank of the FE model. The requiredvalues are mentioned in 2.4.6.

2.5.2. Shear force and bending moment due to local loads

i) The vertical shear forces produced 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 find out shear force and bending moment values.

ii) For beam and oblique sea conditions, horizontal bending moment distribution as a result of dynamic sea pressure and dynamic tank pressure is to be calculated along the length of the middle tank of the FE model.

iii) The following local loads are to be applied for the hull girder shear forces and bending moments calculations:

a. ship structural weight distribution over the length of the 3-tank model (static loads). Where a simple beam model is used, weight of the structure of each tank can be evenly dispersed over the length of cargo tank. The structural weight is to be calculated based on a thickness deduction of $0.5t_{corr}$, as used in the cargo tank FE model construction, see 2.2.1.5.
b. weight of cargo and ballast (static loads)
c. static sea pressure, dynamic wave pressure and, where applicable, green sea load. For the Design Load Combination S (harbour/tank testing load cases), only static sea pressure needs to be applieddynamic tank pressure load for Design Load Combination S+D (seagoing load cases).

2.5.3. Procedure to adjust vertical shear force distribution

i) The required adjustment in shear forces at the transverse bulkhead positions (ΔQaft and ΔQfwd as shown in Figure 4.2.11) are to be produced by applying vertical load at the frame positions as shown in Figure 4.2.12. 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 totalvertical correction loads applied is equal to zero.

ii) The required adjustment in shear forces at the aft and forward transverse bulkheads of the middle tank of the FE model to produce the required shear forces at the bulkheads are given by:

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

$$\Delta\, Q_{fwd} = Q_{targ} - Q_{fw}$$

Where:

ΔQ_{aft} required adjustment in shear force at aft bulkhead of middle tank

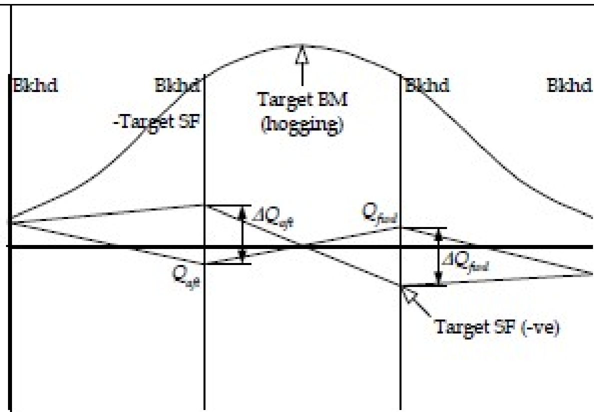
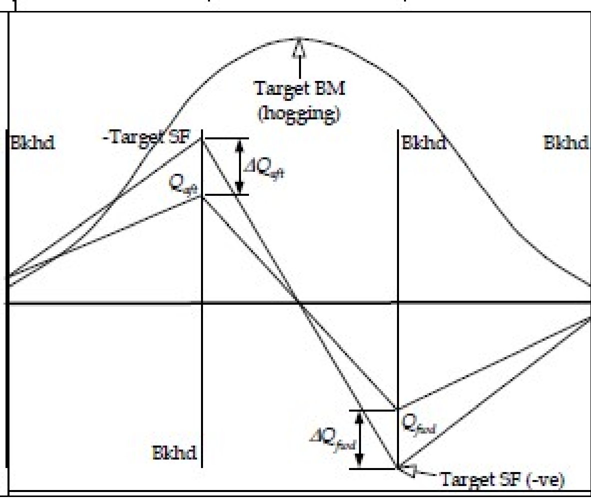
ΔQ_{fwd} required adjustment in shear force at fore bulkhead of the middle tank

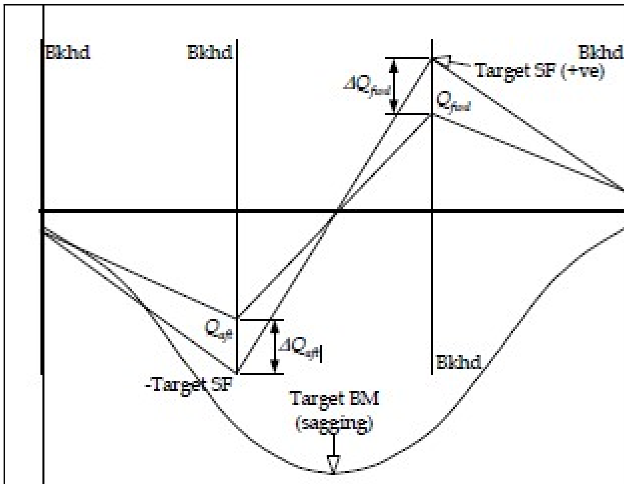
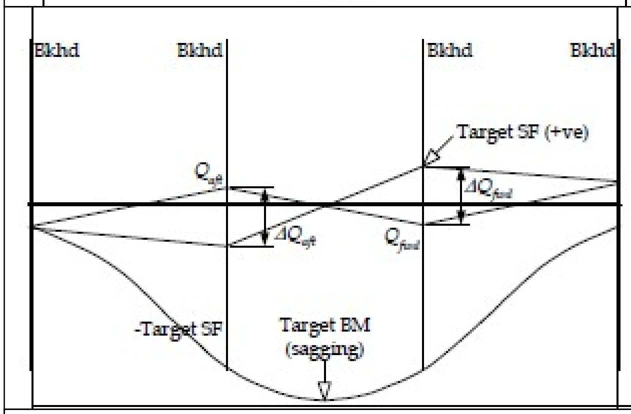
Q_{targ} required shear force value to be achieved at forward bulkhead of middle tank, see 2.4.5.

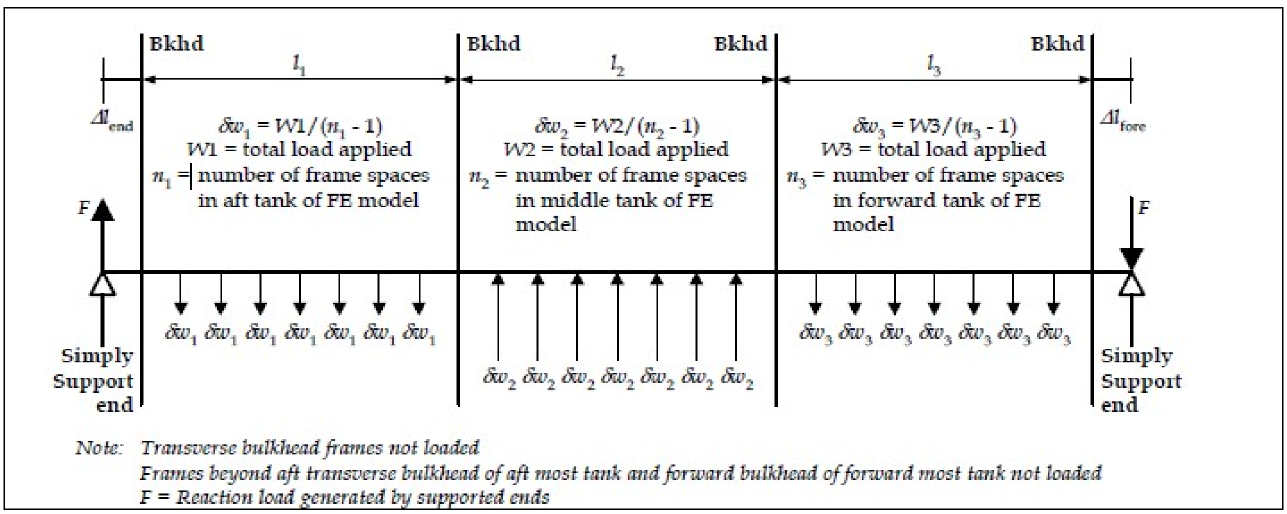
Q_{fwd} shear force due to local loads at fore bulkhead of middle tank, see 2.5.2

Q_{aft} shear force due to local loads at aft bulkhead of middle tank, see 2.5.2

Figure 4.2.11: Position of Target Shear Force and Required Shear Force Adjustment at Transverse Bulkhead Positions

<table>
<tr><th rowspan="2">Condition</th><th colspan="3">Target</th><th colspan="2">Aft Bkhd</th><th colspan="2">Fore Bkhd</th></tr>
<tr><th>BM</th><th>SF</th><th>Bhkd pos</th><th>SF</th><th>ΔQ_{aft}</th><th>SF</th><th>ΔQ_{fwd}</th></tr>
<tr><td>
</td><td>Hog</td><td>-ve</td><td>Fore</td><td>$-Q_{targ}$</td><td>$-Q_{targ} - Q_{aft}$</td><td>Q_{targ} (-ve)</td><td>$Q_{targ} - Q_{fwd}$</td></tr>
<tr><td>
</td><td>Hog</td><td>-ve</td><td>Fore</td><td>$-Q_{targ}$</td><td>$-Q_{targ} - Q_{aft}$</td><td>Q_{targ} (-ve)</td><td>$Q_{targ} - Q_{fwd}$</td></tr>
</table>

	*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 2.5.3.2.							



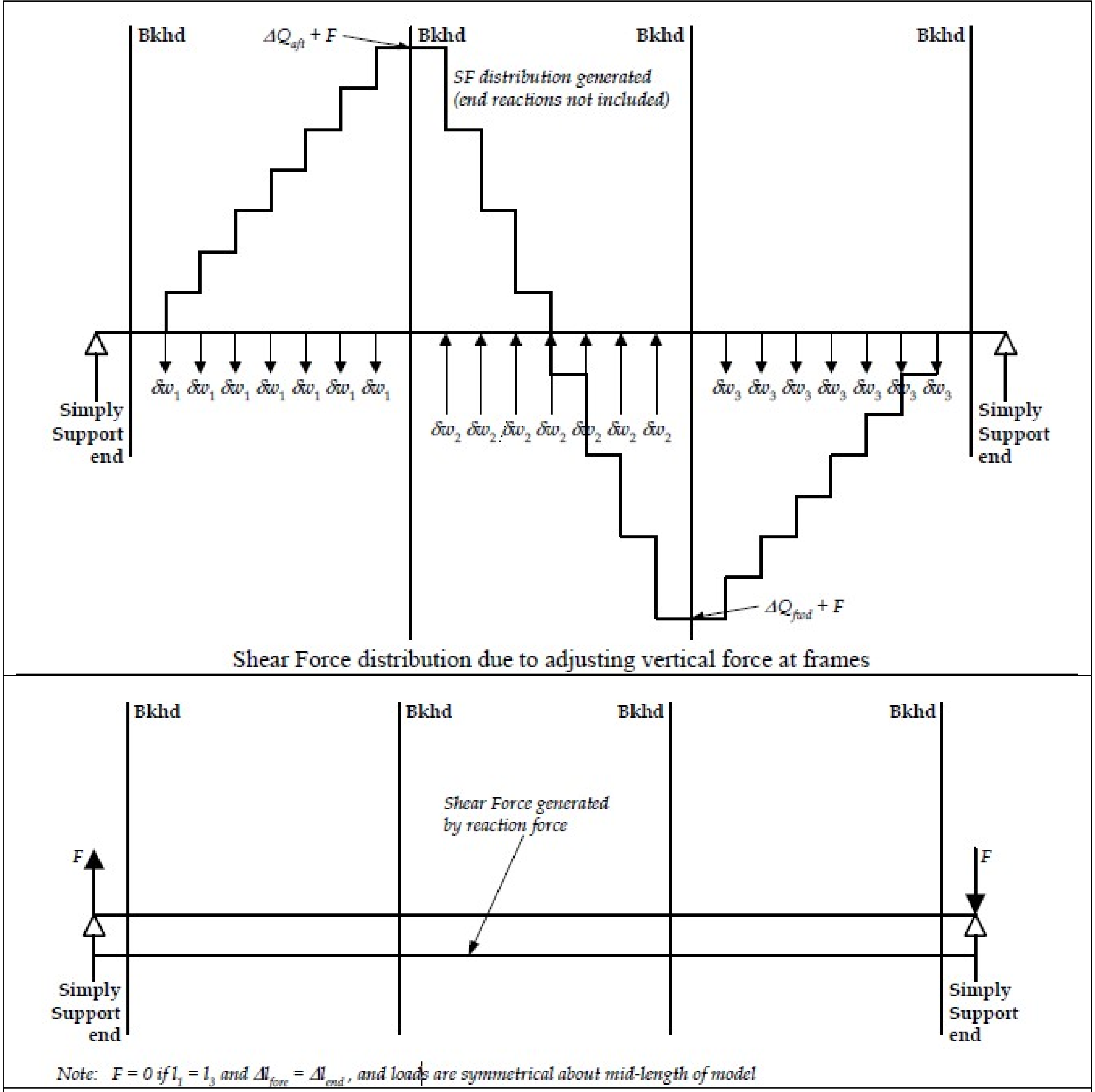


Figure 4.2.12: Distribution of Adjusting Vertical Force at Frames and Resulting Shear Force Distributions

iii) 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 a 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 Table 4.2.8. The length and frame spacing of individual cargo tanks may be different.

Table 4.2.8: Formulae for Calculation of Vertical Loads for Adjusting Vertical Shear Forces
$\delta w_1 = \frac{\Delta Q_{aft}(2l - l_2 - l_3) + \Delta Q_{fwd}(l_2 + l_3)}{(n_1 - 1)(2l - l_1 - 2l_2 - l_3)}$ $F = 0.5\left(\frac{W1(l_2 + l_1) - W3(l_2 + l_3)}{l}\right)$ $\delta w_2 = \frac{(W1 + W3)}{(n_2 - 1)} = \frac{(\Delta Q_{aft} - \Delta Q_{fwd})}{(n_2 - 1)}$ $\delta w_s = \frac{-\Delta Q_{fwd}(2l - l_1 - l_2) - \Delta Q_{aft}(l_1 + l_2)}{(n_s - 1)(2l - l_1 - 2l_2 - l_s)}$
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 Figure 4.2.11 ΔQ_{fwd} required adjustment in shear force at fore bulkhead of middle tank, see Figure 4.2.11 F end reactions due to application of vertical loads to frames, see 2.5.3
W1 total evenly distributed vertical load applied to aft tank of FE model, $(n_1 - 1)\delta w_1$
W2 total evenly distributed vertical load applied to middle tank of FE model, $(n_2 - 1)\delta w_2$
W3 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
δw_1 distributed load at frame in aft cargo tank of FE model δw_2 distributed load at frame in middle cargo tank of FE model δw_3 distributed load at frame in forward cargo tank of FE model
Δlend distance between end bulkhead of aft cargo tank to aft end of FE model Δlfore 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: $= l1 + l2 + l3 + \Delta lend + \Delta lfore$
Notes
1) Positive direction of loads, shear forces and adjusting vertical forces in the formulae is in accordance with Figures 4.2.11 and 4.2.12.
2) $W1 + W3 = W2$
3) Note that the above formulae are only applicable if an uniform frame spacing is used within each tank, see 2.5.3.3. The length and frame spacing of individual cargo tanks may be different.

iv) The amount of adjusting load to be applied to the structural parts of each transverse frame section to generate the vertical load, wi, is to be in accordance with Figure 4.2.13. 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:

$$F_{i-grid} = \frac{\sum_1^n 0.5A_{i-elem-net50}}{A_{s-net50}} F_s$$

Where:

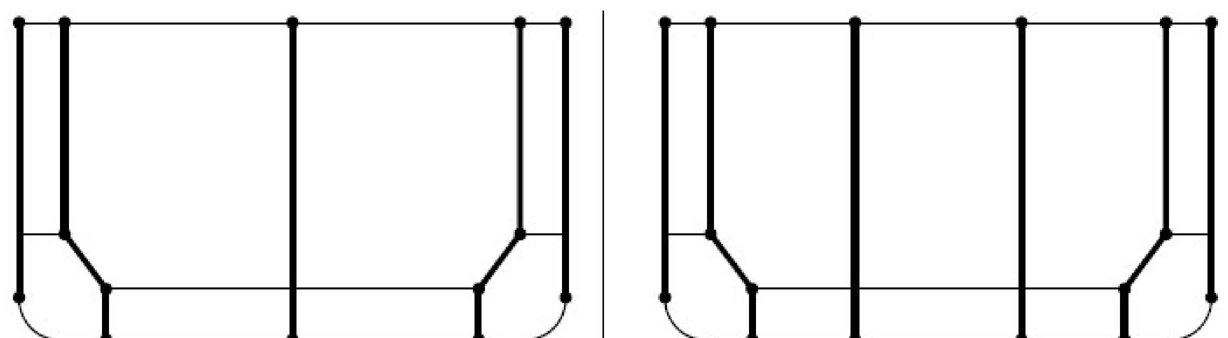
F_{i-grid} load to be applied to the i[th] FE grid point on the individual structural member under consideration, i.e. side shell, longitudinal bulkheads and bottom girders, inner hull longitudinal bulkheads, hopper plates, upper slope plates of inner hull and outboard girders as defined in Figure 4.2.13

$A_{i\text{-}elem\text{-}net50}$ sectional area of each plate element in the individual structural member under consideration (see Figure 4.2.13), 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 individual structural member under consideration, as specified in Figure 4.2.13

$A_{s\text{-}net50}$ 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 Figure 4.2.13.



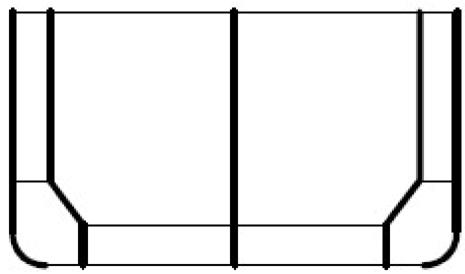
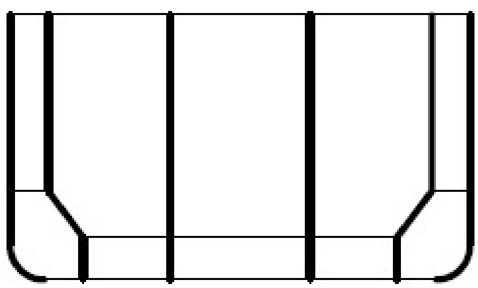
Structural member	Applied load Fs
Side Shell	$f.\delta w_i$
Longitudinal bulkhead including bottom girder beneath	$f.\delta w_i$
Inner hull longitudinal bulkhead (vertical part)	$f.\omega_i.\dfrac{A_{Ih-net50}}{A_{2-net50}}$
Hopper plate	$f.\omega_i.\dfrac{A_{Hp-net50}}{A_{2-net50}}$
Upper slope plating of inner hull	$f.\omega_i.\dfrac{A_{Usp-net50}}{A_{2-net50}}$
Outboard girder	$f.\omega_i.\dfrac{A_{Og-net50}}{A_{2-net50}}$

Where
δw_i, vertical load to be applied to each transverse frame section, see 2.5.3.3 and Table 4.2.8
f shear force distribution factor of structural part calculated at the mid-tank position in accordance with Table 4.2.9
$A_{Ih\text{-}net50}$ plate sectional area of individual inner hull longitudinal bulkhead
$A_{Hp\text{-}net50}$ plate sectional area of individual hopper plate
$A_{Usp\text{-}net50}$Plate sectional area of individual upper slope plate of inner hull
$A_{Og\text{-}net50}$ plate sectional area of individual outboard girder
$A_{2\text{-}net50}$ plate sectional area calculated in accordance with Table 4.2.9

Note
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.

Figure 4.2.13: Distribution of Adjusting Load on a Transverse Section

Table 4.2.9: Shear Force Distribution Factors

	Side Shell $f = 0.055 + 0.097\frac{A_{1-net50}}{A_{2-net}} + 0.020\frac{A_{2-net50}}{A_{3-net}}$ InnerHull $f = 0.193 - 0.059\frac{A_{1-net50}}{A_{2-net50}} + 0.058\frac{A_{2-net50}}{A_{3-net50}}$ CL longitudinal $f = 0.504 - 0.076\frac{A_{1-net50}}{A_{2-net50}} - 0.156\frac{A_{2-net50}}{A_{3-net50}}$ Bulkhead
	Side Shell $f = 0.028 + 0.087\frac{A_{1-net50}}{A_{2-net50}} + 0.023\frac{A_{2-net50}}{A_{3-net50}}$ Inner hull $f = 0.119 - 0.038\frac{A_{1-net50}}{A_{2-net}} + 0.072\frac{A_{2-net50}}{A_{3-net50}}$ Longitudinal bulkhead $f = 0.353 - 0.049\frac{A_{1-net}}{A_{2-net50}} - 0.095\frac{A_{2-net50}}{A_{3-net}}$
Where: $A_{1-net50}$ plate sectional area of individual side shell (i.e. on one side), including bilge $A_{2-net50}$ 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. $A_{3-net50}$ plate sectional area of individual longitudinal bulkhead, including double bottom girder in way	
Note	
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 modelled thickness of the cargo tank FE model, see 2.2.1.5.	
3) For corrugated longitudinal bulkheads, the corrugation thickness for the calculation of shear force distribution factor, f, is to be corrected according to Chapter 1 Section 4/2.6.4.	

2.5.4. Procedure to adjust vertical and horizontal bending moments

i) An additional vertical bending moment is to be applied at both ends of the cargo tank finite element model to produce the required vertical bending moment in the middle tank of the model. This end vertical bending moment can be calculated as given below:

$$M_{v-end} = M_{v-targ} - M_{v-peak}$$

Where:

M_{v-end} additional vertical bending moment to be applied at both ends of finite element model

M_{v-targ} required hogging (positive) or sagging (negative) vertical bending moment, as specified in 2.4.5

M_{v-peak} maximum or minimum bending moment within the length of the middle tank due to the local loads described in 2.5.2.3 and the additional vertical loads applied to generate the required shear force, see 2.5.3. Mv- peak is to be taken as the maximum bending moment if M_{v-targ} is hogging (positive) and as the minimum bending moment if M_{v-targ} is sagging (negative).

M_{v-peak} can be obtained from FE analysis. Alternatively, M_{v-peak} may be calculated as follows based on a simply supported beam model:

$$M_{v-pea} \;\; = Max\,\{M_0 + xF + M_{lineload}\}$$

M_o vertical bending moment at position x, due to the local loads described in 2.5.2.3.

$M_{lineload}$ vertical bending moment at position x, due to application of vertical line loads at frames to generate required shear force, see 2.5.3

F reaction force at ends due to application of vertical loads to frames, see 2.5.3

x longitudinal position of frame in way of the middle tank of FE model from end, see 2.5.4.2

ii) For beam and oblique sea load cases, additional horizontal bending moment is to be applied at ends of the cargo tank FE model to produce 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 given below:

$$M_{h-end} = M_{h-tar} \;\; - \; M_{h-peak}$$

Where:

M_{h-end} additional horizontal bending moment to be applied to ends of FE model

M_{h-targ} required positive or negative horizontal bending moment, see 2.4.6

M_{h-peak} maximum or minimum horizontal bending moment within the length of the middle tank due to the local loads described in 2.5.2.3. M_{h-peak} is to be taken as the maximum horizontal bending moment if M_{h-targ} is positive (starboard side in tension) and as the minimum horizontal bending moment if M_{h-targ} is negative (port side in tension).

iii) The vertical and horizontal bending moments should be calculated over the length of the middle tankof the FE model to identify the value and position of each maximum/minimum bending moment as specifiedin 2.5.4.1 and 2.5.4.2.

iv) The additional vertical bending moment, M_{v-end}, and horizontal bending moment, M_{h-end}, are to be applied to both ends of the cargo tank model. The bending moments may be applied by either of the methods described in 2.5.4.5 and 2.5.4.6.

v) The vertical and horizontal bending moments may be applied at the model ends by dispersing axial nodal forces to all longitudinal elements as per the simple beam theory as given below:

$$(F_x)_i = \frac{M_{v-end}}{I_{y-net50}} \frac{A_{i-net}}{n_i} z_i \text{ for vertical bending moment}$$

$$(F_x)_i = \frac{M_{h-end}}{I_{z-net}} \frac{A_{i-net}}{n_i} y_i \text{for horizontal bending moment}$$

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

$I_{z\text{-}net50}$ hull girder horizontal moment of inertial of the end section about its vertical neutral axis (normally centreline)

$I_{y\text{-}net50}$ hull girder vertical moment of inertial of the end section about its horizontal neutral axis

y_i horizontal distance from the neutral axis to the centre of the cross sectional area of the i^{th} element

z_i vertical distance from the neutral axis to the centre of the cross sectional area of the i^{th} element

$A_{i\text{-}net50}$ cross sectional area of the i^{th} element

n_i = 2 for 4-node plate element

n_i number of nodal points of i^{th} element on the cross section,

vi) The vertical and horizontal bending moments may alternatively be applied to an independent grid point at the intersection of the vertical neutral axis (normally centreline) and the horizontal neutral axis, see Figure 4.2.14. All nodal points of the longitudinal elements on the end section are to be rigidly linked to the independent point in θ_y (for vertical bending), θ_z (for horizontal bending) and δ_x. This independent point is not to be connected to the model except by the rigid link. The rigid links are to maintain the end plane of the model in keeping plane under the action of the applied bending moment, which is equivalent to imposing a prescribed displacement to the nodal points in accordance with the simple beam theory.

2.6. Boundary Conditions

2.6.1. General

i) All boundary conditions described in this section are as per the global co-ordinate systemdefined in Chapter 1 Section 4/1.4. The boundary conditions to be applied at the ends of the cargo tank FE model are given in Table 4.2.10. The analysis may be executed by applying all loads to the model as a complete load case or by combining the stress responses resulting from several separate sub-cases.

ii) 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 inner bottom and bottom shell and grid points along deck, as shown in Figure 4.2.14.

iii) 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 Figure 4.2.14.

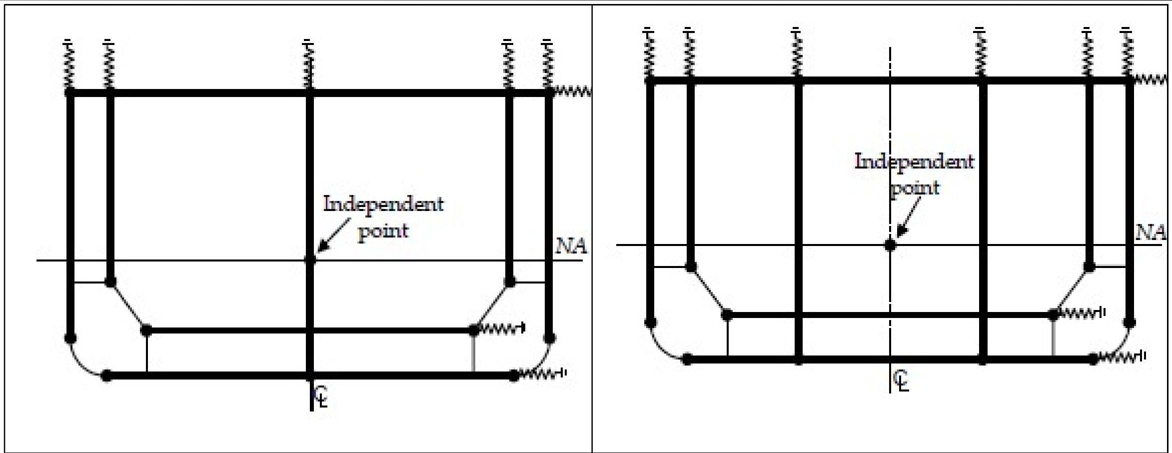


Figure 4.2.14: Spring Constraints at Model Ends

Table 4.2.10: 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 Figure 4.2.14	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 Figure 4.2.14	-	-	-	-	$M_{v\text{-}end}$	$M_{h\text{-}end}$
Deck, inner bottom and outer shell	-	Springs	-	-	-	-
Side, inner skin and longitudinal bulkheads	-	-	Springs	-	-	-

Note
1) All translation and rotation displacements are in accordance with the global coordinate system defined in Chapter 1 Section 4/1.4.
2) Where $M_{h\text{-}end}$ is not applied, the independent points at the fore and aft ends are to be free in θz.
3) Where Mv-end is not applied, the independent points at the fore and aft ends are to be free in θy.
4) Where no bending moment is applied, the independent points at the fore and aft ends are to be free in θy and θz.
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. θy and/or θz).

2.6.2. Calculation of spring stiffness

i) The stiffness, c, of individual spring elements for each structural member, to be applied at each end of the cargo tank model, is given by following formulae:

$$c = \left(\frac{E}{1+v}\right)\frac{A_{s-net}}{l_{tk}n} = 0.77\frac{A_{s-net50}E}{l_{tk}n}\ N/mm$$

Where:

$A_{s-net50}$ is to be calculated based on the thickness of the cargo tank finite element model for areas as indicated in Table 4.2.11 for the appropriate structural member under consideration, in mm^2

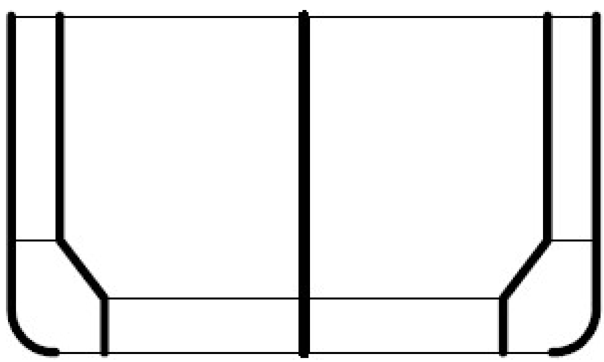
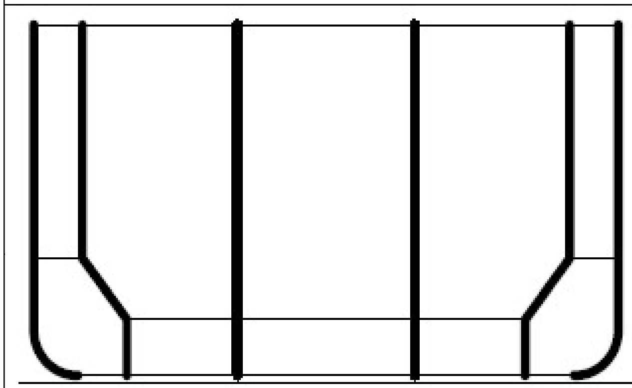
$A_{s-net50}$ shearing area of the individual structural member under consideration, i.e. plating of deck, inner bottom, bottom shell, side shell, inner hull longitudinal bulkheads or oil-tight longitudinal bulkhead.

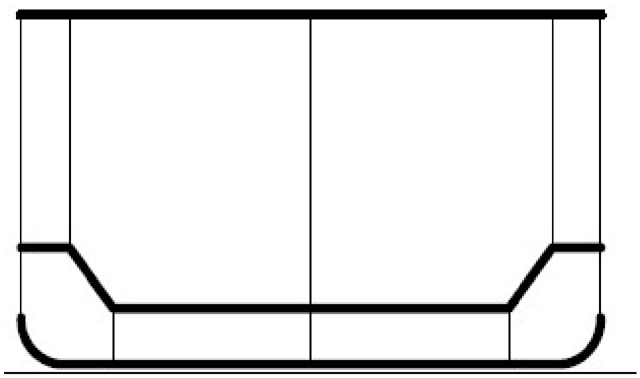
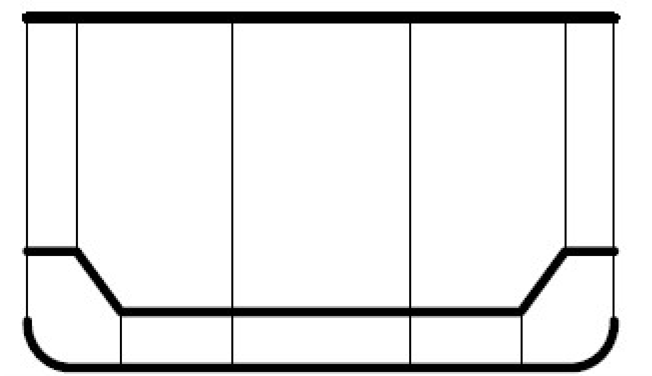
v Poisson's ratio of the material

l_{tk} length of cargo tank, between bulkheads of the middle tank of the FE model, in mm^2

E Modulus of Elasticity, in N/mm^2

n number of nodal points to which the spring elements are applied to the structural member under consideration

<table>
<tr><th colspan="3">Table 4.2.11: Shear Areas to be Considered for the Calculation of Spring Stiffness
Vertical springs</th></tr>
<tr><td rowspan="2"></td><td>Side</td><td>Area of side shell plating, including bilge</td></tr>
<tr><td>Inner hull longitudinal bulkheads</td><td>Area of inner skin plating, including hopper slope plate and double bottom side girder in way</td></tr>
<tr><td rowspan="2"></td><td>Longitudinal bulkheads</td><td>Area of longitudinal bulkhead plating, including double bottom girder in way</td></tr>
<tr><td colspan="2">Note
Where part of the structural member is not vertical, the area is to be calculated using the projected area in the vertical direction.</td></tr>
<tr><td colspan="3">Horizontal springs</td></tr>
</table>

 	Deck Inner bottom Bottom shell	Area of deck plating Area of inner bottom plating, including hopper slope plate and horizontal stringer in way 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.

ii) For vertical corrugated longitudinal bulkheads, corrugation thickness for the calculation of spring stiffness, c, shall be calculated as per Chapter 1 Section 4/2.6.4.

iii) Alternatively, rod elements may be used in lieu of spring elements, the equivalent cross-section area of the rod is (cl)/E, where l is the length of the rod. One end of the rod is to be constrained in all 6 degrees of freedom.

2.7. Result Evaluation

2.7.1. General

2.7.1.1. Result verification against acceptance criteria is to be executed for structural members within longitudinal extent as shown in Figure 4.2.15, which includes middle tanks of the three cargo tanks FE model and the region forward and aft of the middle tanks up to the extent of the transverse bulkhead stringer and buttress structure. For the strength assessment of tanks in the midship cargo region, stress level and buckling capability of longitudinal hull girder structural members, primary supporting structural members and transverse bulkheads are to be verified. For assessment of the required strengthening in way of transverse bulkheads against hull girder shear load, stress level and buckling capability of inner hull longitudinal bulkheads including upper sloped plate where fitted, side shell, hopper, bottom girders and longitudinal bulkheads are to be verified.

2.7.1.2. Assessment of results is to be executed for the standard load cases specified in 2.3.1, and any other load cases specially considered as required by Chapter 2 Section 3/2.2.3.

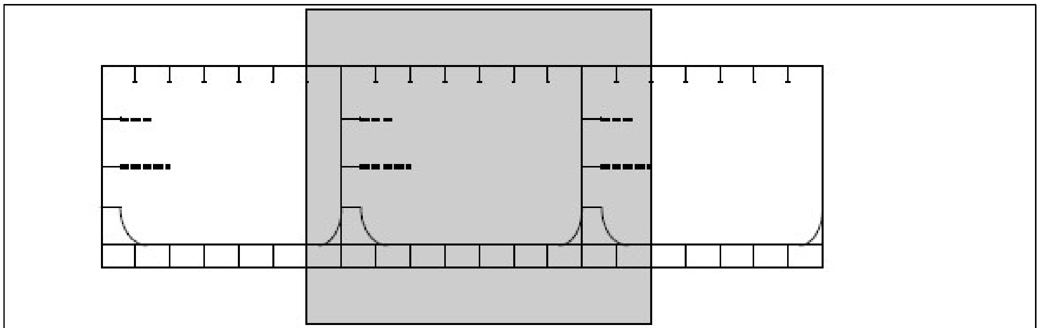


Figure 4.2.15: Extent of FE Model for Verification against Acceptance Criteria

2.7.2. Stress assessment

2.7.2.1. Stresses are not to exceed the permissible values mentioned in Chapter 2 Section 3/2.2.5.

2.7.2.2. The maximum permissible stresses are based on the element types and mesh sizes described in 2.2.

2.7.2.3. The von Mises stress, σ_{vm}, is to be calculated based on membrane direct and shear stresses of the plate element. Where shell elements are used, stresses are to be evaluated at the mid plane of the element. Where plate elements are used, stresses are to be evaluated at the element centroid.

2.7.2.4. Except as in 2.7.2.5, the element shear stress in way of openings in webs is to be corrected for loss in shear area as per the following formula. The corrected element shear stress is to be used to calculate the von Mises stress of the element for verification against the acceptance criteria.

$$\tau_{corr} = \frac{h\, t_{mod-net50}}{A_{s-net}} \tau_{elem}$$

Where:

τ_{cor} corrected element shear stress

h height of web of girder in way of opening, see Figure 4.2.9. Where the geometry of the opening is modelled, h is to be taken as the net height with the height of the modelled opening deducted.

$t_{mod-net50}$ modelled web thickness in way of opening, see Table 4.2.3.

$A_{s-net50}$ actual effective shear area of web, including area lost due to slots for stiffeners, calculated as per Chapter 1 Section 4/2.5. The thickness of the web is to be based on net thickness attainedby deducting $0.5t_{corr}$ from the gross thickness

τ_{elem} element shear stress prior to correction

2.7.2.5. Correction of element shear stress due to presence of openings is not required provided that:

a. all slots for local support stiffeners are fitted with lugs or collar plates;
b. difference between the modelled shear area of the plate and the actual effective shear area, $A_{s-net50}$ calculated as per Chapter 1 Section 4/2.5.1, is less than 20% of the modelled shear area, and
c. the yield utilisation factor is less than 80% of the permissible yield utilisation factor given in Chapter 2 Section 3/Table 2.3.2.

2.7.2.6. Where the corrugation is not modelled with its exact geometric shape, corrected axial stress in the flange of the corrugation, σ_{fl-act}, is to be taken as the greater of:

$$\sigma_{fl-act} = \sigma_{fl\quad FEM} \frac{Z_{corr-FEM-net50}}{Z_{corr-act-net50}} \frac{l_{corr-act}}{l_{corr-FEM}}$$

$$\sigma_{fl-act} = \sigma_{fl-F}$$

Where:

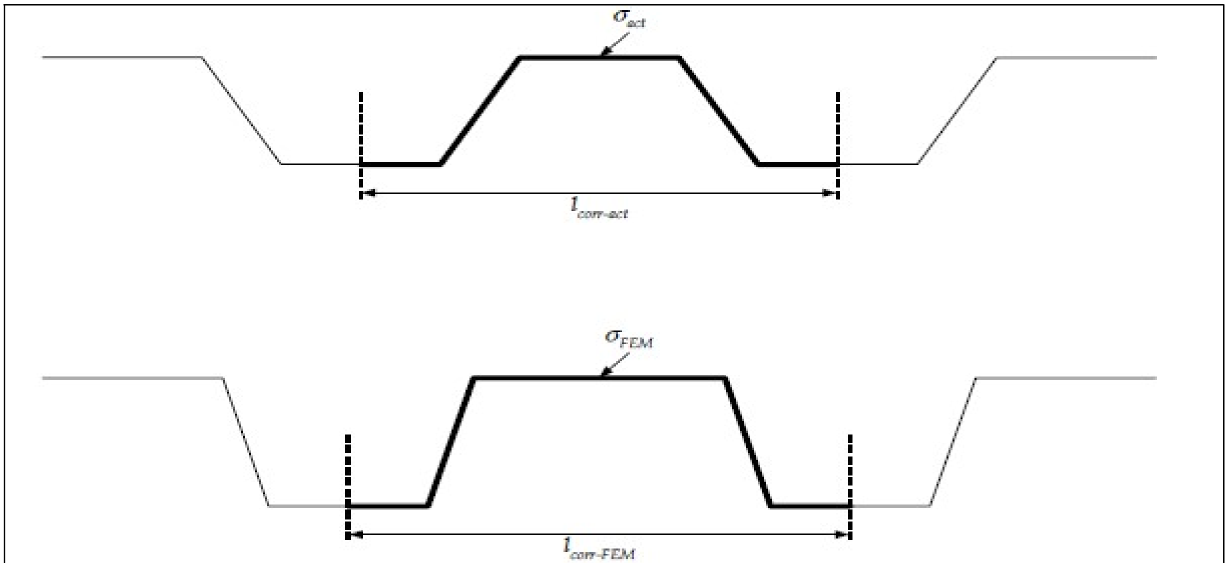
σ_{fl-FEM} axial stress obtained from the finite element analysis, see Figure 4.2.16

$Z_{corr-act-net50}$ is the section modulus of the actual corrugation calculated in accordance with Figure 4.2.16

$Z_{corr-FEM-net50}$ is the section modulus of the modelled corrugation calculated as per Figure 4.2.16

$l_{corr-act}$ length of corrugation section, as shown in Figure 4.2.16

$l_{corr-FEM}$ length of corrugation section, as shown in Figure 4.2.16



Note

$l$corr-act = length of corrugation section, for the calculation of Zcorr-act-net50

$l$corr-FEM = length of corrugation section, for the calculation of Zcorr-FEM-net50

Figure 4.2.16: Axial Bending Stress in Flange Corrugation

2.7.3. Buckling assessment

2.7.3.1. Buckling capability is to be assessed for the plating and stiffened panels of longitudinal hull girder structural members, primary support members and transverse bulkheads, including deck, double side, side, bottom, double bottom, hopper, transverse and vertical web frames, stringers, transverse and longitudinal bulkhead structures. Buckling capability of curved panels (e.g. bilge), face plate of primary support members and tripping brackets is not assessed on basis of stress resultsattained by finite element analysis.

2.7.3.2. The utilisation factor against buckling for all plates and stiffened panels is not to exceed the permissible values specified in Chapter 2 Section 3/2.2.5. The buckling assessment methods used for plates and stiffened panels is described in Chapter 4 Section 4/5.

2.7.3.3. The buckling assessment is to be based on the stresses derived from the finite element analysis in conjunction with buckling capacity model based on net thickness attained by deducting the full corrosion addition, t_{corr}, and any Owner's extras from the proposed thickness. This thickness deduction is applicable to all plating, stiffener webs and face plates.

2.7.3.4. The buckling assessment is to be based on membrane stress evaluated at the centroid of the plate elements. Where shell elements are used, for buckling assessment, stresses at the mid-plane of the element are to be used.

2.7.3.5. In buckling calculation, combined interaction of bi-axial compressive stresses, shear stress and lateral pressure loads are to be considered. The buckling assessment is to be based on the corrected stresses. where a stress correction is to be applied to the finite element stresses as required by 2.7.2.

2.7.3.6. Where there is a cross-tie arrangement in tankers, pillar buckling capability of the cross tie structure is to be assessed based on the buckling formulae given in Chapter 2 Section 4/3.5.1. The average axial compressive stress at the mid span of the cross tie in ship's transverse direction, weighted by cross section area, is to be used for buckling assessment.

2.7.3.7. Where a suitable advanced buckling assessment method is not available as described in Chapter 4 Section 4/5 for the modeling of bulkhead corrugation, assessment of local buckling of unit corrugation flanges is to be as specified in Chapter 2 Section 4/3.5.2 and criteria mentioned in Chapter 2 Section 3/2.2.5. The assessment is to be based only on uni-axial stress (membrane stress evaluated at element centroid) parallel to the corrugation knuckles. Averaged stress between elements is not to be used. For the part of the corrugated plate flange from the lower bulkhead stool top to a level of s/2 above, where s is the breadth of the flange, the stress used for the buckling assessment needs not be taken as greater than the value attained at s/2 above the bulkhead stool top. The stress value at s/2 may be attained by interpolation, if the stress value cannot be directly obtained from a plate element.

2.7.3.8. Where a suitable advanced buckling assessment method is not available, as described in Chapter 2 Section 4/5 for the modelling of panel with opening, local buckling of web plates of primary support members in way of openings is to be assessed as specified in Chapter 2 Section 4/3.4 based on acceptance criteria on buckling utilisation factor mentioned in Chapter 2 Section 3/2.2.5. The assessment is to be based on FE membrane stress evaluated at the centroid of plate elements. Stresses in the area of the web required for buckling assessment are to be attained as averaged stresses of the plate elements within the required area. Stress attained from either the cargo tank analysis or local fine mesh analysis may be used for the assessment. Where the effect of opening is not taken into account in the cargo tank analysis, stresses attained from the finite element analysis are to be corrected as per 2.7.2.4 and 2.7.2.5.

3. Local Fine Mesh Structural Strength Analysis

3.1. General

3.1.1. Application

3.1.1.1. For tankers of conventional arrangements, finite element fine mesh analysis of structural details is to be in accordance with the requirements given in this section.

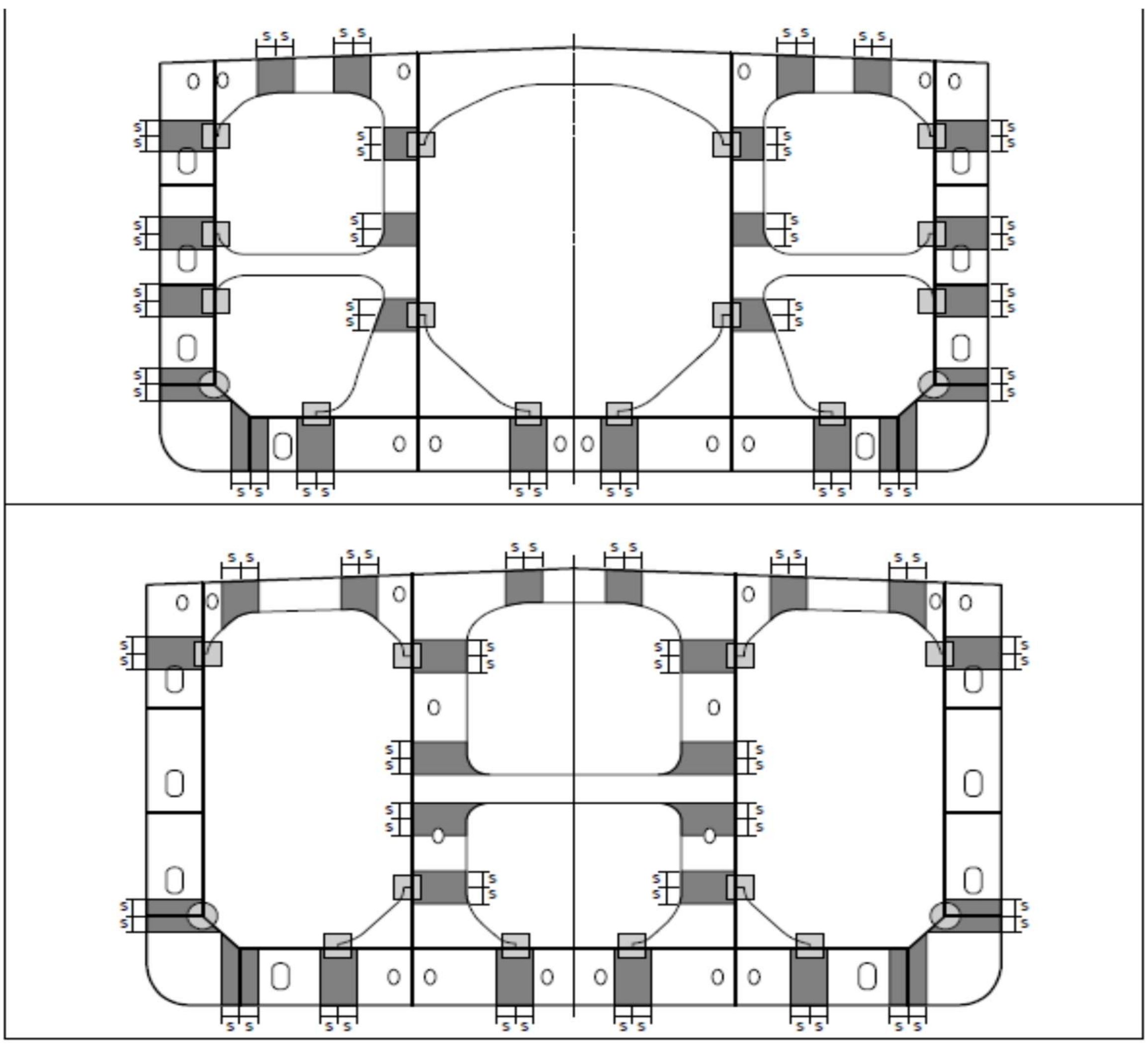
3.1.1.2. Additional requirements of fine mesh analysis are to be in accordance with Chapter 2 Section 3/2.3.1.3 and Chapter 2 Section 4/2.3.1.4.

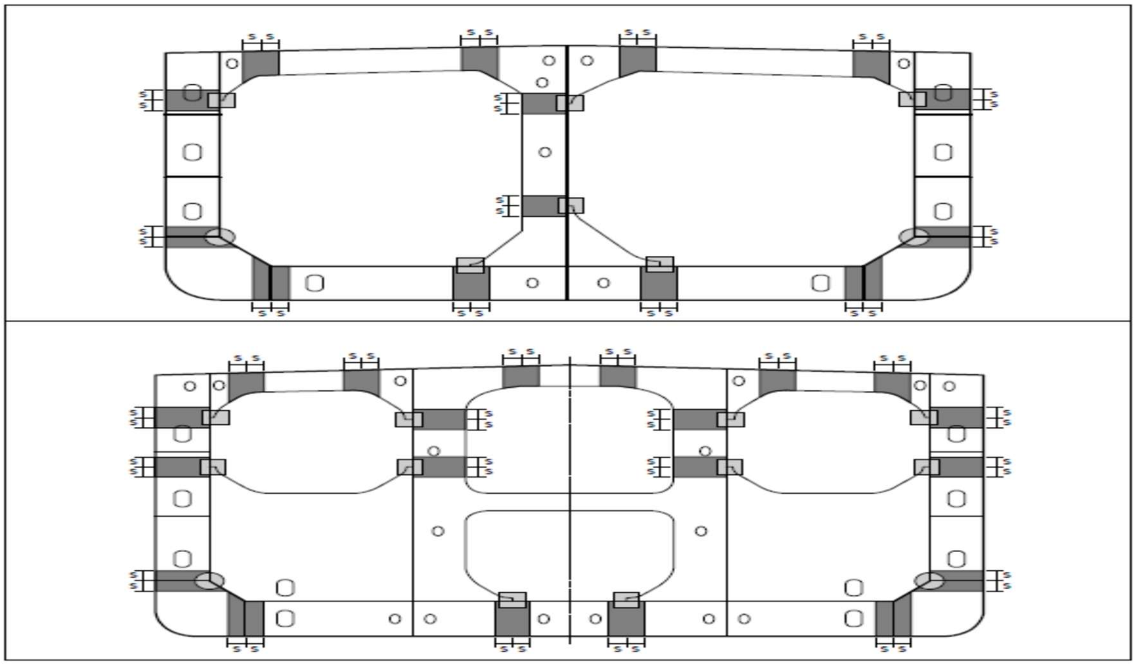
3.1.2. Transverse web frame and wash bulkhead

3.1.2.1. Upper hopper knuckle connections as indicated in Figure 4.2.17 are to be evaluated by fine mesh analysis on a typical transverse web frame in the middle tank of the cargo tank model. Main bracket toes and openings as indicated in Figure B.3.1 are to be evaluated by fine mesh analysis if the screening criteria given in 3.1.6 are not complied with.

3.1.2.2. Where a wash bulkhead is fitted, main bracket toes and openings of the transverse and vertical webs as indicated in Figure 4.2.17 are to be evaluated by fine mesh analysis if the screening criteria given in 3.1.6 are not complied with.

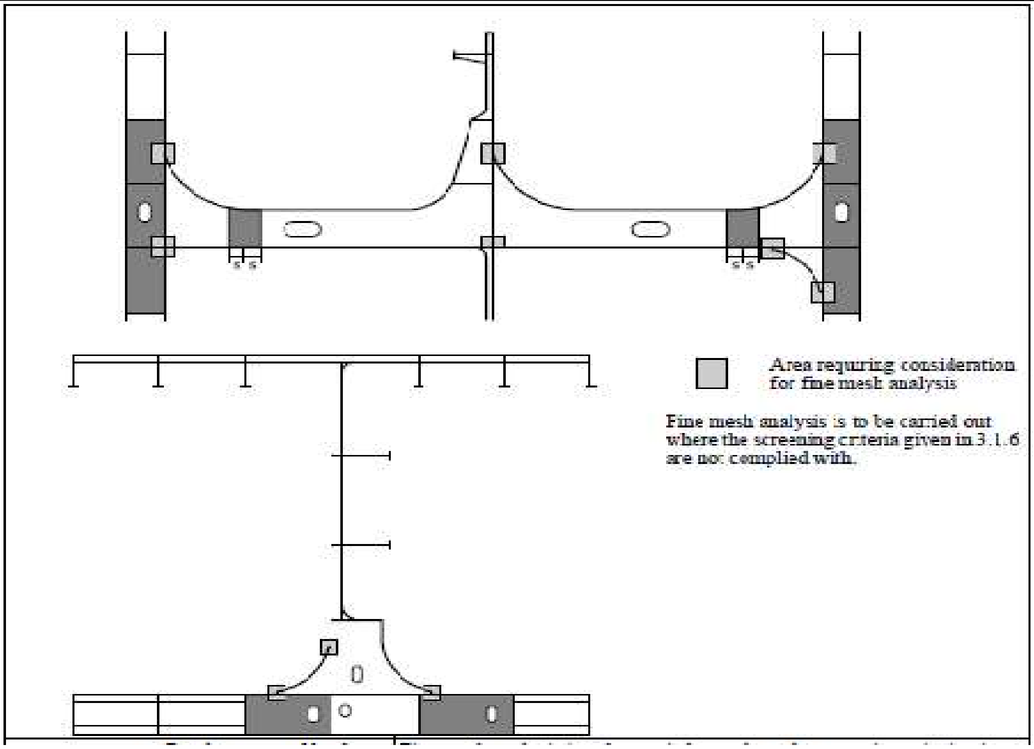
3.1.2.3. The web frame which indicates highest von Mises stresses in way of each structural detail from the cargo tank analysis is to be selected for the fine mesh analysis.





Upper hopper knuckle	Fine mesh analysis of upper hopper knuckle is required for cargo tank typical web frame, see 3.1.2. Fine mesh analysis is not required for upper hopper knuckles on web frame adjacent to transverse bulkhead.
Bracket toes	Fine mesh analysis is to be carried out where the screening criteria given in 3.1.6 are not complied with
Openings (shaded regions)	Fine mesh analysis is to be carried out for all openings in shaded regions where the screening criteria given in 3.1.6 are not complied with
Openings (un-shaded regions)	Fine mesh analysis or evaluation based on screening criteria given in 3.1.6 is not required for openings in un-shaded regions if: • $h_o/h < 0.35$ and $g_o < 1.2$, and, • each end of the opening forms a semi circle arc (i.e. radius of opening equal to b/2). where h_o, h and g_o are defined in Table B.2.2 and b is the smallest of the length and breadth of the opening. Other openings in the un-shaded regions are subjected to fine mesh analysis where the screening criteria given in 3.1.6 are not complied with.

Figure 4.2.17 Areas Requiring Consideration for Fine Mesh Analysis on a Typical Transverse Web Frame, Wash Bulkhead and Web Frame adjacent to Transverse Bulkhead



Bracket toes and heels	Fine mesh analysis is to be carried out where the screening criteria given in 3.1.6 are not complied with
Openings (shaded regions	Fine mesh analysis is to be carried out for all openings in shaded regions where the screening criteria given in 3.1.6 are not complied with
Openings (un-shaded regions)	Fine mesh analysis or evaluation based on screening criteria given in 3.1.6 is not required for openings in un-shaded regions if: • ho/h < 0.35 and go < 1.2, and, • Each end of the opening forms a semi circle arc (i.e. radius of opening equal to b/2). Where ho, h and go are defined in Table B.2.22 and b is the smallest of the length and breadth of the opening. Other openings in the un-shaded Regions are subjected to fine mesh analysis where the screening criteria given in 3.1.6 are not complied with.

Figure 4.2.18 Areas Requiring Consideration for Fine Mesh Analysis on Horizontal Stringer and Transverse Bulkhead to Double Bottom Connections

3.1.3. Transverse bulkhead stringers, buttress and adjacent web frame

3.1.3.1. Fine mesh analysis is to be carried out for the following locations where the screening criteria given in 3.1.6 are not complied with:

a. main bracket toes, heels and openings on horizontal stringers of a transverse bulkhead specified in Figure 4.3.18. The stringers of the forward and aft transverse bulkheads of the middle tank of the FE model which indicate highest von Mises stresses in way of the structural details from the cargo tank analysis is to be selected for the fine mesh analysis.
b. main bracket toes and openings on transverse bulkhead to double bottom connection or buttress structure specified in Figure 4.2.18. The double bottom connection/buttress structure in way of the forward and aft transverse bulkheads of the middle tank of the FE model which indicates highest von Mises stresses in way of the structural details from the cargo tank analysis is to be selected for the fine mesh analysis.
c. main bracket toes and openings specified in Figure 4.2.17 on a web frame adjacent to the transverse bulkhead. Both web frames in way of the horizontal stringers of the forward and aft transverse bulkheads of the middle tank of the cargo tank FE model are to be considered. The web frame which indicates highest von Mises stresses in way of the structural details from the cargo tank analysis is to be selected for the fine mesh analysis.

3.1.3.2. Where the stress level at the heel connection of the transverse bulkhead horizontal stringer to the side horizontal girder exceeds the permissible criteria, it is recommended that a backing bracket be fitted in accordance with Chapter 4 Section 3/2.5 to reduce the stresses.

3.1.4. Deck, double bottom longitudinal and adjoining transverse bulkhead vertical stiffeners

3.1.4.1. End connections and attached web stiffeners of the following structural members are to be assessed:

a. at least one pair of inner and outer bottom longitudinal stiffeners and adjoining vertical stiffener of transverse bulkhead
b. at least one longitudinal stiffener on deck and adjoining vertical stiffener of transverse bulkhead

3.1.4.2. The selection of the longitudinal and vertical stiffeners to be analysed is to be based on the maximum relative deflection between supports, e.g. between floor and transverse bulkhead. Where there is a significant variation in end connection arrangement and scantlings between stiffeners, analysis of additional stiffeners may be required. Figure 4.2.19 shows the areas that require fine mesh analysis in way of deck, inner bottom and bottom longitudinal and transverse bulkhead vertical stiffeners.

3.1.5. Corrugated bulkheads

3.1.5.1. Where no shedder plate or shedder plate without a gusset plate is fitted to a corrugated transverse orlongitudinal corrugated bulkhead, connection of corrugation and below supporting structure to lower stool shelf plate, as shown in Figure 4.2.20, is to be evaluated by fine mesh analysis. Where no lower stool is fitted, connection of corrugation and below supporting structure to inner bottom plate is to be evaluated by fine mesh analysis.

3.1.5.2. Where shedder plate with a gusset plate is fitted to a corrugated transverse or longitudinal corrugated bulkhead, connection of the corrugation at the upper corner of the gusset plate is to be evaluated by fine mesh analysis.

3.1.5.3. The selection of the location of the corrugation unit for fine mesh analysis is to be based on the stress result from the cargo tank analysis. The location with the highest von Mises stress in way of the corrugation connection is to be selected for the analysis.

3.1.5.4. Where transverse and longitudinal corrugated bulkheads are of different arrangements or scantlings, the fine mesh analysis is to be carried out for both bulkheads.

3.1.5.5. Where the stress level at the connection of corrugation to the lower stool exceeds the permissible criteria, it is recommended that shedder plate and gusset plate be fitted in accordance with Chapter 4 Section 3/2.5 to reduce the stresses. See Chapter 2 Section 2/2.5.7.9 for required arrangement of supporting structure for corrugated bulkhead without a lower stool.

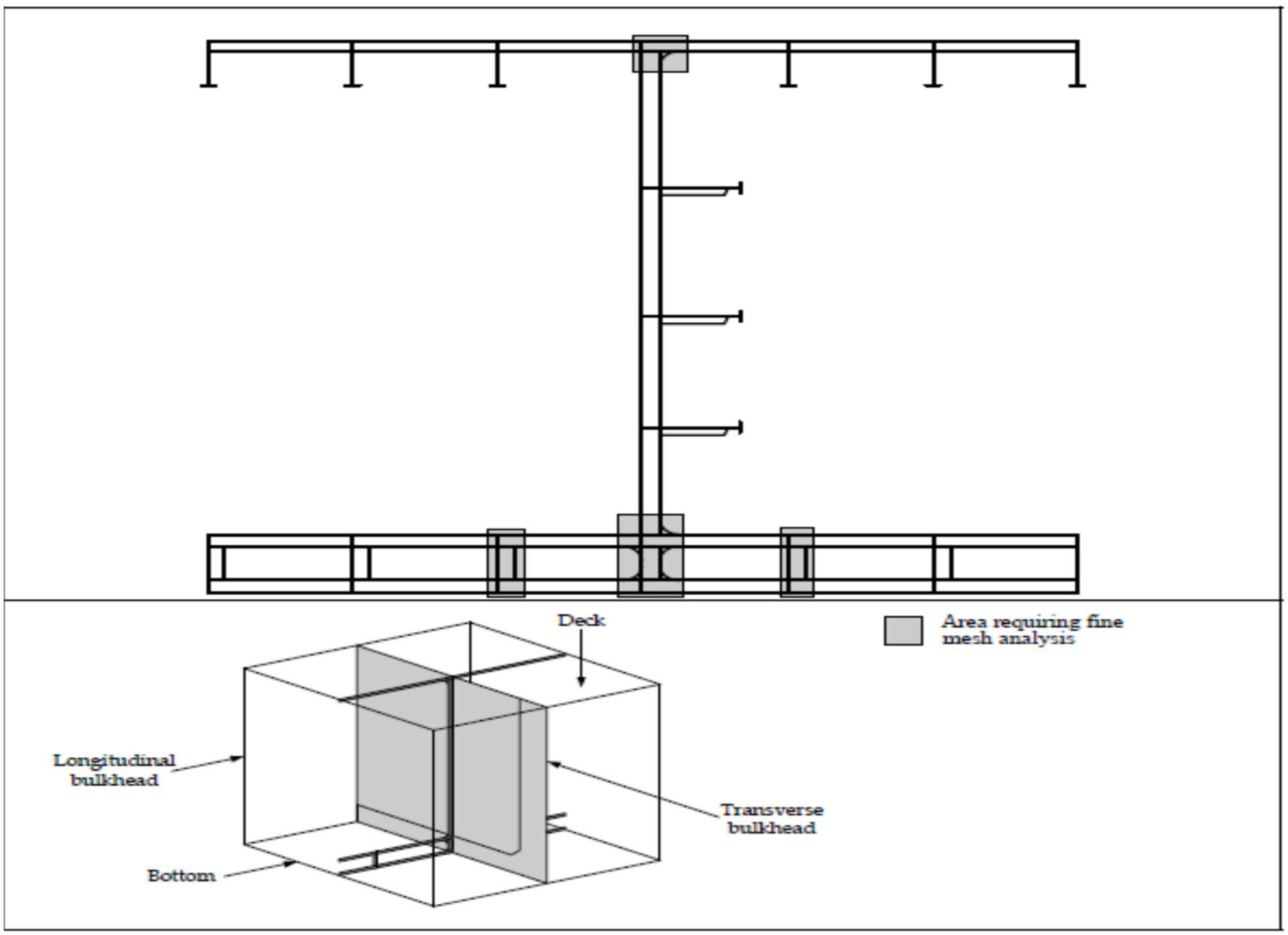
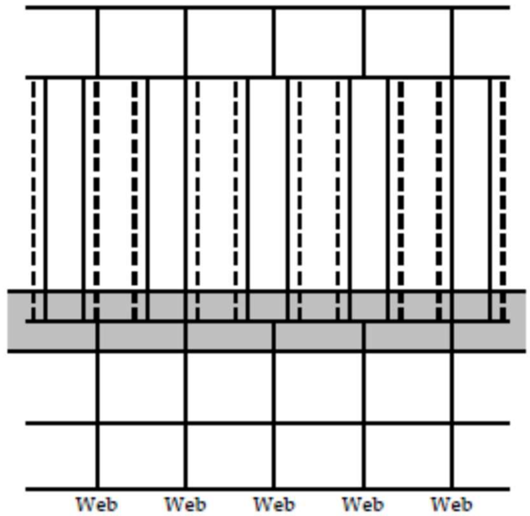


Figure 4.2.19 Areas Requiring Fine Mesh Analysis on Deck, Inner and Outer Bottom Longitudinals



Note : Exact location of corrugation unit to be examined using fine mesh analysis is to be selected based on stress result from cargo tank analysis

Figure 4.2.20 Areas Requiring Fine Mesh Analysis at Connections of Corrugated Bulkhead to Bottom Stool

3.1.6. Screening criteria for Fine Mesh Analysis

3.1.6.1. The criteria given in this section are intended to identify areas that require to be investigated by meansof fine mesh finite element analysis. These criteria apply to openings, bracket toes and heels of transverse web frames, vertical and transverse webs of wash bulkheads, horizontal stringers of transverse bulkhead and adjoining side horizontal girders, buttress and bottom girders.

3.1.6.2. Where the criteria given in this section for the structural detail are complied with, fine mesh finite element analysis of the structural detail may be waived with the exception of 3.1.6.3. The compliance with these criteria is to be verified for all finite element load cases.

3.1.6.3. Large openings, for which their geometry is required to be represented in the cargo tank FE model in accordance with Table 4.2.3, are to be investigated by fine mesh analysis.

Table 4.2.12: Fine Mesh Analysis Screening Criteria for Openings in Primary Support Members

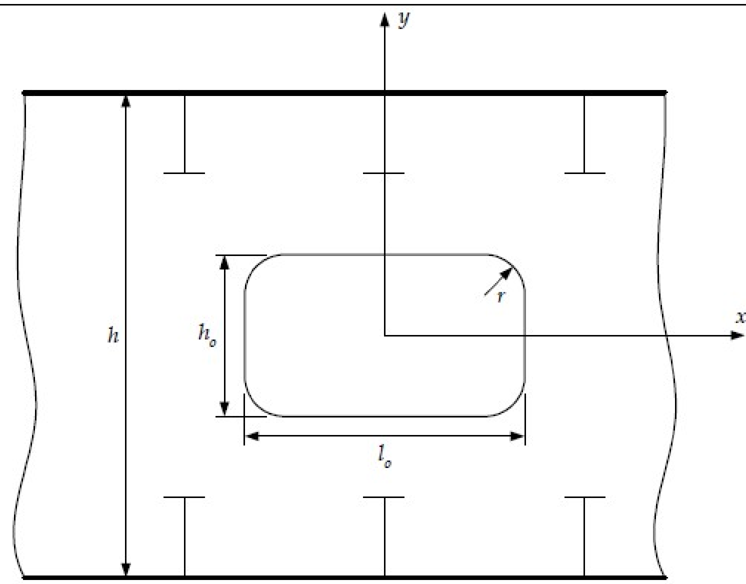
A fine mesh finite element analysis is to be carried out where: $\lambda_y > 1.7$ (load combination S + D) $\lambda_y > 1.36$ (load combination S)
Where: λ_y yield utilisation factor $= 0.85\, C_h \left[\left|\sigma_x + \sigma_y\right| + \left\{2 + \left(\frac{l_o}{2r}\right)^{0.74} + \left(\frac{h_o}{2r}\right)^{0.74}\right\} \left|\tau_{xy}\right| \right] \frac{k}{235}$ $C_h = 1.0 + 0.23\left(\frac{h_o}{h}\right) + 2.12\left(\frac{h_o}{h}\right)^2$ … for openings in vertical web and horizontal girder of wing ballast tank, double bottom floor and girder and horizontal stringer of transverse bulkhead $= 1.0$ … for opening in web of main bracket and buttress (see figures below)
r radius of opening, in mm h_0 height of opening parallel to depth of web, in mm l_0 length of opening parallel to girder web direction, in mm h height of web of girder in way of opening, in mm

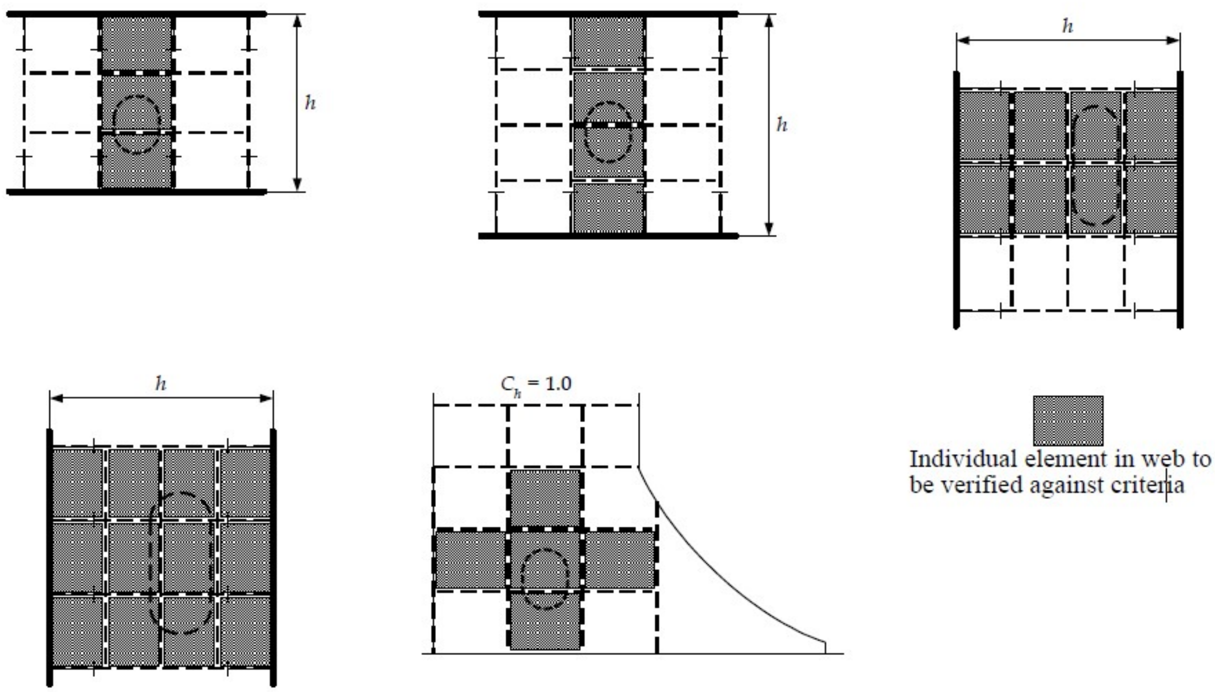
σ_x axial stress in element x direction determined from cargo tank FE analysis according to the coordinate system shown, in N/mm^2

σ_y axial stress in element y direction determined from cargo tank FE analysis according to the coordinate system shown, in N/mm2

τ_{xy} element shear stress determined from cargo tank FE analysis, in N/mm^2, (2)

k higher strength steel factor, as defined in Section 6/1.1.4 but not to be taken as less than 0.78 for load combination S + D





Notes

1) For opening where the modelled shear area in way of the opening is different from the actual net shear area the element shear stress is to be adjusted using the formula given in B.2.7.2.4 prior to the evaluation of yield utilisation factor for verification against the screening criteria.

2) Where the geometry of the opening is required to be modelled in accordance with Table B.2.2, fine mesh FE analysis is to be carried out to determine the stress level. The screening criteria given in this table are not applicable.

3) Screening criteria is only valid if the cargo tank finite element analysis and the derivation of element stresses is carried out in accordance with B/2.

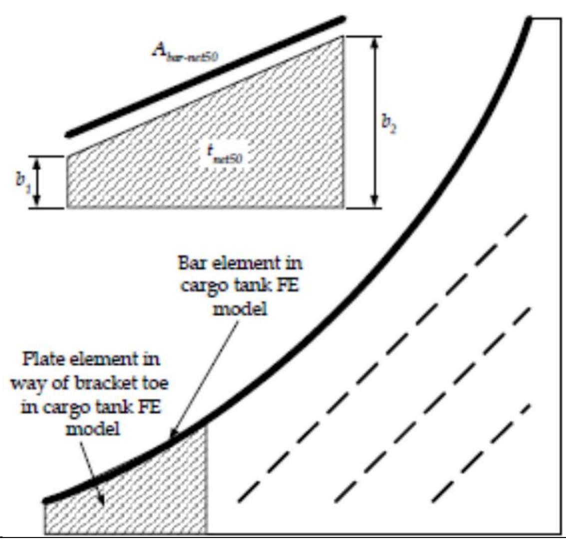
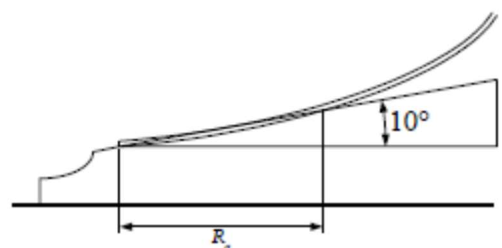
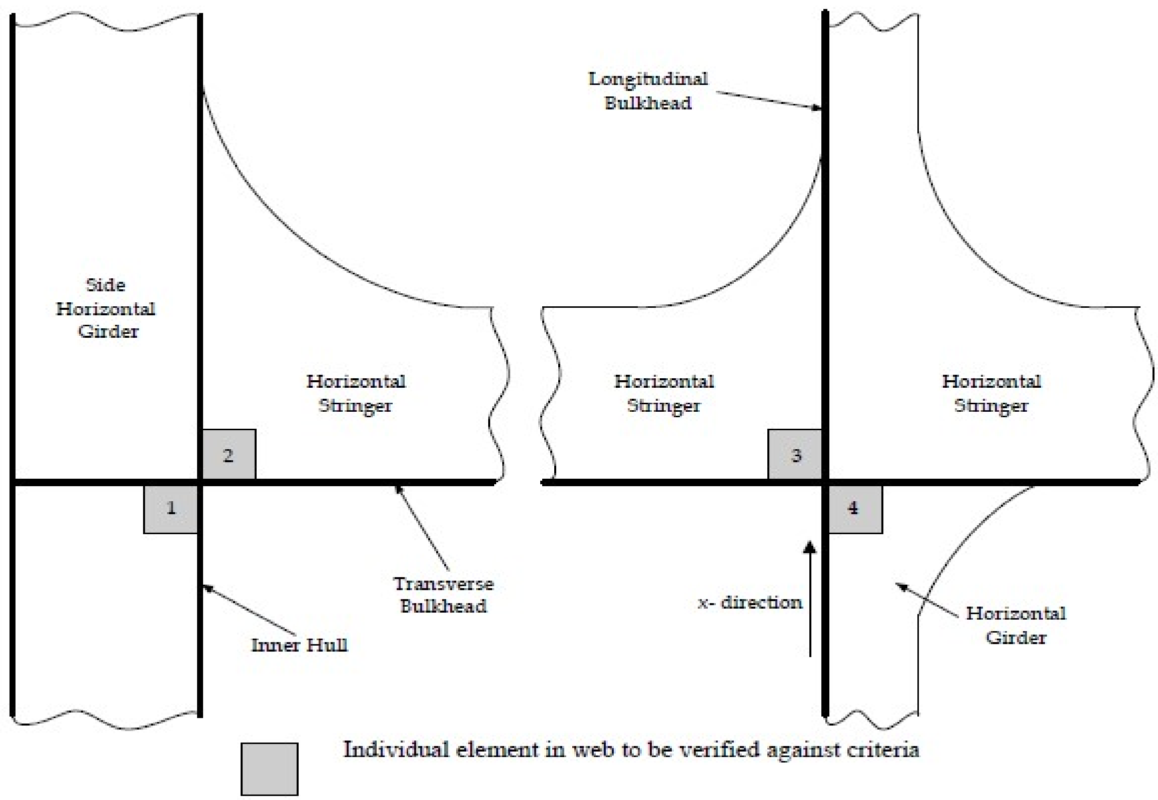
Table 4.2.13: Fine Mesh Analysis Screening Criteria for Bracket Toes of Primary Support Members
A fine mesh finite element analysis is to be carried out where: $\lambda_y > 1.5$ (load combination S + D) $\lambda_y > 1.2$ (load combination S)
Where: λ_y yield utilisation factor $=C_a\left(0.75\left(\frac{b_2}{b_1}\right)^{0.5}\lvert\sigma_{vm}\rvert + 0.55\left(\left(\frac{A_{bar-net50}}{b_1 t_{net50}}\right)^{0.5}\right)\lvert\sigma_{bar}\rvert\right)\frac{k}{235}$ $C_a = 1.0\text{-}0.2\left(\frac{R_a}{1400}\right)^2$ b_1, b_2 height of plate element in way of bracket toe in cargo tank FE model, in mm $A_{bar-net50}$ sectional area of bar element in cargo tank FE model representing the face plate of bracket, in mm^2 σ_{bar} bar element axial stress determined from cargo tank FE analysis, in N/mm^2 σ_{vm} von Mises stress of plate element in way of bracket toe determined from cargo tank FE analysis, in N/mm^2 t_{net50} thickness of plate element in way of bracket toe, in mm R_a leg length distance in mm, not to be taken as greater than 1400mm k higher strength steel factor, as defined in Section 6/1.1.4, but not to be taken as less than 0.78 for load combination S + D
 
Note 1) Screening criteria is only valid if the cargo tank finite element analysis and the derivation of element stresses is carried out in accordance with B/2.

Table 4.2.14 : Fine Mesh Analysis Screening Criteria for Heels of Transverse Bulkhead Horizontal Stringers
A fine mesh finite element analysis is to be carried out where: $\lambda_y > 1.5$ (load combination S + D) $\lambda_y > 1.2$ (load combination S)
Where: λ_y yield utilisation factor $= 3.0\|\sigma_{vm}\|\frac{k}{235}$ for heels at side horizontal girder and transverse bulkhead horizontal stringer, i.e. locations 1, 2 and 3 in figures. 235 $= 5.2\|\sigma_x\|\frac{k}{235}$ for heel at longitudinal bulkhead horizontal stringer, i.e. location 4. σ_x axial stress in element x direction determined from cargo tank FE analysis in accordance with the coordinate system shown, in N/mm^2 σ_{vm} von Mises stress of plate element in way of heel determined from cargo tank FE analysis, in N/mm^2 k higher strength steel factor, as defined in Chapter 1 Section 6/1.1.4, but not to be taken as less than 0.78 for load combination S + D

Note 1) Screening criteria is only valid if the cargo tank finite element analysis and the derivation of element stresses is carried out in accordance with B/2.

3.2. Structural Modelling

3.2.1. General

3.2.1.1. Evaluation of detailed stresses requires the use of refined finite element mesh in way of areas of high stress. This fine mesh analysis can be carried out by means of separate local finite element model with fine mesh zones in conjunction with the boundary conditions obtained from the cargo tank model. Alternatively, fine mesh zones incorporated into the cargo tank model may be used.

3.2.1.2. The extent of the local finite element model is to be such that the calculated stresses at the areas of interest are not significantly affected by the imposed boundary conditions and application of loads. The boundary of the fine mesh model is to coincide with primary support members, such as girders, stringers and floors, in the cargo tank model.

3.2.1.3. The mesh size in the fine mesh zones is not to be greater than 50mm x 50mm. In general, the extent of the fine mesh zone is not to be less than 10 elements in all directions from the area under investigation.

3.2.1.4. All plating within the fine mesh zone is to be represented by shell elements. A smooth transition of mesh density is to be maintained. The aspect ratio of elements within the fine mesh zone is to be kept as close to 1 as possible. Variation of mesh density within the fine mesh zone and the use of triangular elements are to be avoided. In all cases, the elements are to have an aspect ratio not exceeding 3. Distorted elements, with element corner angle less than 60° or greater than 120°, are to be avoided. Stiffeners inside the fine mesh zone are to be modelled using shell elements. Stiffeners outside the fine mesh zones may be modelled using beam elements.

3.2.1.5. The element inside the fine mesh zone is to be modelled based on the net thickness, obtained by deducting the full corrosion addition, tcorr, from the gross thickness. The structure outside the fine mesh zone is to be modelled based on the net thickness obtained by deducting half the corrosion addition, $0.5t_{corr}$, from the gross thickness, as specified in 2.2.1.5, for use in the cargo tank FE analysis.

3.2.1.6. Where fine mesh analysis is required for main bracket end connections, the fine mesh zone is to be extended at least 10 elements in all directions from the area of interest, see Figure 4.2.21. The modeling scantlings in the fine mesh zone are to be in accordance with 3.2.1.5.

3.2.1.7. Where fine mesh analysis is required for an opening, the first two layers of elements around the opening are to be modelled with mesh size not greater than 50mm x 50mm, based on the net thickness with deduction of full corrosion addition, t_{corr},. The elements outside the first two layers are to be based on the net thickness with a deduction of corrosion addition, $0.5t_{corr,}$ see 3.2.1.5. A smooth transition from the fine mesh to the coarser mesh is to be maintained. Edge stiffeners which are welded directly to the edge of an opening are to be modelled with plate elements. Web stiffeners close to an opening may be modelled using rod or beam elements located at a distance of at least 50mm from the edge of the opening. Typical fine mesh zone around an opening is shown in Figure 4.2.22.

3.2.1.8. Face plates of openings, primary support members and associated brackets are to be modelled with at least three elements across their width.

3.2.2. Transverse web frames

3.2.2.1. In addition to the requirements of 3.2.1, the modelling requirements in this sub-section are applicable to the analysis of typical transverse web frame.

3.2.2.2. Where a FE sub model is used, the model is to have an extent of at least 1 + 1 web frame spaces, i.e. one web frame space extending either side of the transverse web frame under investigation. The transverse web frames forward and aft of the web frame under investigation need not be included in the sub model.

3.2.2.3. The full depth and full breadth of the ship shall be modelled, see Figure 4.2.23.

3.2.2.4. Figure 4.2.24 shows a close up view of the finite element mesh at the lower part of the vertical web and backing brackets.

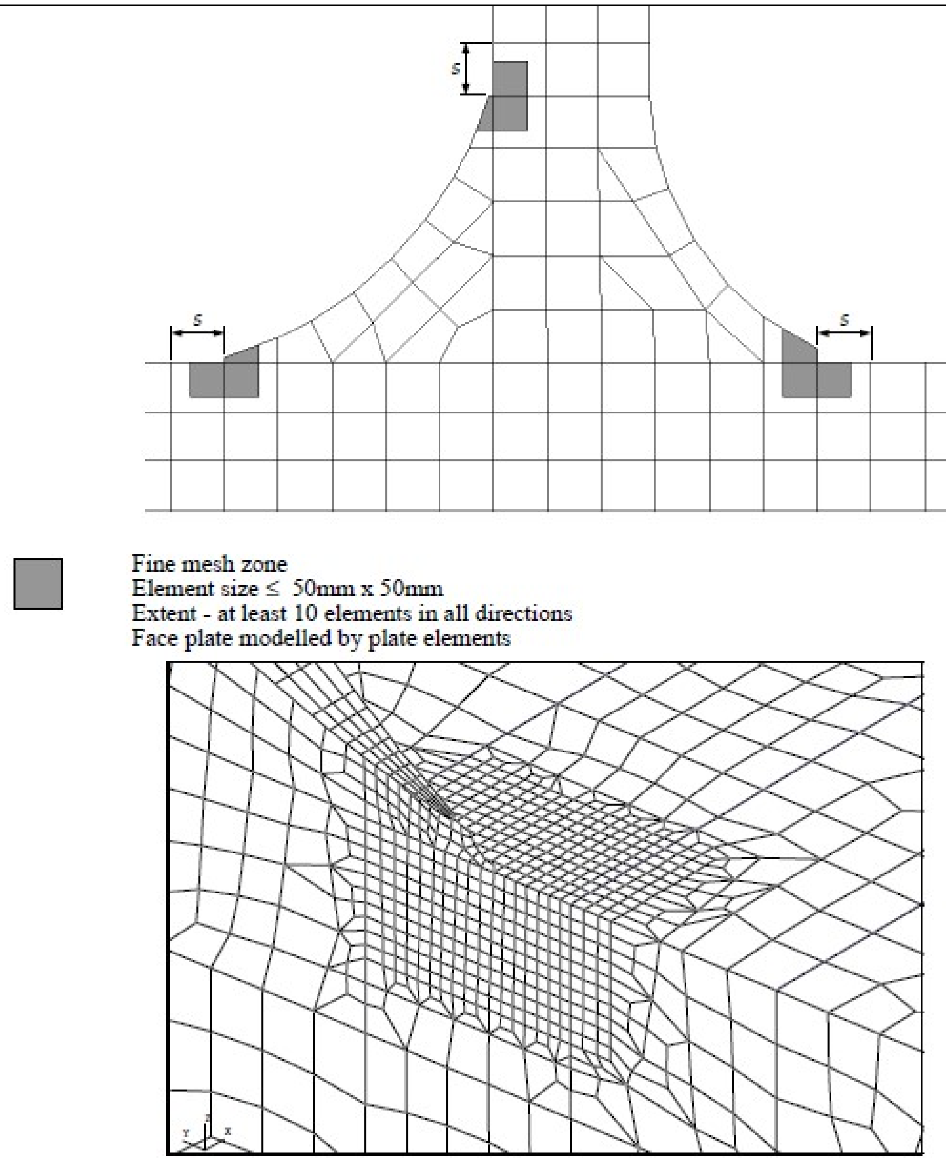


Figure 4.2.21: Fine Mesh Zone Around Bracket Toes

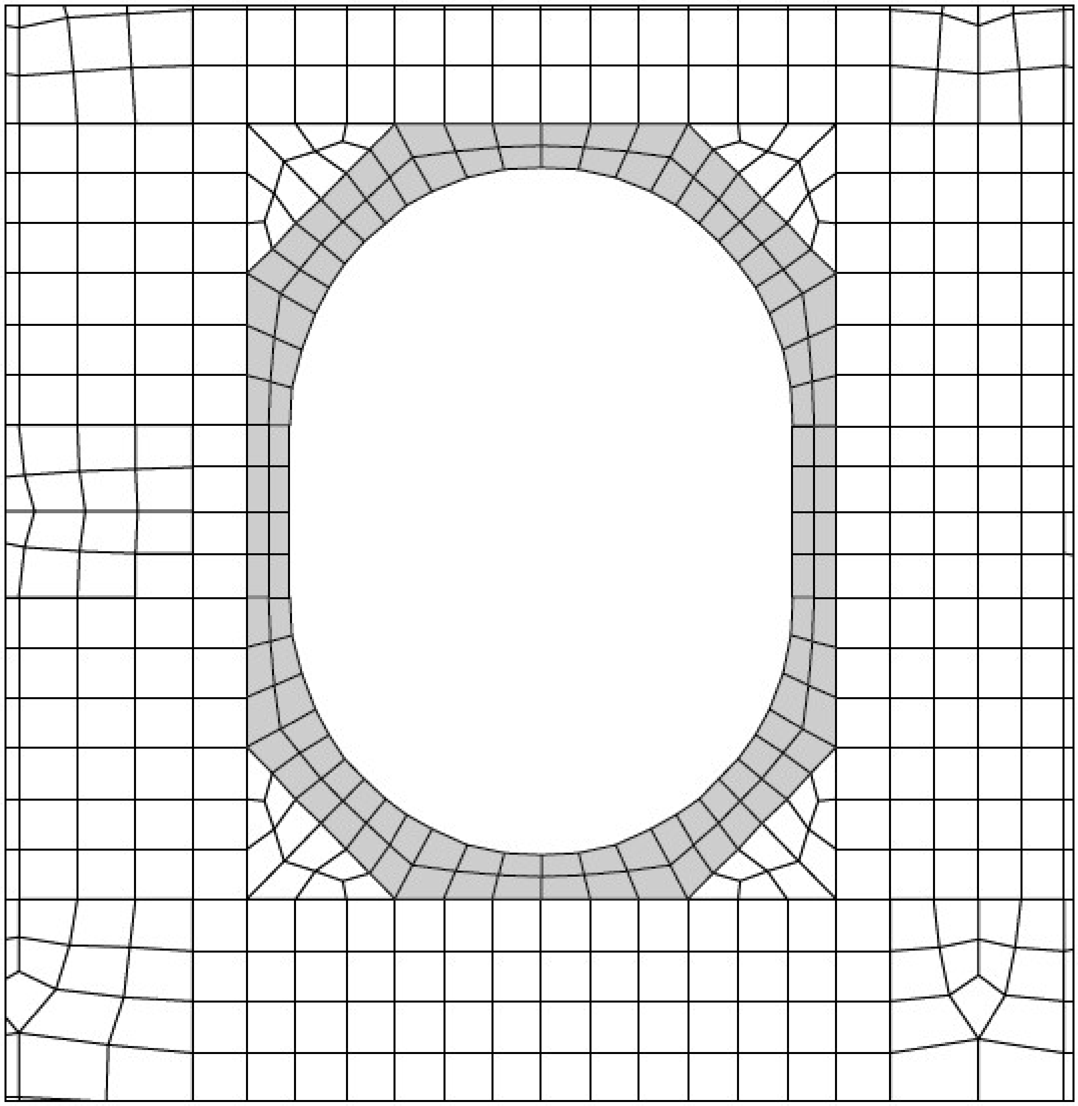


Figure 4.2.22: Fine Mesh Zone Around an Opening

3.2.3. Transverse bulkhead stringers, buttress and adjacent web frame

3.2.3.1. In addition to 3.2.1, the modelling requirements in this sub-section are applicable to the analysis of transverse bulkhead and adjacent web frame as described in 3.1.3.

3.2.3.2. Due to the structural interaction between the transverse bulkhead, horizontal stringers, web frames, deck and bottom, it is recommended that the FE sub-model represents a full section of the hull. Longitudinally, the ends of the model should at least be extended one web frame space beyond the areas that require investigation, see Figure 4.2.25. The full breadth and depth of the ship should be modelled.

3.2.3.3. Alternatively, it is acceptable to use a number of sub-models, as shown in Figure 4.2.26, to analyse different parts of the structure. For the analysis of the transverse bulkhead horizontal stringers the full breadth of the ship should be modelled. For the analysis of buttress structure, the sub-model width should be at least 4+ 4 longitudinal spaces, i.e. four longitudinal spaces at each side of the buttress.

3.2.3.4. Figure 4.2.27 shows the finite element mesh on a transverse bulkhead horizontal stringer. Figure 4.2.28 shows the sub-model for the analysis of buttress connections to transverse bulkhead and double bottom structure, and openings.

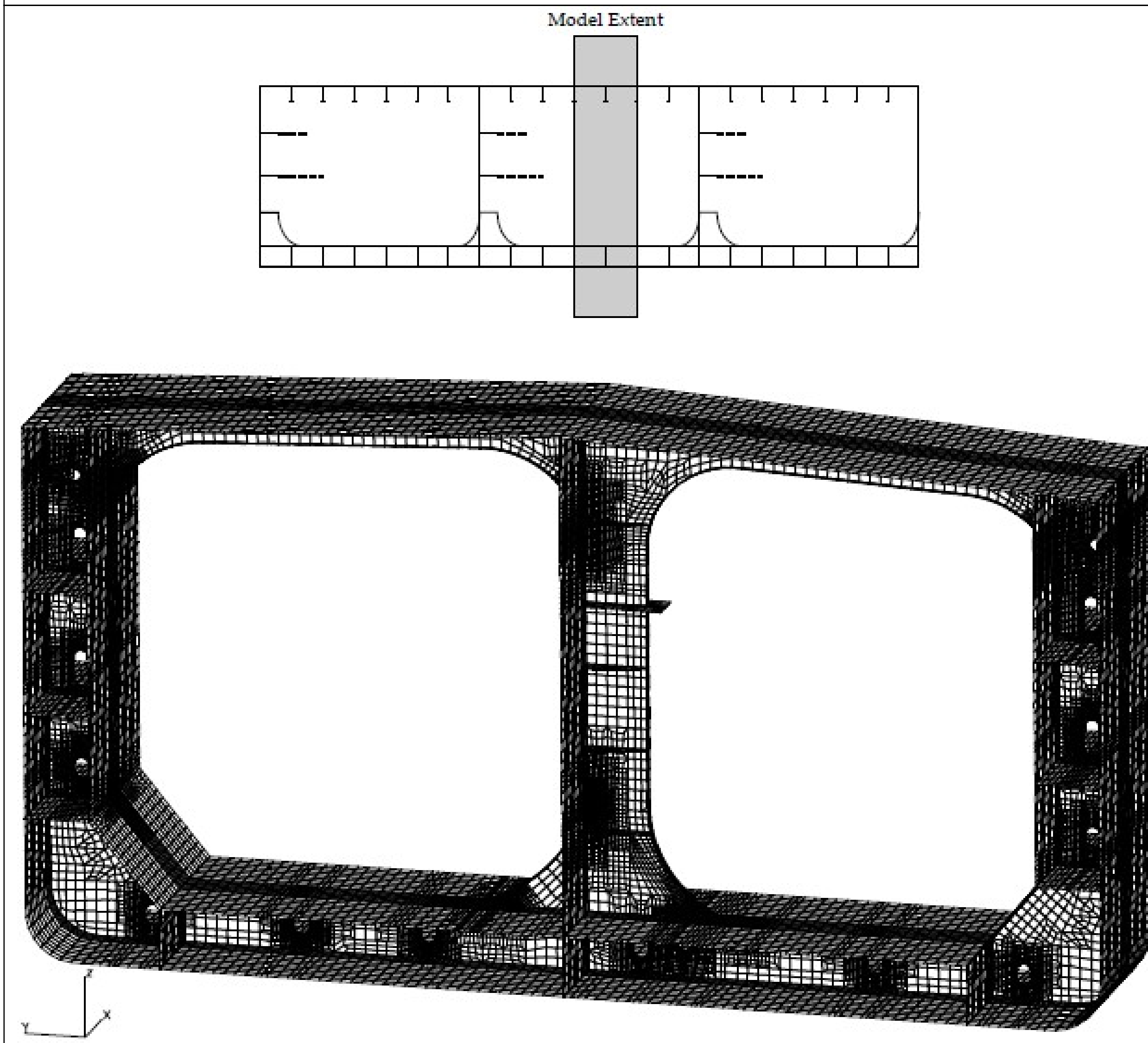


Figure 4.2.23: Extent of Sub Model for Fine Mesh Analysis of Web Frame Bracket Connections and Openings

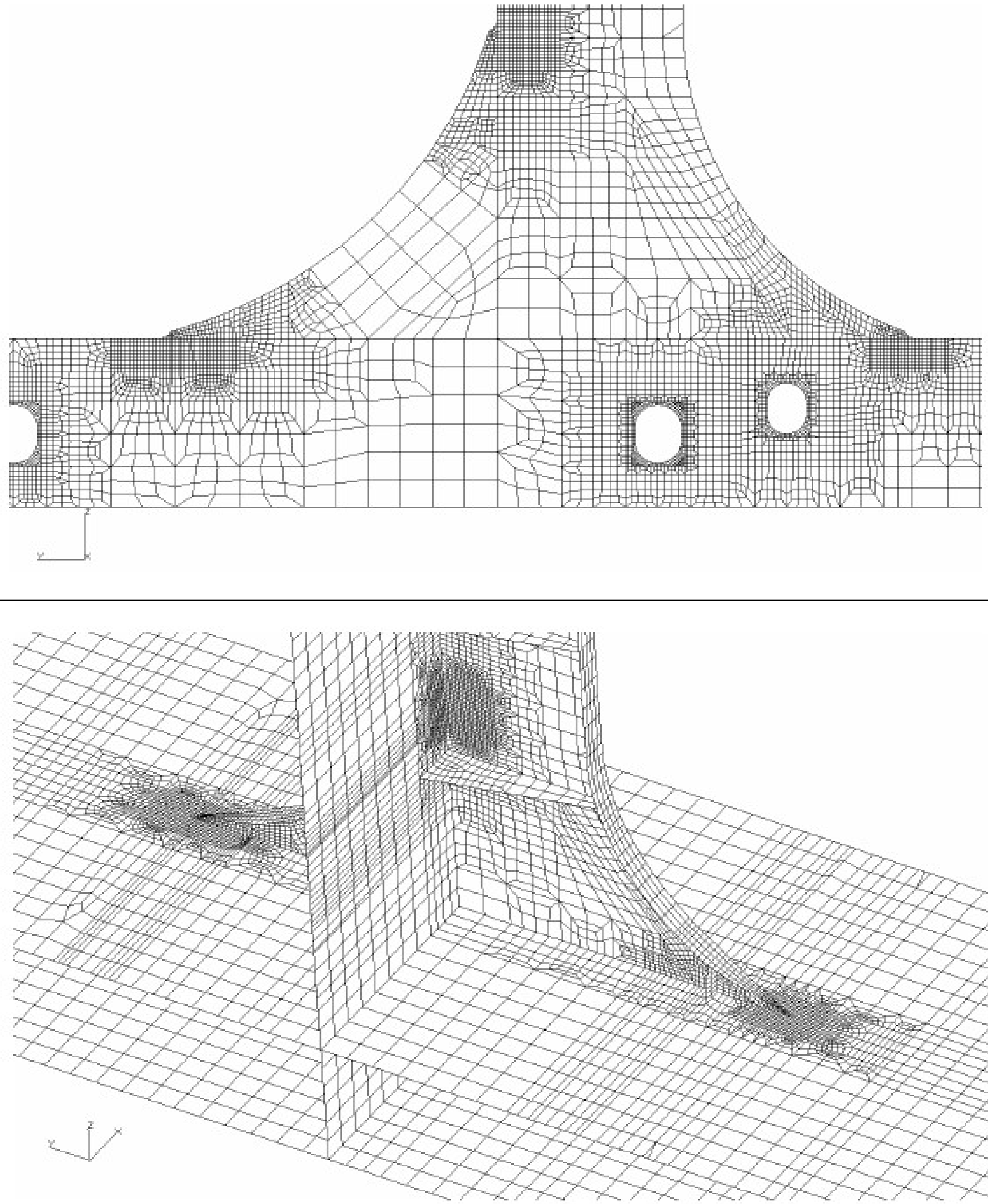


Figure 4.2.24: Close up View of Finite Element Mesh at the Lower Part of a Vertical Web Frame and Backing Brackets

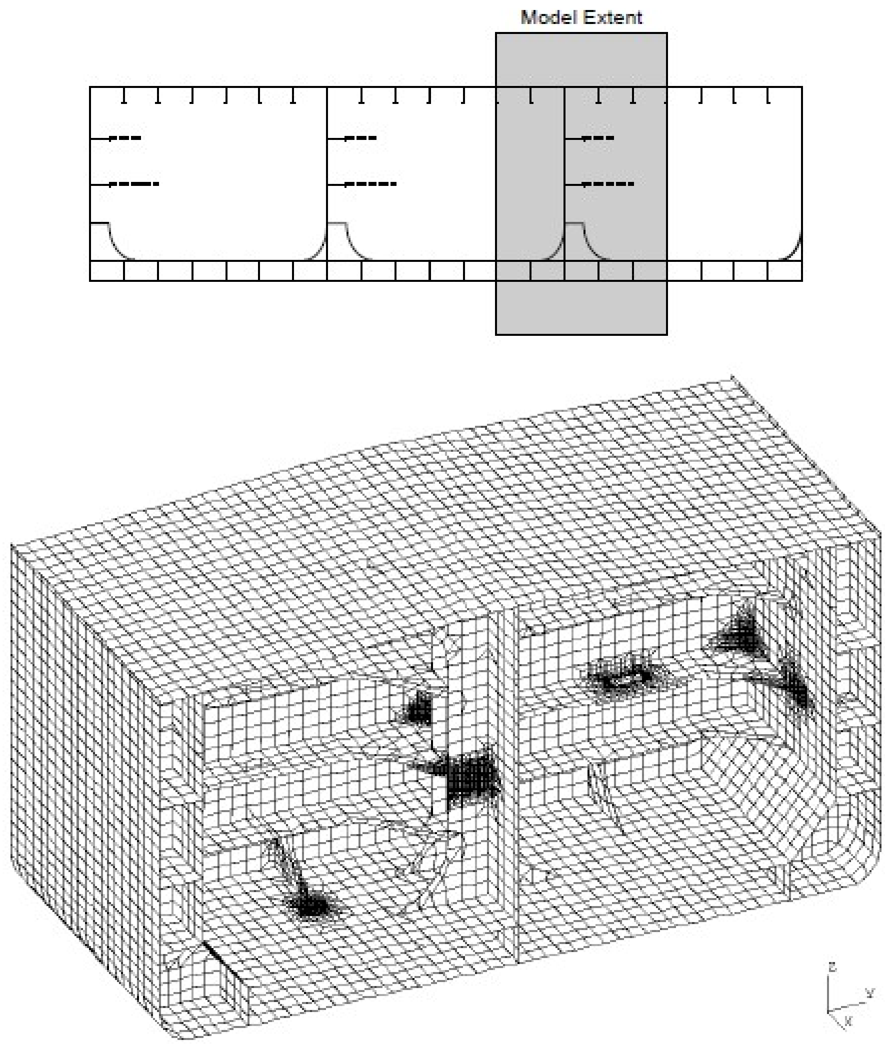


Figure 4.2.25: Extent of SubModel for Fine Mesh Analysis of Transverse Bulkhead and Adjacent Structure

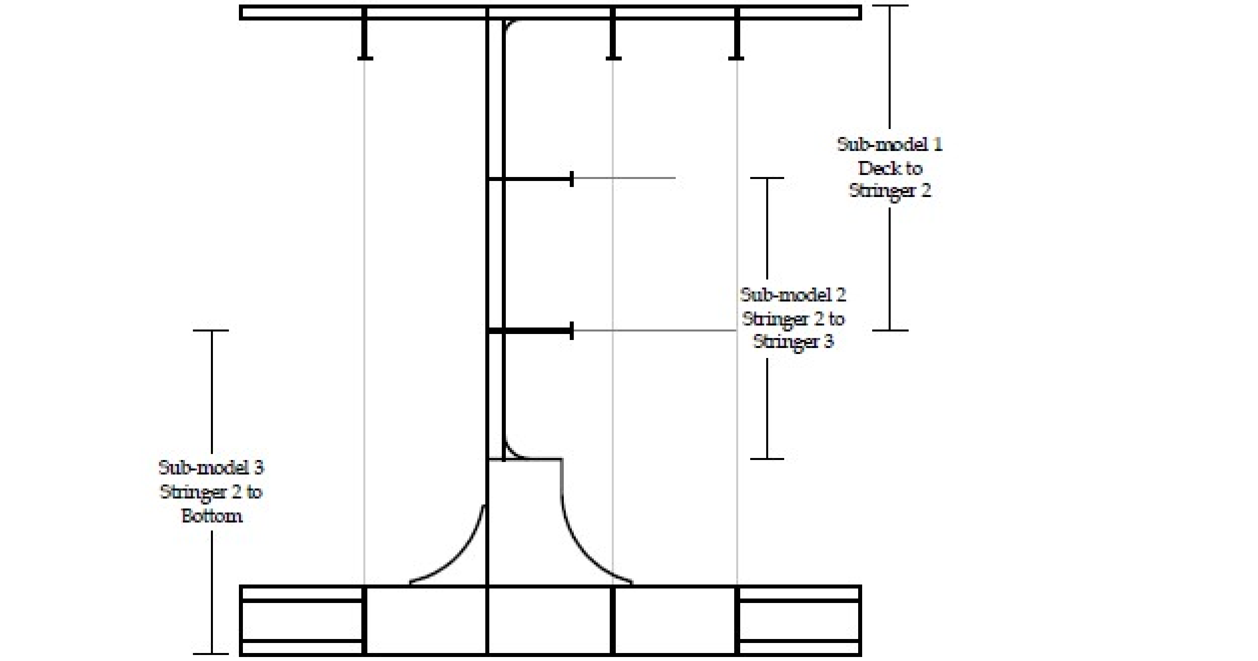


Figure 4.2.26: Analysis of Transverse Bulkhead Structure Using Sub Models

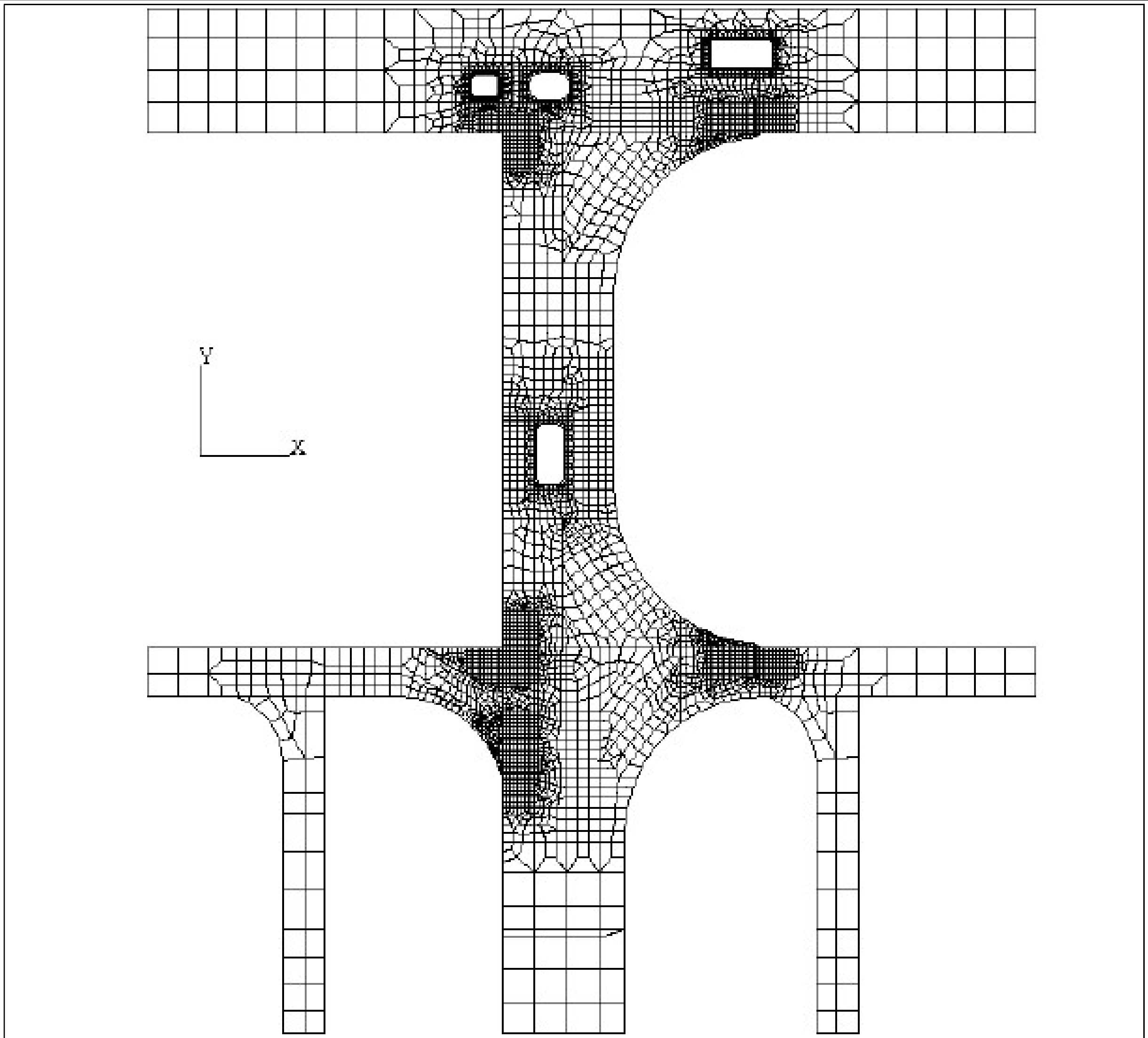
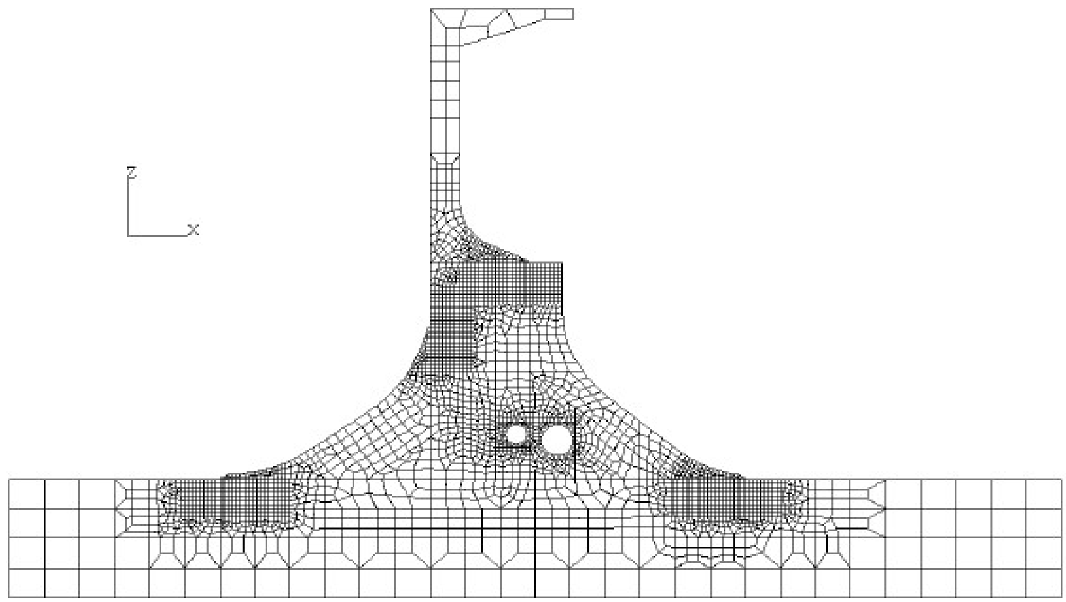


Figure 4.2.27: Finite Element Mesh on Transverse Bulkhead Horizontal Stringer (figure shows port side of model)



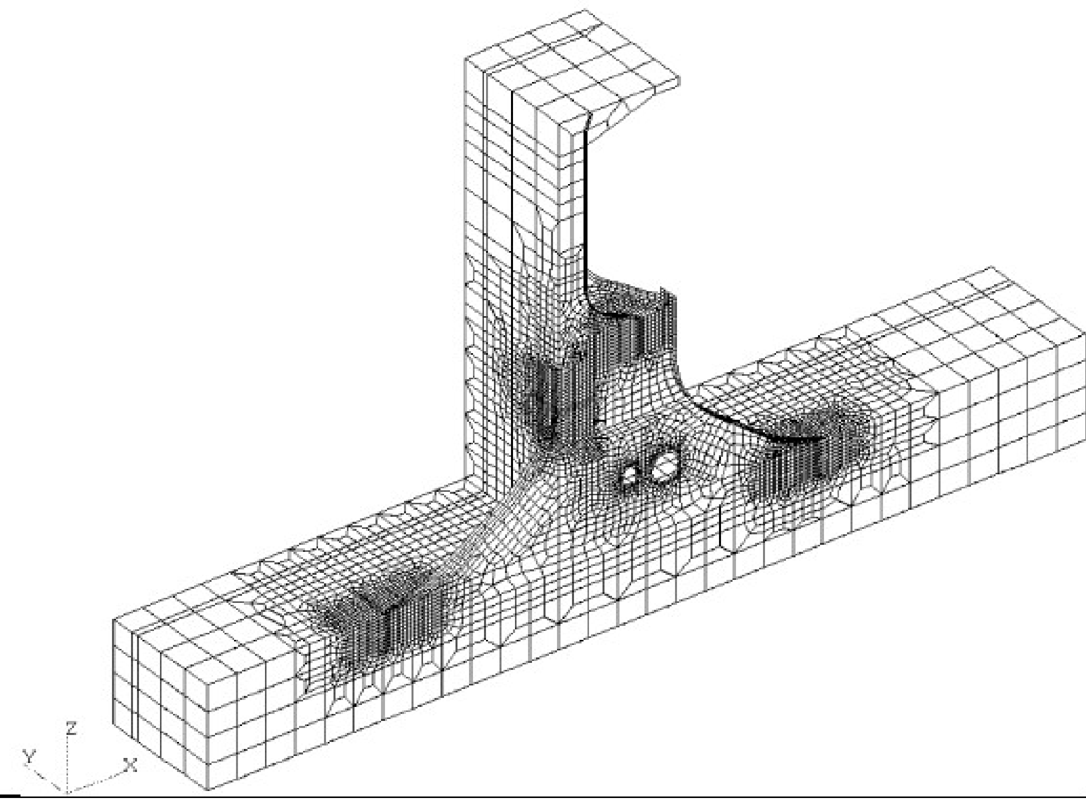


Figure 4.2.25: Sub-Model for the Analysis of Buttress Connections to Bulkhead and Double Bottom Structure (figure shows port half of model)

3.2.4. Deck, double bottom longitudinal and adjoining transverse bulkhead vertical stiffeners

3.2.4.1. The modelling requirements in this sub-section are applicable specifically to the analysis of longitudinal and vertical stiffener end connections and attached web stiffeners as described in 3.1.4.

3.2.4.2. Where a local FE model is used, each end of the model is to be extended longitudinally at least two web frame spaces from the areas under investigation. The model width is to be at least 2 + 2 longitudinal spaces. Figure 4.2.29 shows the longitudinal extent of the sub-model for the analysis of deck and double bottom longitudinal stiffeners and adjoining transverse bulkhead vertical stiffener.

3.2.4.3. The prescribed displacements or forces obtained from the cargo tank FE model should be applied to all boundary nodes which coincide with the cargo tank model.

3.2.4.4. The longitudinal and vertical stiffeners under investigation, including web, faceplate, attached plating (within ½ + ½ longitudinal spaces) and associated brackets are to be modelled based on the gross thickness with deduction of the full corrosion addition t_{corr}. Other areas are to be based on gross thickness with deduction of half corrosion addition, $0.5t_{corr}$

3.2.4.5. The web of the longitudinal stiffeners should be represented by at least 3 shell elements across its depth. Similar size elements should be used to represent the plating of the bottom shell and inner bottom. The face plate of the longitudinal stiffeners and brackets should be modelled with at least three elements across its width. 3.2.4.6 The mesh size and extent of the fine mesh zone is to be in accordance with 3.2.1.3, see also Figure 4.2.29.

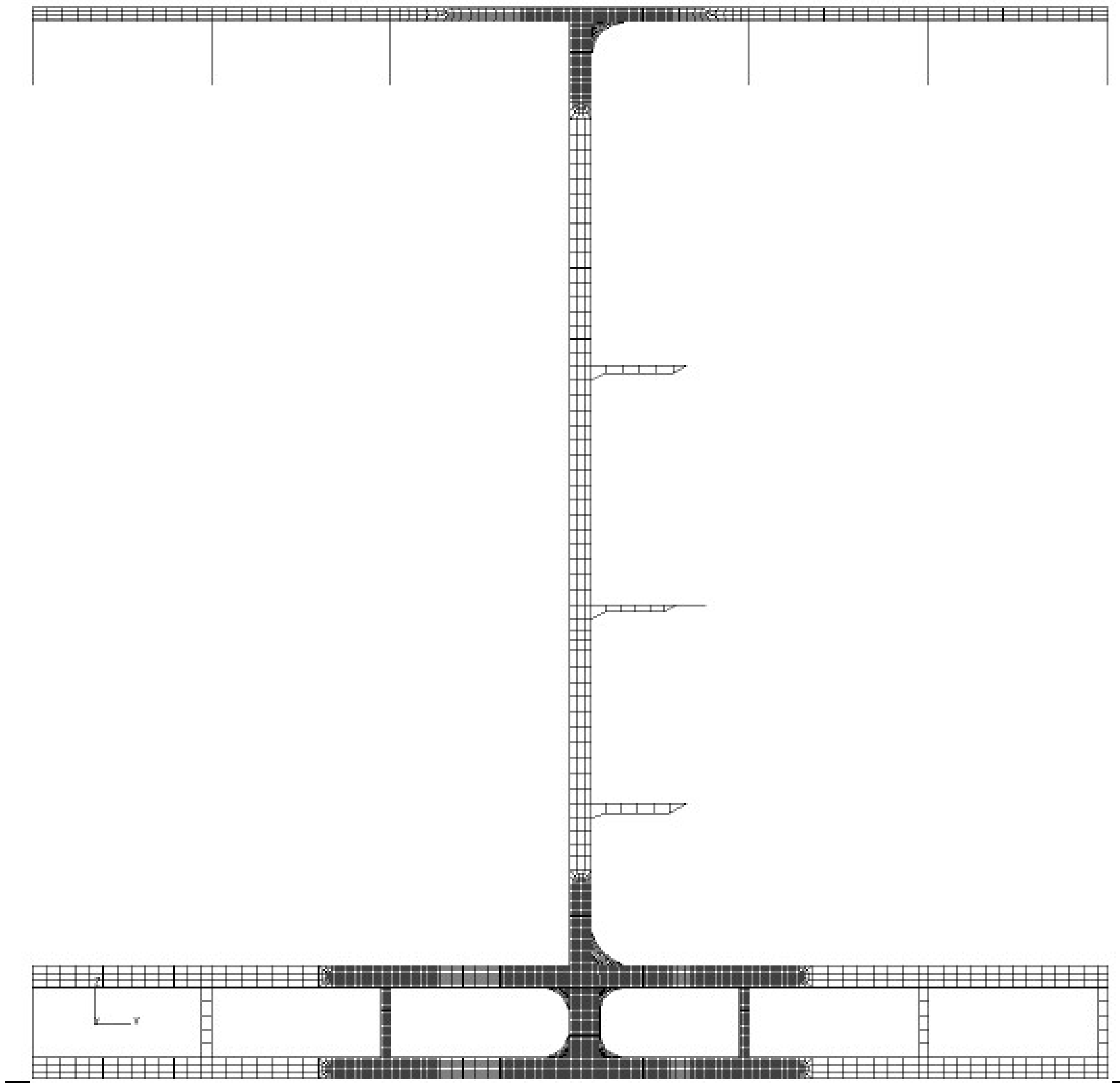
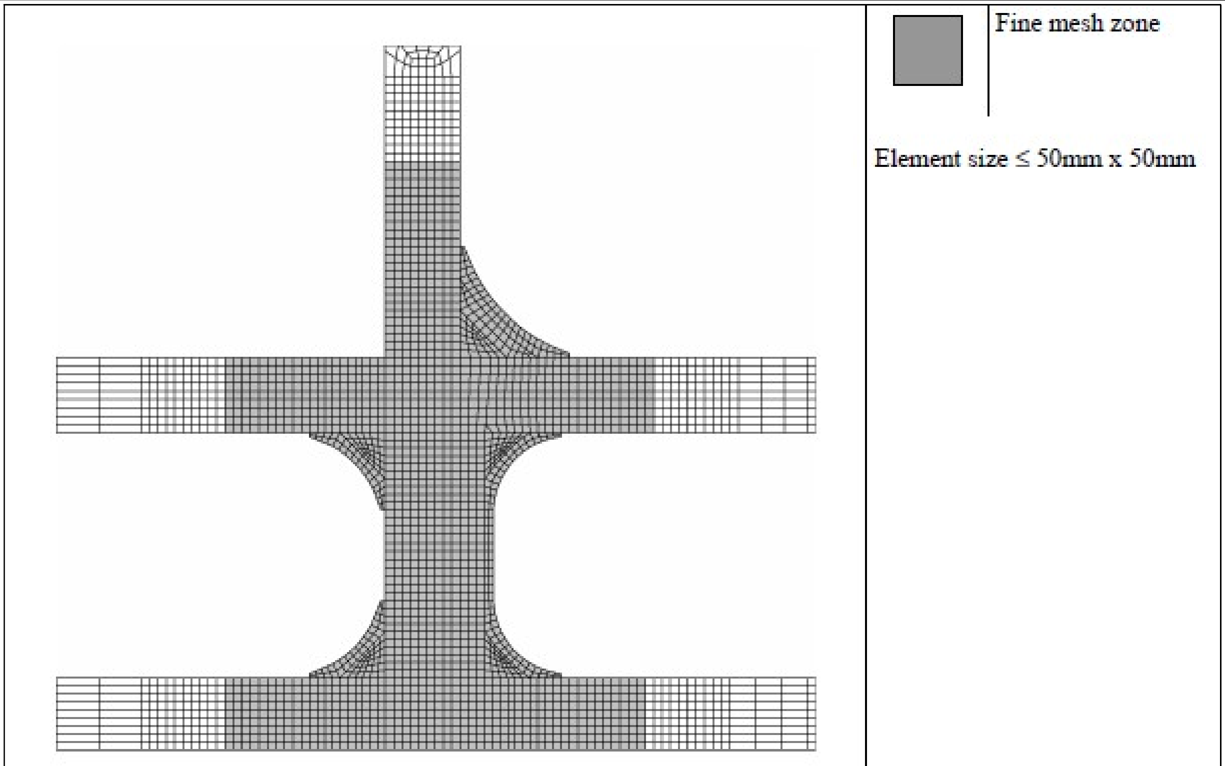


Figure 4.2.26: Sub Model for Fine Mesh Analysis of End Connections and Web Stiffeners of Deck and Double Bottom Longitudinals



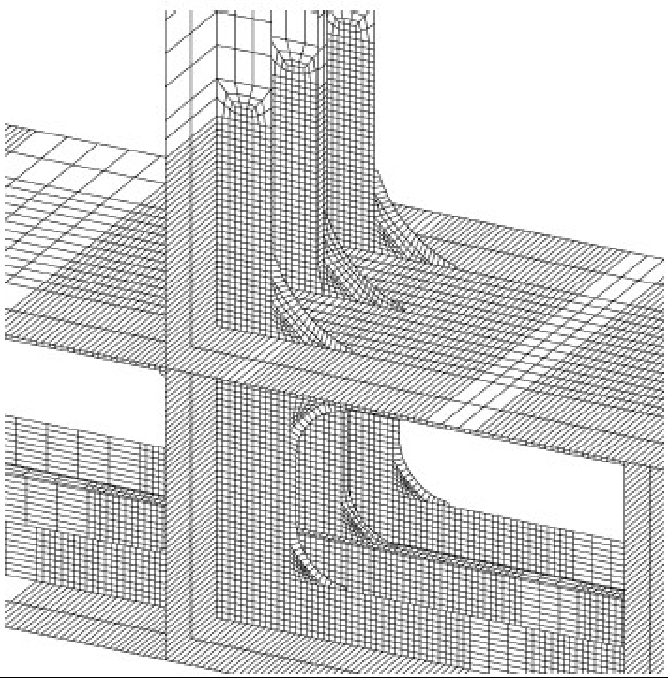


Figure 4.2.26 (Continued) Sub Model for Fine Mesh Analysis of End Connections and Web Stiffeners of Deck and Double Bottom Longitudinals

3.2.5. Corrugated bulkheads

3.2.5.1. In addition to 3.2.1, the modelling requirements in this sub-section are applicable to the analysis of connections of corrugated bulkheads to lower bulkhead stools as described in 3.1.5.

3.2.5.2. The minimum extent of the sub-model is as follows, see also Figure 4.2.30:

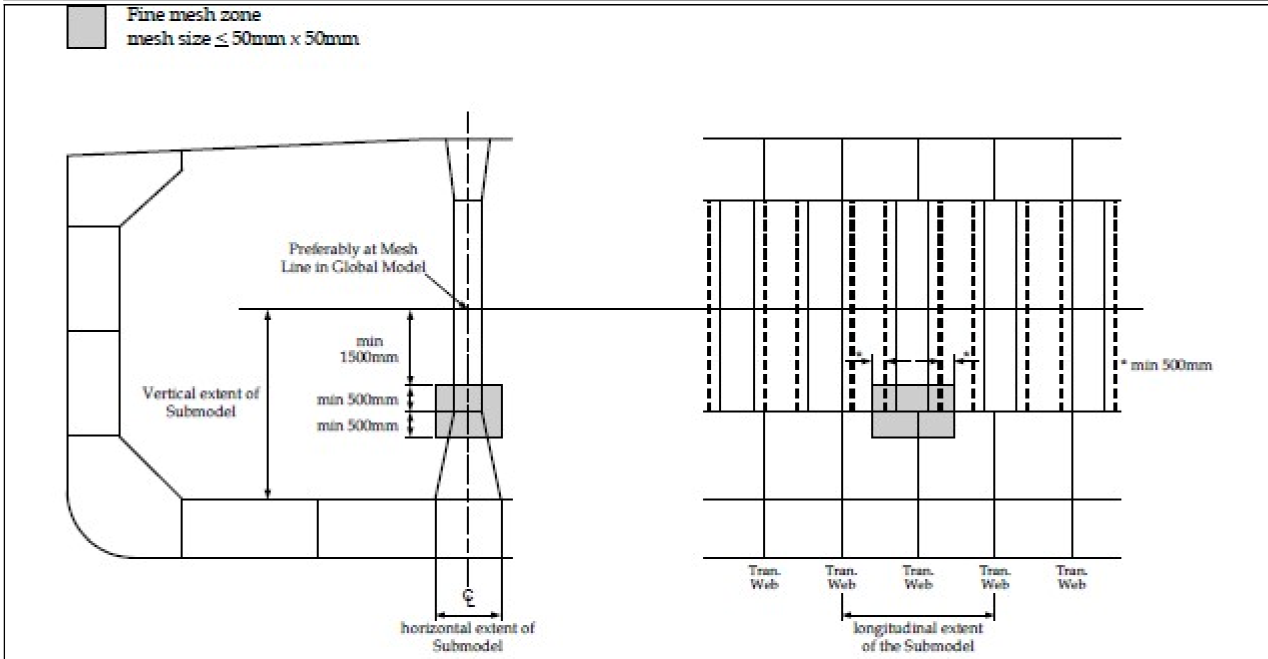
a. vertically, from the bottom of the bottom bulkhead stool to a level at least 2m above the connection of the corrugation to the upper part of the bulkhead stool. The upper boundary of the sub-model should be coincident with the horizontal mesh line of the cargo tank FE model
b. for transverse corrugated bulkheads, the sub-model is to be extended transversely to the nearest diaphragm web in the lower stool on each side of the fine mesh zone (i.e. the sub-model covers two bulkhead stool transverse web spaces). The end diaphragms need not be modelled
c. for longitudinal corrugated bulkheads, the sub-model is to be extended to the nearest web frame on each side of the fine mesh zone (i.e. the sub-model covers two frame spaces). The end web frames need not be modelled
d. where the area under investigation is located close to the intersection of transverse and longitudinal corrugated bulkheads, the sub-model should cover the structure between the diaphragms (in transverse direction) and web frames (in longitudinal direction) closest to the detail, whichever relevant. In addition the sub-model is to be extended at least one diaphragm/web frame outside the intersection of the stools.

3.2.5.3. The fine mesh zone is to be extended at least 500mm (10 elements) from the corrugation connectionin a vertical direction, see Figure 4.2.30. In a horizontal direction, the fine mesh zone is to cover at least thecorrugation flange under investigation, the adjacent corrugation webs and a further extension of 500mm from each end of the corrugation web (i.e. the fine mesh zone covers four corrugation knuckles), see Figure 4.2.30. The mesh size within the fine mesh zone is not to be greater than 50mm x 50mm.

3.2.5.4. Diaphragm webs, brackets inside the lower stool and vertical stiffeners on the stool side plate are to be modelled at their actual positions within the extent of the sub-model. Shell elements are to be used for modelling of diaphragm, bracket and stiffener webs. Beam elements may be used to represent the flange of stiffeners and brackets.

3.2.5.5. Horizontal stiffeners on the lower stool side plate are to be represented by beam elements.

3.2.5.6. Figure 4.2.31 shows the finite element sub-model for the fine mesh analysis of longitudinal bulkhead to lower stool connection.



Note
Above figures show extent of sub-model and fine mesh zone on longitudinal corrugated bulkhead connection to lower stool. Similar extent applies to transverse corrugated bulkhead.

Figure 4.2.30: Extent of Sub-Model and Fine Mesh Zone for the Analysis of Corrugated Bulkhead Connection to Lower Stool

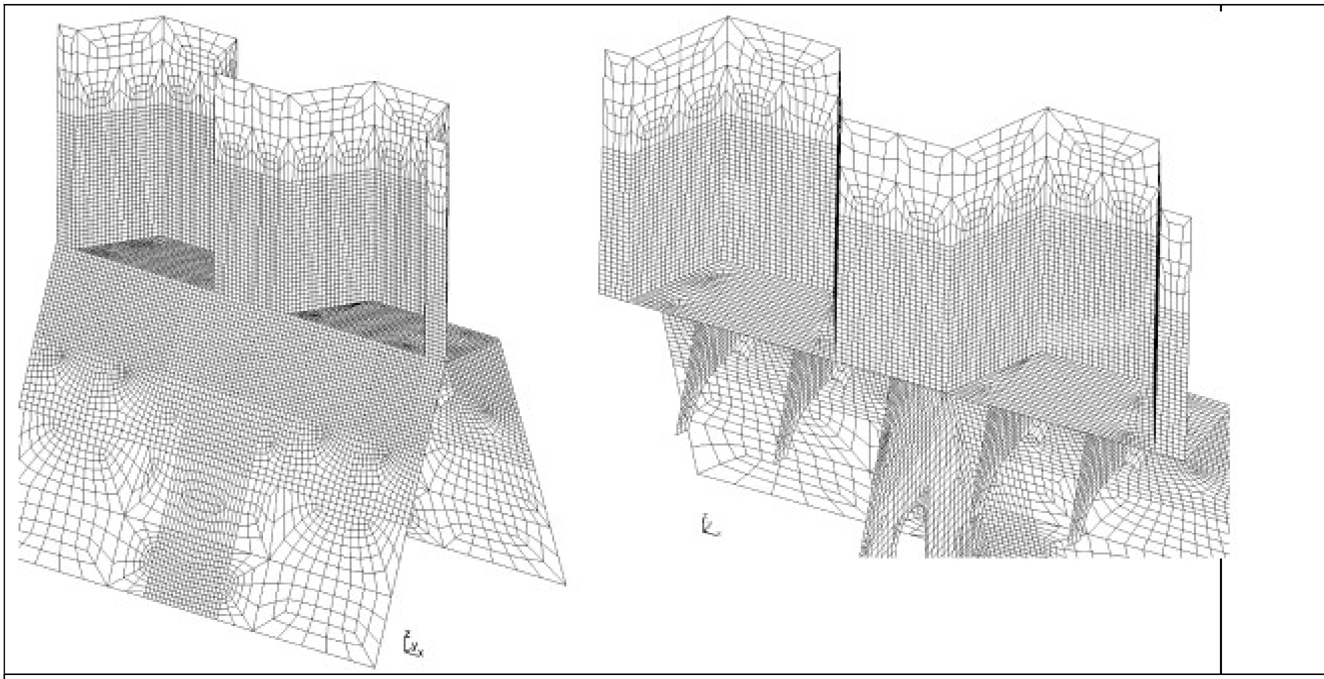


Figure 4.2.31: Sub-Model for the Analysis of Connection of Longitudinal Corrugated Bulkhead to Lower Stool

3.3. Loading Conditions

3.3.1. Stress analysis

3.3.1.1. The fine mesh detailed stress analysis is to be carried out for the standard load cases specified in 2.3.1, and any other load cases specially considered as required by Chapter 2 Section 3/2.2.3.

3.4. Application of Loads and Boundary Conditions

3.4.1. General

3.4.1.1. Where a separate local finite element model is used for the fine mesh detailed stress analysis, the nodal displacements from the cargo tank model are to be applied to the corresponding boundary nodes on the local model as prescribed displacements. Alternatively, equivalent nodal forces from the cargo tank model may be applied to the boundary nodes.

3.4.1.2. Where there are nodes on the local model boundaries which are not coincident with the nodal points on the cargo tank model, it is acceptable to impose prescribed displacements on these nodes using multi-point constraints. The use of linear multi-point constraint equations connecting two neighbouring coincident nodes is considered sufficient.

3.4.1.3. All local loads, including any vertical loads applied for hull girder shear force correction, in way of the structure represented by the separate local finite element model are to be applied to the model.

3.5. Result Evaluation and Acceptance Criteria

3.5.1. Stress assessment

3.5.1.1. Stress assessment of the fine mesh analysis is to be carried out for the load cases specified in 3.3.1.

3.5.1.2. The von Mises stress, σ_{vm}, is to be calculated based on the membrane direct axial and shear stresses of the plate element evaluated at the element centroid. Where shell elements are used, the stresses are to be evaluated at the mid plane of the element.

3.5.1.3. The resulting von Mises stresses are not to exceed the permissible membrane values specified in Chapter 2 Section 3/2.3.5.

3.5.1.4. The maximum permissible stresses are based on the mesh size of 50mm x 50mm as specified in 3.2.1.

3.5.1.5. Where a smaller mesh size is used, an average von Mises stress calculated over an area equal to the specified mesh size may be used to compare with the permissible stresses. The averaging is to be based only on elements with their entire boundary located within the desired area. The average stress is to be calculated based on stresses at element centroid; stress values obtained by interpolation and/or extrapolation are not to be used.
Stress averaging is not to be carried across structural discontinuities and abutting structure.

4. Evaluation of Hot Spot Stress for Fatigue Analysis

4.1. Application

4.1.1. General

4.1.1.1. This Section provides the procedure to perform a finite element analysis using very fine meshes for the evaluation of geometric hot spot stresses used in the determination of fatigue damage ratio as per Chapter 4 Section 3/2.

4.1.1.2. The locations where a finite element analysis based fatigue assessment is to be done, asmentioned in Chapter 2 Section 3/3.3.

4.2. Structural Modelling

4.2.1. General

4.2.1.1. Evaluation of hot spot stresses for fatigue assessment requires use of very fine finite element meshes in way of areas of high stress concentration. This very fine mesh analysis can be executedwith help ofof separate local finite element models with very fine mesh zones in conjunction with boundary conditions attained from a cargo tank model. Alternatively, very fine mesh zones incorporated in the cargo tank model may be used.

4.2.1.2. All structural parts, within an extent of at least 500mm in all directions leading up to the fatigue hot spot position, are to be modelled based on the net thickness i.e. attained by deducting half the corrosion addition (i.e. $0.5t_{corr}$) from the gross thickness.

4.2.1.3. The cargo tank finite element model for fatigue assessment is to be modelled as per 2.2, but based on net thickness attained by deducting a quarter of the corrosion addition (i.e. $0.25t_{corr}$) from the proposed thickness. Alternatively, if the cargo tank FE model for the strength assessment is used, which is based on a thickness deduction of $0.5t_{corr}$, calculated stresses are to be corrected employing modeling reduction factor, f_{model}, mentioned in Chapter 4 Section 3/2.4.2.7.

4.2.1.4. Where a separate local finite element model is used, extent of the local model is to be such that the calculated stresses are not significantly affected by the imposed boundary conditions and application of loads.
The boundary of the fine mesh model is to coincide with the primary support members, such as girders, stringers and floors, in the cargo tank model. The extent of the local finite element model of a hopper knuckle is specified in 4.2.2.

4.2.1.5. The hot spot stress evaluation is to be based on shell element of mesh size t_{net50} x t_{net50}, where $t_{net50}$is the net thickness of the plate where a potential fatigue crack is most likely to begin. This mesh size is to be maintained within the very fine mesh zone, extending over at least 10 elements in all directions leading to the fatigue hot spot position. A uniform quadratic mesh is to be used within very fine mesh zone. A smooth transition of mesh density leading to the very fine mesh zone is to be maintained.

4.2.1.6. Four-node shell elements with bending and membrane properties are to be used inside very fine mesh zone. The shell elements are to represent the mid plane of the plating and the bending properties of the plate. The geometry of the weld and structural misalignment does not require modelling.

4.2.1.7. Where stresses are to be evaluated on a free edge or corner welds, such as cut-outs for stiffener connections at web frames, butt welds on edge of plating and around hatch corners, a rod element of insignificantcross-section area, e.g. 1mm^2, is to be used to attain the required stress value.

4.2.1.8. All structure situated close to the very fine mesh zones is to be modelled explicitly with shell elements. Triangular elements are to be avoided, wherever possible. Use of extreme aspect ratio (e.g. aspect ratio greater than 3) and distorted elements (e.g. element's corner angle less than 60° or greater than 120°) are to be avoided.

4.2.2. Hopper knuckle connection

4.2.2.1. Besides, general requirements in 4.2.1, the modelling requirements in this sub-section are applicable to modelling of welded hopper knuckle connections.

4.2.2.2. Fatigue assessment is to be executed for the knuckle joint between inner bottom and hopper plate for at least 1 transverse frame in the midship cargo tank region, refer to Chapter 2 Section 3/3.3.3. The fatigue assessment is only required to be done on the structural detail at one side of the hull.

4.2.2.3. Generally, the hopper knuckle connection at the mid position between transverse bulkheads is to be assessed. Where a wash bulkhead is present, the hopper knuckle connection at the mid position between the wash bulkhead and cargo tank end bulkhead is generally to be assessed. The cargo tank FE analysis results described in 2.2 should be examined for the highest transverse in-plane stress on the inner bottom plate adjacent to the lower hopper knuckle line to identify the exact frame position and the side of the hull where the fatigue assessment should be executed.

4.2.2.4. Where a separate local finite element model is used, minimum extent of the local model is as given below:

a) longitudinally, model is to cover two web frame spaces (i.e. one web frame space extending either side of the transverse web frame of interest). Transverse web frames at the end of the local model need notbe represented in the sub-model
b) vertically, the model is to extend from the base line to the lower stringer in the double side water ballast tank. Where a fatigue assessment is also done for the upper knuckle connection, model is to be extended to 4 longitudinal spaces above the lower stringer in the double side ballast tank
c) transversely, model is to extend from the ship side to 4 longitudinal spaces inboard of the double bottom side girder.

4.2.2.5. Mesh size in way of the knuckle connection is to be t_{net50} x t_{net50}, where $t_{net50}$is the net thickness of the inner bottom plate in way of the connection obtained by deducting 0.5$t_{corr}$from the gross thickness as mentioned in 4.2.1.2. The minimum extent of the t_{net50} x t_{net50} mesh is to be (also see Figure 4.2.32):

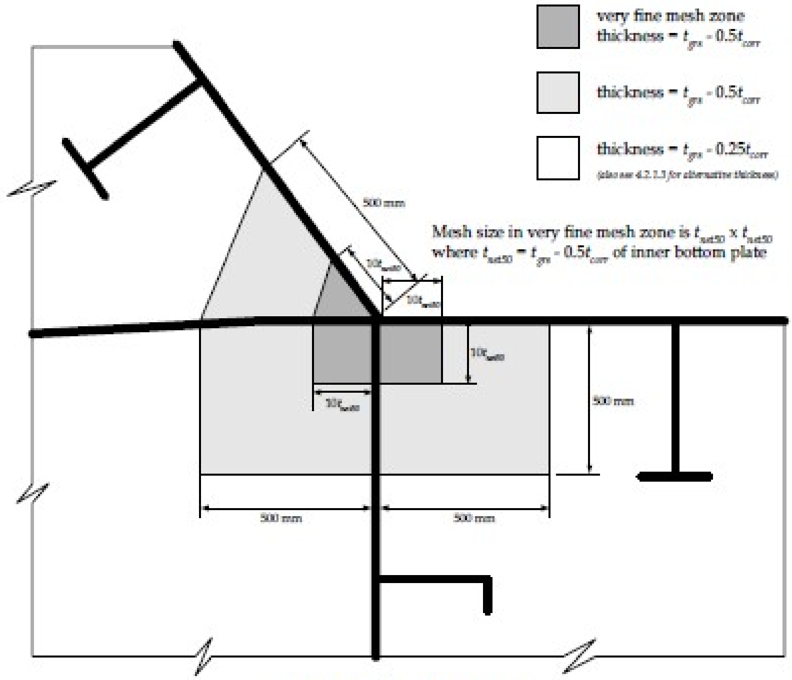
- inner bottom plate – 10 elements from knuckle in transverse direction, 10 elements forward and aft of the floor in the longitudinal direction
- floor/hopper web – 10 elements from the hopper knuckle in transverse and vertical directions respectively.
- hopper sloping plate – 10 elements from knuckle in transverse direction, 10 elements forward and aft of the hopper web in the longitudinal direction

- scarfing bracket/inner bottom overhang – 10 elements from knuckle in transverse direction, 10 elements forward and aft of the floor in the longitudinal direction
- girder – 10 elements from knuckle in vertical direction, 10 elements forward and aft of the floor/hopper web in the longitudinal direction

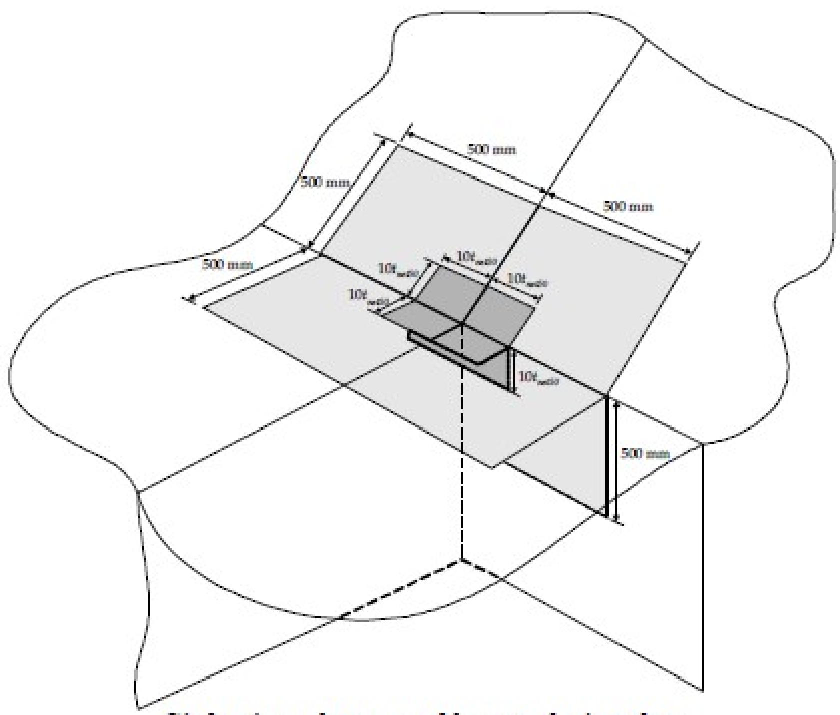
4.2.2.6. Any scarfing brackets on the web frame adjoining the inner bottom plating, the first longitudinal stiffeners away from the knuckle as well as any carlings and brackets offset from the main frames are to be explicitly modelled with help of shell elements. Longitudinal stiffeners further away from the knuckle may be modelled by beam elements. The inner bottom plate "overhang" outboard of the girder is to be modelled using shell elements to the extent of the scarfing bracket. Away from the scarfing bracket, the inner bottom plate “overhang” may be modelled using line elements of equivalent area. Any perforations, such as cut-outs for cabling, pipes and access that are within one stiffener space from the knuckle point are to be explicitly modelled.

4.2.2.7. Figure 4.2.32 illustrates extent of the t_{net50} x t_{net50} mesh zone and extension of the areas of local thickness reduction.

4.2.2.8. Figures 4.2.33 to 4.2.35 illustrates typical local finite element models of the hopper knuckle connection and close-up views of the t_{net50} x t_{net50} mesh zone.



Floor and hopper web



Girder, inner bottom and hopper sloping plate

Figure 4.2.32: Minimum Extent of tnet50 x tnet50 Mesh Zone and Local Thickness Reduction Zone at Lower Hopper Joint

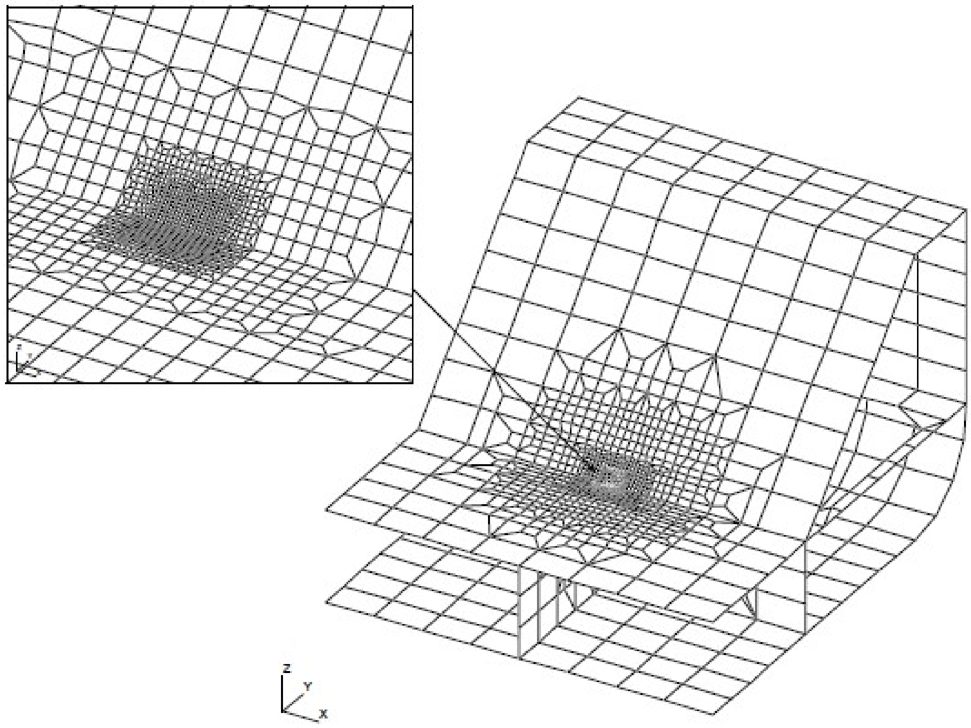


Figure 4.2.33: Typical Local Finite Element Model of Hopper Knuckle Connection tnet50 x tnet50 Mesh on Inner Bottom and Hopper Plate

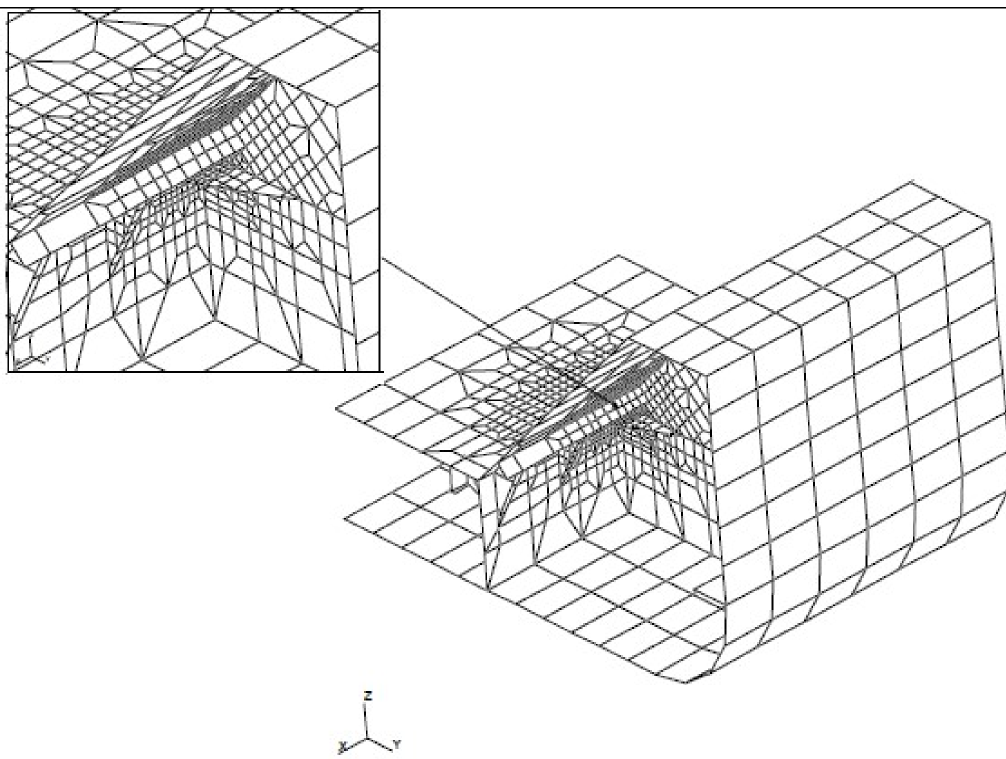


Figure 4.2.34: Typical Local Finite Element Model of Hopper Knuckle Connection tnet50 x tnet50 Mesh on Hopper Plate Web Frame Girder and Bracket in way

4.3. Loading Conditions

4.3.1. General

4.3.1.1. The ship loading conditions to be used to evaluate dynamic stress ranges for fatigue assessment are to be as per Chapter 4 Section 3/1.3.2.

4.3.1.2. The cargo density to be used for the fatigue assessment is to be:

i) longitudinal end connections - the greater of the cargo density specified for the homogeneous scantling draught condition and 0.9t/m^3

ii) connection between inner bottom and hopper plate - 0.9t/m^3.

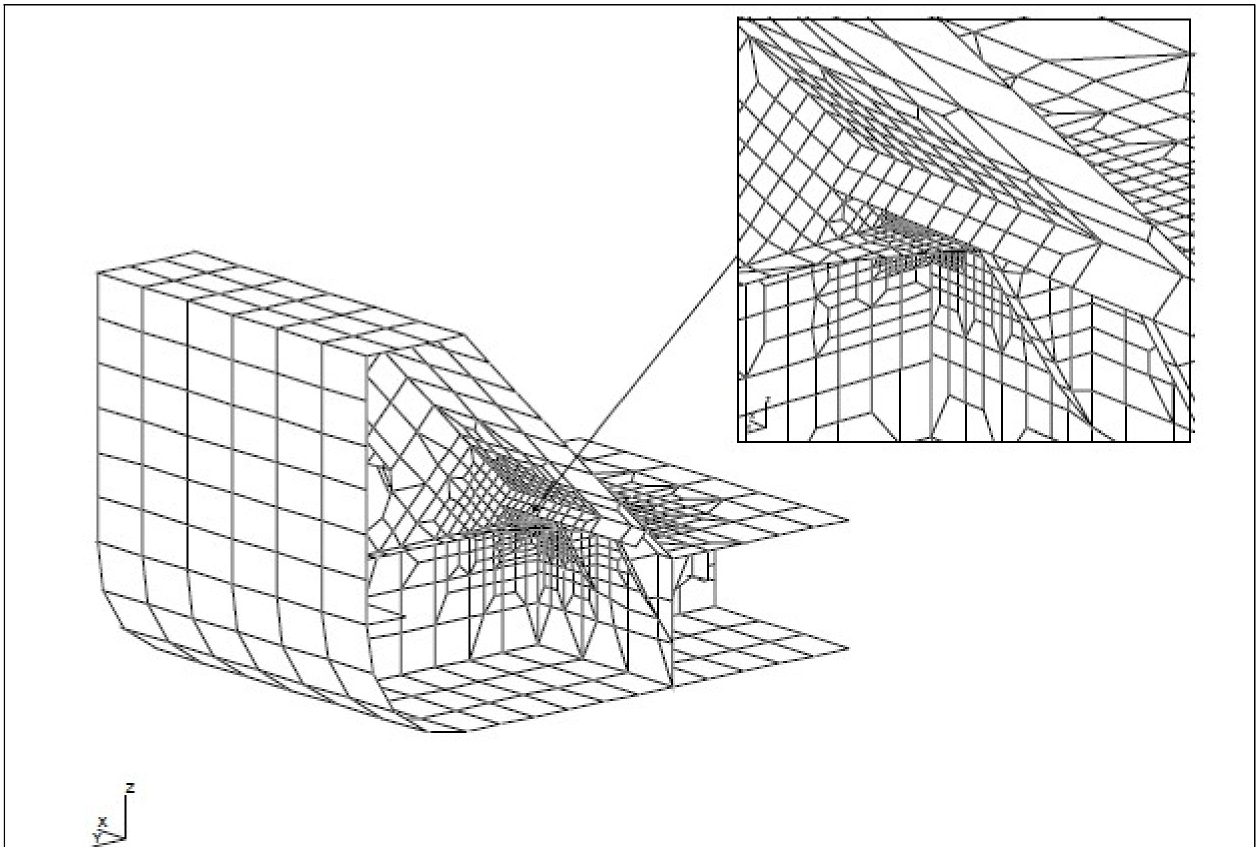


Figure 4.2.35: Typical Local Finite Element Model of Hopper Knuckle Connection tnet50 x tnet50 Mesh on Hopper Plate, Web Frame, Girder and Bracket in way

4.3.2. Finite element load cases for hopper knuckle connection

4.3.2.1. The requirements given in this sub-section are particularly applicable to evaluation of hot spot stress range at hopper knuckle connection.

4.3.2.2. Only dynamic loads are considered for the evaluation of fatigue stress range and static loads need not be included in the finite element analysis.

4.3.2.3. In Table 4.2.32 , the load cases required to derive the component stress ranges for determining the combined stress ranges, see Chapter 4 Section 3/2.4.2.7, are given.Stresses induced by horizontal and vertical hull girder bending moments are not to be included in the stress range for fatigue assessment. Stress caused by the bending effect of the hull girder is to be calculated anddeduced from the fatigue stress range result as per the procedure described in 4.5.2.

Table 4.2.13: Load Cases for the Evaluation of Component Stress Range for Hopper Knuckle Joint			
Load case	*Component Stress*	*Applied Load*	*Parameters for calculation of loads*
Full load condition			
L1	s_{e1}	Dynamic wave pressure (full range) applies only to the side of the hull where the hopper knuckle is analysed.	Ship draught = midship draught from departure homogeneous full load condition in the ship loading manual, see Chapter 4 Section 3/1.3.2. GM: see Chapter 2 Section 1/3.1.3.4 $r_{roll-gyr}$: see Chapter 2 Section 1/3.1.3.4 Cargo density = 0.9t/m^3(minimum, see 4.3.1.2)
L2	s_{e2}	Dynamic wave pressure (full range) applies only to the side of the hull where the hopper knuckle is not analysed.	
L3	s_{ix}	Dynamic tank pressure (full range) due to longitudinal acceleration.	
L4	s_{iy}	Dynamic tank pressure (full range) due to transverse accelerations.	
L5	s_{iz}	Dynamic tank pressure (full range) due to vertical acceleration.	
L6	s_{e1}	Dynamic wave pressure (full range) applies only to the side of the hull where the hopper knuckle is analysed.	Ship draught = midship draught from departure normal ballast condition in the ship loading manual. If normal ballast condition is not defined, then the midship draught from light ballast condition is to be used, see Chapter 4 Section 3/1.3.2
L7	s_{e2}	Dynamic wave pressure (full range) applies only to the side of the hull where the hopper knuckle is not analysed.	
Load cases for bending moment correction			
C1	s_{VBM}	Unit vertical bending moment applies to ends of cargo tank model	No other loads are to be applied
C2	s_{HBM}	Unit horizontal bending moment applies to ends of cargo tank model	

Where:

s_{e1}, s_{e2}, s_{ix}, s_{iy},s_{iz} component stresses (with proper sign convention used) before correction for bending moment effect (5)

s_{VBM}stress response due to the application of unit vertical bending moment at ends of cargo tank model

s_{HBM}stress response due to the application of unit horizontal bending moment at ends of cargo tank models

Notes

1) For dynamic wave pressure load cases, the pressure distribution is to be calculated at mid-ship and this distribution is to be applied along the full length of the cargo tank FE model.
2) For dynamic tank pressure load cases, vertical, transverse and longitudinal accelerations are calculated at the centre of gravity position of the midship cargo tanks. The accelerations calculated for each tank are to be applied to all corresponding cargo tanks along the length of the FE model.
3) Longitudinal, transverse and vertical accelerations at tank centre of gravity position are to be calculated in accordance with Chapter 2 Section 1/3.3. The dynamic tank pressure amplitudes due to accelerations are to be calculated in accordance with Chapter 2 Section 1/3.5.4.7. The dynamic tank pressure (full range) is to be obtained as two times the dynamic tank pressure amplitude and distributed in accordance with Figure 2.1.17. Note that these pressure distributions are different from those used for strength analysis.
4) The dynamic wave pressure amplitude is to be calculated according to Chapter 2 Section 1/3.5.2.3. The dynamic wave pressure (full range) is to be obtained as two times the dynamic wave pressure amplitude. Note that the dynamic wave pressure and distribution is different from that used for strength analysis.
5) Component stresses (with proper sign convention used) calculated from load cases L1 to L7 are to be corrected to deduct the component due to vertical and horizontal bending moment effect, see 4.5.2.2.

4.4. Boundary Conditions

4.4.1. Cargo tank model

4.4.1.1. The boundary conditions to be applied to the ends of the cargo tank model are to be as per 2.6. The application of unit vertical and horizontal bending moment at the model ends is to be as per 2.5.4.5 or 2.5.4.6.

4.4.2. Local finite element models

4.4.2.1. Where separate local finite element model is used for evaluation of the hot spot stress range, nodaldisplacements or equivalent nodal forces from the cargo tank model are to be applied to the correspondingboundary nodes on the local model.

4.4.2.2. Where there are nodes on the local model boundaries not coinciding with the nodal points on the cargo tank model, it is acceptable to impose prescribed displacements on these nodes by employing multi-point constraints. The use of linear multi-point constraint equations connecting two neighbouring coincident nodes is considered adequate.

4.4.2.3. Upon the model, all local loads in way of the structure represented by the separate local finite element model are to be applied.

4.5. Result Evaluation

4.5.1. General

4.5.1.1. The fatigue damage calculation is to be based on the hot spot stress range that is evaluated close to the potential crack location in a direction normal to the potential direction of the crack.

4.5.1.2. For welded structural details, hot spot stress range is to be derived as surface stress acting in a direction normal to the weld at a distance of $0.5t_{net50}$ from the weld toe location, where $t_{net50}$is the net thickness of the plate where the fatigue crack is likely to start, see Chapter 4 Section 3/2.4.2.6.

4.5.1.3. For fatigue assessment of the free edge, a rod element is used to determinestress at free edge. The basis for stress range is the axial stress in the rod element.

4.5.1.4. For fatigue damage calculation of hopper knuckle connection, refer4.5.2.

4.5.2. Hopper knuckle connection

4.5.2.1. Hot spot stress ranges for fatigue assessment of welded hopper knuckle joints are to be based on element direct stress along a direction normal to intersection of the hopper plate and inner bottom plate. The stress ranges are to be evaluated on the upper surface of the hopper and inner bottom plate at a distance of $0.5t_{net50} + x_{wt}$ from the intersection line, where t_{net50} is the net thickness of the inner bottom plate and $x_{wt}$is weld toe distance, see Figure 4.3.13. The stress at the required location can be attained by linear interpolation based on the surface stresses evaluated at the centroid of the 1st and 2nd elements from the intersection of the hopper slope plate, and the inner bottom plate.

4.5.2.2. The component stress ranges are to be attained by eliminating the stress induced by hull girder vertical and horizontal bending moments from the component stress determined from load cases L1 to L7 in Table 4.2.13 as given below:

$$S_{c\_i} = \left|S_{c\_i} - M_{v_i} s_{VBM} - M_{H\_i} s_{HRM}\right|$$

Where:

S_{c_i} S_{e1}, S_{e2}, S_{ix}, S_{iy} or S_{iz}, component stress range after correction for bending moment effects

s_{c_i} s_{e1}, s_{e2}, s_{ix}, s_{iy} or s_{iz}, component stress (with proper sign convention used) including vertical and horizontal bending moment effects obtained from load cases L1 to L7, see Table 4.2.13

s_{VBM} stress due to unit vertical bending moment obtained from load case C1, see Table 4.2.13

s_{HBM} stress due to unit horizontal bending moment obtained from load case C2, see Table 4.2.13

M_{H_i} is the horizontal hull girder bending moment due to loads applied to the cargo tank FE model obtained from load case L1, L2, L3, L4, L5, L6 or L7. The bending moment is to be calculated at the longitudinal position where the centroid of shell element under evaluation is located

M_{V_i} is the vertical hull girder bending moment due to loads applied to the cargo tank FE model obtained from load case L1, L2, L3, L4, L5, L6 or L7. The bending moment is to be calculated at the longitudinal position where the centroid of shell element under evaluation is located

4.5.2.3. The hull girder horizontal and vertical bending moments in 4.5.2.2 may be evaluated at the frame position where the hopper knuckle is under evaluation if the longitudinal distance from the element centroid to the frame position is less than 500mm.

4.5.2.4. The component stress range, S_i, due to dynamic tank pressure resulting from longitudinal, transverse and vertical accelerations for the full load condition is given by following formulae:

$$S_i = 0.4|S_{ix}| + 0.9|S_{iy}| + 0.9|S_{iz}|$$

4.5.2.5. The combined hot spot stress ranges required for fatigue damage calculation are to be calculated as per Chapter 4 Section 3/2.4.2.7.

4.5.2.6. Fatigue damage and fatigue life calculation is to be as per Chapter 4 Section 3/1.4.1.

SECTION 4 FATIGUE STRENGTH ASSESSMENT

Contents

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2. Hot Spot Stress (FE Based) Approach 596

1. Nominal Stress Approach

1.1. General

1.1.1. Applicability

1.1.1.1. Ships fatigue strength can be assessed by using the simplified procedure given in this section. The assessment technique uses the nominal stress based approach on beam theory.

1.1.1.2. For the steel has a minimum yield strength of less than 400N/mm^2, the fatigue assessment is to be applied to welded connections

1.1.2. Assumptions

1.1.2.1. The following assumptions are prepared in the fatigue assessment:

a) In connection with the S-N data in 1.4.5 a linear cumulative damage model, i.e. Palmgren-Miner's Rule, has been used
b) For longitudinal stiffener end connections, nominal stresses get by empirical formulae, see 1.4.2 to1.4.4, and Rule based loads, see 1.3, form the basis of the nominal stress based fatigue assessment
c) Using a modified Weibull probability distribution parameter,ξ, as described in 1.4.1.5 and 1.4.1.6 the long term stress ranges of a structural detail can be characterized.
d) Structural details are idealized and classified in 1.5.

1.1.2.2. The structural detail classification in 1.5 is based on typical joint geometry under simple loadings. Joint geometry under simple loading conditions is made use of when structural detail classification as given in 1.5 is done.A suitable finite element (FE) analysis should be used to express the competence of the structural detail in terms of fatigue strength when a it is considered different from those shown in 1.5. See 2.1.1.3.

1.1.2.3. A finite element (FE) analysis of the detail is to be performed to determine the fatigue stress of that detail; when the loading or geometry considered is too complex for a simple classification. The detailed procedure for a finite element based assessment to determine hot spot stresses that is to be used for weldtoe locations that are in general found at welded hopper knuckle connections in way of transverse primary support members is given in Subsection 2. For bent type knuckle connections, reference is given in 2.1.1.2.

1.2. Corrosion Model

1.2.1. Net thickness

1.2.1.1. As indicated in Chapter 1 Section 6/3, the net thickness and corrosion additions, are to be included into the illustration of the structural capacity models.

1.3. Loads

1.3.1. General

1.3.1.1. The types of loads to which ship structures are subjected to comprise of:

a) Static loads including cargo and lightship weights
b) Wave induced loads
c) Impact loads, such as bottom slamming, bow flare impacts and sloshing in partially filled tanks

d) Cyclic loads resulting from main engine or propeller induced vibratory forces
e) Transient loads such as thermal loads
f) Residual stresses.

1.3.1.2. The fatigue strength analysis takes in to account of the following wave induced loads for calculation of the longterm distribution of stresses:
a) hull girder loads (i.e. vertical and horizontal wave bending moments)
b) dynamic wave pressures
c) Dynamic tank pressure loads resulting from ship motions.

1.3.2. Selection of loading conditions

1.3.2.1. According to the intended ship's operation, Fatigue analyses are to be carried out for representative loading conditions. The following two loading conditions are to be checked:
a) Full load condition at design draught at departure, T_{full}, See Chapter 1 Section 4/1.1.5.4
b) Ballast condition at normal ballast draught at departure, T_{bal-n}, see Chapter 1 Section 4/1.1.5.3. If a normal ballastcondition is not defined in the loading manual, minimum ballast draught, T_{bal}, see Chapter 1 Section 4/1.1.5.2, should be used.

1.3.2.2. The relevant draught at mid ships is to be used for the determination of fatigue loads.

1.3.3. Determination of loads

1.3.3.1. To determine the stress ranges for the related loading conditions loads applied to the structure are to be assessed.

1.3.3.2. In accordance with 1.4.4, combined stresses resulting from the action of global and local loads are to be assessed with consideration given to the probability level of 10^{-4}.

1.3.4. Vertical wave bending moment

1.3.4.1. Based on Chapter 2 Section1/3.4.1, the vertical wave bending moment is to be assessed. The pseudo amplitude(half range) values of the vertical wave bending moment, Mwv-v-amp, for full load and ballast condition are to be taken as:

$$\mathrm{M_{wv-v-amp}} = 0.5\left(\mathrm{M_{wv-hog}} - \mathrm{M_{wv-s}}\right) \qquad \mathrm{kNm}$$

Where:
$\mathrm{M_{wv-h}}$ Hogging vertical wave bending moment, in kNm
$\mathrm{M_{wv-sa}}$ Sagging vertical wave bending moment, in kNm

1.3.5. Horizontal wave bending moment

1.3.5.1. Based on Chapter 2 Section 1/3.4.2, the horizontal wave bending moment is to be assessed. The pseudo amplitude (half range) values of the horizontal wave bending moment, Mwv-h-amp, for full load and ballast condition are to be taken as:

$$M_{wv-h-amp} = 0.5\left(M_{wv-h-pos} - M_{wv-h-neg}\right)\ \text{kNm}$$

Where:
$M_{wv-h-pos}$horizontal wave bending moment, in kNm
= Mwv-h
$M_{wv-h-neg}$horizontal wave bending moment, in kNm
= -Mwv-h

1.3.6. Dynamic wave pressure

1.3.6.1. Calculation of dynamic wave pressure is According to Chapter 2 Section 1/3.5.2

1.3.6.2. Considering the stretching of the external pressure due to intermittent wet and dry area, a pseudo amplitude of external pressure (half pressure range), Pex-amp, is explained in Chapter 2 Section 1/3.5.2.3 in detail and detailed in Figure 4.3.1.

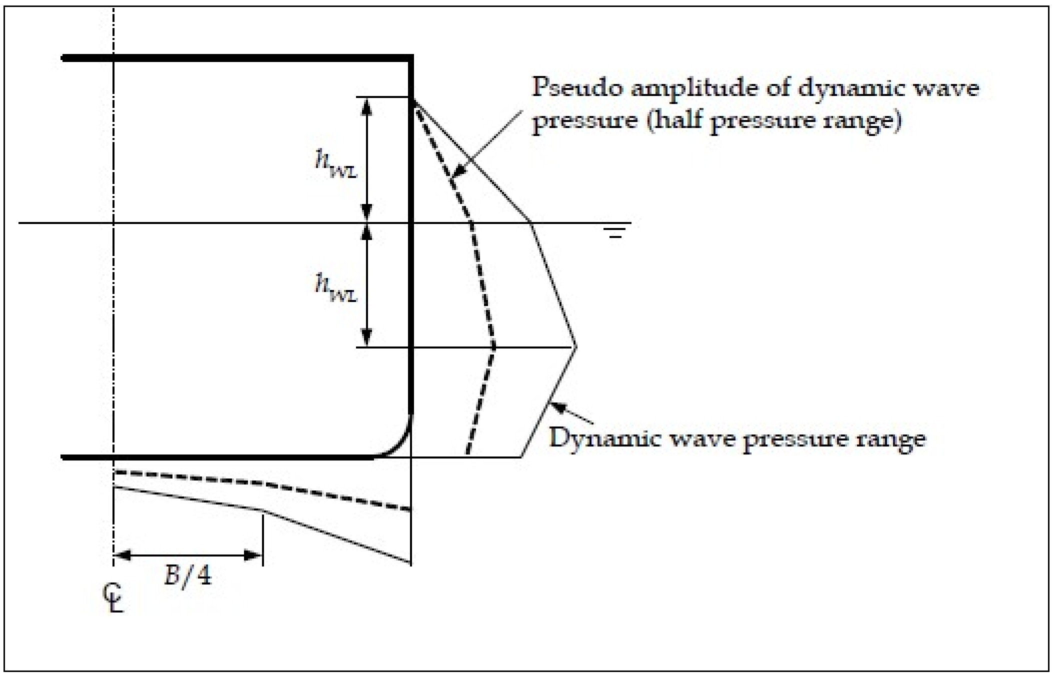


Figure 4.3.1 Dynamic Pressure

1.3.7. Dynamic tank pressure

1.3.7.1. By using Chapter 2 Section 1/3.5.4.5. and Chapter 2 Section 1/3.5.4.6. , assessment of dynamic tank pressure amplitude, Pin-ampis is done, for the deck no dynamic internal pressure is considered.

1.4. Fatigue Damage Calculation

1.4.1. Fatigue strength determination

1.4.1.1. The assessment fatigue of the structure is generally based on the application of the Palmgren-Miner cumulative damage rule given below.

The fatigue capability of the structure is not acceptable if the cumulative fatigue damage ratio, DM, is greater than 1, DM is to be taken as:

$$DM = \sum_{i=1}^{i=n_{tot}} \frac{n_i}{N_i}$$

Where:
n_iNumber of cycles of stress range Si
N_iNumber of cycles to failure at stress range Si
n_{tot}Total number of stress range blocks

1.4.1.2. There are 3 phases in Assessment of the fatigue strength of welded structural members:

a) Calculation of stress ranges
b) Selection of the design S-N curve
c) Calculation of the cumulative damage.

1.4.1.3. For the design life of the ship the cumulative fatigue damage ratio, DM, is to be less than 1. The design life is not to be less than 25 years. Unless otherwise specified the resultant cumulative damage is to be taken as:

$$DM = \sum_{i=1}^{2} D \quad _i$$

Where:
DM_iCumulative fatigue damage ratio for the applicable loading condition
i = 1 for full load condition
= 2 for normal ballast condition

1.4.1.4. Assuming the long term distribution of stress ranges fit a two-parameter Weibull probability distribution, the cumulative fatigue damage DMi for each relevant condition is to be taken as:

$$DM_i = \frac{\alpha_i N_L}{K_2} \frac{S_{Ri}^m}{(ln \quad _R)^{m/\xi}} \mu_i \Gamma\left(1 + \frac{m}{\xi}\right)$$

Where:
N_LNumber of cycles for the expected design life. Unless stated otherwise, NL to be taken as:

$$= \frac{f_o U}{4logL}$$

For a design life of 25 years generally the value of NL is between 0.6×10^8 and 0.8×10^8 cycles
f_o0.85, factor taking into account non-sailing time for operations such as loading and unloading, repairs, etc.
U Design life, in seconds
= 0.788×10^9 for a design life of 25 years
L rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1
m S-N curve parameter as defined in 1.4.5.5
K_2 S-N curve parameter as defined in 1.4.5.5
α_iProportion of the ship's life:
α_1 = 0.5 for full load condition
α_2 = 0.5 for ballast condition
S_{Ri}Stress range at the representative probability level of 10^{-4}, in N/mm^2
N_R10000, number of cycles corresponding to the probability level of 10^{-4}

ξ Weibull probability distribution parameter, as defined in 1.4.1.6
Γ Gamma function
μ_i Coefficients taking into account the change in slope of the S-N curve

$$\mu_i = 1 - \frac{\left\{\gamma\left(1 + \frac{m}{\xi}, v_i\right) - v_i^{-\Delta m/\xi}\gamma\left(1 + \frac{m+\Delta m}{\xi}, v_i\right)\right\}}{\Gamma\left(1 + \frac{m}{\xi}\right)}$$

$$v_i \left(\frac{S_q}{S_{Ri}}\right)^{\xi} \quad lnN_R$$

S_q Stress range at the intersection of the two segments of the S-N curve, see Table 4.3.6, in N/mm^2
Δm Slope change of the upper-lower segment of the S-N curve
=2
$\gamma(a, x)$ Incomplete Gamma function, Legendre form

1.4.1.5. The probability density function of the long term distribution of stress ranges (hull girder + local bending) is to be represented by a two-parameter Weibull distribution. This assumption enables the use of a closed form equation for calculation of the fatigue life when the two parameters of the Weibull distribution are determined. The probability density function, f(S), is to be taken as:

$$f(S) = \frac{\xi}{f_1}\left(\frac{S}{f_1}\right)^{\xi-1} exp\left(-\left(\frac{S}{f_1}\right)^{\xi}\right)$$

Where:

Stress range, in N/mm^2

ξ Weibull probability distribution parameter, as defined in 1.4.1.6

f_1 Scale parameter

$$= \frac{S_R}{(lnN_R)^{1/\xi}}$$

N_R Number of cycles corresponding to the probability of exceedance of 1/N$_R$
S_R Stress range with probability of exceedance of 1/N$_R$, in N/mm^2

1.4.1.6. For each structural detail considered, the Weibull shape parameter is to be selected with due consideration given to the load categories contributing to the cyclic stresses. The Weibull probability distribution parameter, ξ, is to be taken as:

$$\xi = f_{Weibull}\left(1.1 - 0.35\frac{L - 100}{300}\right)$$

Where:
L rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1
D moulded depth, in m, as defined in Chapter 1 Section 4/1.1.4.1
$f_{Weibull}$ area dependent modification factor, as given in Table 4.3.1 and Figure 4.3.2

Table 4.3.1 Distribution of f Weibull factors	
Plating Area	f Weibull (see note)
Bottom	0.9 at centreline and 0.95 at side
Side and bilge	1.1 at up to draught TLC and 1.0 at deck
Deck	1.0
Inner bottom	1.0
Inner Hull Longitudinal Bulkhead	1.1 up to D/2 and 1.0 at deck
Inner Longitudinal Bulkhead	1.1 up to D/2 and 1.0 at deck
Centreline Longitudinal Bulkhead	1.1 up to D/2 and 1.0 at deck
Note: Intermediate values to be linearly interpolated	

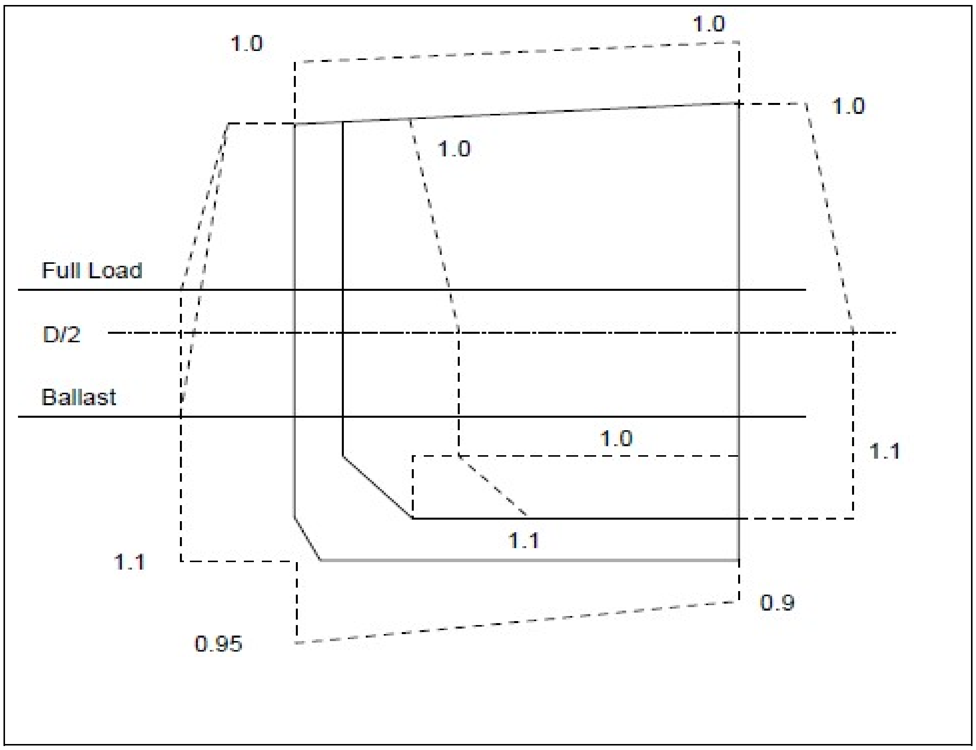


Figure 4.3.2 Distribution of f Weibull factors

The cumulative fatigue damage ratio, DM, may be converted to a calculated fatigue life using the relationship given below. In this format, the calculated fatigue life is to be equal or greater than the design life of the ship.

$$Fatigue\ life = \frac{Design\ life}{DM} \quad years$$

1.4.2. Stresses to be used

1.4.2.1. By taking into account the overall geometric changes of the detail the nominal stresses are to be determined. Here the effect of stress concentrations owing to structural discontinuities, presence of attachments and the weld profile is not considered.

1.4.3. Nominal stress calculation

1.4.3.1. This Sub-Section describes about a simplified approach to determine the combination of global and localstress components of the stress response of the ship.

1.4.3.2. Stress responses are to be calculated with varying levels of detail. The following approach has been adopted in this simplified procedure:

a) To attaining reasonable approximations to the nominal stress level in longitudinal hull girder elements the hull girder is treated as a simple beam. This is used for the assessment of hull girder stress levels in way of critical details
b) The structural member with effective attached plating is used in determining the nominal stress response of longitudinal and transverse frames due to dynamic wave pressure and dynamic tank pressure loads. The member end restraints and moments are considered.

1.4.4. Definition of stress components

1.4.4.1. Dynamic stress variations are referred to as either stress range, S, or stress amplitude, σ.
1.4.4.2. The global dynamic stress components (primary stresses) considered in fatigue analysis are vertical wave hull girder bending stress,σ_v and horizontal wave hull girder bending stress, σ_h.
1.4.4.3. The local dynamic stress amplitudes considered are defined as the total local stress amplitude due to dynamic wave pressure loads or dynamic tank pressure loads, σ_{e-i}.
1.4.4.4. The local stress components are defined as secondary stress resulting from bending of girder systems,σ_2 stress amplitude produced by bending of stiffeners between girder supports, σ_{2A}, and tertiary stress amplitude produced by bending of un-stiffened plate elements between longitudinals and transverse frames, σ_3. See figure 4.3.3.
1.4.4.5. The total local stress due to dynamic wave or dynamic tank pressure loads, σ_{e-i}, is to be taken as:

$$\sigma_{e-i} = \sigma_2 + \sigma_{2A} + \sigma_3 \quad N/mm^2$$

σ_2Local stress component, in N/mm^2, as defined in 1.4.4.4
σ_{2A}Local stress component, in N/mm^2, as defined in 1.4.4.4
σ_3Local stress component, in N/mm^2, as defined in 1.4.4.4

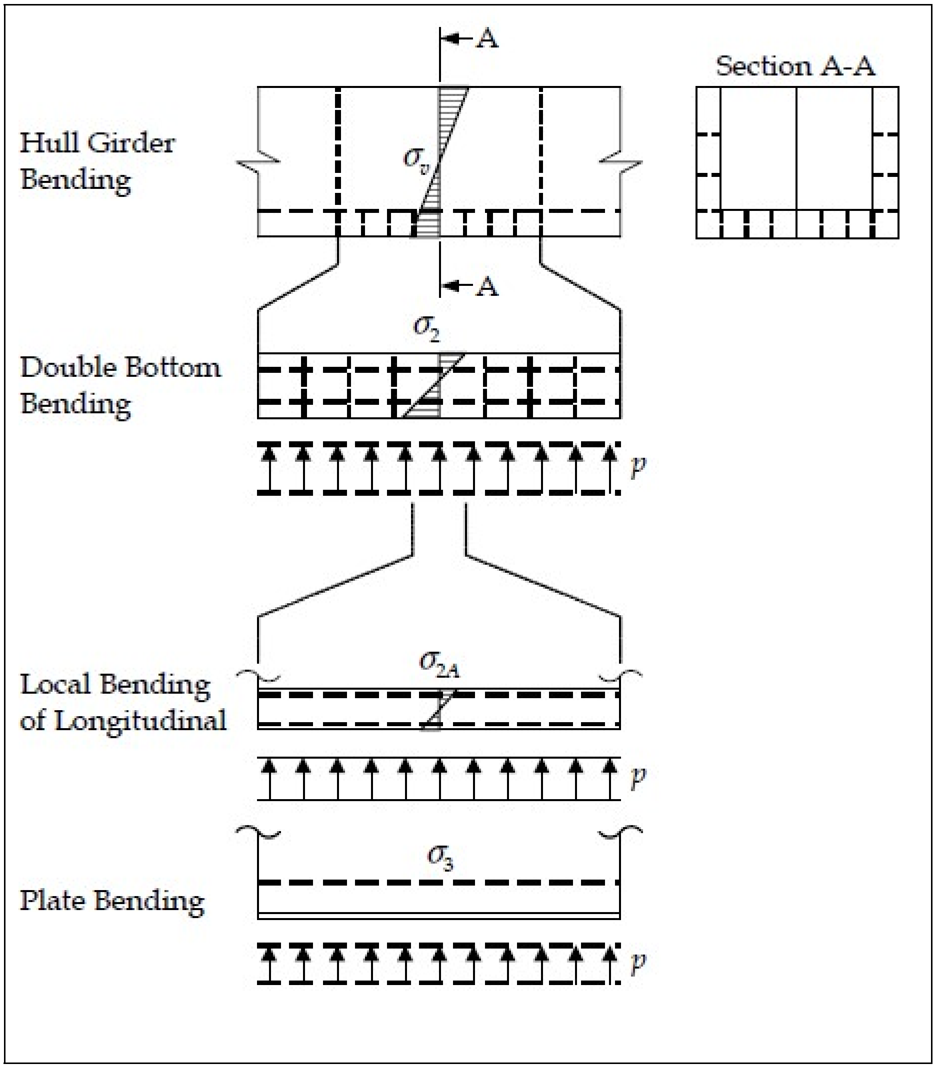


Figure 4.3.3 Definition of Local Stress Components

1.4.4.6. For the calculation of stress components, the vertical wave hull girder stress, σ_v, is given by:

$$\sigma_v = \frac{M_{wv-v-amp}}{Z_{v-net75}} 10^{-3} \qquad N/mm^2$$

Where:

$M_{wv-v-amp}$ Pseudo amplitude (half range), in kNm, as defined in 1.3.4

$Z_{v-net} \quad = \frac{I_{v-net}}{|z-z_{NA-net75}|} m^3$ See Chapter 1 Section 4/2.6.1

$I_{v-net75}$ Net vertical hull girder moment of inertia, of hull cross-section about transverse neutral axis, in m^4

$I_{v-net75}$ Is to be calculated based on gross thickness, minus the corrosion addition 0.25tcorr of all effective structural elements, see Chapter 1 Section 4/2.6.1

z Distance from baseline to the critical location of the considered member, i.e. top of flange of longitudinal stiffener, in m

$z_{NA-net75}$ Distance from baseline to horizontal neutral axis consistent with $I_{v-net75}$, in m

1.4.4.7. The corresponding stress range due to vertical wave bending moment, Sv, is to be taken as:

$$S_v = 2\sigma_v \quad N/mm^2$$

Where:

σ_v Vertical wave hull girder stress, in N/mm^2, as defined in 1.4.4.6

1.4.4.8. The horizontal wave hull girder stress, σ_h, is to be taken as:

$$\sigma_h = \frac{M_{wv-h-amp}}{Z_{h-net75}} 10^{-3} \quad N/mm^2$$

Where:

$M_{wv-h-amp}$ In kNm, as defined in 1.3.5

$Z_{h-net75}$ $\frac{I_{h-net}}{|y|}$ See Chapter 1Section 4/2.6.2

y Distance from vertical neutral axis of hull cross section to the critical location of the considered member, in m. i.e. top of face plate of longitudinal stiffener

I_{h-net} Net horizontal hull girder moment of inertia, of the hull cross-section about the vertical neutral axis, in m^4.

I_{h-net} Is to be calculated based on gross thickness, minus the corrosion addition 0.25tcorr for all effective structural elements, see Chapter 1 Section 4/2.6.2

1.4.4.9. The corresponding stress range due to horizontal wave bending moment, Sh, is to be taken as:

$$S_h = 2\sigma_h \quad N/mm^2$$

Where:

σ_h Horizontal wave hull girder stress, in N/mm^2, as defined in 1.4.4.8

1.4.4.10. The effect of secondary stress σ_2, as defined in 1.4.4.4, is in general small for double hull tankers and is therefore not taken into consideration.

1.4.4.11. The stress amplitude produced by bending of stiffeners between girder supports (e.g. frames, bulkheads), σ_{2A}, is to be taken as:

$$\sigma_{2A} = K_N K_d \frac{M}{Z_{net50}} 10^3 \quad N/mm^2$$

Where:

K_N Stress factor for unsymmetrical profiles, as defined in 1.4.4.15 K_d Stress factor for bending stress in longitudinal stiffeners caused by relative deformation between supports, may be determined by FE analysis of the cargo hold model where the actual relative deformation is considered or taken as follows:

1.0 At frame connections

1.15 For all longitudinals at transverse bulkhead connections including wash bulkheads except:

- in full load condition:

1.3 for side and bilge longitudinals at mid position between lowest side stringer and deck at side 1.15 for side and bilge longitudinals at lowest side stringer and deck at side to be linearly interpolated between these two positions 1.5 for bottom longitudinals at mid position between longitudinal bulkhead, bottom girders or buttress structure 1.15 for bottom longitudinals at longitudinal bulkhead, bottom girders or buttress structure to be linearly interpolated between these two positions See Figure 4.3.4

- in ballast condition:

1.5 for bottom longitudinals in the mid position between longitudinal bulkhead, bottom girders or buttress structure 1.15 for bottom longitudinals at longitudinal bulkhead, bottom girders or buttress structure to be linearly interpolated between these two positions

M Moment at stiffener support adjusted to weld toe location at the stiffener (e.g. at bracket toe), in kNm:

$$= \frac{Psl_{bdg}^{2} 10^{-3}}{12} r_p$$

s Stiffener spacing, in mm

lbdgEffective bending span, of longitudinal stiffener, as shown in Figure 4.3.5, in m. See also Figure 1.4.4 and 1.4.5 in Chapter 1 Section 4 for soft toe brackets. Top stiffeners with a soft toe are to be treated the same asflat bars with a soft toe bracket. The span point is to be taken at the point where the depth of the endbracket, measured from the face of the member, is equal to half the depth of the member

Z_{net50}Section modulus of longitudinal stiffener with attached effective plate flange b_{eff}, in cm^3, calculated based on gross thickness minus the corrosion addition $0.5t_{corr}$.

beff as defined in Chapter 1 Section 4/2.3.3

r_pMoment interpolation factor, for interpolation to weld toe location along the stiffener length:

$$\left| 6\left(\frac{x}{l_{bdg}}\right)^2 - 6\left(\frac{x}{l_{bdg}}\right) + 1.0 \right| \text{Where} 0 \le x \le l_{bdg}$$

Where x is the distance to the hot spot, in m. See Figure 4.3.5.

P Lateral dynamic pressure amplitude at the mid-span between the frame considered and the neighbouring frame, in kN/m^2.

$P_{in\text{-}amp}$ for dynamic tank pressure, is to be taken as defined in 1.3.7

$P_{ex\text{-}amp}$ for dynamic wave pressure, is to be taken as defined in 1.3.6

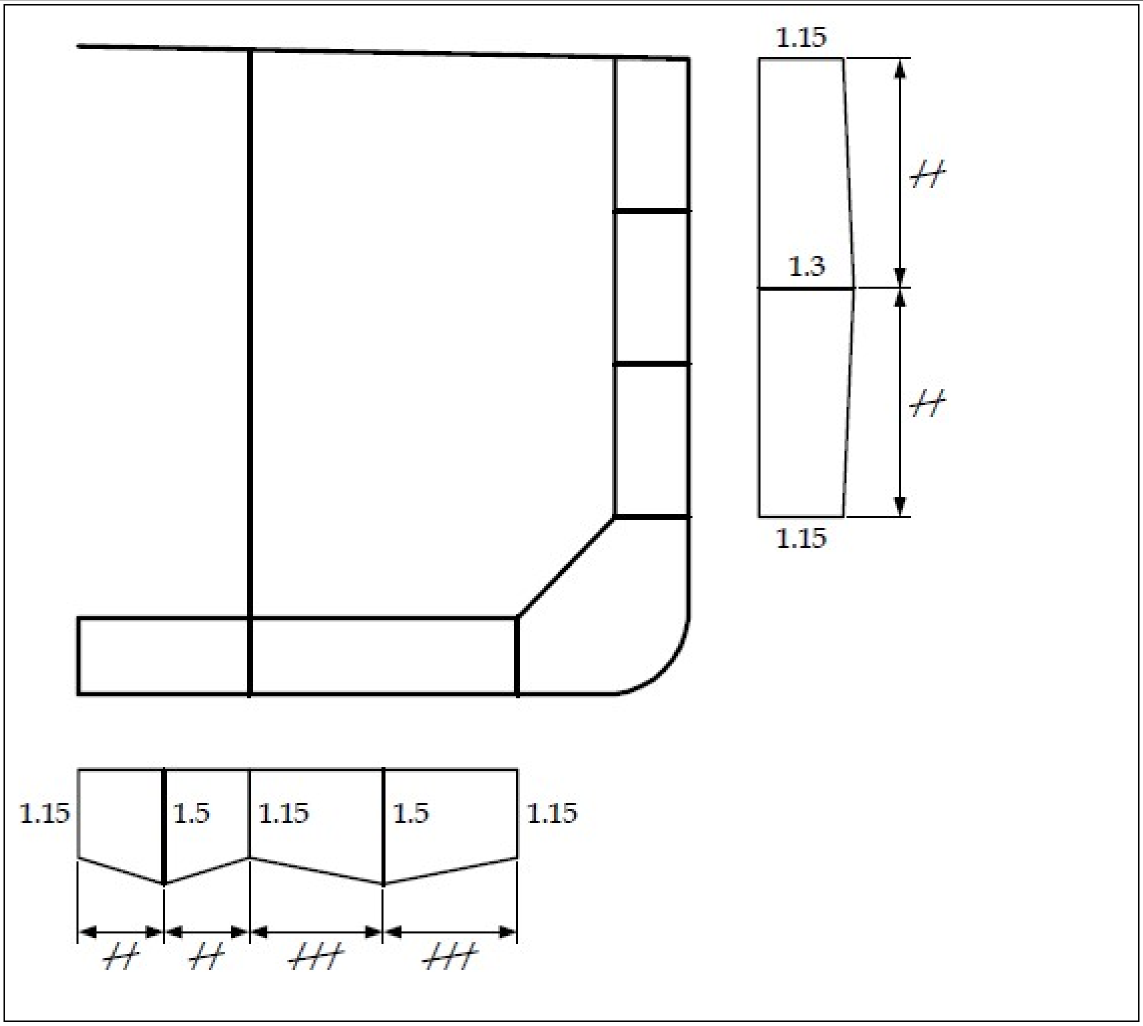


Figure 4.3.4 Variation of Bulkhead Factor K_d in Full Load Condition

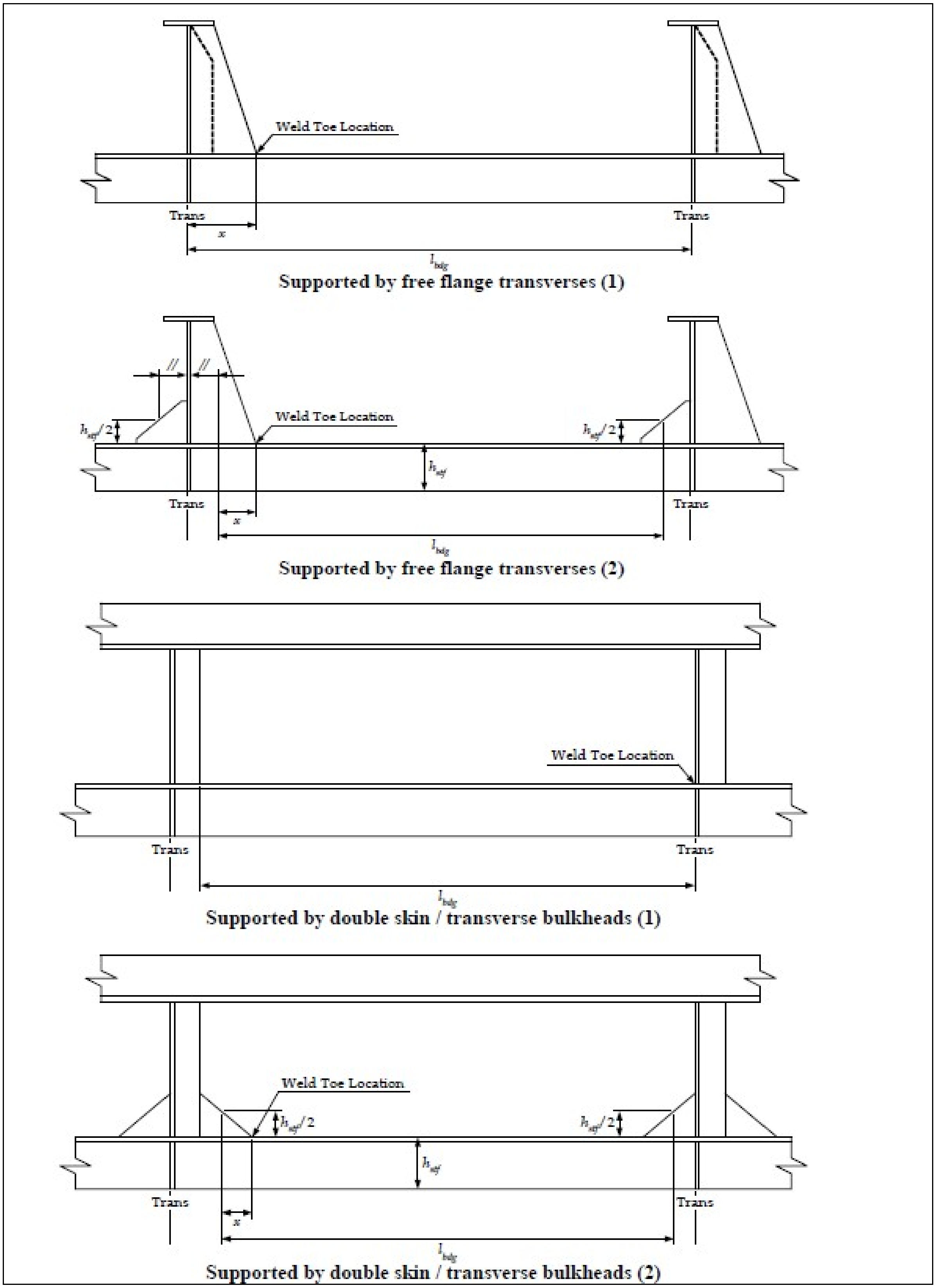


Figure 4.3.5 Definition of Effective Span Lengths

1.4.4.12. The stress range due to external wave or internal tank pressure, Se or Si, is to be determined as:

Where:

$$S_e = 2\sigma_{2A} \quad N/mm^2$$
$$S_i = 2\sigma_{2A} \quad N/mm^2$$

Where

$2\sigma_{2Ae}$ Stress amplitude, in N/mm^2, as defined in 1.4.4.11 when $P_{ex\text{-}amp}$ is used

$2\sigma_{2Ai}$Stress amplitude, in N/mm^2, as defined in 1.4.4.11 when $P_{in\text{-}amp}$ is used

1.4.4.13. Longitudinal local tertiary plate bending stress amplitude in the weld at the plate, transverse frame orbulkhead intersection, σ_3, is not relevant to the critical locations being considered and is to be neglected.

1.4.4.14. The effective breadth of plate flanges of stiffeners (longitudinals) in bending (due to the shear lag effect), exposed to uniform lateral load for bending at ends, is defined in Chapter 1 Section 4/2.3.3.

1.4.4.15. The stress concentration factors at the flange of un-symmetrical stiffeners on laterally loaded panels,K_{n1} and K_{n2}, as shown in Figure 4.3.6, are to be taken as:

$K_{n1} = \frac{1+\lambda\beta}{1+\lambda\beta^2\psi_z}$At the flange edge

$K_{n2} = \frac{1+\lambda\beta^2}{1+\lambda\beta^2\psi_z}$At the web

K_{n2}Is typically used in the fatigue analysis of longitudinal end connections

Where:

$\beta 1 - \frac{2b_g}{b_f}$For built-up profiles

$1 - \frac{t_{w-net50}}{b_f}$For rolled angle profiles

b_gBreadths of flange from web centreline, in mm, see Figure 4.3.7

$t_{w-net50}$Net web thickness, in mm

$d_w$depth of stiffener web, see Figure 4.3.7, in mm

λ Factor, as defined in 1.4.4.17

ψ_z Ratio between section modulus of the stiffener web with plate flange, as calculated at the flange and the section modulus of the complete panel stiffener

$\frac{d_w^2 t_{w-net50}}{4Z_{net50}10^3}$ May be used as an approximate value

Z_{net50} Section modulus of stiffener including the full width of the attached plate, s, with respect to a neutral axis normal to the stiffener web, in cm3. It is to be calculated based on the gross thickness minus the corrosion addition 0.5tcorr

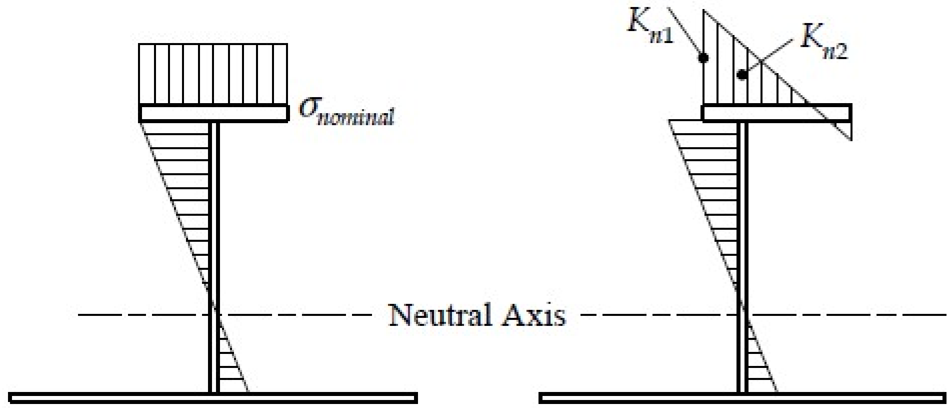


Figure 4.3.6 Bending Stress in Symmetrical and Un-symmetrical PanelStiffener with Same Web and Flange Areas

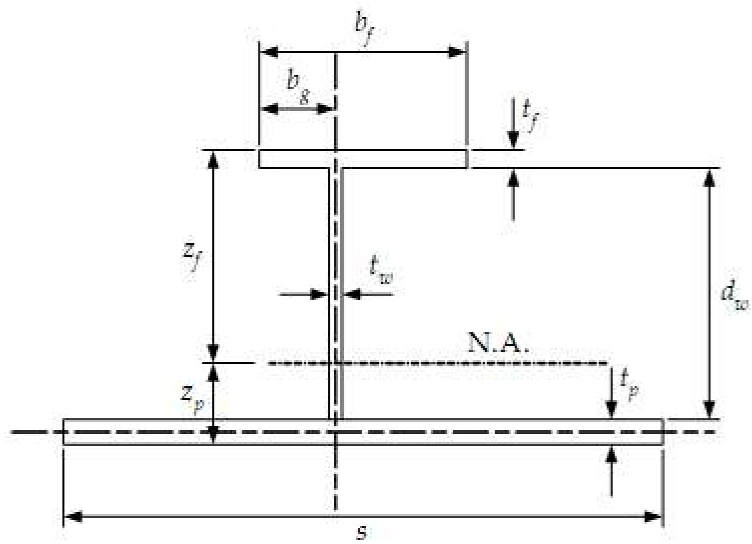


Figure 4.3.7 Stiffener Geometry

1.4.4.16. The formulations are not unswervingly applicable for bulb profiles. For these, the equivalent built-up profile is to be taken into account, see Figure 4.3.8. The assumed built-up flange is to have the similar properties as the bulb flange for cross-sectional area and moment of inertia about the vertical axis and neutral axis position. For HP bulb profiles, the equal built up profile dimensions are to be found. Several examples are tabulated in Table 4.3.2.

1.4.4.17. For continuous stiffeners (fixed ends) the λ-factor at supports is to be taken as:

$$\lambda = \frac{3\left(1+\frac{\eta}{280}\right)}{1+\frac{\eta}{40}}$$

Where $\eta = \dfrac{l_{bdg}^{4}10^{12}}{b_f^3 t_{f-net50} h_{stf}^2\left(\frac{4h_{stf}}{t_{w-net}^3}+\frac{s}{t_{p-net50}^3}\right)}$

l_{bdg} Bending span, of longitudinal stiffener, in m

b_fBreadth of flange, in mm
t_{f-net} Flange thickness, in mm
h_{stf}Stiffener height, including face plate, in mm
$t_{w-net50}$Web thickness, in mm
t_{p-net} Net plate thickness, in mm
Splate width between stiffeners, in mm

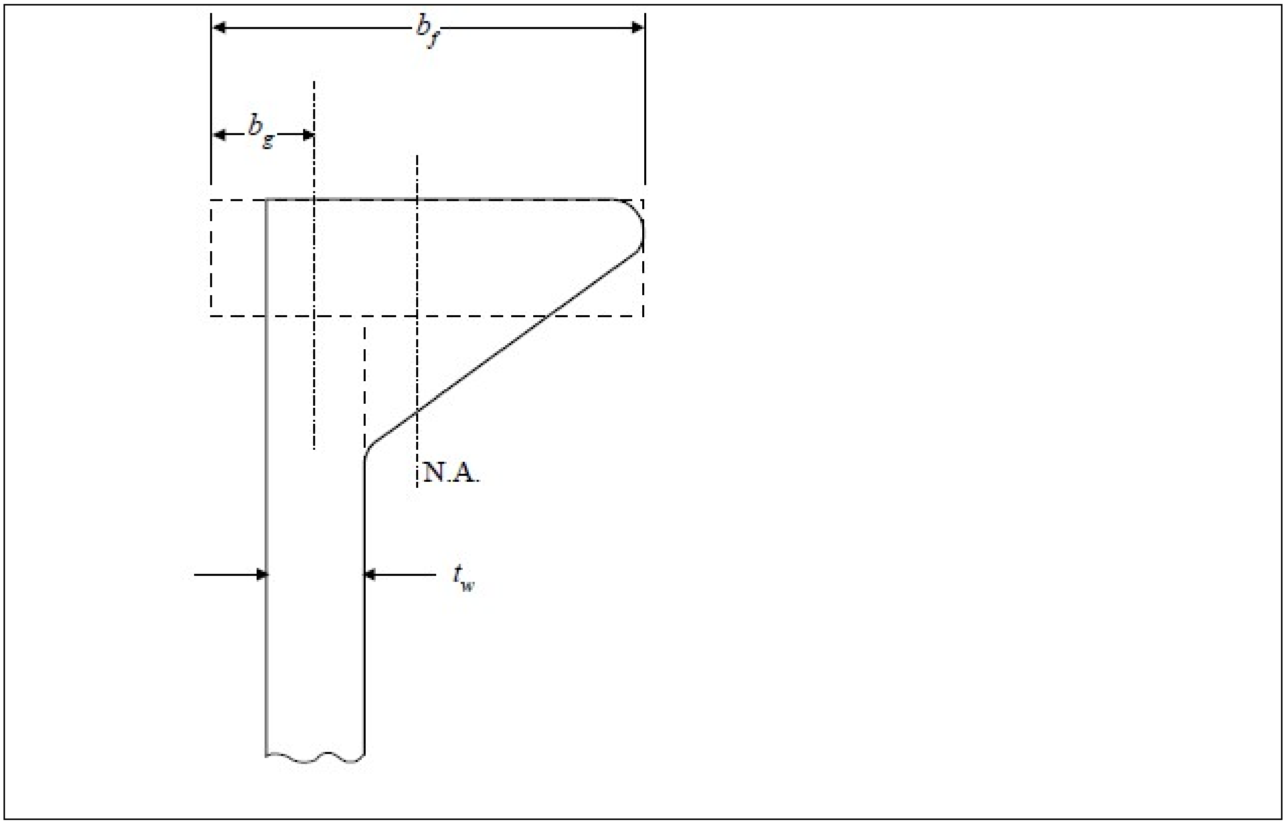


Figure 4.3.8 Bulb Profile and Equivalent Built-up Flange

Table 4.3.2 HP Equivalent Built-up Profile Dimensions				
HP- bulb		Equivalent built-up flange		
Height (mm)	Web thickness t_w (mm)	b_f (mm)	t_f (mm)	b_g (mm)
200	9 – 13	t_w + 24.5	22.9	(t_w + 0.9)/2
220	9 - 13	t_w+ 27.6	25.4	(t_w + 1.0)/2
240	10 – 14	t_w + 30.3	28.0	(t_w + 1.1)/2
260	10 – 14	t_w + 33.0	30.6	(t_w + 1.3)/2
280	10 – 14	t_w+ 35.4	33.3	(t_w + 1.4)/2
300	11 – 16	t_w+ 38.4	35.9	(t_w + 1.5)/2
320	11 – 16	t_w + 41.0	38.5	(t_w + 1.6)/2
340	12 – 17	t_w + 43.3	41.3	(t_w + 1.7)/2
370	13 – 19	t_w + 47.5	45.2	(t_w + 1.9)/2
400	14 – 19	t_w + 51.7	49.1	(t_w + 2.1)/2
430	15 – 21	t_w + 55.8	53.1	(t_w + 2.3)/2

1.4.4.18. For each loading condition, along with global stress components induced by hull girder wave bending , combined local stress components due to simultaneous dynamic tank and dynamic wave pressure loads are to be joined

1.4.4.19. Total combined stress range, S, is given by:

$$S = f_{SN|f_1 S_v + f_2 S_h + f_3 S_e + f_4 S_i|} \quad N/mm^2$$

Where:

$f_1 + f_2 + f_3 + f_4$Stress range combination factors, representing the phase correlation between total stress range and each stress range component which is between 1.0 and -1.0, as defined in Table 4.3.3 to 4.3.5. Where the factor is greater than 1.0 it is to be taken as 1.0. Where the factor is less than -1.0 it is to be taken as -1.0

f_{SN} 1.06, factor to account for joints in combined protected and unprotected environment.

S_vCorresponding stress range due to vertical bending moment, in N/mm2, as defined in 1.4.4.7

S_hCorresponding stress range due to horizontal bending moment, in N/mm^2, as defined in 1.4.4.9

S_eStress range due to external wave or internal tank pressure, in N/mm^2, as defined in 1.4.4.12

$S_i$stress range due to external wave or internal tank pressure, in N/mm^2, as defined in 1.4.4.11.4.4.20 The stress range combination factors, f_1, f_2, f_3 and f_4, which are to be applied to the

Following zones are given in Tables 4.3.2 to 4.3.4:

a) Zone M: Amidships region. This zone extends over the full length of all tanks where the tank LCG lies between 0.35L and 0.8L from AP.

b) Zone A: Aft region. This zone starts at the middle of the tank immediately aft of Zone M and extends aft wards to include all the aft most tanks.

c) Zone F: Forward region. This zone starts at the middle of the tank immediately forward of Zone M and extends forwards to include all the foremost tanks.

d) Zone AT: Aft transition region between Zone M and Zone A. The stress range combination factors are tobe calculated by linear interpolation between the stress range combination factors for Zones M and A.

e) Zone FT: Forward transition region between Zone M and Zone F. The stress range combination factors areto be calculated by linear interpolation between the stress range combination factors for Zones M and F.

Note:

Where ballast tanks, Centre and wing cargo tanks do not have the same lengths the middle position is to be taken at the middle of the longer tank e.g. if slop tank is present

Table 4.3.3 Stress Range Combination Factors for Zone M

	Stiffener location		f_1	f_2	f_3	f_4	f_i
Ballast	Bottom shell	a_i	-0.49	0.49	-1.04	-0.13	$a_i(\|y\|/B) + b_i$
		b_i	0.97	0.17	0.87	0.56	
	Side shell and bilge below D/2	a_i	-1.48	0.50	-0.64	0.72	$a_i(z/D) + b_i$
		b_i	0.94	0.40	0.72	0.04	
	Side shell above D/2	a_i	1.70	-1.00	-1.10	-0.60	$a_i(z/D) + b_i$
		b_i	-0.65	1.15	0.95	0.70	
	Inner bottom and Lower stool	a_i	-0.18	0.34	0.00	-0.30	$a_i(\|y\|/B) + b_i$
		b_i	0.90	0.22	0.00	0.74	
	Inner hull below D/2 (including hopper plate)	a_i	-1.70	-0.90	0.00	1.04	$a_i(z/D) + b_i$
		b_i	1.15	0.70	0.00	0.45	
	Inner hull above D/2	a_i	1.40	0.50	0.00	-1.94	$a_i(z/D) + b_i$
		b_i	-0.40	0.00	0.00	1.94	
	Deck and Upper stool	a_i	-0.15	1.05	0.00	0.00	$a_i(\|y\|/B) + b_i$
		b_i	1.02	-0.27	0.00	0.00	
	Centreline longitudinal bulkhead Below D/2	ai	0.00	0.00	0.00	0.00	$a_i(z/D) + b_i$
		b_i	1.00	0.00	0.00	0.00	
	Centreline longitudinal bulkhead Above D/2	a_i	0.00	0.00	0.00	0.00	$a_i(z/D) + b_i$
		b_i	1.00	0.00	0.00	0.00	
	Longitudinal bulkhead below D/2	a_i	-0.20	1.30	0.00	0.00	$a_i(z/D) + b_i$
		b_i	1.00	0.10	0.00	0.00	
	Longitudinal bulkhead above D/2	a_i	0.20	-1.30	0.00	0.00	$a_i(z/D) + b_i$
		b_i	0.80	1.40	0.00	0.00	
Loaded	Bottom shell	a_i	-0.43	0.78	-0.77	0.00	$a_i(\|y\|/B) + b_i$
		b_i	0.98	0.13	0.75	0.00	
	Side shell and bilge below D/2	a_i	-0.29	-0.47	0.14	0.00	$a_i(z/D) + b_i$
		b_i	0.19	0.78	0.92	0.00	
	Side shell above D/2	a_i	1.77	-0.05	-1.20	0.00	$a_i(z/D) + b_i$
		b_i	-0.84	0.57	1.59	0.00	
	Inner bottom and Lower stool	a_i	-0.71	1.13	0.00	0.55	$a_i(\|y\|/B) + b_i$
		b_i	1.03	0.18	0.00	-0.18	
	Inner hull below D/2 (including hopper plate)	a_i	-0.80	-1.70	0.00	2.60	$a_i(z/D) + b_i$
		b_i	0.55	1.20	0.00	-0.35	
	Inner hull above D/2	a_i	1.90	0.30	0.00	-1.70	$a_i(z/D) + b_i$
		b_i	-0.80	0.20	0.00	1.80	
	Deck and Upper stool	a_i	-0.26	1.40	0.00	0.00	a_i $(\|y\|/B) + b_i$
		b_i	1.02	-0.16	0.00	0.00	
	Centreline longitudinal bulkhead below D/2	a_i	-1.40	0.00	0.00	1.00	$a_i(z/D) + b_i$
		b_i	0.75	0.00	0.00	0.60	
	Centreline longitudinal bulkhead above D/2	a_i	1.70	0.00	0.00	-1.20	$a_i(z/D) + b_i$
		b_i	-0.80	0.00	0.00	1.70	
	Longitudinal bulkhead below D/2	a_i	-0.60	0.40	0.00	1.10	$a_i(z/D) + b_i$
		b_i	1.00	0.40	0.00	0.05	
	Longitudinal bulkhead above D/2	a_i	0.60	-0.84	0.00	-0.84	$a_i(z/D) + b_i$
		b_i	0.40	1.02	0.00	1.02	

Table 4.3.4 Stress Range Combination Factors for Zone A

	Stiffener location		f_1	f_2	f_3	f_4	f_i
Ballast	Bottom shell	A_i	-0.20	-0.80	1.20	1.50	$a_i(\lvert y\rvert/B) + b_i$
		B_i	0.00	0.50	-0.25	1.07	
	Side shell and bilge below D/2	A_i	-1.00	1.20	-0.80	2.00	$a_i(z/D) + b_i$
		b_i	0.20	0.00	0.60	-0.40	
	Side shell above D/2	a_i	3.40	-1.20	-2.80	-0.80	$a_i (z/D) + b_i$
		b_i	-2.00	1.20	1.60	0.20	
	Inner bottom and Lower stool	a_i	-0.50	-1.90	0.00	0.30	$a_i(\lvert y\rvert/B) + b_i$
		b_i	-0.05	0.60	0.00	0.85	
	Inner hull below D/2	a_i	8.20	-2.80	0.00	0.20	$a_i(z/D) + b_i$
		b_i	-3.50	1.00	0.00	0.90	
	Inner hull above D/2	a_i	0.60	2.80	0.00	-0.50	$a_i(z/D) + b_i$
		b_i	0.30	-1.80	0.00	1.25	
	Deck and Upper stool	a_i	0.00	0.70	0.00	0.00	$a_i(\lvert y\rvert/B) + b_i$
		b_i	1.00	0.00	0.00	0.00	
	Inner longitudinal bulkhead Below D/2	a_i	-1.20	2.00	0.00	0.00	$a_i(z/D) + b_i$
		b_i	1.10	0.00	0.00	0.00	
	Inner longitudinal bulkhead Above D/2	a_i	1.50	-2.70	0.00	0.00	$a_i(z/D) + b_i$
		b_i	-0.25	2.35	0.00	0.00	
	Centreline longitudinal bulkhead Below D/2	a_i	0.00	0.00	0.00	0.00	$a_i(z/D) + b_i$
		b_i	1.00	0.00	0.00	0.00	$a_i(z/D) + b_i$
	Centreline longitudinal bulkhead Above D/2	a_i	0.00	0.00	0.00	0.00	$a_i(z/D) + b_i$
		b_i	1.00	0.00	0.00	0.00	$a_i(z/D) + b_i$
Loaded	Bottom shell	a_i	-2.20	1.50	2.60	0.00	$a_i (\lvert y\rvert/B) + b_i$
		b_i	1.20	-0.15	-0.30	0.00	
	Side shell and bilge below D/2	a_i	-1.20	-1.20	0.60	0.00	$a_i(z/D) + b_i$
		b_i	0.30	0.80	0.70	0.00	
	Side shell above D/2	a_i	3.00	-0.30	-0.50	0.00	$a_i(z/D) + b_i$
		b_i	-1.80	0.35	1.25	0.00	
	Inner bottom and Lower stool	a_i	-1.00	2.30	0.00	-0.20	$a_i(\lvert y\rvert/B) + b_i$
		b_i	1.00	-0.10	0.00	0.00	
	Inner hull below D/2	a_i	-0.80	1.00	0.00	1.00	$a_i (z/D) + b_i$
		b_i	0.20	0.00	0.00	0.50	
	Inner hull above D/2	a_i	3.20	-1.00	0.00	-0.80	$a_i(z/D) + b_i$
		b_i	-1.80	1.00	0.00	1.40	
	Deck and Upper stool	a_i	-0.10	1.50	0.00	0.00	$a_i(\lvert y\rvert/B) + b_i$
		b_i	1.00	-0.15	0.00	0.00	
	Inner longitudinal bulkhead Below D/2	a_i	-0.80	0.30	0.00	1.00	$a_i(z/D) + b_i$
		b_i	1.00	0.50	0.00	0.30	
	Inner longitudinal bulkhead Above D/2	a_i	0.20	-0.90	0.00	-0.08	$a_i(z/D) + b_i$
		b_i	0.50	1.10	0.00	0.84	
	Centreline longitudinal bulkhead Below D/2	a_i	-1.10	0.00	0.00	0.44	$a_i(z/D) + b_i$
		b_i	0.60	0.00	0.00	0.80	$a_i(z/D) + b_i$
	Centreline longitudinal bulkhead Above D/2	a_i	1.30	0.00	0.00	-0.56	$a_i(z/D) + b_i$
		b_i	-0.60	0.00	0.00	1.30	$a_i(z/D) + b_i$

Table 4.3.5 Stress Range Combination Factors for Zone F

	Stiffener location		f_1	f_2	f_3	f_4	f_i
Ballast	Bottom shell	a_i	-0.90	1.00	2.40	-1.20	$a_i(\|y\|/B) + b_i$
		b_i	0.85	-0.10	-1.00	1.10	
	Side shell and bilge below D/2	a_i	-0.60	-0.40	1.00	-1.80	$a_i(z/D) + b_i$
		b_i	0.00	0.50	-0.15	0.90	
	Side shell above D/2	a_i	0.60	-0.90	-2.70	3.00	$a_i (z/D) + b_i$
		b_i	-0.60	0.75	1.70	-1.50	
	Inner bottom and Lower stool	a_i	-0.30	-1.00	0.00	0.00	$a_i (\|y\|/B) + b_i$
		b_i	0.90	0.25	0.00	1.00	
	Inner hull below D/2	a_i	-12.00	-2.40	0.00	1.20	$a_i(z/D) + b_i$
		b_i	5.00	1.00	0.00	0.50	
	Inner hull above D/2	a_i	3.00	1.40	0.00	-0.90	$a_i(z/D) + b_i$
		b_i	-2.50	-0.90	0.00	1.55	
	Deck and Upper stool	a_i	0.00	1.00	0.00	0.00	$a_i(\|y\|/B) + b_i$
		b_i	1.00	-0.10	0.00	0.00	
	Inner longitudinal bulkhead Below D/2	a_i	-1.80	1.90	0.00	0.00	$a_i(z/D) + b_i$
		b_i	1.30	0.00	0.00	0.00	
	Inner longitudinal bulkhead Above D/2	a_i	1.80	-2.50	0.00	0.00	$a_i(z/D) + b_i$
		b_i	-0.50	2.20	0.00	0.00	
	Centreline longitudinal bulkhead Below D/2	a_i	0.00	0.00	0.00	0.00	$a_i(z/D) + b_i$
		b_i	1.00	0.00	0.00	0.00	$a_i(z/D) + b_i$
	Centreline longitudinal bulkhead Above D/2	a_i	0.00	0.00	0.00	0.00	$a_i(z/D) + b_i$
		b_i	1.00	0.00	0.00	0.00	$a_i(z/D) + b_i$
Loaded	Bottom shell	a_i	-0.60	-0.15	0.00	0.00	$a_i (\|y\|/B) + b_i$
		b_i	-0.45	0.05	1.00	0.00	
	Side shell and bilge below D/2	a_i	-1.20	0.18	0.00	0.00	$a_i(z/D) + b_i$
		b_i	0.00	-0.03	1.00	0.00	
	Side shell above D/2	a_i	4.00	0.02	0.00	0.00	$a_i(z/D) + b_i$
		b_i	-2.60	0.05	1.00	0.00	
	Inner bottom and Lower stool	a_i	2.80	2.20	0.00	-1.00	$a_i(\|y\|/B) + b_i$
		b_i	-0.80	-0.30	0.00	1.10	
	Inner hull below D/2	a_i	10.20	1.60	0.00	0.00	$a_i (z/D) + b_i$
		b_i	-4.50	-0.60	0.00	1.00	
	Inner hull above D/2	a_i	-0.80	-0.90	0.00	0.00	$a_i(z/D) + b_i$
		b_i	1.00	0.65	0.00	1.00	
	Deck and Upper stool	a_i	-0.24	1.80	0.00	0.00	$a_i (\|y\|/B) + b_i$
		b_i	1.00	0.00	0.00	0.00	
	Inner longitudinal bulkhead Below D/2	a_i	-2.10	-1.00	0.00	1.50	$a_i(z/D) + b_i$
		b_i	1.15	0.60	0.00	0.35	
	Inner longitudinal bulkhead Above D/2	a_i	0.40	-0.30	0.00	-0.40	$a_i(z/D) + b_i$
		b_i	-0.10	0.25	0.00	1.30	
	Centreline longitudinal bulkhead Below D/2	a_i	-0.60	0.00	0.00	0.00	$a_i(z/D) + b_i$
		b_i	0.25	0.00	0.00	1.00	$a_i(z/D) + b_i$
	Centrelinelongitudinal bulkhead Above D/2	a_i	0.20	0.00	0.00	0.00	$a_i(z/D) + b_i$
		b_i	-0.15	0.00	0.00	1.00	$a_i(z/D) + b_i$

1.4.5. Selection of S-N curves

1.4.5.1. The capacity of welded steel joints with respect to fatigue strength is characterized by S-N curveswhich give the relationship between the stress ranges applied to a given detail and the number of constantamplitude load cycles to failure.

1.4.5.2. For ship structural details, S-N curves are represented by:

$$S^m N = K_K$$

Where:

S stress range, in N/mm^2, as defined in 1.4.4.19

N predicted number of cycles to failure under stress range S

m constant depending on material and weld type, type of loading, geometrical configuration and environmental conditions (air or sea water), as defined in 1.4.5.5.

K_2constant depending on material and weld type, type of loading, geometrical configuration and environmental conditions (air or sea water), as defined in 1.4.5.5.

1.4.5.3. Experimental S-N curves are defined by their mean fatigue life and standard deviation. The mean SN curve gives the stress level S at which the structural detail will fail with a probability level of 50 percent after N loading cycles. S-N curves considered in the present Rules are based upon a statistical analysis of appropriate experimental data and represent two standard deviations below the mean lines.

1.4.5.4. Unless direct experimental measurements are available, the S-N curves described in 1.4.5.5 to 1.4.5.16 are to be used for assessment of the fatigue strength of structural details.

1.4.5.5. As shown in Figure 4.3.9, the basic design curves consist of linear relationships between log(S) andlog(N), which are to be expressed as follows. The S-N curves have a change of inverse slope from m to m + 2 at N = 10^7cycles (which corresponds to stress range S_q).

log(N) = log (K_2) –m log(S)

where:

log(K_2) = log K_1 -2(δ)

N predicted number of cycles to failure under stress range S

K_1constant relating to the mean S-N curve, as given in Table 4.3.6

δ standard deviation of log(N)

m inverse slope of the S-N curve, as given in Table 4.3.6

S_qStress range corresponding to 10^7 cycles of the S-N curve, in N/mm^2 , as given in Table 4.3.6

Table 4.3.6 Basic S-N Curve Data, In-Air

Class	*K_1*			m	*Standard Deviation*		K_2	S_qN/mm^2
		log_{10}	*log_e*		*log_{10}*	*log_e*		
B	2.343E15	15.3697	35.3900	4.0	0.1821	0.4194	1.01E15	100.2
C	1.082E14	14.0342	32.3153	3.5	0.2041	0.4700	4.23E13	78.2
D	3.988E12	12.6007	29.0144	3.0	0.2095	0.4824	1.52E12	53.4
E	3.289E12	12.5169	28.8216	3.0	0.2509	0.5777	1.04E12	47.0
F	1.726E12	12.2370	28.1770	3.0	0.2183	0.5027	0.63E12	39.8
F_2	1.231E12	12.0900	27.8387	3.0	0.2279	0.5248	0.43E12	35.0
G	0.566E12	11.7525	27.0614	3.0	0.1793	0.4129	0.25E12	29.2
W	0.368E12	11.5662	26.6324	3.0	0.1846	0.4251	0.16E12	25.2

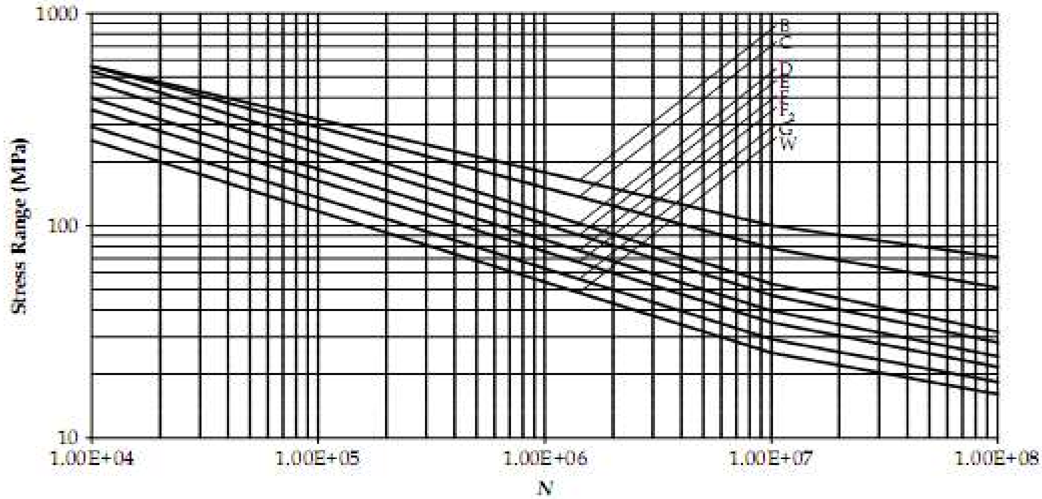


Figure 4.3.9 Basic design S-N curves, In-Air

1.4.5.6. The class of S-N curve chosen for determination of the cumulative fatigue damage, DM, is to be constant with the fatigue calculation methods used and the type of detail to be analyzed.

1.4.5.7. Experimental S-N curves give the relation between the nominal stress range and the number of cycles to failure. Because of that, when using these S-N curves, the calculated stresses are to keep up a correspondence to the nominal stresses used in creating these curves.

1.4.5.8. The basic S-N curves to be used in this Section for fatigue assessment of longitudinal stiffener end connections are given in 1.4.5.5, with the S-N curve parameters given in Table 4.3.6.

1.4.5.9. Generally adjustments to the S-N curves to take into account the following can be made

a.) Effect of mean stresses
b.) Effect of plate thickness
c.) Weld improvement
d.) Influence of the environment

1.4.5.10. Depending on whether the mean stress is tensile or compressive the stress range may be reduced. The effect of mean stress may be taken into account by assuming a stress range equivalent to the tensile component plus 60% of the compressive component in the event that it can be demonstrated that a compressive stress is present and can be quantified. The actual still water bending moment (SWBM) and the applicable static sea and tank pressures for the full load condition or ballast condition as suitable are to be used in order to determine the mean stress level.

1.4.5.11. The total stress range considering the mean stress effect is to be taken as follows:

$S_{RI} = \sigma_{tensile} - 0.6\sigma_{cpmpressive}$ if $\sigma_{cpmpressive} < 0$ *and* $\sigma_{tensile} > 0$

$S_{RI} = S$ if $\sigma_{cpmpressive} \geq 0$

$S_{RI} = 0.6S$ if $\sigma_{tensile} \leq 0$

Where, $\sigma_{tensile}$ mean stress plus half stress range, in N/mm^2

$= \sigma_{\text{mean}} + S/2$

$\sigma_{\text{cpmpressive}}$ Mean stress minus half stress range, in N/mm^2

$= \sigma_{\text{mean}} - S/2$

σ_{mean} Mean stress due to static load components in the full load condition or ballast condition as appropriate, in N/mm^2, see section 1.3.2
For the nominal stress approach, S and σ_{mean} are to be calculated as follows:
S total combined stress range in N/mm^2 , as defined in 1.4.4.19

$$= \sigma_{tensile} - \sigma_{compressive}$$

$$\sigma_{\text{mean}} = \sigma_{hg} - \sigma_{ex} + \sigma_{in}$$

σ_{hg} Mean stress due to hull girder bending, to be derived using σ_{v} from 1.4.4.6 with $M_{wv\text{-}v\text{-}amp}$ taken as the actual SWBM for the full load condition as appropriate, see 1.3.2
σ_{ex} mean local bending stress due to external static sea pressure, if applicable, σ_{ex} is to be derived using σ_{2A} from 1.4.4.11 with { calculated based on the actual draught for the full load condition or ballast condition as appropriate, see 1.3.2, where P= P_{hys} see Chapter 2 Section 1/2.2.2.1
σ_{in} mean local bending stress sue to internal static tank pressure, if applicable σ_{in} is to be derived using σ_{2A} from 1.4.4.11 with P calculated based on the head to the Top of tank and the tank contents for the full load condition or ballast condition as appropriate, see 1.3.2 where P=$P_{in\text{-}tk}$ see Chapter 2 section 1/2.2.3.1

Notes

1) P is to be taken as negative when the pressure is acting on the plate side and positive when acting on the stiffener side. This gives compressive stress with a negative sign

2) Where the stiffener is on the boundary between two cargo tanks, then the mean stress is to be taken as the net stress acting on the stiffener.

3) The fluid density is to be taken, where cargo density is not to be less than 0.9 tonnes/m^3, it is to be understood that water ballast and cargo tanks are 100% full. In accordance with Chapter 2 Section 1/2.2.3. The mean stress, σmean, is to be calculated by applying the applicable static loads to the FE model for the full load condition or ballast condition as appropriate for the hot spot stress approach in Sub Section 2. On the other hand, in lieu of applying the static loads to the FE model, the total stress range is to be calculated in accordance with 2.4.2.8.

1.4.5.12. The fatigue performance of a structural depends on member thickness. Intended for the same stress range the joint's fatigue resistance may decrease as the member thickness increases. This effect (also called the 'scale effect') is caused by the local geometry of the weld toe related to the thickness of the adjoining plates and the stress gradient over the thickness. The basic design S-N curves are appropriate to thicknesses that do not go beyond the reference thickness of 22mm. The S-N curve for a joint member for members with thickness greater than 22mm, with net thickness, t_{net50}, in mm, is to be taken as:

$$\log(\text{N}) = \log(\text{K}_2) - \text{mlog}\left(\frac{\text{S}_{\text{Ri}}}{(22/\text{t}_{\text{net50}})^{0.25}}\right)$$

Where

$$\log(\mathrm{K}_2) = \log K_1 - 2\delta$$

N the predicted number of cycles to failure under stress range S

K_1 constant relating to the mean S-N curve, as given in Table 4.3.6

δ Standard deviation of log (N)

m inverse slope of the S-N curve, as given in Table 4.3.6

S_{Ri} Stress range, as defined in 1.4.5.11, in N/mm^2

1.4.5.13. Where the longitudinal stiffeners are flat bars or bulb plates the thickness effect described in 1.4.5.12 is not applicable.

1.4.5.14. The benefits of weld toe grinding should not be considered at the design stage. Nevertheless, if the calculated fatigue life is greater than one half of the design fatigue life or minimum 17 years apart from the grinding effects whichever is greater, then there is exception for the weld connection between the hopper plate and inner bottom . Wherever grinding is applied, full details of the grinding standard together with the extent, smoothness particulars, final weld profile, and grinding workmanship and quality acceptance criteriaare to be clearly shown on the appropriate drawings and submitted for review together with supporting calculations signifying the proposed factor on the calculated fatigue life. Grinding is be performed by rotary burr and to extend below the plate surface for removing toe defects and the ground area is to have effective corrosion protection .The treatment is to generate a smooth concave profile at the weld toe, with the depth of the depression penetrating into the plate surface to at least 0.5 mm below the bottom of any visible undercut. The depth of groove formed is to be kept to a minimum, and, generally, kept to a maximum of 1mm, in any circumstances the grinding depth to do not exceed 2mm or 7% of the plate gross thickness, whichever is smaller. Grinding has to expand to areas well outside the highest stress region.An improvement in fatigue life up to the design fatigue life will be granted provided these suggestions are followed.

1.4.5.15. Joints located in air or details exposed to sea water but satisfactorily protected from corrosion by effective coating. As shown in Figure 4.3.6 or these joints basic design S-N curves are valid .The basic S-N curves are to be reduced by a factor of 2 on fatigue life for exposed joints in sea water.

1.4.5.16. As shown in Figure 4.3.6, the basic design S-N curves are used in this Section. To account for the fact that the joint will spend part of the time in a protected environment and part of time in an exposed environment, a factor fSN, has been commenced into the total nominal stress range calculation.

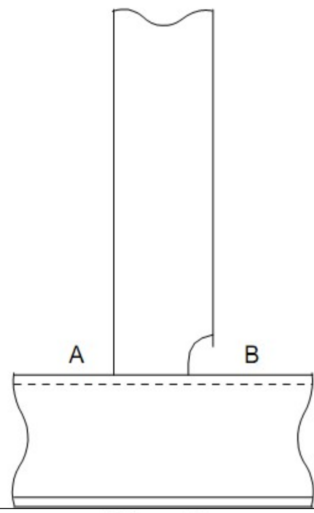
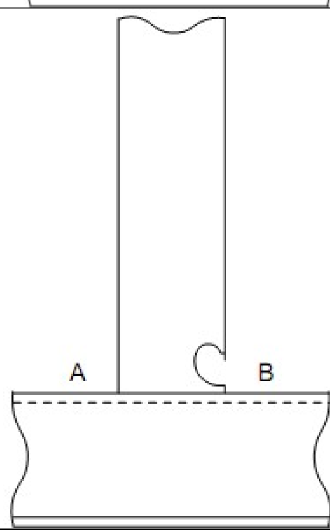
1.5. Classification of Structural Details

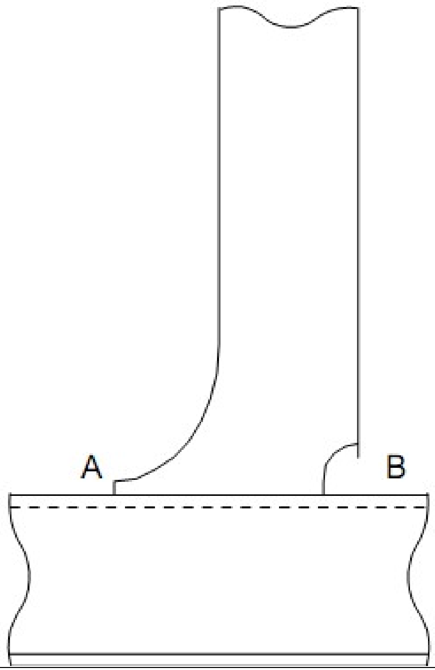
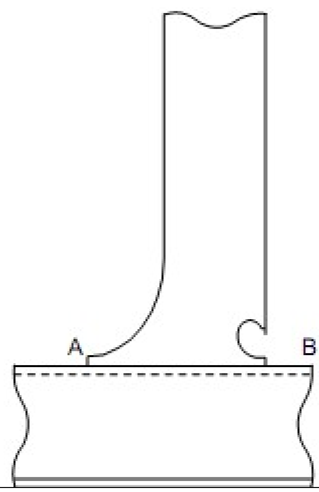
1.5.1. General

1.5.1.1. The classification of is to be done using Table 4.3.7 where the design of soft toes and backing brackets corresponds to those displayed in Figure 4.3.10. The adequacy in terms of fatigue strength is to be established using a suitable finite element analysis when alternative designs are proposed. See 2.1.1.3.

1.5.1.2. where the primary support member web stiffeners are absent or not connected to the longitudinals in way of bottom, side and inner hull.See Note 6 of Table 4.3.7

Table 4.3.7 Classification of Structural Details

ID	Connection type	Critical Locations Notes (1), (2), (3)	
		A	B
1		F2	F2
2		F2	F2(4)

ID	Connection type	Critical Locations Notes (1), (2), (3)	
		A	B
3		F	F2
4		F	F2(4)

ID	Connection type	Critical Locations Notes (1), (2), (3)	
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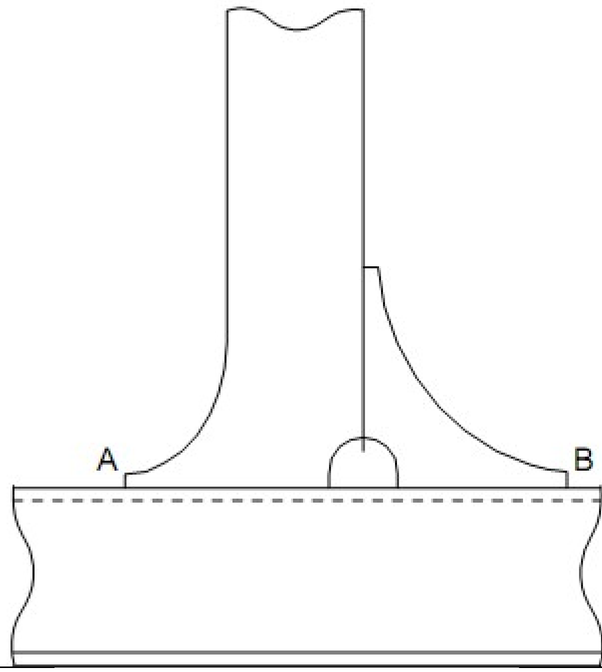
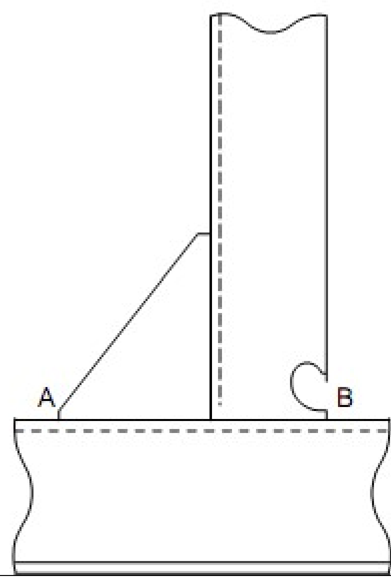
5		F	F
6		F2	F2(4)

ID	Connection type	Critical Locations Notes (1), (2), (3)	
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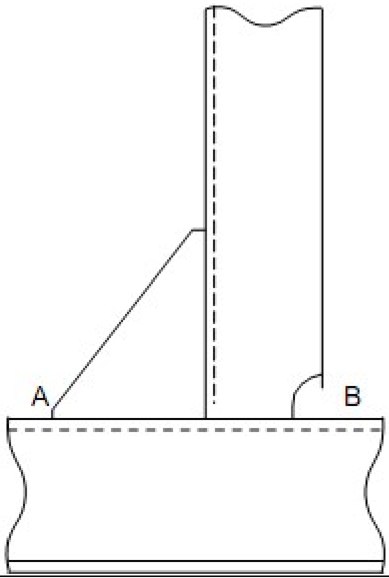
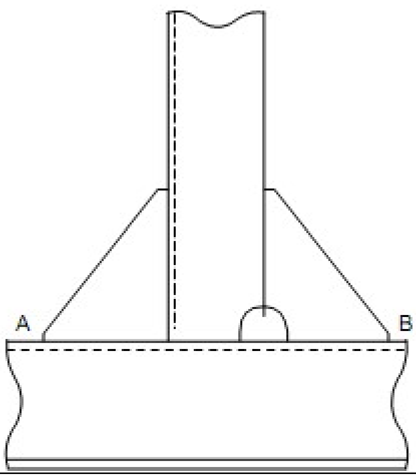
7		F2	F2
8		F2	F2

ID	Connection type	Critical Locations Notes (1), (2), (3)	
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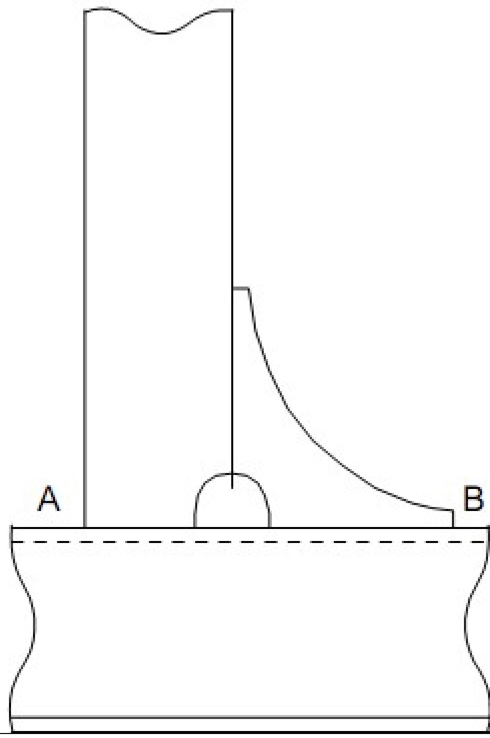
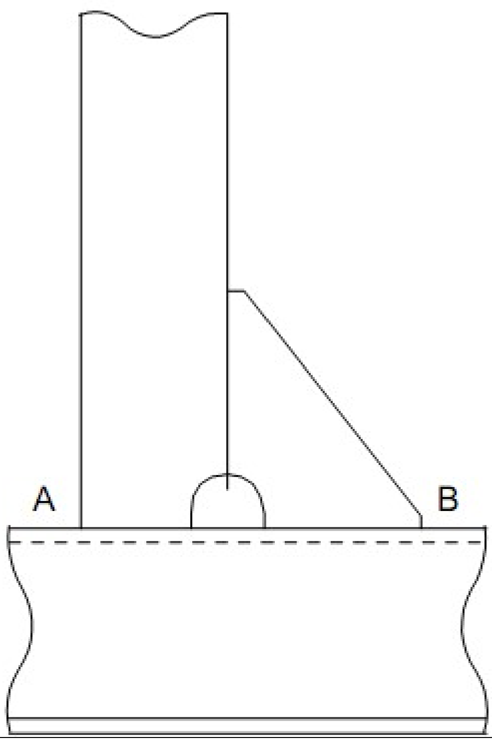
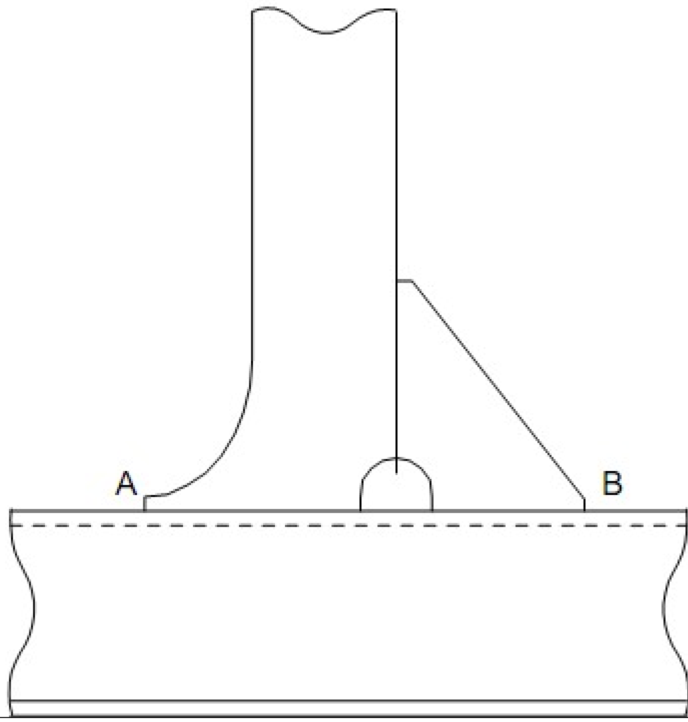
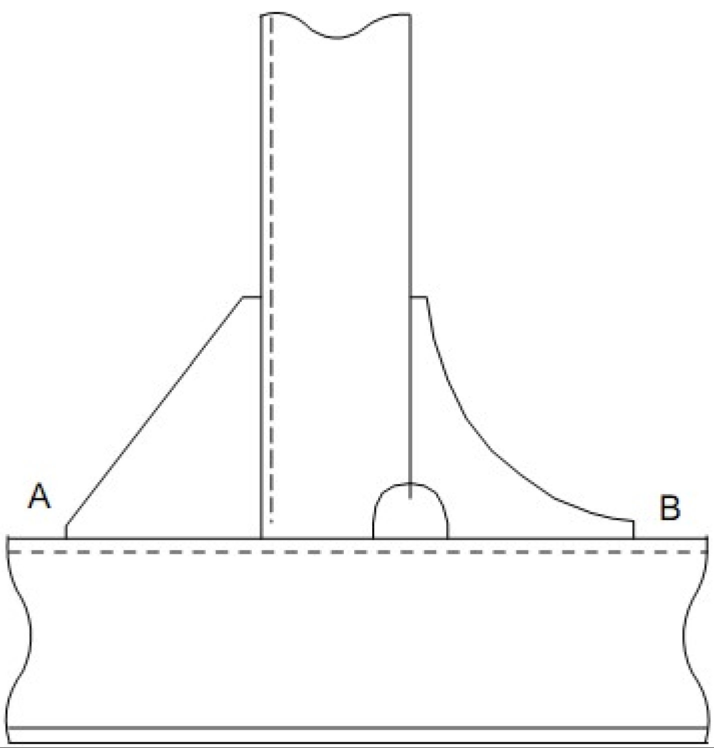
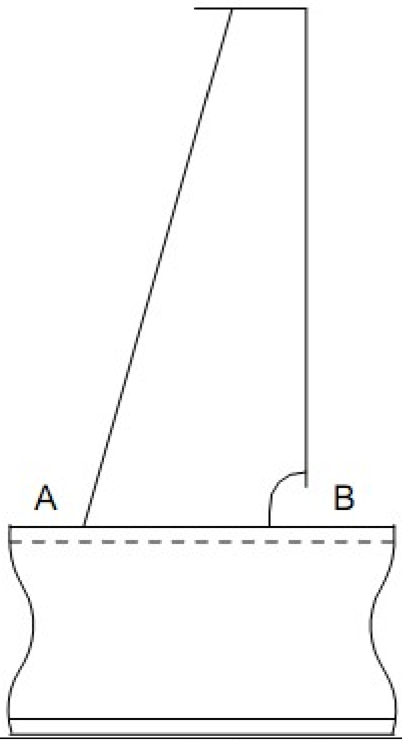
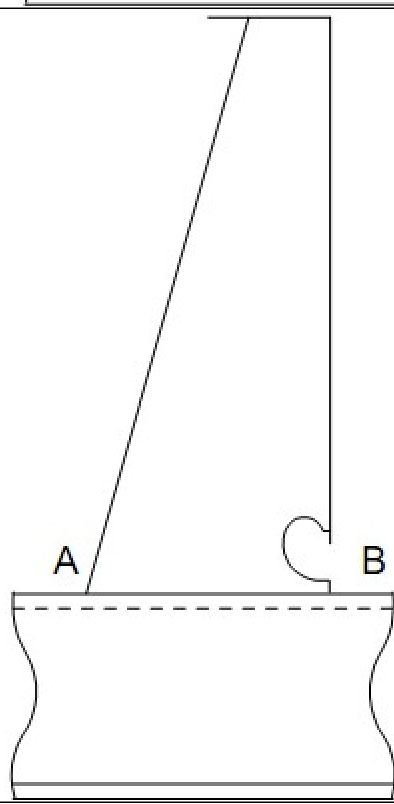
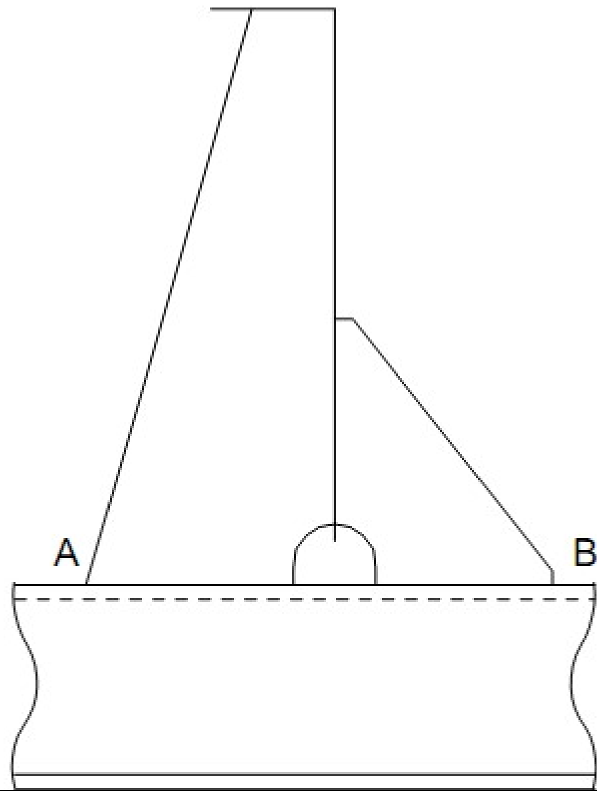
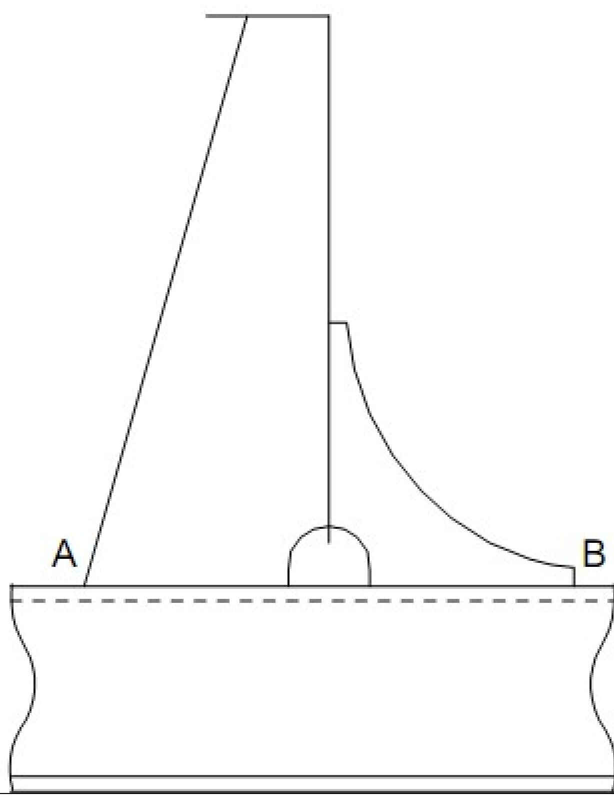
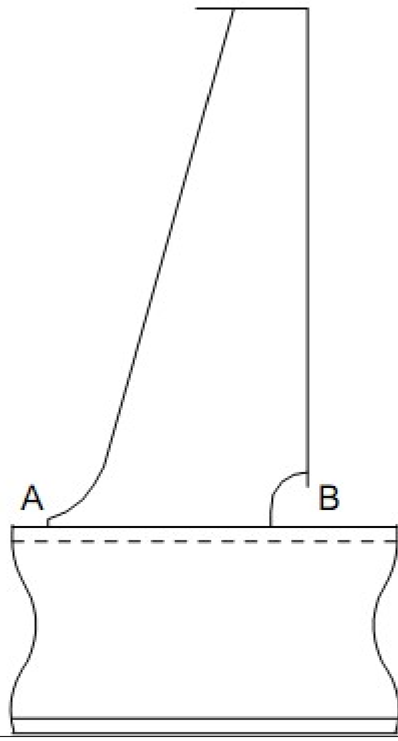
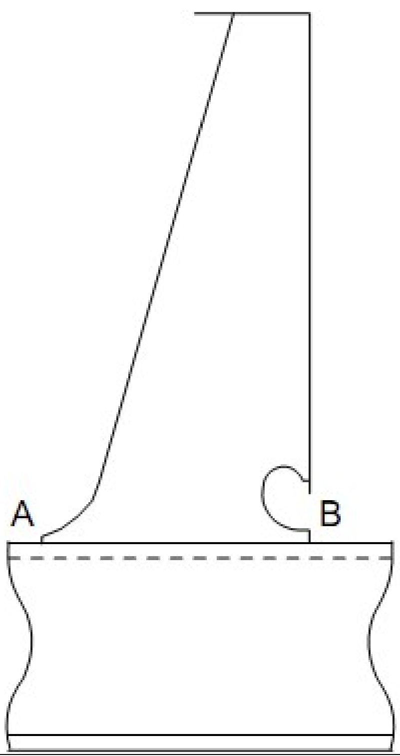
9		F2	F
10		F2	F2

ID	Connection type	Critical Locations Notes (1), (2), (3) A	Critical Locations Notes (1), (2), (3) B
11		F	F2
12		F2	F

ID	Connection type	Critical Locations Notes (1), (2), (3)	
		A	B
13		F2	F2
14		F2	F2(4)

ID	Connection type	Critical Locations Notes (1), (2), (3)	
		A	B
15		F2	F2
16		F2	F

ID	Connection type	Critical Locations Notes (1), (2), (3)	
		A	B
17		F	F2
18		F	F2(4)

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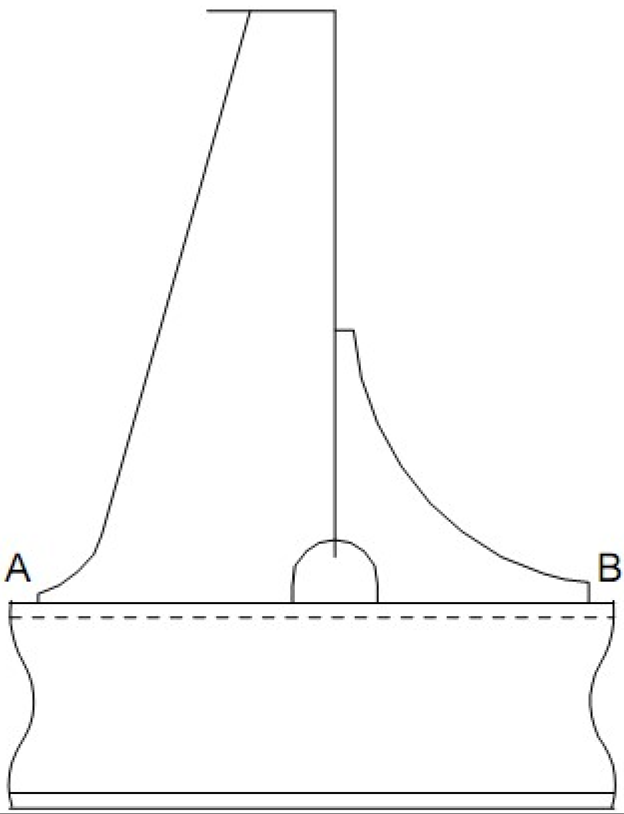
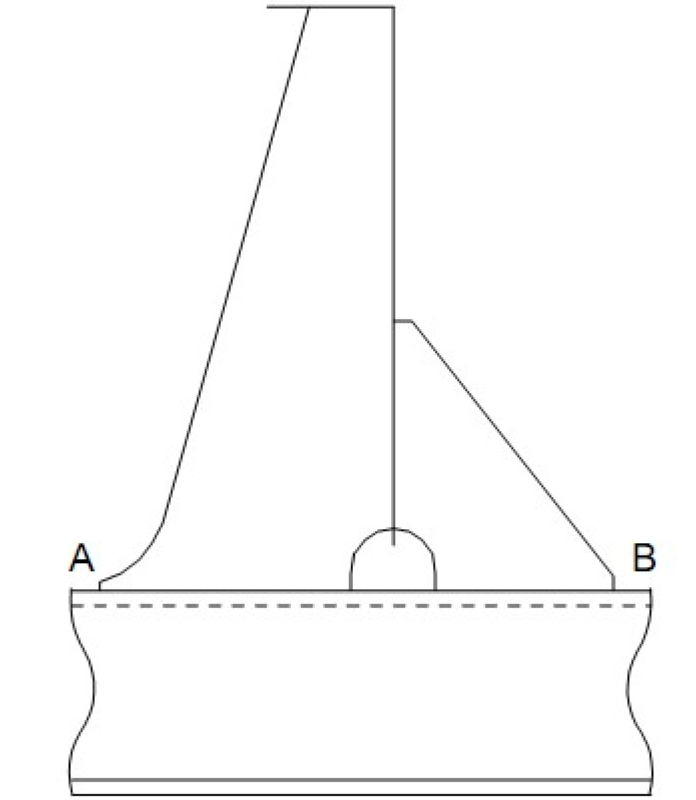
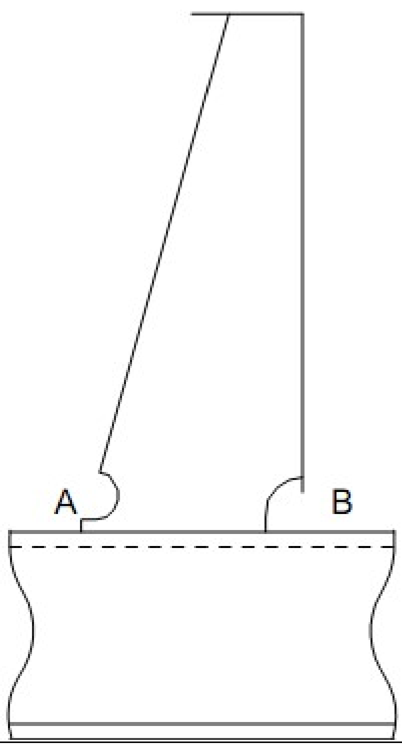
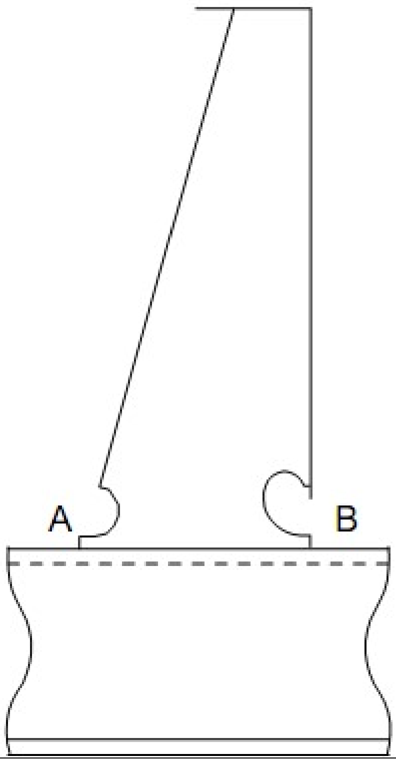
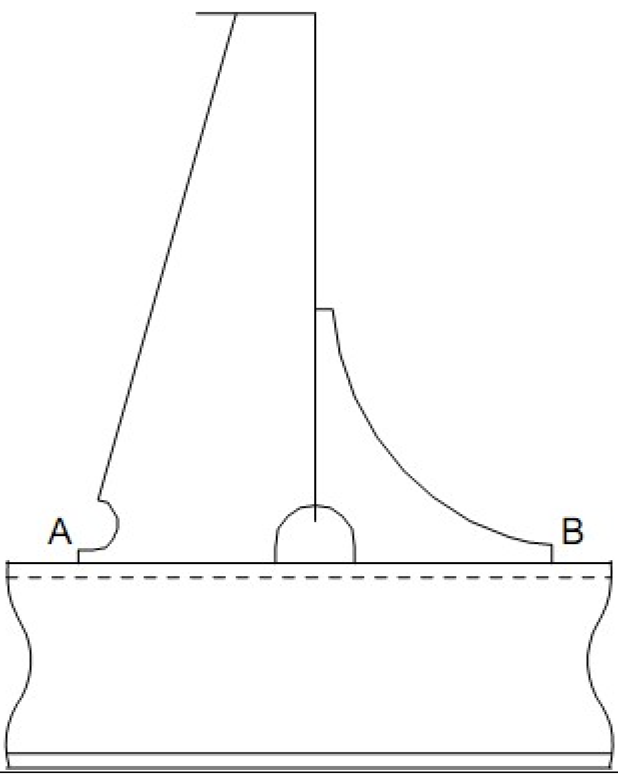
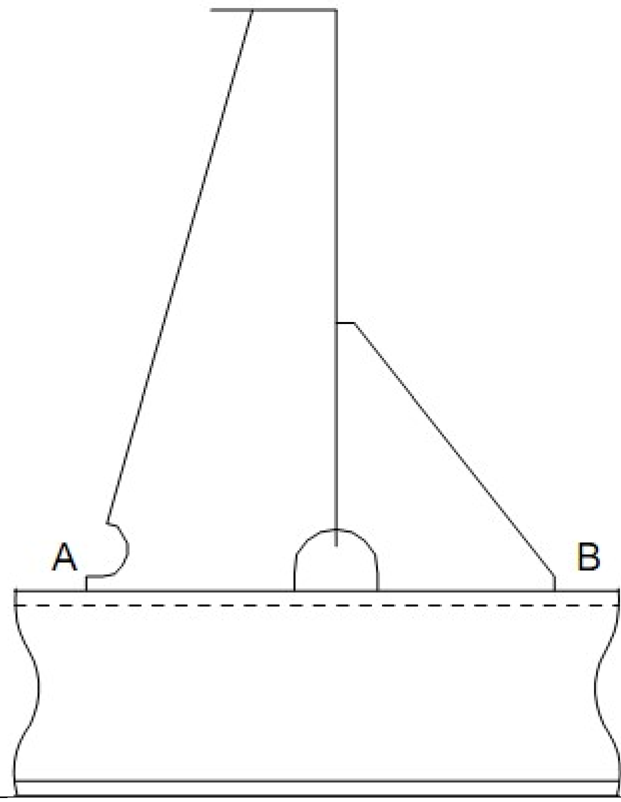
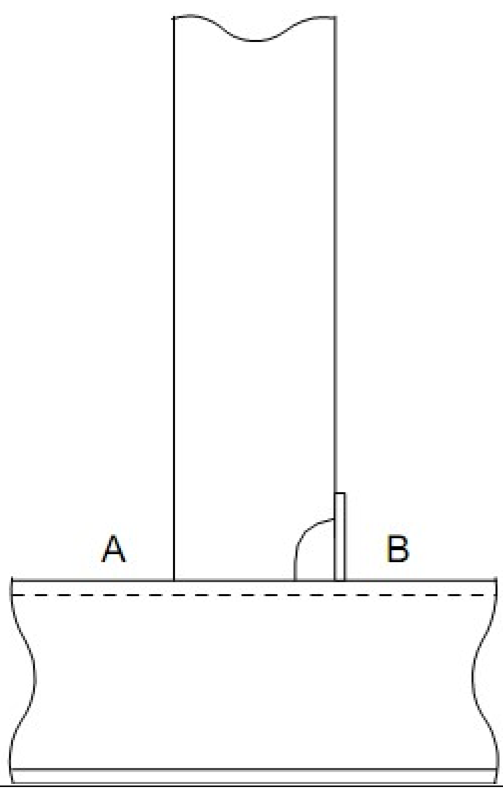
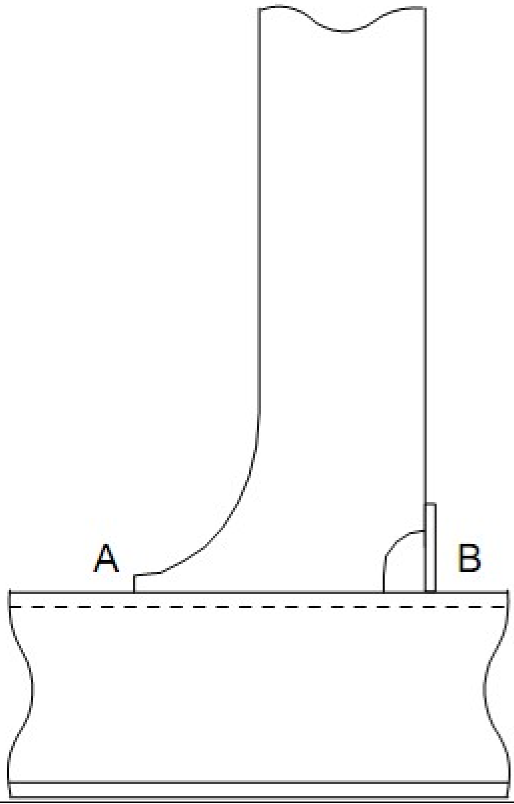
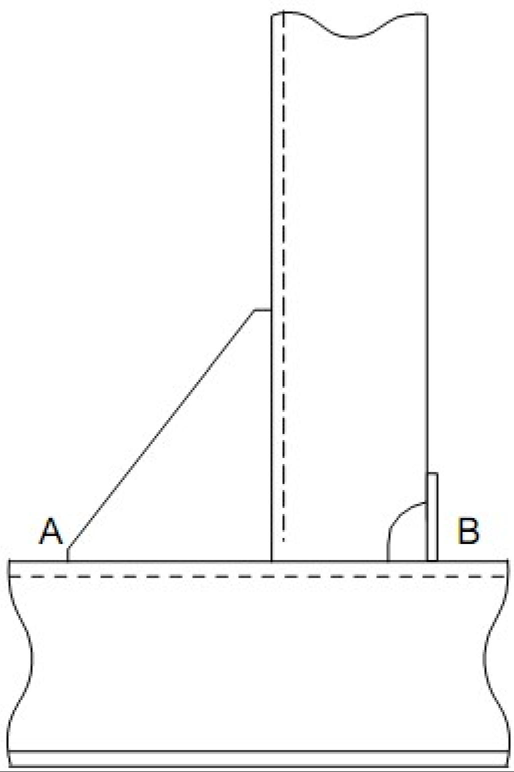
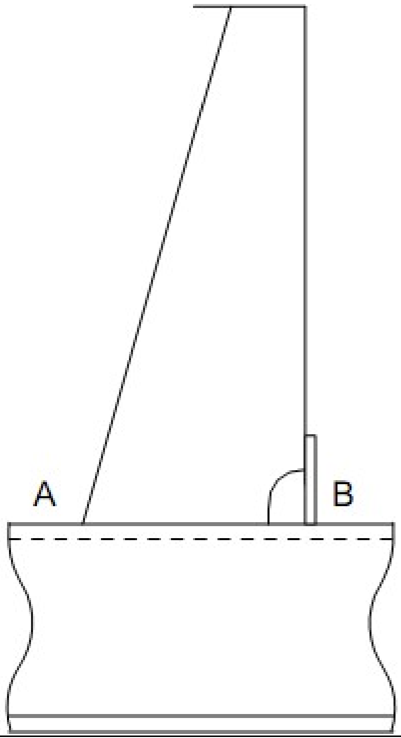
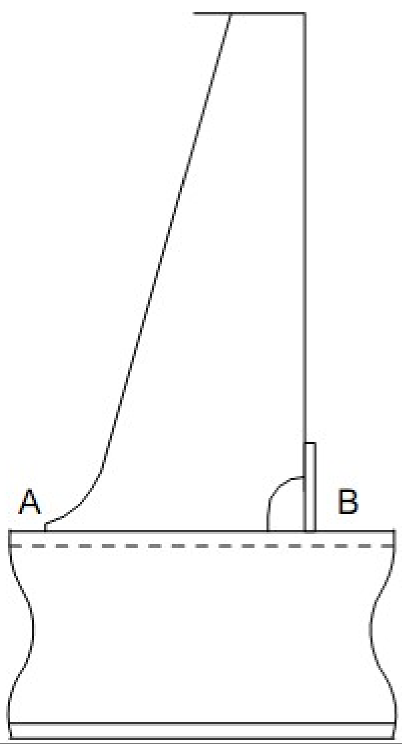
19		F	F

ID	Connection type	Critical Locations Notes (1), (2), (3)	
		A	B
20		F	F2
21		F	F2

ID	Connection type	Critical Locations Notes (1), (2), (3)	
		A	B
22		F	F2(4)
23		F	F2

ID	Connection type	Critical Locations Notes (1), (2), (3)	
		A	B
24		F	F2
25		F2	F2(5 ONLY)

ID	Connection type	Critical Locations Notes (1), (2), (3)	
		A	B
26		F	F2(5 ONLY)
27		F2	F2(5 ONLY)

ID	Connection type	Critical Locations Notes (1), (2), (3)	
		A	B
28		F2	F2(5 ONLY)
29		F	F2(5 ONLY)

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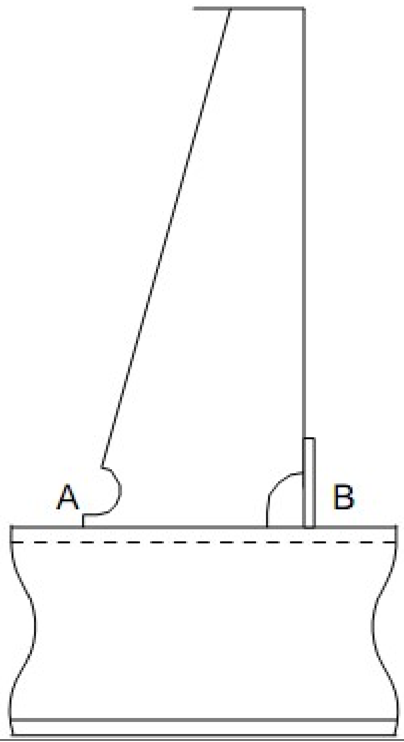
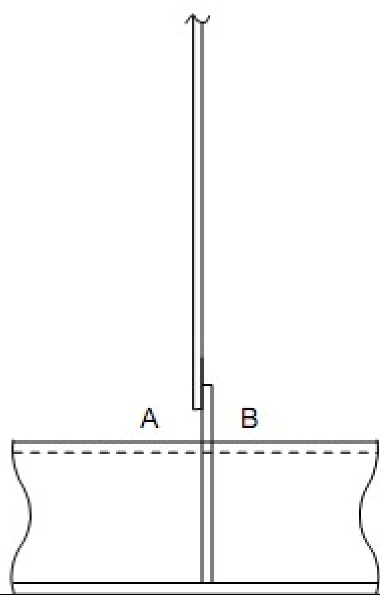
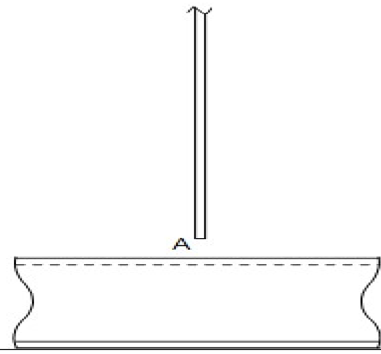
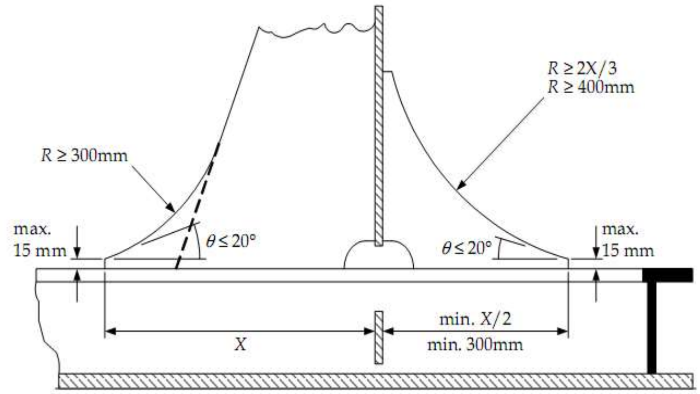
30		F	F2(5 ONLY)
31		F2(5,6 ONLY)	F2(5,6 ONLY)

ID	Connection type	Critical Locations Notes (1), (2), (3)	
		A	B
32		F(6,7)	N/A

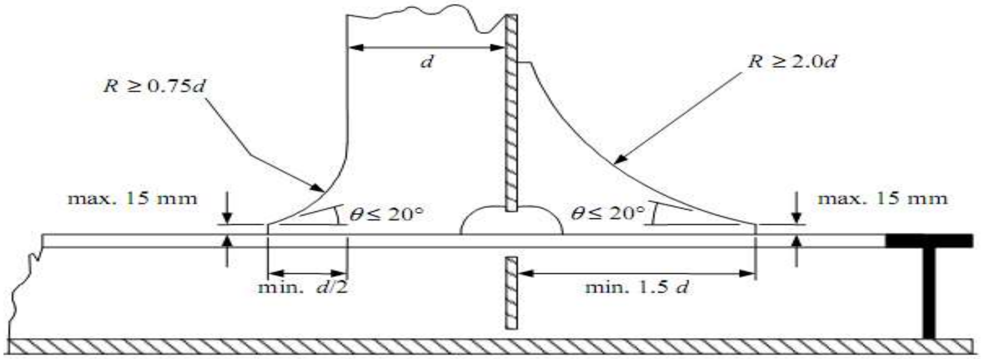
Notes:
1) Where the attachment length is less than or equal to 150 mm, the S-N curve may be upgraded one class from those specified in the table. For example, if the class shown in the table is F2, upgrade to F. Attachment length is defined as the length of the weld attachment on the longitudinal stiffener face plate without deduction of scallop.
2) Where the longitudinal stiffener is a flat bar and there is a stiffener/bracket welded to the face, the S-N curve is to be downgraded by one class from those specified in the table. For example, if the class shown in the table is F, downgrade to F2; if the class shown in the table is F2, downgrade to G. This also applies to unsymmetrical profiles where there is less than 8mm clearance between the edge of the stiffener flange and the face of the attachment, e.g. bulb or angle profiles where the stated clearance cannot be Achieved.
3) Lapped connections (attachments welded to the web of the longitudinals) should not be adopted and therefore these are not covered by the table.
4) For connections fitted with a soft heel, class F may be used if it is predominantly subjected to axial loading. Stiffeners fitted on deck and within 0.1D below deck at side are considered to satisfy this condition.
5) For connections fitted with a collar around the face plate (i.e., connection type ID25 through 30) or a full collar (i.e., connection type ID31), class F may be used if subjected to axial loading. Stiffeners fitted on deck and within 0.1D below deck at side are considered to satisfy this condition
6) ID31 and 32 show details where web stiffeners are omitted or are not connected to the longitudinal stiffener face plate. A full collar (i.e. connection type ID 31) or alternatively a detail design for cutouts as shown in Figure 4.3.11 or equivalent is required in way of:

- Side below the the highest point of the wave wetted zone or below 0.1D from the deck at side, whichever is lower.
- Bottom
- Inner hull longitudinal bulkhead below 0.1D from the deck at side
- Hopper
- Inner bottom

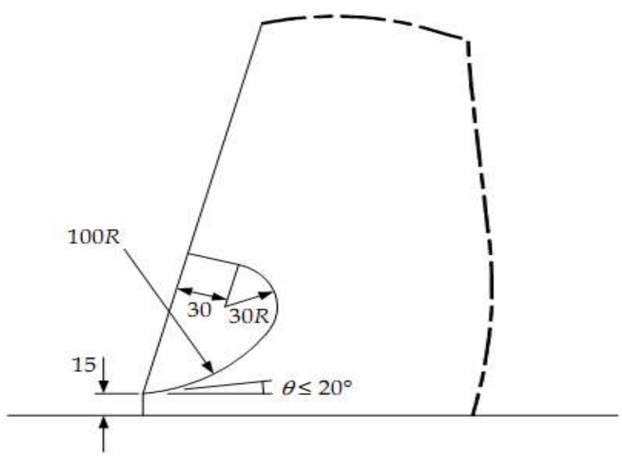
The highest point of the wave wetted zone is defined as the full load draft plus hWL as shown in Fig. 4.3.1. Equivalence to Figure C.1.11 is to be demonstrated through a satisfactory fatigue assessment by using comparative FEM based hot spot stress of the cutout in the primary support member and the collar.
7) For connection type ID32 having no collar welded to the face plate, class F is to be used in way of longitudinals in the strength deck irrespective of slot configuration. In other areas class E may be used irrespective of slot configuration.



Recommended Design of Soft Toes and Backing Bracket of Tripping Brackets



Recommended Design of Soft Toes and Backing Bracket of Pillar Stiffeners



Recommended Alternative Design of Soft Toes of Tripping Brackets

Figure 4.3.10 Detail Design for Soft Toes and Backing Brackets

Figure 4.3.11: Design for Cut Outs in cases where Web Stiffeners are omitted

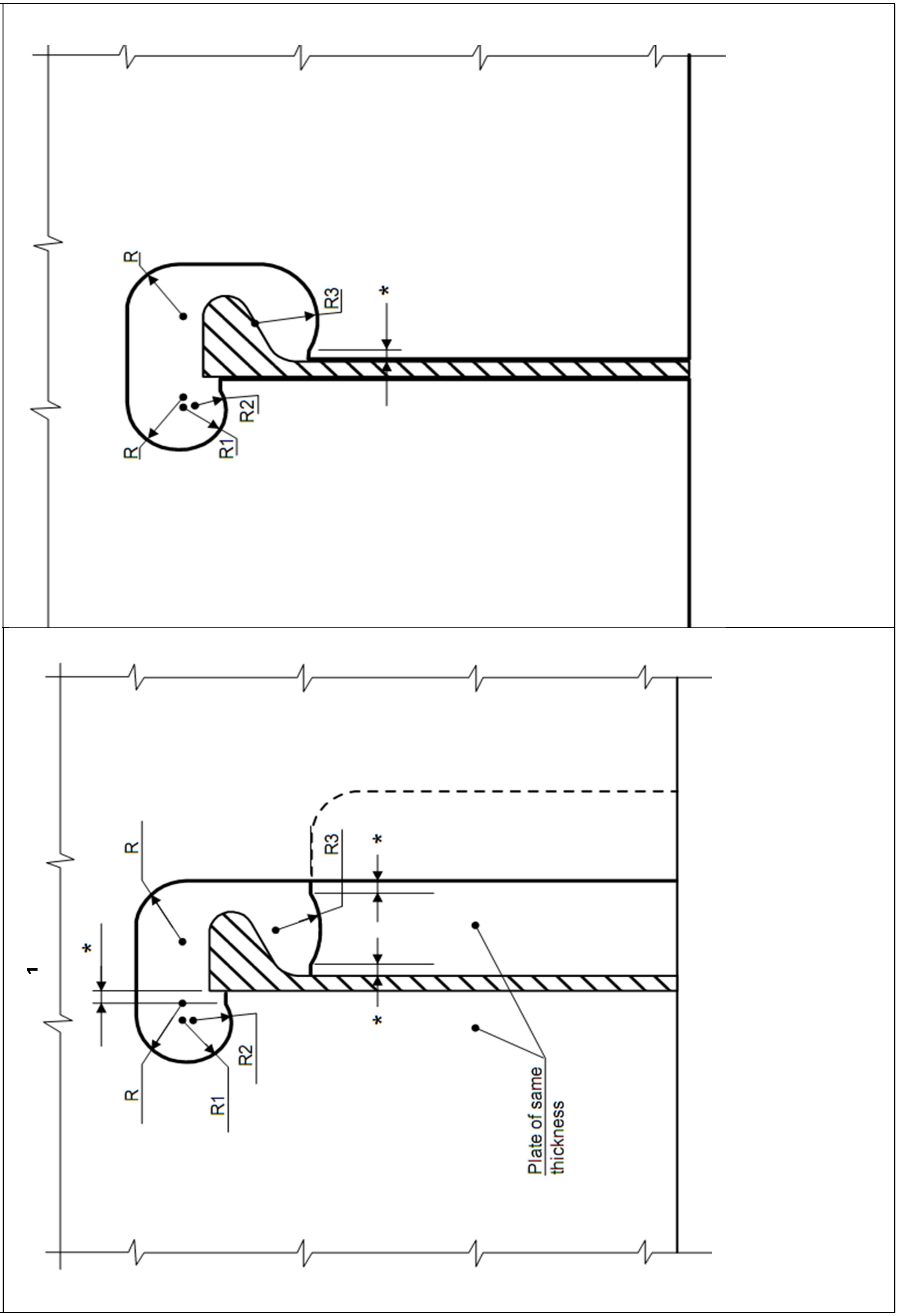
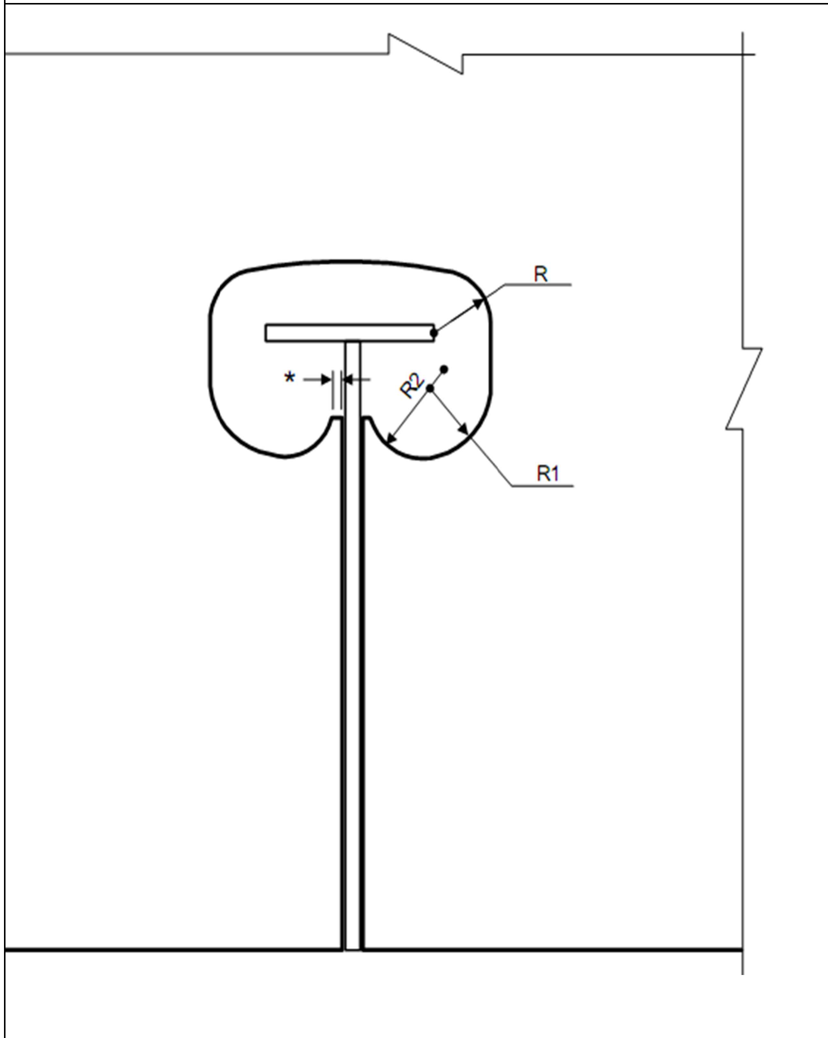
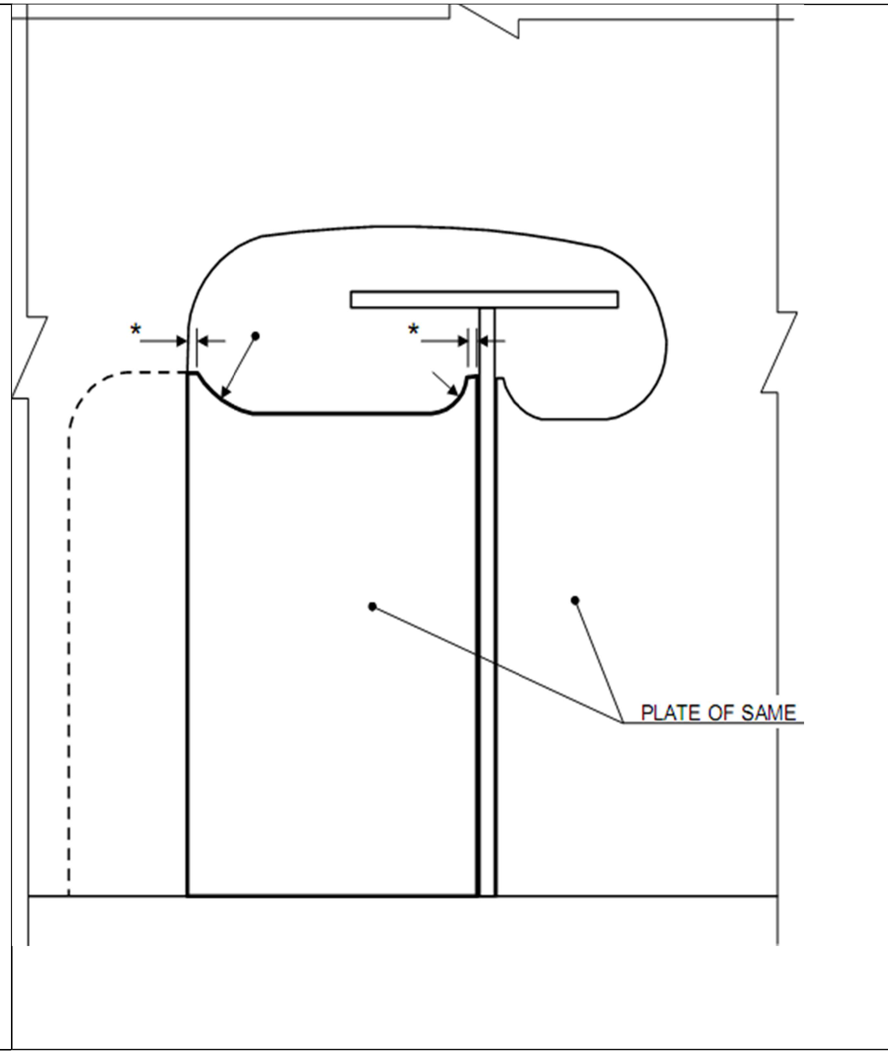


Figure 4.3.11: Design for Cut Outs in cases where Web Stiffeners are omitted (Continued)



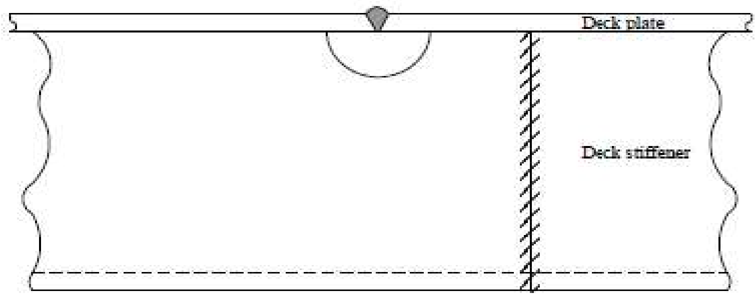


<u>Notes</u>
1) Soft toes marked "*" are to be dimensioned to suit the weld leg length such that smooth transition from the weld to the radiused part can be achieved. Max. 15 mm.
2) Configurations 1 and 4 indicate acceptable lapped lug plate connections; alternatively, butted lug plates with similar shape may be adopted.
3) Designs that are different than shown in the above sketches are acceptable subject to a satisfactory fatigue assessment by using comparative FEM based hot spot stress.

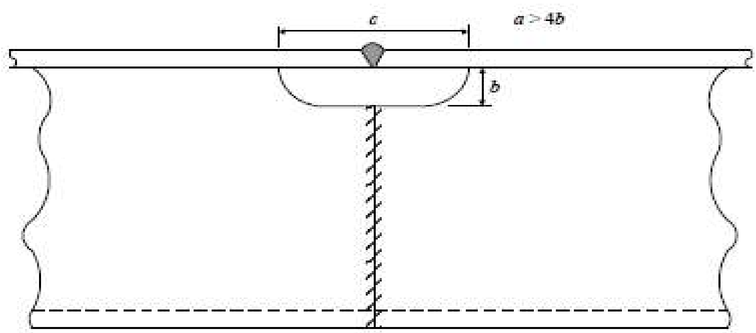
1.6. Other Details

1.6.1. Scallops in way of block joints

1.6.1.1. According to Figure 4.3.12 scallops in way of block joints in the cargo tank region, located on the strength deck, and down to 0.1D from the deck at side are to be designed unless the specification in Chapter 2 Section 2/1.5.1.3 for class F2 is satisfied.



(II) Elongated scallop on stiffener



(III) Closing scallop with collar

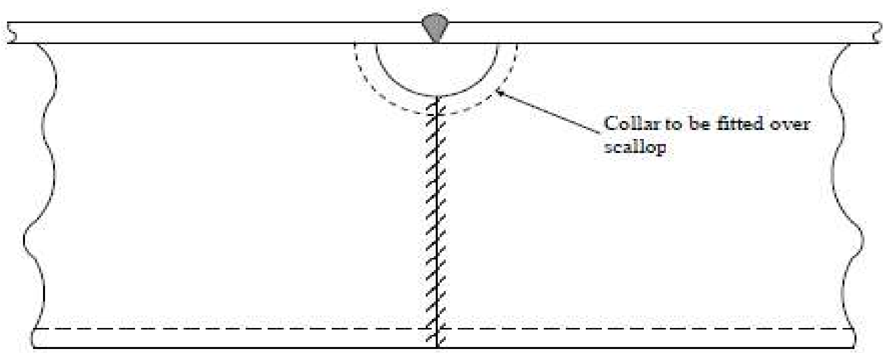


Figure 4.3.12 Welding of Deck Stiffeners in way of Block Joints

Note:

Alternative scallop geometry to that shown in option II may be accepted subject to demonstration of satisfactory fatigue life based on hull girder loads taking into account additional stress concentration factor in way of weld, determined using fine mesh FEM and applying class D S-N curve.

2. Hot Spot Stress (FE Based) Approach

2.1. General

2.1.1. Applicability

2.1.1.1. This section explains the procedure applies to welded knuckles between inner bottom and hopper plate fatigue analysis using a finite element (FE) based hot spot stress approach. A parallel application method is explained in Sub-Section 1 for the nominal stress approach is used except where indicated in the following sections.

2.1.1.2. Hot spot stress fatigue evaluation is not a constraint provided the detail design standard described in 2.5.1.2 is followed where the hopper knuckle between inner bottom and hopper plate is of the bent type.A suitable finite element (FE) analysis should be used to express theequivalency of the detail in terms of fatigue strength when another design is proposed.

2.1.1.3. Where the hot spot stress approach is considered required for illustration of the adequacy of longitudinal stiffener end connection in lieu of the nominal stress approach, the procedure detailed in Sub-Section 1 is in general to be followed with the exception that S_v, S_h, S_i, and S_e are to be determined unswervingly from the finite element (FE) analysis by means of the surface hot spot stress component perpendicular to the weld attained by linear extrapolation to the Centre-line of the attachment, and then to the weld toe position. The S-N curveaccording to 2.4.3 is applicable.

2.1.2. Assumptions
The assumptions made are given in 1.1.2.

2.2. Corrosion Model

2.2.1. Net thickness

2.2.2.1. As explained in Chapter 4 Section 2/4 the net thickness and corrosion additions given in Chapter 1 Section 6/3 are to be included into the demonstration of the FE structural capacity models.

2.3. Loads

2.3.1. General

2.3.1.1. Dynamic wave and tank pressures are to be taken into considerations for the FE based fatigue analysis of knuckles between inner bottom and hopper plates, see 1.3.6 and 1.3.7.

2.4. Fatigue Damage Calculation

2.4.1. Fatigue strength determination

2.4.1.1. The procedure outlined in 1.4 is to be applied.

2.4.1.2. The Weibull probability distribution parameter which is related to welded knuckles between inner bottom and hopper plate, ξ, is to be taken as:

$$\xi = 1.1 - 0.35\frac{L-100}{300}$$

Where: L=Rule length, in m, as defined in Chapter 1 Section 4/1.1.1.1

2.4.2. Stresses to be used

2.4.2.1 To determine hot spot stresses, local 2D or 3D very fine mesh stress analyses, in combination with a 3D coarse mesh analysis are to be used. In highly stressed areas the level of stresses depends on the size of elements because of the high stress gradient, particularly in the vicinity of structural discontinuities. If the stress field is more complex than a uniaxial field the stresses adjacent to the potential crack location are to be used. A uniform mesh is to be used with smooth transition and averting of abrupt changes in mesh size.

2.4.2.2 The following defines a general basis for the modeling of local structures:

a.) By using an idealized welded joint with no misalignments Hot spot stresses are to be calculated. The finite element mesh is to be fine enough near the hot spot such that stresses and stress gradients can be definite with sufficient accuracy.

b.) Plating, webs and face plates of primary and secondary members are modelled by 4-node thin shell elements. In cases of steep stress gradients, 8-node thin shell elements are to be used.

c.) The structure is to be modeled at the mid face of the plates when thin shell elements are used. For practical purposes, adjacent plates of different thickness may be unspecified to be median line aligned, i.e., no staggering in way of thickness change is needed.

d.) The aspect ratio of elements is not to be greater than three in the vicinity of the hot spot.

e.) The size of elements placed in the vicinity of the hot spot is to be relative to the net thickness of the structural member

f.) In order to considering into account the plate bending moment, where relevant. Stresses are to be assessed at the surface of the plate with a view.

2.4.2.3 A detailed description of hot spot stress calculation using finite element modeling is provided by Chapter 4 Section 2/4.

2.4.2.4 In General, at the Gaussian integration points the element stresses are derived. Depending on the element type, to determine the actual stress at the considered hot spot location it may be necessary to carry out quite a few interpolations.

2.4.2.5 Generally hot spot stresses are highly reliant on the finite element model used for demonstration of the structure for, critical structural details. Unconventional procedures to those described here, for the derivationof the hot spot stress, are to be documented by reference to available fatigue test results for related structural details.

2.4.2.6 As shown in Figure 4.3.12 the hot spot stress is specified as the surface stress at 0.5t away from the weld toe position. The hot spot stress is to be attained by linear interpolation in the ship's transverse direction using the respective stress at the 1st and 2nd element from the structure intersection.

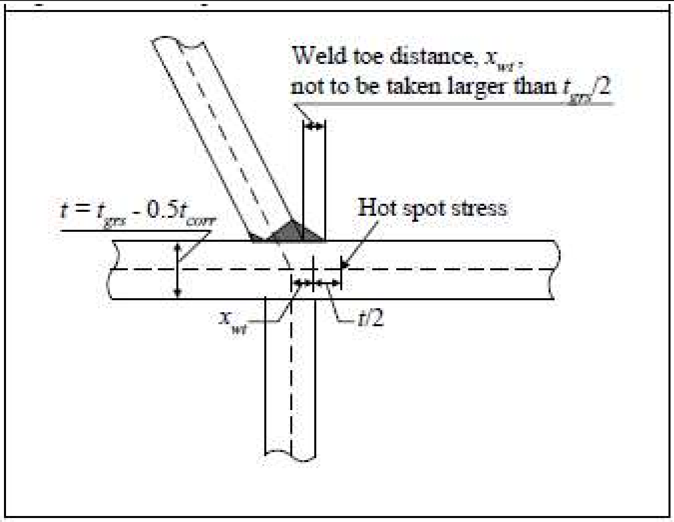


Figure 4.3.12 Hot Spot Stress

2.4.2.7 Due to the loads defined in 2.3 stress range components along the direction perpendicular to the weld, are to be assessed based on Section B/4. The total combined stress range, S, is to be taken as:

$S = f_{model}|0.85(S_{e1} + 0.25S_{e2}) - 0.3S_i|$for full load condition

$S = f_{model}|S_{e1} - 0.2S_{e2}|$for ballast load condition

Where:

S_{e1} stress range due to dynamic wave pressure applied to FE-model on the side where the hopper knuckle is to be investigated, in N/mm^2, see Table 4.2.13

S_{e2} Stress range due to dynamic wave pressure applied to FE-model on the side of the hull where the Hopper knuckle is not analyzed, in N/mm^2, see Table 4.2.13

S_i Stress range due to dynamic tank pressure applied to FE-model, in N/mm^2; see Chapter 4 Section 2/ 4.5.2.4 and Table 4.2.13

f_{model} 1.0 if the FE model is made according to net thickness for fatigue, i.e. using corrosion addition of 0.25tcorr for the FE model except in way of critical location (in way of a knuckle and within 500mm in all directions), which uses corrosion addition of 0.5t_{corr} 0.95 if the FE model for strength assessment is used. FE model for strength assessment applies a corrosion addition of 0.5tcorr for the whole model including structure in way of critical location

2.4.2.8 To account for the mean stress effect, in lieu of applying the static loads to the FE model, the total stress range may be taken as:

$S_{Ri} = 1.0S\ for\ full\ Load\ condition$

$S_{Ri} = 0.6\ S\ for\ ballast\ Load\ condition$

Where

S total combined stress range, in N/mm^2 as defined in 2.4.2.7

2.4.3. Selection of S-N curves

2.4.3.1. The fatigue analysis is to be carried out applying the Class D S-N curve for welded details if the hot spot stress is calculated according to 2.4.2.8. The thickness effect according to 1.4.5.12 will be applicable.

2.5. Detail Design Standard

2.5.1. Hopper knuckles

2.5.1.1. Design details for the welded knuckle between hopper plating and inner bottom plating are to be as displayed in Figure 4.3.13.

Note:

Figure 4.3.14 may be used as another way to increase fatigue strength at the hopper connection.

2.5.1.2. Design details for the bent knuckle between hopper plating and inner bottom plating are to be as shown in Figure 4.3.15.

2.5.2. Transverse Bulkhead Horizontal Stringer Heel

2.5.2.1. For reducing the stress level and escalating fatigue strength at the horizontal stringer heel location between transverse oil-tight and wash bulkhead plating and inner hull longitudinal bulkhead plating the detail design modification specified in Figure 4.3.16 is suggested. This suggestion should be considered in association with fine mesh FE analysis as needed in Section B/3.1.3

2.5.3. Transverse and longitudinal corrugated bulkhead connection to lower stool

2.5.3.1. Detail design improvement provided for reducing the stress level at the connection of transverse and longitudinal corrugated bulkhead to lower stool is in Figure 4.3.17. This suggestion should be taken in to account in association with fine mesh FE analysis as needed in Chapter 4 Section 2/3.1.5.

Figure 4.3.13 Hopper Knuckle Connection Detail, Without Bracket

Connections of floors in double bottom tanks to hopper tanks Hopper corner connections employing welded inner bottom and hopper sloping plating

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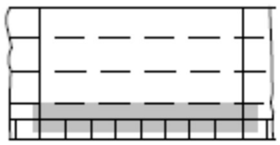

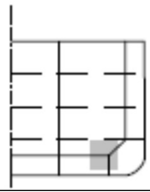

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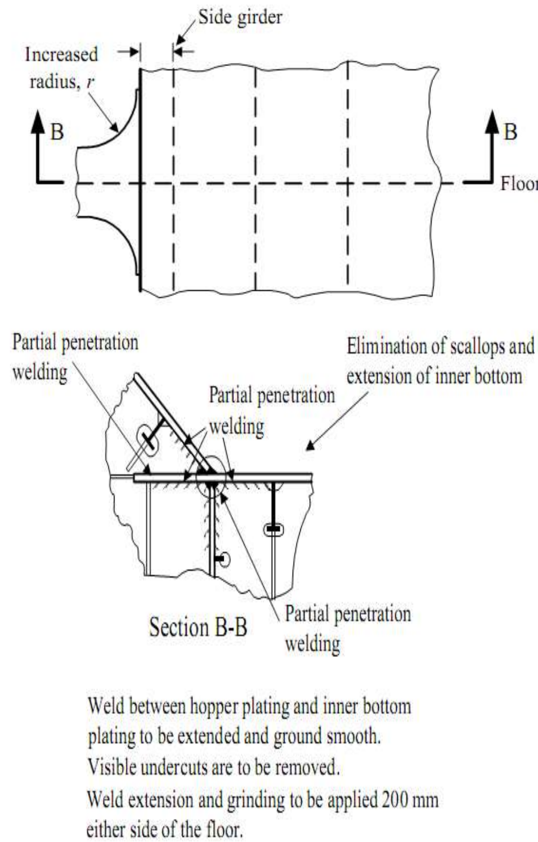
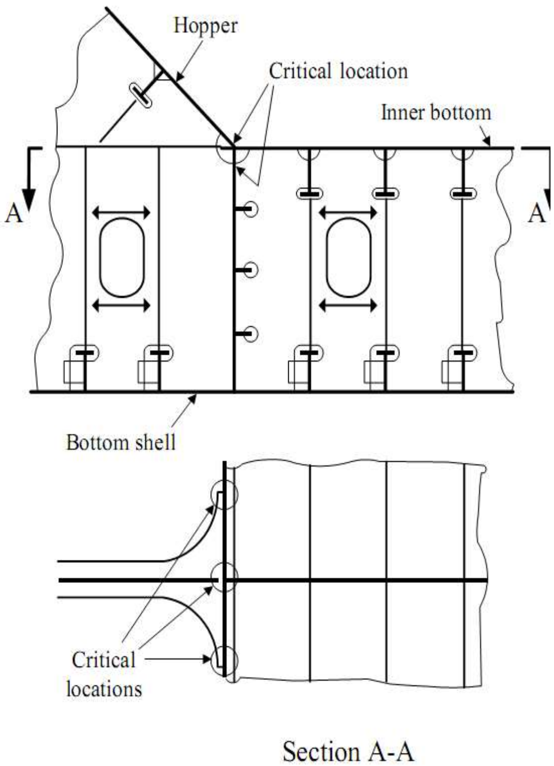


Note:
1) A root face with a maximum of 1/3 of the abutting plate thickness is acceptable for the partial penetration welding, see Chapter 1 Section 6/5.3.4.
2) Grinding need not be applied in the No.1 tank in which floor spans are reduced due to shape.
3) Grinding need not be applied for the knuckle joints at transverse bulkhead positions, or at the floor adjacent to the transverse bulkhead.

</td></tr>
<tr><td>CRITICAL LOCATIONS</td></tr>
<tr><td>



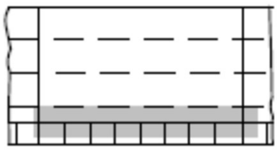
</td></tr>
</table>

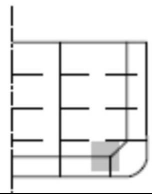
Minimum Requirement	As a minimum, detail design standard A or B is to be fitted. Further consideration will be given where the hopper angle exceeds 50 degrees. The ground surface is to be protected by a stripe coat, of suitable paint composition, where the lower hopper knuckle region of cargo tanks is not coated
Critical Location	Hopper sloping plating connections to inner bottom plating in way of floors. Floor connections to inner bottom plating and side girders in way of hopper corners.
Detail Design Standard	Elimination of scallops in way of hopper corners, extension of inner bottom plating to reduce level of resultant stresses arising from cyclic external hydrodynamic pressure, cargo inertia pressure and hull girder loads. Scarfing bracket thickness is to be close to that of the inner bottom in way of knuckle
Building Tolerances	Median line of hopper sloping plate is to be in line with the median line of the girder with an allowable tolerance of t/3 or 5mm, whichever is less, where t is the inner bottom thickness. The allowable tolerance is to be measured parallel to the inner bottom.
Welding Requirements	Partial penetration welding (hopper sloping plating to inner bottom plating). Partial penetration weld (connection of floors to inner bottom plating and to side girders, connection of hopper transverse webs to sloping plating, to inner bottom plating, and to side girders in way of hopper corners).

Figure 4.3.14 Hopper Knuckle Connection Detail, Without Bracket

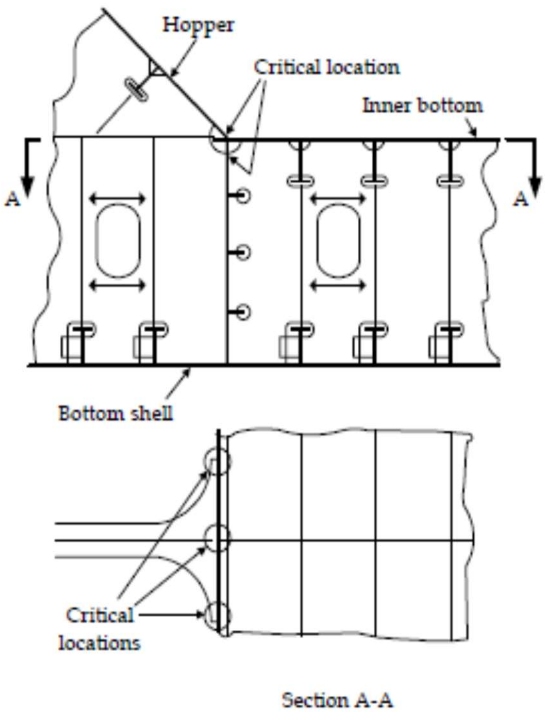
Connections of floors in double bottom tanks to hopper tanks Hopper corner connections employing welded inner bottom and hopper sloping plating

CRITICAL AREAS

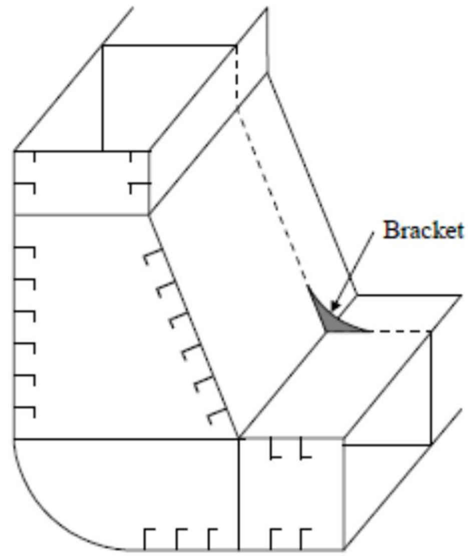




CRITICAL LOCATIONS



DETAIL DESIGN STANDARD B



Note:
1) Bracket to be fitted inside cargo tank
2) Bracket to extend approximately to the first longitudinal
3) The bracket toes are to have a soft nose design
4) Full penetration welding at bracket toes
5) Bracket material to be same as that of inner bottom
6) Buckling of bracket to be checked:

$$\frac{d}{t_{bkt}} < 21\sqrt{\frac{235}{\sigma_{yd}}}$$

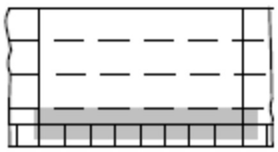
where:
d = bracket max depth, as defined in Table 2.4.3
t_{bkt}= bracket thickness
σ_{yd}= specified minimum yield stress of material

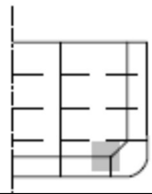
Minimum Requirement	As a minimum, detail design standard A or B is to be fitted. Further consideration will be given where hopper angle exceeds 50degrees.
Critical Location	Hopper sloping plating connections to inner bottom plating in way of floors. Floorconnections to inner bottom plating and side girders in way of hopper corners
Detail Design Standard	Elimination of scallops in way of hopper corners, extension of inner bottom plating to reduce level of resultant stresses arising from cyclic external hydrodynamic pressure, cargo inertia pressure and hull girder loads. Scarfing bracket thickness to be close to that of the inner bottom in way of knuckle.
Building Tolerances	Median line of hopper sloping plate is to be in line with the median line of girder with an allowable tolerance of t/3 or 5mm, whichever is less, where t is the inner bottom thickness.
Welding Requirements	Partial penetration welding (hopper sloping plating to inner bottom plating). Partialpenetration weld (connection of floors to inner bottom plating and to side girders, connection of hopper transverse webs to sloping plating, to inner bottom plating, and to side girders in way of hopper corners).

Figure 4.3.15 Hopper Knuckle Connection Detail, Bent Type

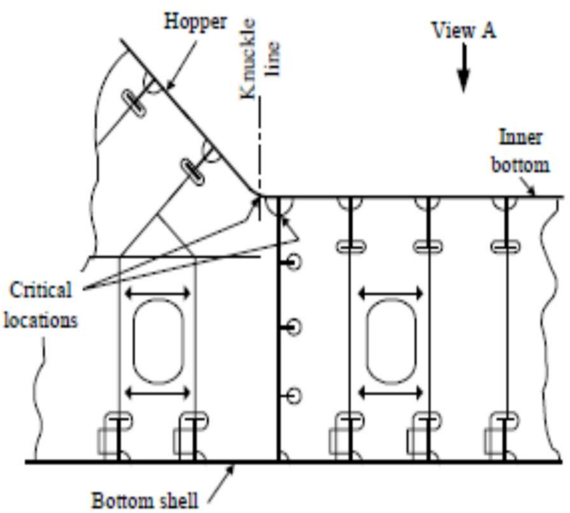
Connections of floors in double bottom tanks to hopper tanks
Hopper corner connections employing bent knuckle inner bottom and hopper sloping plating

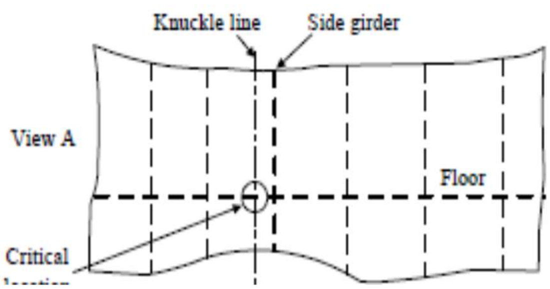
CRITICAL AREAS



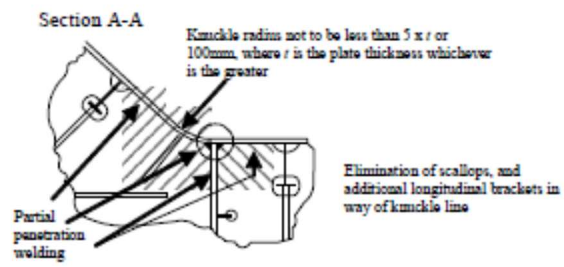


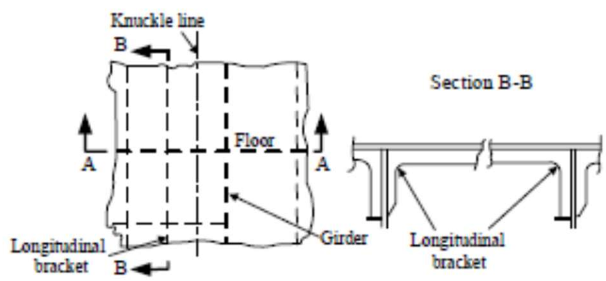
CRITICAL LOCATIONS





DETAIL DESIGN STANDARD C





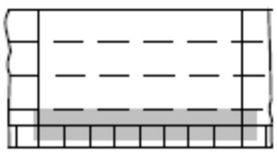
Note: Longitudinal brackets may be omitted if it can be demonstrated
that the girder provides sufficient support at the knuckle line.

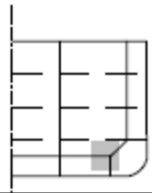
Minimum Requirement	As a minimum, the detail design standard C is to be fitted..
Critical Location	Side girder connections to inner bottom plating in way of floors. Floor and hopper transverse web connections to inner bottom plating and to side girders in way of hopper corners.
Detail Design Standard	Elimination of scallops in way of hopper corners and additional longitudinal brackets to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure, cargo inertia pressure, and hull girder global loading
Building Tolerances	Enhanced alignment standard. The nominal distance between the centres of thickness of the two abutting members (e.g. floor and hopper web plate and additional supporting brackets) should not exceed 1/3 of the table member thickness
Welding Requirements	Partial penetration welding with a maximum root face of 1/3 of the abutting plats Thickness (Connection of side girders to inner bottom plating. Connection of floors to Inner bottom plating and to side girders. Connection of hopper transverse webs to sloped inner bottom plating and to side girders in way of hopper corners).

Figure 4.3.16 Option: Transverse Bulkhead Horizontal Stringer Heel

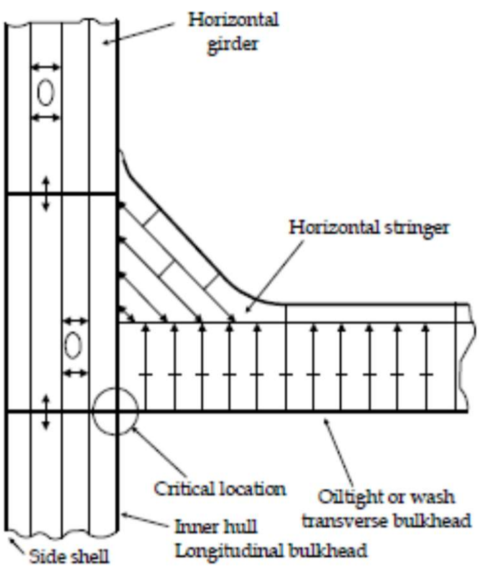
Connections of horizontal girder in double side tanks to transverse bulkheads
Connection of horizontal stringer on plane oil tight transverse or wash bulkheads to inner hull longitudinal bulkhead

CRITICAL AREAS

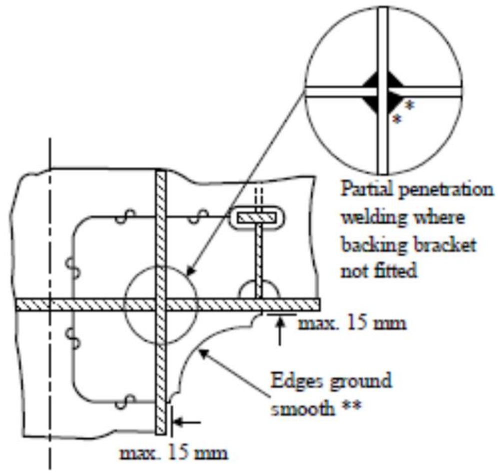




CRITICAL LOCATIONS



DETAIL DESIGN IMPROVEMENT



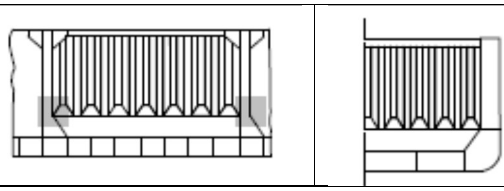
Note:
*Weld toe to be ground smooth, visible undercuts to be removed where brackets not fitted.
**Where a face plate is considered necessary, it is
recommended that design features be adopted to reduce the stress concentration at the face plate termination
(e.g., taper and soft nose).

Critical Location	Intersections of webs of transverse bulkhead horizontal stringer and double side tank Horizontal girder forming square corners.
Detail Design improvement	Elimination of scallops in way of cruciform joint and fitting a localized 'D' grade steel insert plate, with minimum thickness of 7 mm in addition to the Rule required thickness, to reduce the peak and range of resultant stresses arising from cyclic cargo inertia pressure and hull girder global loading. In addition, a soft toed backing bracket of suitable dimension is to be fitted. The following bracket sizes are recommended: • VLCC: 800x800x30 R600 with soft toe as shown in Figure • Suezmax and Aframax tankers: 800x600x25 R550 with soft toe as shown in Figure, where the longer arm length is in way of the inner skin. The actual bracket design is to be verified by fine mesh finite element analysis in accordance with Chapter 4 section 2/3.1.3.
Building Tolerances	Enhanced alignment standard. The nominal distance between the centres of thickness of the two abutting members should not exceed 1/3 of the table member thickness
Welding Requirements	Fillet welding having minimum weld factor of 0.44, where backing bracket is fitted or partial penetration welding where backing bracket is not fitted. The extent of partial penetration should be of the order of longitudinal spacing. A small scallop of suitable shape, which is to be closed by welding after completion of the continuous welding of bulkhead, should be provided where scallop is eliminated

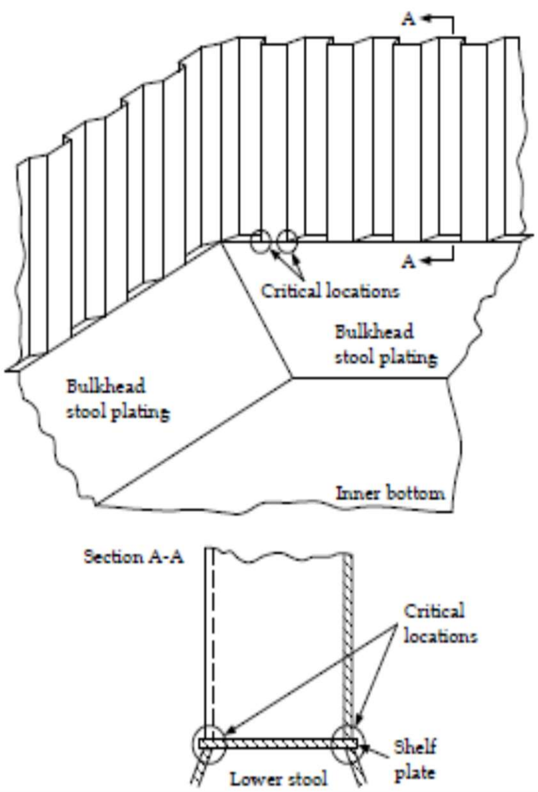
Figure 4.3.17 Transverse and Longitudinal Bulkhead Connection to Lower Stool

Connections of side stringers in double side tanks to transverse bulkheads
Higher tensile stringers to horizontal girders on plane oiltight transverse or wash bulkheads

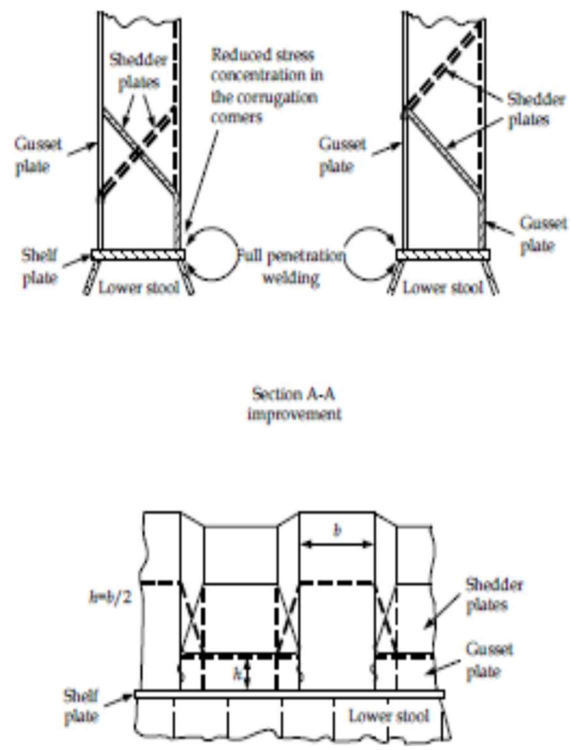
CRITICAL AREAS



CRITICAL LOCATIONS



DETAIL DESIGN IMPROVEMENT



Note:
* Full penetration weld is to be applied at the connectionof the corrugated bulkhead and stool plate to the shelfplate of the lower stool.
** Where adjacent shedder plates cross, a bracket stiffener is to be provided at the crossing point.

Critical Location	1. Connections of corrugated bulkhead to lower stool and shelf plate 2. Connections of corrugated bulkhead to shedder plate if fitted without a gusset plate.
Detail Design improvement	1. Gusset plate should be fitted to the shelf plate in line with the face of the corrugation to reduce stress concentrations at the corrugated corners. The minimum height of the gusset plate should be taken as half the corrugated bulkhead flange width. 2. To reduce stress concentration at the crossing of the shedder plates, shedder plates may be arranged in an alternate configuration as shown in figure. Alternatively, bracketed stiffener may be fitted at the crossing points underneath the shedder plates.
Building Tolerances	Ensure good alignment between lower stool sloping plates and corrugation faces as far as possible. The nominal distance between the centres of thickness of the two abutting members should not exceed 1/3 of the table member thickness.
Welding Requirements	Full penetration welding should be used at the connections of the bulkhead corrugations, gusset plates and the lower stool sloping plates to the lower stool shelf plate (Grade Z steel is recommended). Start and stop of welding should be as far away as practicable from the corners of the corrugations

SECTION 5 BUCKLING STRENGTH ASSESSMENT

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1. Advanced Buckling Analysis

1.1. General

1.1.1. Scope

1.1.1.1. This sub-section describes the advanced buckling analysis method and its application as per the Rules. The advanced buckling analysis method depends on nonlinear analysis techniques, or equivalent, which envisage the complex behavior of stiffened and un-stiffened panels.

1.1.2. Alternative procedures

1.1.2.1. The general purpose or direct calculation techniques to be employed are described in this sectionbut alternative advanced buckling and ultimate strength analysis procedures may be used, provided they give comparable and consistent results to those obtained using the reference advanced buckling procedure given in the Background to Section 4 of this chapter which is the basis for the permissible buckling utilisation factors in Chapter 2 Section 3/ Table 2.3.3. See also 1.1.2.3.

1.1.2.2. Where an alternative advanced procedure is used, for review and acceptance, documentation of the alternative advanced buckling analysis methodologies and detailed comparison of its results with those of the reference advanced buckling procedure given in Background to Section 4 of this chapter and software tools are to be supplied.

1.1.2.3. The use of alternative buckling procedures to the reference advanced buckling procedure is acceptable provided that the alternative procedure is verified against the test cases specified in the Background to Section 4 of this chapter and where the permissible utilisation buckling factor for the alternative method, $\eta_{all-alt}$, conforms to:

$$\eta_{all-alt} \leq \eta_{all} \cdot \left(\frac{\eta_{alt-i}}{\eta_{ref-i}}\right)_{min}$$

Where,

η_{all} permissible utilization factor against buckling for plate and stiffened panels as specified in Section9/Table 2.3.3

η_{ref-i} utilization factor for reference advanced buckling procedure for test case i specified in Background to Section 4

η_{alt-i} utilization factor for alternative buckling procedure for test case i specified in Background to Section 4

1.1.3. Definitions

1.1.3.1. “Buckling” is a generic term used to describe the strength of structures, generally under in-plane compressions and/or shear. The buckling strength or capacity can take into account the internal redistribution of loads depending upon the situation.

1.1.3.2. Buckling capacity accepting local elastic plate buckling with load redistribution is called as Method 1. The load that results in the first occurrence of membrane yield stress anywhere in the stiffened panel is called as buckling capacity. Based on this principle buckling capacity gives a lower bound estimate of ultimate capacity, or the maximum load that the panel can carry without suffering major permanent set. Method 1 buckling capacity assessment utilizes the positive elastic post-buckling effect for plates and accounts for load redistribution between the structural components, such as between plating and stiffeners. For slender structures the capacity calculated using this method is much higher than the ideal elastic buckling stress (minimum Eigen-value). Considering elastic buckling of structural components in slender stiffened panels implies that large elastic deflections and reduced in-plane stiffness will occur at higher buckling utilization levels.

1.1.3.3. Method 2 buckling capacity does not accept load redistribution between structural components and refers to the minimum of value of the ideal elastic buckling stress and the Method 1 buckling capacity. In this method, buckling capacity normally equals the same strength as Method 1 for stocky panels, while it is the ideal elastic buckling stress (minimum Eigen-value cut-off) for slender panels. By applying the ideal elastic buckling stress limitation, large elastic deflections and reduced in-plane stiffness will be avoided at higher buckling utilization levels.

1.1.3.4. A “buckling failure mode” refers to a specific pattern of buckling failure. Typical failure modes of stiffened panels with open profiles are:
a) plate buckling
b) torsional stiffener buckling
c) stiffener web plate buckling
d) lateral stiffener buckling.

2. Advanced Buckling Analysis Method

2.1. General

2.1.1. Effects to consider

1.1.1.1. The advanced buckling assessment method must be able to consider the following effects:

a) Nonlinear geometrical behaviour
b) Inelastic material behaviour
c) Initial deflections - geometrical imperfections/out-of flatness
d) Welding residual stresses
e) Interactions between buckling modes and structural elements; plates, stiffeners, girders etc.
f) Simultaneous acting loads; bi-axial compression/tension, shear and lateral pressure
g) Boundary conditions.

1.1.1.2. The detailed requirements for items listed in 2.1.1.1 are given in 2.1.2 to 2.1.8. Additional requirements applicable to non-linear finite element models are given in 2.1.9 and 2.1.10.

2.1.2. Nonlinear geometrical behavior

2.1.2.1. The buckling method is based on non-linear large deflection plate theory or equivalent. Second order membrane strains due to geometrical non-linearity are to be accounted for.

2.1.2.2. The Non-linear plate theory given by von Karman and Marguerre is acceptable for assessing the strength beyond the ideal elastic buckling level.

2.1.3. Material behavior and properties

2.1.3.1. The behavior of inelastic material is to be considered plasticity. The redistributed stress fields due to non-linear geometrical behavior and geometrical imperfections are to be limited to below the von Mises yield criterion, if the buckling method is not capable of handling nonlinear material.

2.1.3.2. Alternatively, a bi-linear material model is to be used with a conservative strain-hardening coefficient in the plastic region, if the buckling method is capable of handling nonlinear material.

2.1.3.3. Yield strength and Young's Modulus are the characteristic values which are used as the material property assumptions. Where appropriate, a bi-linear isotropic elasto-plastic material model (excluding strain rate effects) is to be used or the Tangent Modulus is to be taken as a conservative value. A plastic tangent modulus of 1000M Pa is acceptable for normal and higher strength steel.

2.1.4. Initial deflections – geometrical imperfections/out-of-flatness

2.1.4.1. The buckling assessment should include the initial deflections.

2.1.4.2. The geometrical imperfections are to be transformed to a regular model pattern for the deterministic strength assessment.

2.1.4.3. The imperfections may be divided into local imperfections (plate out-of-flatness and stiffener sideways out-of-straightness), and global imperfections of the stiffeners (stiffener lateral/vertical out-of Amended straightness).

2.1.4.4. The shape of the initial deflections is to be such that the most critical failure modes are represented and triggered by the analysis. In general, a combination of the lowest buckling Eigen-modes will be appropriate. In case of plates with high slenderness and in the case of simultaneously acting loads, where the critical failure mode may be different from the lowest Eigen-modes, will be considered.

2.1.4.5. The default maximum values of the imperfections are considered to be consistent with the Shipbuilding and Quality Repair Standard. However, regular model imperfection amplitudes may be taken less than the maximum tolerance specified. The regular model imperfections may typically be case dependent (load ratio dependent) and are also to cover imperfections due to welding. The IRS must approve the actual level of model imperfections which will depend on the method of analysis, extension of model, etc.

2.1.5. Welding induced residual stress

2.1.5.1. Residual stresses are not required to be explicitly included in the buckling assessment, see 2.1.4.5.

2.1.6. Interactions between buckling modes and structural elements

2.1.6.1. The advanced buckling analysis method is to accurately explain the interactions between the various structural components and hence between the different buckling modes.

2.1.6.2 All the critical initial imperfection shapes are to be included, see 2.1.4.

2.1.7. Simultaneous acting loads

2.1.7.1. The method must be able to model any combination of biaxial in-plane compressive and shear membrane loads and lateral pressure.

2.1.7.2. To generate the deformed shape, any lateral pressure is first applied and after that it should be kept constant.

2.1.7.3. The effect of lateral pressure enforcing deflections in different patterns than in-plane loads is to be included in a manner that the most critical buckling mode is developed.

2.1.8. Boundary conditions

2.1.8.1. The boundary conditions represent the actual response of the plate or stiffened panel. Both in-plane and out-of-plane boundary conditions are to be considered.

2.1.8.2. The edges may be taken as free to move in-plane, but forced to remain straight where a panel is an integral part of a larger continuous area of stiffened plating, such as bottom or side panels,. Where a panel is not supported in-plane by adjacent structure, such as a stringer web panel or bottom girder web, then the edges are to be considered as completely free.

2.1.8.3. Rotational restraint on the plate from the stiffeners is to be accounted for by direct analysis of the plate and stiffener interaction. Prescribed boundary conditions are, in general, not acceptable.

2.1.8.4. The panels can be taken as supported in the lateral/vertical direction at the primary support members. The stiffeners may be taken as horizontally supported at the crossing of primary support members (preventing tilting at crossings). The geometrical rotational restraint of the plate from the primary support members is to be ignored.

2.1.9. Model extent

2.1.9.1. The extent of the model that is to be used in the buckling assessment must be sufficient to account for the structure that is surrounding the panel of interest, and also to reduce the uncertainties introduced through the boundary conditions.

2.1.9.2. In general, the model is to include more than one stiffener span in the stiffener direction and the portion between two primary support members in the direction normal to the stiffeners.

2.1.10. Element size for non-linear finite element models

2.1.10.1. In order to describe the buckling deflections accurately, the element size is to be small.

2.1.10.2. The mesh size will depend on the complexity of the geometry and loads and the type of element used, but generally, at least five elements across a half-buckling wave length is required.

3. Application and Structural Modelling Principles

3.1. General

3.1.1. Scope

3.1.1.1. This section specifies the standard assumptions which are to be applied for the application of the advanced buckling method. These assumptions may be refined when the advanced buckling method is capable of more accurate representation of the structure.

3.1.2. Boundary conditions

3.1.2.1. The boundary conditions are to accurately account for the in-plane and rotational constraints imposed by the adjacent structures (such as stiffeners, primary support members and adjacent plates). Those assumptions are applied which are defined in 3.1.2.3 to 3.1.2.4.

3.1.2.2. The boundary conditions are divided into two main groups mainly for “free edge plating” and “continuous plating”. The latter group represents large stiffened panels such as deck plating, bottom plating, ship sides, etc., while the other represents girders, floors, stringers, etc.

3.1.2.3. Elements having in-plane support conditions by the surrounding structure are represented by the continuous plating conditions. The boundary conditions for stiffened panels are to be taken as:

a) panel edges perpendicular to stiffeners are to be considered simply supported
b) panel edges parallel to stiffeners are to be considered as having rotational support equivalent to that provided by stiffeners within the panel
c) the ends of stiffeners are to be considered as part of a continuous panel and supported sideways by the primary support members
d) all edges of the panel are to be constrained to remain straight but are free to displace inwards.

3.1.2.4. Elements having weak in-plane support along one or more edges are represented by free edge plating conditions, e.g. vertically stiffened double bottom floors. The boundary conditions for stiffened panels are to be taken as:

a) panel edges perpendicular to stiffeners are considered as simply supported
b) panel edges parallel to stiffeners are to be considered as having rotational support equivalent to that provided by stiffeners within the panel
c) When attached directly to adjacent structure, the ends of stiffeners are to be considered as supported sideways, otherwise they are to be assumed simply supported
d) All free edges of the panel are free to displace inwards, whereas rotational restraints of the edge reinforcements on the free edges may be considered.

3.1.2.5. The boundary conditions for un-stiffened panels are to be taken as:

a) Unless otherwise stated, panel edges are to be considered simply supported
b) Free edges of the panel, if any, are free to displace inwards. However, continuous edges are to be constrained to remain straight.

3.1.3. Structural idealization

3.1.3.1. The structural modelling and buckling assessment method applicable for free edge plating is to be taken as:
a) Parallel to the stiffener direction: one frame bay is normally sufficient for structures having significant stress gradients. For uniformly compressed elements with the free edges parallel to the stiffener direction, such as longitudinal girders, multi-bay models are to be considered
b) Normal to the stiffener direction: between primary support members, but may be limited to six stiffener spacings
c) Assessment method: Method 2 - buckling capacity with no allowance for redistribution of load unless otherwise specified.

3.1.3.2. The structural modelling and buckling assessment method applicable for continuous plating is to be taken as:
a) Parallel to the stiffener direction: at least two frame bays, in order to model imperfections between adjacent panels
b) Normal to the stiffener direction: between primary support members, but may be limited to six stiffener spacings
c) Assessment method: Method 1 - buckling capacity with allowance for redistribution of load unless otherwise specified.

4. Assessment Criteria

4.1. General

4.1.1. Buckling strength assessment methods

4.1.1.1. The buckling capacity value is to be based on one of the following assessment methods:
1) Buckling Capacity with allowance for redistribution of load
2) Buckling Capacity with no allowance for redistribution of load

In 3.1.3, the application of which assessment method to use is given.

4.1.2. Method 1: Buckling capacity with allowance for redistribution of load

4.1.2.1. The buckling capacity value is taken as the load that results in the first occurrence of membrane yield stress anywhere in the stiffened panel. This includes the redistribution of load as indicated in 1.1.3.2. In particular the following locations are to be checked for von Mises stresses equivalent to yield:
a) At the plate’s edges
b) Along the intersection line of the plate and stiffeners, especially at the ends and at the stiffener mid-point
c) Along the stiffeners flanges, especially at the ends of the stiffener and at the stiffener mid-point.

4.1.3. Method 2: Buckling capacity with no allowance for redistribution of load
The buckling capacity value or the load that results in the first occurrence of membrane yield stress anywhere in the stiffened panel, see 1.1.3.3.

4.2. Utilisation Factors

4.2.1. General

4.2.1.1. The utilisation factor, η , is used as a measure of safety margin against buckling strength failure. The ratio between the applied loads and the corresponding ultimate capacity or buckling strength is referred as the utilization factor.

4.2.1.2. A structure is considered to have an acceptable buckling strength if it satisfies the following criteria:

$$\eta_{act} \leq \eta_{allow}$$

Where:

η_{allow} allowable buckling utilisation factor, as defined in Chapter 2 Section 3/2.2.5

η_{act} actual buckling utilisation factor based on the applied design loads

4.2.1.3. For combined loads, the utilisation factor, η, is to be taken as the ratio between the applied equivalent load and the corresponding buckling capacity, see Figure 4.4.1, and is to be taken as:

$$\eta = \frac{W_{act}}{W_u}$$

Where:

W_{act} applied equivalent load due to the combined membrane loads

$$= \sqrt{\sigma_{dx}^2 + \sigma_{dy}^2 + \tau_d^2} \quad N/mm^2$$

W_u equivalent load due to the combined membrane loads which result in the buckling capacity point, see Figure 4.4.1

$$= \sqrt{\sigma_{cx}^2 + \sigma_{cy}^2 + \tau_{cr}^2} \quad N/mm^2$$

Where combined loads are factored by the same ratio and the applied pressure load is to be kept constant.

σ_{dx} applied axial stress in x direction, in N/mm^2

σ_{dy} applied axial stress in y direction, in N/mm^2

τ_d applied shear stress, in N/mm^2

σ_{cx} buckling strength due to compression in x direction, in N/mm^2

σ_{cy} buckling strength due to compression in y direction, in N/mm^2

σ_{cr} buckling strength in shear, in N/mm^2

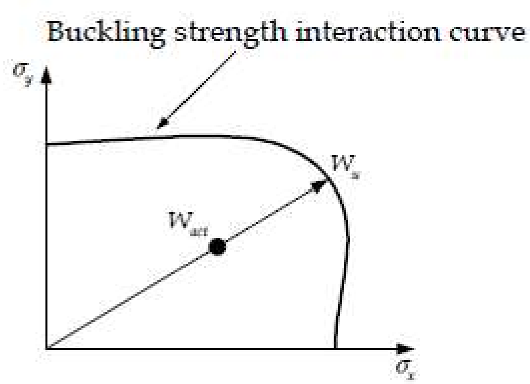


Figure 4.4.1: Definition of Utilisation Factor Example Showing a Bi-Axial Loading Pattern

5. Strength Assessment (FEM) – Buckling Procedure

5.1. General

5.2.1. Scope

5.1.1.1. As part of the Design Verification procedure, the following procedure is to be used for the assessment of the buckling requirements for the Strength Assessment (FEM), as stated in Chapter 2 Section 3/2.

5.1.1.2. For all structural elements, finite element analysis is to be assessed individually. Each stiffener with attached plate and all un-stiffened panels are to be assessed.

5.1.1.3. The buckling performance of each member is considered acceptable if it satisfies the following:

$$\eta_{act} \leq \eta_{allow}$$

Where:

η_{allow} allowable buckling utilization factor, as defined in Chapter 2 Section 3/2.2.5

η_{act}actual buckling utilization factor based on the applied design loads, see 4.2.1

5.2. Structural Modelling and Capacity Assessment Method

5.2.1. General

5.2.1.1. As specified in Table 4.4.1 and Figure 4.4.2, the longitudinally effective structure of the hull girder is to be modelled as stiffened panels or unstiffened panels These provide the standard assumptions to be used for the buckling capacity assessment method.

5.2.1.2. The structural models are based on the net thickness which is obtained by deducting the full corrosion addition, i.e. $-1.0t_{corr}$, and any owner'sextras from the proposed thickness. This thickness reduction applies to the plating and the stiffener web and face plate.

5.2.2. Stiffened panels

5.2.2.1. Each stiffener with attached plate is to be represented as a stiffenedpanel of the extent defined in Table 4.4.1 and hence is assumed to be apart of a larger structural entity to correctly model the overall bucklingbehaviour.

5.2.2.2. The assessment method is generally used to enable changes in plate thickness, stiffener size and spacing. However, where the advanced buckling method fails to model these changes, the calculations are to be performed separately for each stiffener and plate between the stiffeners. Plate thickness, stiffener properties and stiffener spacing at the considered location are to be assumed for the whole panel. The calculations are to be performed for all configurations of the panel if the plate thickness, stiffener properties and stiffener spacing varies within the stiffened panel. The weighted average thickness may be used for the thickness of the plating for assessment of the corresponding stiffener/plating combination, where the panel between stiffeners consists of several plate thicknesses. Calculation of weighted average is to be done in accordance with.

5.2.2.3. See Figure 4.4.7.

5.2.3. Un-stiffened panels

5.2.3.1. The assessment method is used to enable changes in plate thickness and panel geometry.

5.2.3.2. The geometry of the panel (i.e. plate bounded by web stiffeners/face plate) may not have a rectangular shape in way of web frames, stringers and brackets. Where the advanced buckling method fails to model the panel geometry, then an equivalent rectangular panel is to be defined as shown in Figure 4.4.6. Where web stiffeners are not connected to the intersecting stiffeners, then the panel may be defined as shown in Figure 4.4.7. In order to derive realistic stress values for application to the equivalent rectangular panel, the FE analysis is used to represent the actual structure. In accordance with 5.3.2.1, the stresses of all elements whose centroids are within the equivalent plate panel are required to be considered for stress average.

5.2.3.3. Where the advanced buckling method fails to enable changes in net plate thickness across a panel, and the panel consists of a number of finite plate elements, then the average thickness is to be taken as:

$$t_{avr} = \frac{\sum A_j t_j}{\sum A_j}$$

Where:

A_j area of the jth plate element making up the panel

t_j net thickness of the jth plate element making up the panel

Table 4.4.1: Structural Elements for the Strength Assessment (FEM)

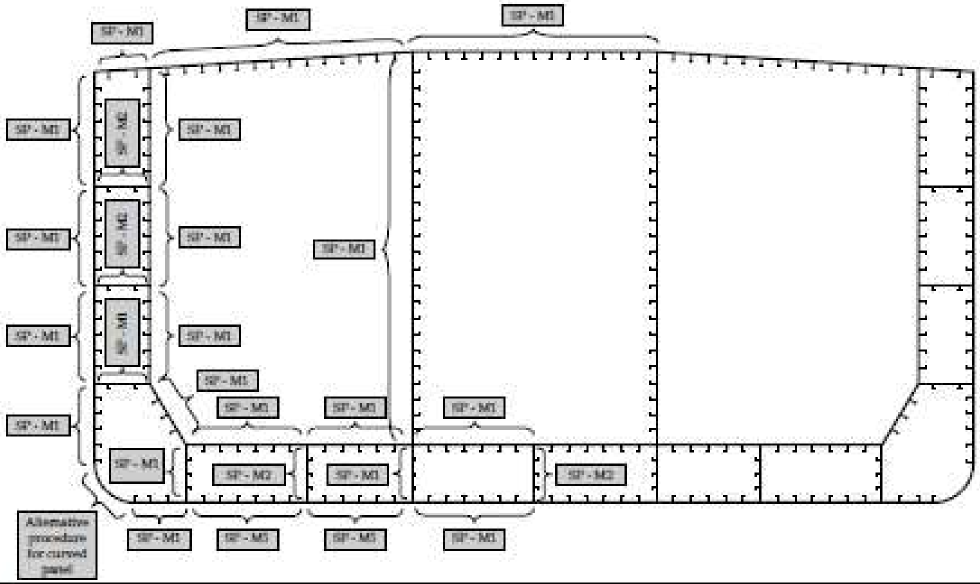
Structural Elements	Idealisation	Assessment method (1)	Normal panel definition (2)
Longitudinal structure, see Figure 4.4.2			
Longitudinally Stiffened panels Shell envelope Deck Inner hull Hopper tank side Longitudinal bulkheads Centerline bulkheads	Stiffened panel	Method 1	Length: between web frames Width: between primary support members (PSM) (2)
Double bottom longitudinal girders in line with longitudinal bulkhead or connected to hopper tank side	Stiffened panel	Method 1	Length: between web frames Width: full web depth
Web of horizontal girders in double side tank connected to hopper tank side	Stiffened panel	Method 1	Length: between web frames Width: full web depth
Web of double bottom longitudinal girders not in line with longitudinal bulkhead or not connected to hopper tank side	Stiffened panel	Method 2	Length: between web frames Width: full web depth
Web of horizontal girders in double side tank not connected to hopper tank side	Stiffened panel	Method 2	Length: between web frames Width: full web depth
Web of single skin longitudinal girders	Un-stiffened panel	Method 2	Between local stiffeners/face plate/PSM
Transverse structure, see Figure 4.4.3			
Web of transverse deck girders including brackets	Un-stiffened panel	Method 2	Between local stiffeners/face plate/PSM
Vertical web in double side tank	Stiffened panel	Method 2	Length: full web depth Width: between primary support members
All irregularly stiffened panels, e.g. Web panels in way of hopper tank and bilge	Un-stiffened panel	Method 2	Between local stiffeners/face plate/PSM
Double bottom floors	Stiffened panel	Method 2	Length: full web depth Width: between primary support members
Vertical web frame including brackets	Un-stiffened panel	Method 2	Between vertical web stiffeners/face plate/PSM
Cross tie web plate	Un-stiffened panel	Method 2	Between vertical web stiffeners/face plate/PSM
Transverse Oil-tight and Watertight bulkheads, see Figure 4.4.4 and Transverse wash bulkheads, see Figure 4.4.5			
All regularly stiffened bulkhead panels	Stiffened panel	Method 1	Between local stiffeners/face plate/PSM
Regularly stiffened bulkhead with secondary buckling stiffeners perpendicular to regular stiffeners (3)	Stiffened panel	Method 1	Length: full web depth Width: between primary support members
All irregularly stiffened bulkhead panels e.g. web panels in way of hopper tank and bilge	Un-stiffened panel	Method 2	Between local stiffeners/face plate/PSM
Web Plate of bulkhead stringers including brackets	Un-stiffened panel	Method 2	Between web stiffeners/face plate
Transvers corrugated bulkheads			
Upper/lower stool including stiffeners	Stiffened panel	Method 1	Length: between internal web diaphragms Width: length of stool sides
Stool internal web diaphragm	Un-stiffened panel	Method 2	Between local stiffeners/face plate/PSM

Note:

1.The assessment method specifies which buckling strength assessment method is to be used, see 4.1

2. See structural idealization, 3.1.3.

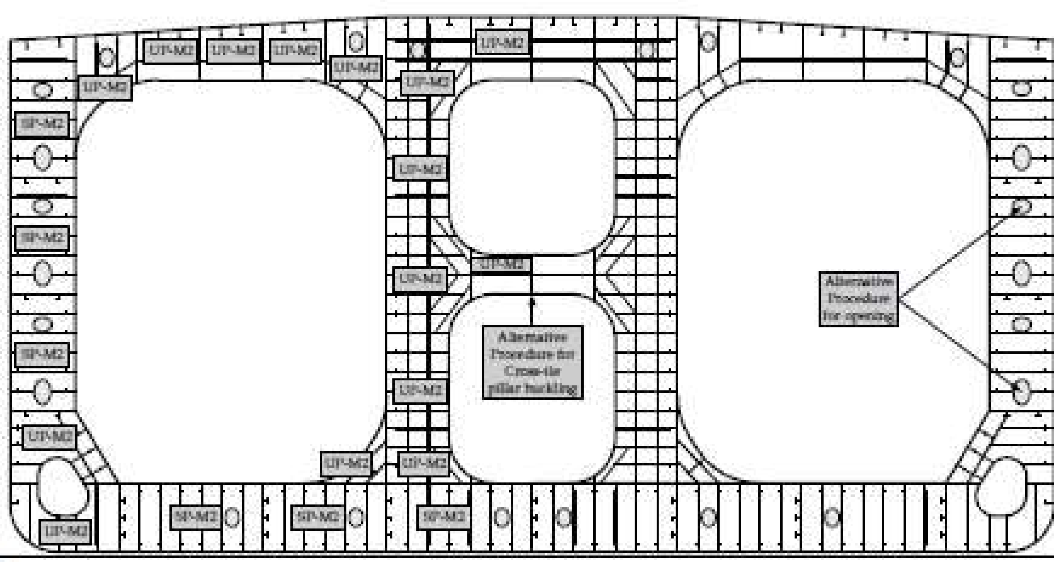
3. The secondary stiffener can be modeled as “sniped” or “continuous”. The stiffener is considered “sniped” unless rotational end supports are provided at both ends. An area stiffened by irregular buckling stiffeners only should be assessed by considering each plate in the panel as Unstiffened panel using Method 2.



Notes

1) SP – M1 denotes stiffened panel – buckling strength assessed using Method 1
2) SP – M2 denotes stiffened panel – buckling strength assessed using Method 2

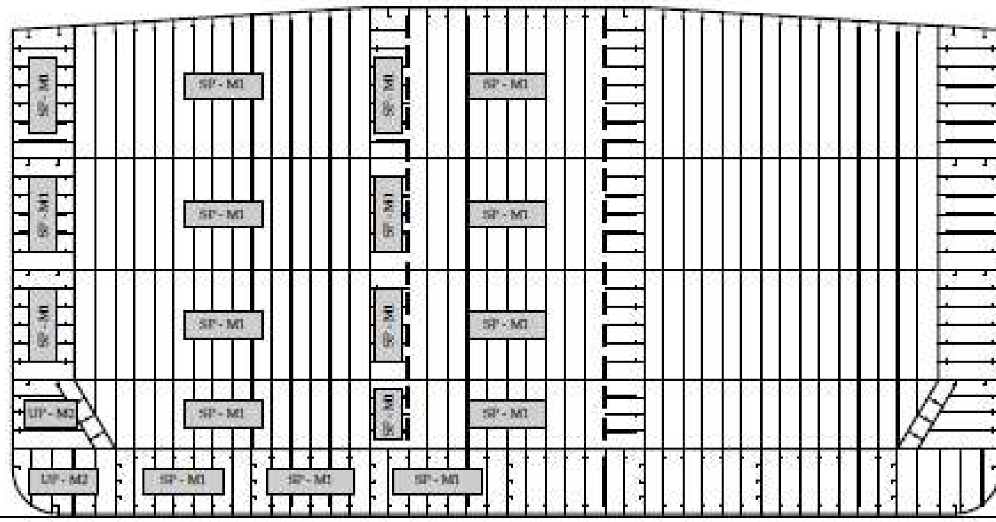
Figure 4.4.2 : Advanced Buckling Assessment for longitudinal strength



Notes

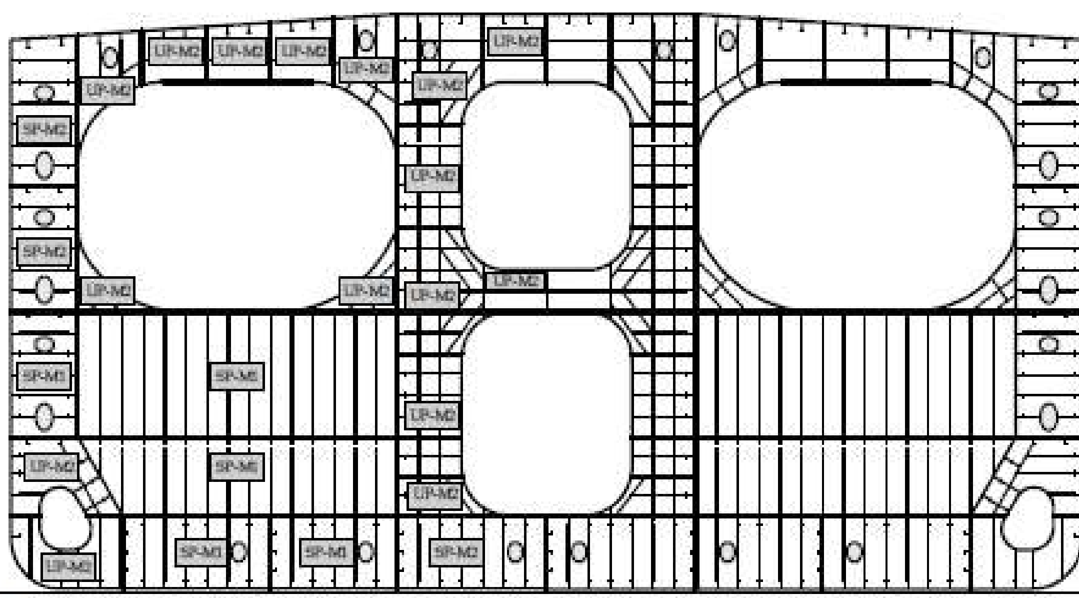
SP – M1 denotes Stiffened Panel – buckling strength assessed using Method 1
UP – M2 denotes Un-stiffened Panel – buckling strength assessed using Method 2
SP – M2 denotes Stiffened Panel – buckling strength assessed using Method 2

Figure 4.4.3: Transverse Web frames



Notes
SP – M1 denotes Stiffened Panel – buckling strength assessed using Method 1.
UP – M2 denotes Un-stiffened Panel – buckling strength assessed using Method 2

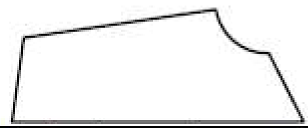
Figure 4.4.4: Transverse Bulkhead



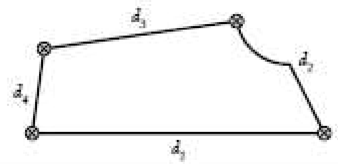
Notes
SP – M1 denotes Stiffened Panel – buckling strength assessed using Method 1
UP – M2 denotes Un-stiffened Panel – buckling strength assessed using Method 2
SP – M2 denotes Stiffened Panel – buckling strength assessed using Method 2

Figure 4.4.5: Cross-tie

a) The four corners closest to a right angle, 90degrees, in the bounding polygon for the plate are identified

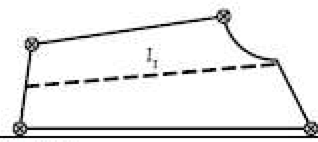


b) The distances along the plate bounding polygon between the corners are calculated, i.e. the sum of all the straight line segments between the end points



c) The pair of opposite edges with the smallest total length is identified, i.e. minimum of d_1+d_3 and d_2+d_4

d) A line is joined between the middle points of the chosen opposite edges (i.e. a mid point is defined as the point at half the distance from one end). This line defines the longitudinal direction, x_1, for the capacity model. The length of the line defines the length of the capacity model, l_1 or d_2 measured from one end point.



e) The width of the model, l_2, is to be taken as:

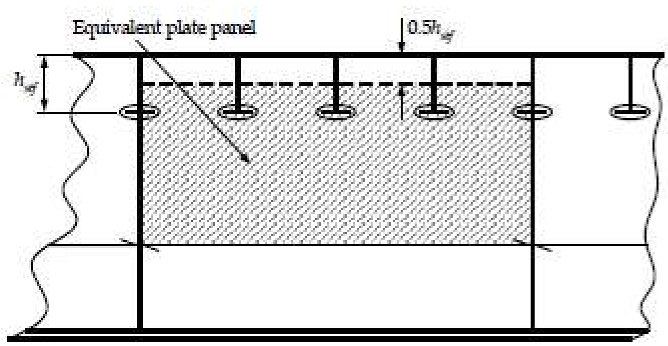
$$l_2 = A_{pl} / l_1$$

Where:

A_{pl} area of the plate

f) The stresses from the FE analysis are to be resolved into the local coordinate system of the equivalent rectangular panel. These stresses are to be used for the buckling assessment.

Figure 4.4.6: Modelling Of an Unstiffened Panel with Irregular Geometry



Note
The correction of panel breadth is applicable also for other slot configurations provided that the web or collar plate is attached to at least one side of the passing stiffener.

Figure 4.4.7: Capacity Model for Web Plate

5.3. Load Application

5.3.1. General

5.3.1.1. The ultimate capacity or buckling strength is required to be assessed for the effects of the combined bi-axial and shear membrane stresses acting on the structural panel.

5.3.1.2. The FE analysis provides the axial compressive and shear stress distribution is which are applied to the buckling model. The stresses from the FE analysis are not required to be adjusted for the required change in thickness for buckling, i.e. -0.5t_{corr} used in the FE analysis and 1.0t_{corr} used for the buckling assessment.

5.3.1.3. The lateral pressure is also required to be applied to the buckling assessment in addition to the FE analysis.

5.3.1.4. The stresses may be applied by means of enforced displacements obtained from the finite element analysis or by loads applied to the panel edges.

5.3.1.5. The stresses and pressures may be averaged as defined in 5.3.2 and 5.3.3 where the advanced buckling method fails to model changes in axial or shear stress across a panel.

5.3.2. Average membrane stresses

5.3.2.1. When the plate panel consists of a number of finite plate elements, the average membrane stress is to be calculated using a weighted average approach, as given by:

$$\sigma_{xm} = \frac{\sum_1^n A_i \sigma_{xmi}}{\sum_1^n A_j} \quad N/mm^2$$

$$\sigma_{ym} = \frac{\sum_1^n A_i \sigma_{ymi}}{\sum_1^n A_i} \quad N/mm^2$$

$$\tau_{xym} = \frac{\sum_1^n A_i \tau_{xymi}}{\sum_1^n A_i} \quad N/mm^2$$

Where,

σ_{xmi} Membrane stress in x-direction at the centroid of the i^th plate element of the panel, in N/mm^2

σ_{ymi} Membrane stress in y-direction at the centroid of the i^th plate element of the panel, in N/mm^2

τ_{xymi} Membrane shear stress at the centroid of the ith plate element of the Panel, in N/mm^2

A_i area of the ith plate element making up the panel, in mm^2

n number of elements in the panel

When $\sigma_{xmi}\ or\ \sigma_{ymi}$ are in tension, then the respective value is to be taken as zero

5.3.3. Average lateral pressure

5.3.3.1. Where the plate panel consists of a number of finite elements, the average pressure, P_{avr} is to be calculated using a weighted average approach, as given by:

$$P_{avr} = \frac{\sum_1^n A_i P_i}{\sum_1^n A_i} \quad kN/m^2$$

Where:

P_i pressure acting on the ith plate element making up the panel, in kN/m^2

A_i area of the ith plate element making up the panel, in mm^2

n number of elements in the panel

1.1. Limitations of the Advanced Buckling Assessment Method

5.4.1. General

5.4.1.1. In the absence of a suitable advanced buckling method, then the following structural elements can be assessed as per Table 4.4.2.

Table 4.4.2: Requirements for structures where there is no advanced buckling method available

Structural elements	Buckling mode	Rule Reference
Bilge plate	Transverse elastic buckling	Chapter 2 Section 2/2.2.3
Primary support members	Global (overall) buckling and torsional buckling	Chapter 2 Section 4/2.3
Web plate of primary support members in way of openings	Buckling of web plate	Chapter 2 Section 4/3.4
Cross ties	Global (overall) buckling	Chapter 2 Section 4/3.5
Corrugated bulkheads	Flange panel buckling	Chapter 2 Section 4/3.2
	Global (overall) buckling	Chapter 2 Section 4/3.5

2. Ultimate Hull Girder Strength Assessment

6.1. General

6.1.1. Scope

2.1.1.1. This procedure is required for the assessment of the ultimate hull girder strength assessment as part of the Design Verification procedure, refer Chapter 2 Section 3/1.

2.1.1.2. All structural elements of the strength deck are to be individually assessed.

6.2. Load Application

6.2.1. General

6.2.1.1. At the stiffener/plate intersection point, the uni-axial compressive stress used for the ultimate capacity assessment of longitudinally stiffened deck panels is required to be calculated.

6.2.1.2. The hull girder stresses are based on the section modulus properties using a deduction of half the corrosion addition, i.e. -0.5t_{corr}, and owner's extra from the proposed thickness.

6.2.1.3. The buckling assessment for hull girder ultimate strength does not includes lateral pressure.

6.3. Structural Modelling and Buckling Assessment

6.3.1. General

6.3.1.1. To derive the ultimate capacity, the longitudinally effective structure of the strength deck is to be modelled as stiffened panels using Method 1.

6.3.1.2. Each deck stiffener with attached plate is to be represented as a stiffened panel with the transverse extent being between two adjacent primary support members.

6.3.1.3. The buckling capacity models are to be based on the net thickness obtained by deducting half the corrosion addition, i.e. $-0.5t_{corr}$, and any owner's extras from the proposed thickness. This thickness reduction applies to the plating and the stiffener web and face plate.

6.3.1.4. The assessment method is generally used to enable changes correctly in plate thickness, stiffener size and spacing. However where the advanced buckling method is fails to enable these changes, the calculations are to be performed separately for each stiffener and plate between the stiffeners. Plate thickness, stiffener properties and stiffener spacing at the considered location are to be assumed for the whole panel. The calculations are to be performed for all configurations of the panel, if the plate thickness, stiffener properties and stiffener spacing varies within the stiffened panel.