2024

Rules for the Classification of Steel Ships

Part 14 Structural Rules for Container Ships

2024

Guidance Relating to the Rules for the Classification of Steel ships

Part 14 Structural Rules for Container Ships

2024

Rules for the Classification of Steel Ships

Part 14

Structural Rules for Container Ships

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APPLICATION OF PART 14
"STRUCTURAL RULES FOR CONTAINER SHIPS"

1. Unless expressly specified otherwise, the requirements in the Rules apply to ships for which contracts for construction are signed on or after 1 July 2024.
2. The amendments to the Rules for 2023 edition and their effective date are as follows;

Effective Date : 1 July 2024

CHAPTER 1 General Priciples

Section 2 Rule Principles

- Table 3 has been amended.

CHAPTER 2 General Arrangement

Section 3 Compartment Arrangement

- 1.2.4 has been amended.

CHAPTER 3 Structural Design Principles

Section 3 Corrosion Additions

- Table 1 has been amended.

Section 6 Structural Detail Principles

- 10.4 has been newly added.
- 10.4.1 to 10.4.6 have been newly added.

CHAPTER 4 Loads

Section 2 Dynamic Load Cases

- Symbols has been amended.
- 2. has been amended.
- 2.1.1 has been amended.
- 3. has been newly added.
- 3.1 has been amended.
- 3.1.1 has been amended.
- Table 7 to Table 9 have been amended.
- 3.2 has been newly added.
- 3.2.1 has been newly added.
- Table 10 to Table 12 have been newly added.

Section 3 Ship Motions and Accelerations

- 2.1.1 and 2.1.2 have been amended.
- 2.2.1 to 2.2.5 have been amended.

Section 4 Hull Girder Loads

- Symbols has been amended.
- 2.2.1 has been amended.
- 2.4.1 has been amended.
- 3.2.1 has been amended.
- 3.3.1 has been amended.
- 3.4.1 has been amended.
- 3.5.1 has been amended.
- 3.6.1 has been amended.

Section 5 External Loads

- 1.3.2 to 1.3.8 have been amended.
- 1.4 has been newly added.
- 1.4.1 to 1.4.6 have been newly added.
- Table 32 to Talbe 50 have been newly added.
- 3.2 has been amended.
- 3.2.1 has been amended.
- 3.2.2 has been newly added.
- 3.3 has been amended.
- 3.3.1 has been amended.
- 3.4 has been amended.
- 3.4.1 has been amended.
- 3.5 has been newly added.
- 3.5.1 has been newly added.
- Figure 3 has been newly added.

Section 6 Internal Loads

- Symbols has been amended.
- 1.2.1 and 1.2.2 have been amended.
- 1.3.1 has been amended.
- 4.1.1 has been amended.
- 5.1.1 has been amended.
- Table 2 has been amended.

CHAPTER 6 Hull Local Scantling

Section 2 Load Application

- Table 1 has been amended.

Section 4 Plating

- 1.2 has been newly added.
- 1.2.1 to 1.2.3 have been newly added.

- Table 2 and Table 3 have been newly added.

CHAPTER 7 Direct Strength Analysis

Section 2 Cargo Hold Structural Strength Analysis

- Table 8 has been amended.

Section 3 Local Structural Strength Analysis

- 4.2.1 has been amended.
- 4.2.2 has been newly added.

CHAPTER 8 Buckling

Section 1 General

- 1.1.1 has been amended.
- Table 1 has been amended.

Section 2 Slenderness Requirements

- 1.1.1 has been amended.

Section 3 Prescriptive Buckling Requirements

- 1.1.1 has been amended.
- 3.4 has been newly added.
- 3.4.1 has been newly added.
- 3.5 has been newly added.
- 3.5.1 has been newly added.

Section 4 Buckling Requirements for DSA

- 1.1.2 has been amended.
- Table 1 has been amended.
- 3. has been newly added.
- 3.1 to 3.4 have been newly added.
- Table 2 and Figure 10 have been newly added.

Section 5 Buckling Capacity

- 1.1.1 has been amended.
- 2.2.3 has been amended.
- 3.2 has been newly added.
- 3.2.1 has been newly added.

CHAPTER 10 Other Sturctures

Section 1 Fore Part

- Synbols has been amended.
- 3.2.4, 3.2.5 and 3.2.7 have been amended.
- 3.3.4 to 3.3.6 have been amended.

Section 3 Aft Part

- Symbols has been amended.
- 5.2.3 to 5.2.5 have been amended.

Section 4 Tanks Subject to Sloshing

- 1.2.1 has been amended.
- 1.3.1 has been amended.
- Table 1 has been amended.

CHAPTER 11 Superstructure, Deckhouse and Hull Outfitting

Section 1 Superstructure and Deckhouse

- Symbols has been amended.
- 1.1.1 has been amended.
- Table 1 has been newly added.
- 1.2.1 has been amended.
- 2.2.1 has been amended.
- 3.1.1 has been amended.
- 3.1.2 has been deleted.
- 3.2 has been amended.
- 3.2.1 to 3.2.4 have been amended.
- 3.4 has been deleted.

Section 5 Hatchways

- 1. has been amended.
- 1.1.1 has been amended.
- 1.2 to 1.6 has been deleted.
- 2. and 3. have been deleted.

CHAPTER 12 Construction

Section 1 Construction and Fabrication

- 3.2 has been newly added.
- 3.2.1 has been newly added.
- 3.3.1 has been amended.

Section 3 Design of Weld Joints

- 2.4.5 has been amended.
- Figure 4 has been amended.

CONTENTS

Chapter 1

General Principles

Section 1 Application

1. Scope of application

1.1 General

1.1.1

These Rules apply to the following ships:

a) Container ships and:

b) Being self-propelled ships with unrestricted navigation.

Note 1: "Container Ship" means a ship designed exclusively for the carriage of containers in holds and on deck.

Note 2: Unrestricted navigation means that the ship is not subject to any geographical restrictions (i.e. any oceans, any seasons) except that limited by the ship's capability for operation in ice.

1.1.2

These Rules apply to ships constructed of welded steel structures and composed of stiffened plate panels.

1.2 Scope of application for container ships

1.2.1

These Rules apply to double bottom ships of double side skin construction, intended to carry containers in holds or on deck. The requirements of hull equipment are generally to comply with those in **Pt 4**. The requirements of container ships with a length less than 90 m are generally to comply with those in **Pt 4** and **Pt 10**.

The ship's structure is to be longitudinally and transversely framed with full transverse bulkheads and intermediate web frames. Typical midship sections are shown in **Figure 1**.

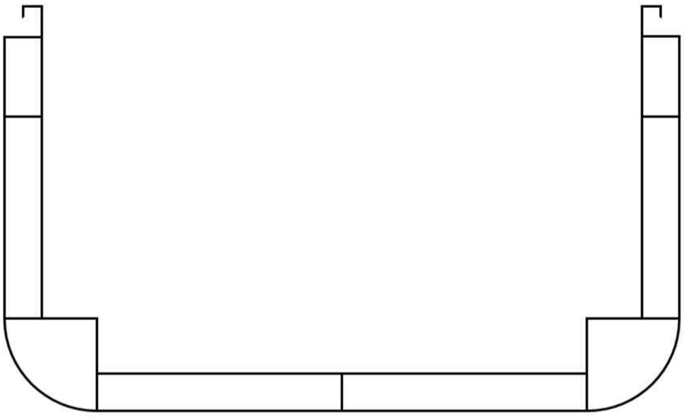


Figure 1 : Container ship of double side skin construction

2. Rule application

2.1 Rule description

2.1.1 Rule structure

This Rules are structured in chapters giving instructions for detail application and requirements which are applied in order to satisfy the rule objectives.

2.1.2 Numbering

The system of numbering is given in **Table 1**.

Table 1 : Rule numbering and abbreviations

Order	Levels	Example	Abbreviations
1	Chapter	Chapter 1 - General Requirements	**Ch 1**
2	Section	Section 1 - Application	**Sec 1**
3	Article	1. Scope of application	**[1.]**
4	Sub-article	1.1 General	**[1.1]**
5	Requirements	1.1.1 These Rules apply to...	**[1.1.1]**

2.2 Rule requirements

2.2.1

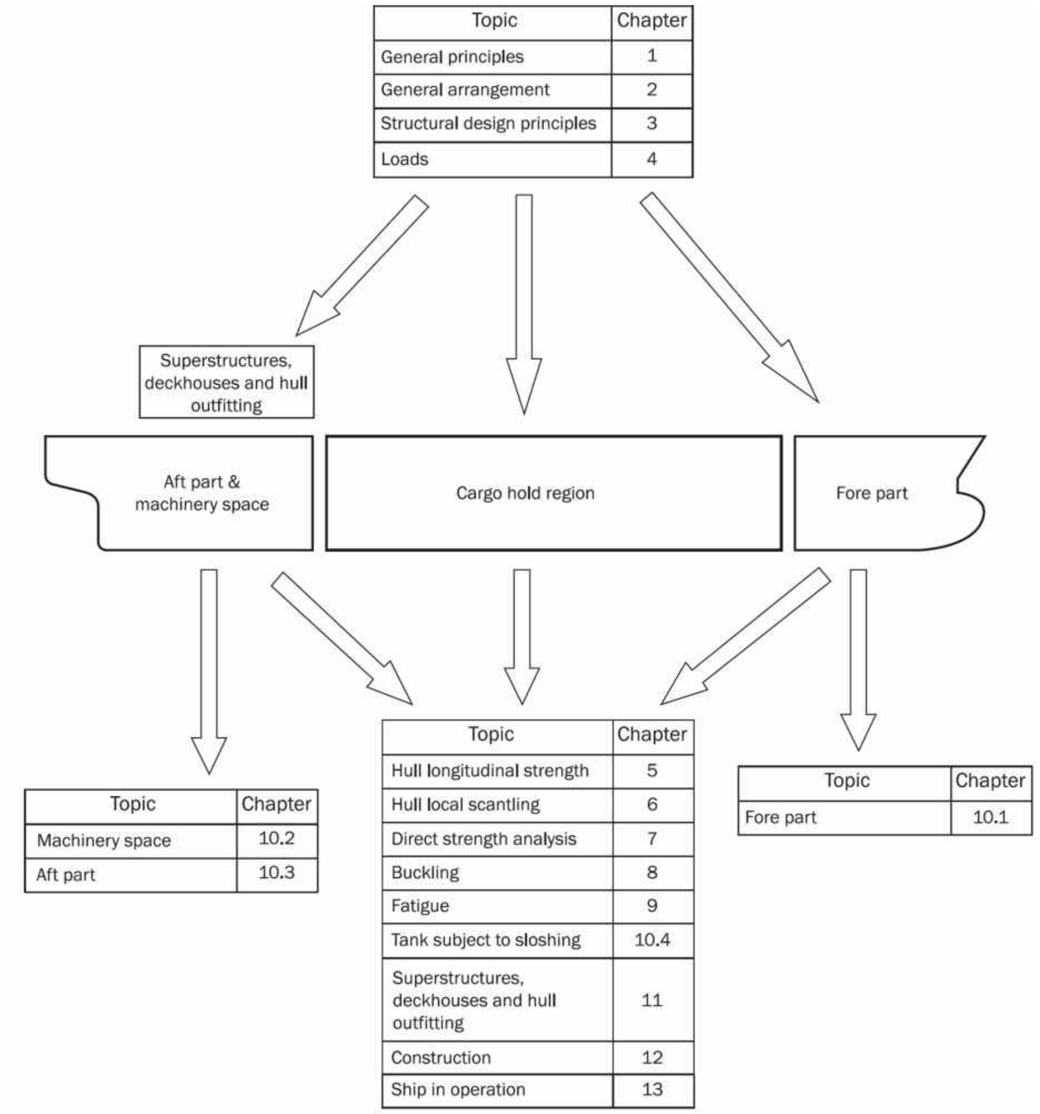
These Rules provides requirements common to container ship as follow:

- Chapter 1 : General Principles
- Chapter 2 : General Arrangement
- Chapter 3 : Structural Design Principles
- Chapter 4 : Loads
- Chapter 5 : Hull Girder Strength
- Chapter 6 : Hull Local Scantling
- Chapter 7 : Direct Strength Analysis
- Chapter 8 : Buckling
- Chapter 9 : Fatigue
- Chapter 10 : Other Structures
- Chapter 11 : Superstructure, Deckhouses and Hull Outfitting
- Chapter 12 : Construction
- Chapter 13 : Ship in Operation - Renewal Criteria
- Chapter 14 : Lashing Equipment

The provisions of the **Ch 1, 2, 3, 4, 5, 6, 8, 12, 13, 14** and **Ch 10, Sec 4** are applicable all over the ship length. The **Ch 7, 9, 10** and **11** define their own scope of application.

2.2.2 Application of the Rules

The ship arrangement and scantlings are to comply with the relevant chapters of the Rules as it is given in **Figure 2**.



Topic	Chapter
General principles	1
General arrangement	2
Structural design principles	3
Loads	4

Topic	Chapter
Machinery space	10.2
Aft part	10.3

Topic	Chapter
Hull longitudinal strength	5
Hull local scantling	6
Direct strength analysis	7
Buckling	8
Fatigue	9
Tank subject to sloshing	10.4
Superstructures, deckhouses and hull outfitting	11
Construction	12
Ship in operation	13

Topic	Chapter
Fore part	10.1

Figure 2 : Application of the Rules

2.2.3 General criteria

The ship arrangement, the proposed details and the offered scantling in net or gross, as the case may, are to comply with the requirements and the minimum scantling given the Rules.

2.3 Structural requirements

2.3.1 Materials and welding

The Rules apply to welded hull structures made of steel having characteristics complying with requirements in **Ch 3, Sec 1.** The Rules applies also to welded steel ships in which parts of the hull, such as superstructures or small hatch cover, are built in material other than steel, complying with requirements in **Ch 3, Sec 1**.

Ships whose hull materials are different than those given in the first paragraph are to be individually considered by the Society, on the basis of the principles and criteria adopted in the present rules.

2.4 Ship parts

2.4.1 General

For the purpose of application of the present rules, the ship is considered as divided into the following five parts:

- Fore part.
- Cargo hold region.
- Machinery space.
- Aft part.
- Superstructures and deckhouse.

2.4.2 Fore part

The part is that part of the ship located forward of the collision bulkhead, i.e.:

- The fore peak structures.
- The stem.

2.4.3 Cargo hold region

The cargo hold region is the part of the ship that contains cargo holds. It includes the full breadth and depth of the ship, the collision bulkhead and the transverse bulkhead at its aft end.

2.4.4 Machinery space

The machinery space is the part of the ship between the aft peak bulkhead and the transverse bulkhead at the aft end of the cargo hold region.

2.4.5 Aft part

The aft part includes the structures located aft of the aft peak bulkhead.

2.4.6 Superstructures and deckhouses

A superstructure is 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 0.04 B. A deckhouse is a decked structure on the freeboard or superstructure deck which does not comply with the definition of a superstructure.

Section 2 Rule Principles

1. General

1.1 Rule objectives

1.1.1

The objectives of the Rules are to establish the classification minimum requirements to mitigate the risks of major hull structural failure in order to help improve the safety of life, environment and property and to contribute to the durability of the hull structure for the ship's design life.

2. Design basis

2.1 General

2.1.1

This sub-section specifies the design parameters and the assumptions about the ship operation that are used as the basis of the design principles of the Rules.

2.1.2

Ships are to be designed to withstand, in the intact condition, the environmental conditions as defined in **[4.3.2]** and **[4.3.3]** anticipated during the design life, for the appropriate loading conditions. Structural strength is to be determined against buckling and yielding. Ultimate strength calculations have to include ultimate hull girder capacity and ultimate strength of plates and stiffeners.

2.1.3

Ship are to be designed to have sufficient reserve strength to withstand loads in damaged condition, e.g. flooded scenarios.

2.1.4 Finite element analysis

The scantling of the structural members within the cargo hold region of ships having a length L of 150 m or above is to be assessed according to the requirements specified in **Ch 7**.

2.1.5 Fatigue life

Ships having a length L of 150 m or above are to be assessed according to the design fatigue life for structural details specified in **Ch 9**.

2.2 Hull form limit

2.2.1

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

- $90\ \mathrm{m} \le L \le 500\ \mathrm{m}$
- $5 \le L/B \le 9$
- $2 \le B/T_{SC} \le 6$
- $B/D < 2.5$
- $0.55 \le C_B \le 0.9$

For ships except above mentioned hull form, the wave loads are to be in accordance with **Pt 13, Annex 13-1**.

2.3 Design life

2.3.1

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

2.4 Environmental conditions

2.4.1 North Atlantic wave environment

The rule requirements are based on a ship trading in the North Atlantic wave environment for its entire design life. The wave environment for fatigue strength is to be in accordance with **Ch 9**.

2.4.2 Wind and current

The effects of wind and current with regard to the strength of the structure are not considered.

2.4.3 Ice

The effects of ice and ice accretion are not taken into account by the Rules.

2.4.4 Design temperatures

The Rules assume that the structural assessment of hull strength members is valid for the following design temperatures:

- Lowest mean daily average temperature in air is -10 °C.
- Lowest mean daily average temperature in seawater is 0.0 °C.

Materials for ships intended to operate in areas with lower mean daily average temperature are to be in accordance with **Pt 3, Ch 1, 406**.

In the above, the following definitions apply:

- Mean : Statistical mean over observation period (at least 20 years).
- Daily Average : Average during one day and night.
- Lowest : Lowest during year.

For seasonally restricted service the lowest value within the period of operation applies.

2.4.5 Thermal loads

The effects of thermal loads and residual stresses are not taken into account in the Rules.

2.5 Operating conditions

2.5.1

The Rules specify minimum loading conditions that are to be assessed for compliance.

Specification of loading conditions other than those required by the Rules is the responsibility of the owner. These other loading conditions are to be documented and also be assessed for compliance.

2.6 Operating draughts

2.6.1

The design operating draughts are to be specified by the builder / designer subject to acceptance by the owner and are to be used to derive the appropriate structural scantlings. All operational loading conditions in the loading manual are to comply with the specified design operating draughts. The following design operating draughts are as a minimum to be considered:

- Scantling draught for the assessment of structure.
- Minimum ballast draught at midship for assessment of structure.

- Minimum draughts at forward perpendicular and aft end for the assessment of forward and stern bottom structure subjected to slamming loads, as defined in **Ch 4, Sec 5**.

2.7 Maximum service speed

2.7.1

The maximum service speed is to be specified in the design specification. Although the hull structure verification criteria takes into account the service speed this does not relieve the responsibilities of the owner and personnel to properly handle the ship.

2.8 Owner’s extras

2.8.1

Owner’s specification of requirements above the general classification or statutory requirements may affect the structural design. Owner’s extras may include requirements for:

- Vibration analysis.
- Maximum percentage of high strength steel.
- Additional scantlings above that required by the Rules.
- Additional design margin on the loads specified by the Rules, etc.
- Improved fatigue resistance, in the form of a specified increase in design fatigue life or equivalent.

Owner’s extras are not specified by these Rules. Owner’s extras, if any, that may affect the structural design are to be clearly specified in the design documentation.

3. Design principles

3.1 Overall principles

3.1.1 Introduction

This sub-section defines the underlying design principles of the Rules in terms of loads, structural capacity models and assessment criteria and also construction and in-service aspects.

3.1.2 General

The Rules are based on the following overall principles:

- The safety of the structure can be assessed by addressing the potential structural failure mode(s) when the ship is subjected to operational loads and environmental loads / conditions.
- The design complies with the design basis, see **Ch 1, Sec 3**.
- The structural requirements are based on consistent design load sets which cover the appropriate operating modes of container ship.

3.1.3 Limit state design principles

The rules are based on the principles of limit state design.

Limit state design is a systematic approach where each structural element is evaluated with respect to possible failure modes related to the design scenarios identified. For each retained failure mode, one or more limit states may be relevant. By consideration of all relevant limit states, the limit load for the structural element is found as the minimum limit load resulting from all the relevant limit states.

The limit states defined in **Ch 3, Sec 5** are divided into the four categories:

- Serviceability Limit State (SLS)
- Ultimate Limit State (ULS)
- Fatigue Limit State (FLS)
- Accidental Limit State (ALS).

The Rules include requirements to cover the relevant limit states for the various parts of the structure.

3.2 Loads

3.2.1 Design load scenarios

The structural assessment of the structure is based on the design load scenarios encountered by the ship. Refer to **Ch 4, Sec 7**.

The design load scenarios are based on static and dynamic loads as given below:

- Static design load scenario (S):
  Covers application of relevant static loads and typically covers load scenarios in harbour, sheltered water.
- Static plus Dynamic design load scenario (S + D):
  Covers application of relevant static loads and simultaneously occurring dynamic load components and typically cover load scenarios for seagoing operations.
- Impact design load scenario (I):
  Covers application of impact loads such as bottom slamming and bow impact encountered during seagoing operations.
- Sloshing design load scenario (SL):
  Covers application of sloshing loads encountered during seagoing operations.
- Fatigue design load scenario (F):
  Covers application of relevant dynamic loads.
- Accidental design load scenario (A):
  Covers application of some loads not occurring during normal operations.
- Tank testing design load scenario (T):
  Covers application of maximum loads during tank testing

3.3 Structural capacity assessment

3.3.1 General

The basic principle in structural design is to apply the defined design loads, identify plausible failure modes and employ appropriate capacity models to verify the required structural scantlings.

3.3.2 Capacity models for ULS, SLS and ALS

The strength assessment method is to be capable of analysing the failure mode in question to the required degree of accuracy.

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

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

3.3.3 Capacity models for FLS

The fatigue assessment method provides Rule requirements to assess structural details against fatigue failure.

The fatigue capacity model is based on a linear cumulative damage summation (Palmgren-Miner's rule) in combination with a design S-N curve, a reference stress range and an assumed long-term stress distribution curve.

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

3.3.4 Net scantling approach

The objective of the net scantling approach is to:

- Provide a relationship between the thickness used for strength calculations during the newbuilding stage and the minimum thickness accepted during the operational phase.
- Enable the status of the structure with respect to corrosion to be clearly ascertained throughout the life of the ship.

The net scantling approach distinguishes between local and global corrosion. Local corrosion is defined as uniform corrosion of local structural elements, such as a single plate or stiffener. Global corrosion is defined as the overall average corrosion of larger areas, such as primary supporting members and the hull girder. Both the local and global corrosion are used as a basis for the newbuilding review and are to be assessed during operation of the ship.

No credit is given in the assessment of structural capability for the presence of coatings or similar corrosion protection systems. The application of the net thickness approach to assess the structural capacity is specified in **Ch 3**, **Sec 2**.

3.3.5 Intact structure

All strength calculations for ULS, SLS and FLS are based on the assumption that the structure is intact.

4. Rule design method

4.1 General

4.1.1 Design methods

Scantling requirements are specified to cover the relevant limit states (ULS, SLS, FLS and ALS) as necessary for various structural parts. The criteria for the assessment of the scantlings are based on one of the following design methods:

- Working Stress Design (WSD) method, also known as the permissible or allowable stress method.
- Partial Safety Factor (PSF) method, also known as Load and Resistance Factor Design (LRFD).

For both WSD and PSF, two design assessment conditions and corresponding acceptance criteria are given. These conditions are associated with the probability level of the combined loads, A and B.

4.1.2 WSD method

- $W_{stat} \le \eta_1 R$ for condition A
- $W_{stat} + W_{dyn} \le \eta_2 R$ 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. specified minimum 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.

4.1.3 PSF method

- $\gamma_{sta-1} W_{sta} + \gamma_{dyn} W_{dyn} \le \frac{R}{\gamma_R}$ for condition A
- $\gamma_{sta-1} W_{sta} + \gamma_{dyn} W_{dyn} \le \frac{R}{\gamma_R}$ for condition B

where

γ_{sta-i} : Partial safety factor that accounts for the uncertainties related to static loads.

γ_{dyn-i} : Partial safety factor that accounts for the uncertainties related to dynamic loads.

γ_{R} : Partial safety factor that accounts for the uncertainties related to structural capacity.

The acceptance criteria for both the WSD method and PSF method are calibrated for the various requirements such that consistent and acceptable safety levels for all combinations of static and dynamic load effects are derived.

4.2 Minimum requirements

4.2.1

Minimum requirements specify the minimum scantling requirements which are to be applied irrespective of all other requirements, hence thickness below the minimum is not allowed.

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

- Minimum thickness, which is independent of the specified minimum yield stress.
- Minimum stiffness and proportion, which are based on buckling failure modes.

4.3 Load-capacity based requirements

4.3.1 General

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

The identified load scenarios are addressed by the Rules in terms of design loads, design format and acceptance criteria set, as given in **Table 2**.

The table is schematic and only intended to give an overview. Load based prescriptive requirements provide scantling requirements for all plating, local support members, most primary supporting members and the hull girder and cover all structural elements including deckhouses, foundations for deck equipment.

In general, these requirements explicitly control one particular failure mode and hence several requirements may be applied to assess one particular structural member.

4.3.2 Design loads for SLS, ULS and ALS

The structural assessment of compartment boundaries, e.g. bulkheads, is based on loading condition deemed relevant for the type of ship and the operation the ship is intended for.

To provide consistency of approach, standardised Rule values for parameters, such as GM, R_{roll}, T_{sc} and C_B are applied to calculate the Rule load values.

The probability level of the dynamic global, local and impact loads (see **Table 1**) is 10^{-8} and is derived using the long-term statistical approach. The probability level of the sloshing loads (see **Table 1**) is 10^{-4}.

The design load scenarios for structural verification apply the applicable simultaneously acting local and global load components. The relevant design load scenarios are given in **Ch 4, Sec 7**.

The simultaneously occurring dynamic loads are specified by applying a dynamic load combination factor to the dynamic load values given in **Ch 4**. The dynamic load combination factors that define the dynamic load cases are given in **Ch 4, Sec 2**.

Design load conditions for the hull girder ultimate strength are given in **Ch 5, Sec 2**.

Table 1 : Load scenarios and corresponding rule requirements

Operation	Load type	Design load scenario	Acceptance criteria
Seagoing operations			
Transit	Static and dynamic loads in heavy weather	S+D	AC-SD
	Impact loads in heavy weather	Impact (I)	AC-I
	Internal sloshing loads	Sloshing (SL)	AC-S
	Cyclic wave loads	Fatigue (F)	-
BWE by flow through or sequential methods	Static and dynamic loads in heavy weather	S + D	AC-SD
Harbour and sheltered operations			
Loading, unloading and ballasting	Typical maximum loads during loading, unloading and ballasting operations	S	AC-S
Special conditions in harbour	Typical maximum loads during special operations in harbour, e.g. propeller inspection afloat	S	AC-S
Accidental condition			
Collision conditions	Maximum loads on internal watertight subdivision structure including cofferdam bulkheads in collision	A	AC-A
Flooded conditions	Typically maximum loads on internal watertight subdivision structure in accidental flooded conditions	A	AC-A
Testing condition			
Tank testing	Typical maximum loads during tank testing operations	T	AC-T

4.3.3 Design loads for FLS

For the fatigue requirements given in **Ch 9**, the load assessment is based on the expected load history and an average approach is applied. The expected load history for the design life is characterised by the 10^{-2} probability level of the dynamic load value, the load history for each structural member is represented by Weibull probability distributions of the corresponding stresses.

The considered wave induced loads include:

- Hull girder loads.
- Dynamic wave pressures.
- Dynamic pressure from cargo.

The load values are based on Rule parameters corresponding to the loading conditions, e.g. GM and C_B and the applicable draughts at amidships.

The simultaneously occurring dynamic loads are accounted for by combining the stresses due to the various dynamic load components. The stress combination procedure is given in **Ch 9.**

4.3.4 Structural response analysis

In general, the following approaches are applied 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.

4.4 Acceptance criteria

4.4.1 General

The acceptance criteria are categorised into five acceptance criteria sets. These are explained below and shown in **Table 2** and **Table 3**. The specific acceptance criteria set that is applied in the rule requirements is dependent on the probability level of the characteristic combined load.

a) The acceptance criteria set AC-S is applied for the static design load combinations, and for the sloshing design loads. The allowable stress for such loads is lower than that for an extreme load to take into account effects of:
   - Repeated yield.
   - Allowance for some dynamics.
   - Margins for some selected limited operational mistakes.

b) The acceptance criteria set AC-SD is applied for the S+D design load combinations where considered loads are extreme loads with a low probability of occurrence.

c) The acceptance criteria set AC-I is typically applied for impact loads, such as bottom slamming and bow impact loads.

d) The acceptance criteria set AC-A is applied for the static design loads in accidental flooded condition

e) The acceptance criteria set AC-T is applied for the design loads in tank testing condition.

Table 2 : Acceptance criteria – prescriptive requirements

Acceptance criteria	Plate panels and local support members(1)		Primary supporting members(1)		Hull girder members	
	Yield	Buckling	Yield	Buckling	Yield	Buckling
AC-S AC-SD AC-A AC-T	Permissible stress: Ch 6, Sec 4 Ch 6, Sec 5	Control of stiffness and proportions: Ch 8 Sec 2	Permissible stress: Ch 6, Sec 6	Control of stiffness and proportions: Ch 8, Sec 1, 2 Pillar buckling	Permissible stress: Ch 5, Sec 1	Allowable buckling utilisation factor: Ch 8 Sec 1 [3]
AC-I(2)	Plastic criteria: Ch 10 Sec 1 [3] Ch 10 Sec 3 [5]	Control of stiffness and proportions: Ch 8, Sec 2 Ch 10 Sec 1 [3] Ch 10 Sec 3 [5]	Plastic criteria: Ch 10 Sec 1 [3] Ch 10 Sec 3 [5]	Control of stiffness and proportions: Ch 8, Sec 2 Ch 10 Sec 1 [3] Ch 10 Sec 3 [5]	N/A	N/A

(1) Refer to Ch 10 for Other structures and to Ch 11 for Superstructure, deckhouses and hull outfitting
(2) If necessary, direct analysis guidance specified Classification Society can be applied.

Table 3 : Acceptance criteria – FE analysis

Acceptance criteria	Cargo hold analysis		Fine mesh analysis
	Yield	Buckling	Yield
AC-S, AC-SD, AC-A, AC-T	Permissible stress: **Ch 7, Sec 2, [5]**	Allowable buckling utilisation factor: **Ch 8, Sec 1, [3]**	Permissible Von Mises stress: **Ch 7, Sec 3, [4]**

4.4.2 Acceptance criteria

The specific acceptance criteria applied in the working stress design requirements are given in the detailed Rule requirements in **Ch 5** to **Ch 8**, **Ch 10** and **Ch 11**.

To provide a general informational summary overview of the acceptance criteria, refer to **Table 2** and **Table 3** below for the different design load scenarios covered by these Rules for the yield and buckling failure modes.

For the yield criteria the permissible stress is proportional to the specified minimum yield stress of the material. For the buckling failure mode, the acceptance criteria are based on the control of stiffness and proportions as well as on the buckling utilization factor.

4.5 Design verification

4.5.1 Design verification - hull girder ultimate strength

The requirements for the ultimate strength of the hull girder are based on a Partial Safety Factor (PSF) method. A safety factor is assigned to each of the basic variables, the still water bending moment, wave bending moment and ultimate capacity. The safety factors were determined using a structural reliability assessment approach, the long-term load history distribution of the wave bending moment was derived using ship motion analysis techniques suitable for determining extreme wave bending moments.

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

4.5.2 Design verification - global finite element analysis

The global finite element analysis is used to verify the scantlings given by the load-capacity based prescriptive requirements to better consider 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.

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

4.5.3 Design verification - fatigue assessment

The fatigue assessment is required to verify that the fatigue life of critical structural details is adequate. A simplified fatigue requirement is applied to details such as end connections of longitudinal stiffeners using stress concentration factors (SCF) to account the actual detail geometry. A fatigue assessment procedure using finite element analysis for determining the actual hot spot stress of the geometric detail is applied to selected details. In both cases, the fatigue assessment method is based on the Palmgren-Miner linear damage model.

4.5.4 Relationship between prescriptive scantling requirements and FE analysis

The scantlings defined by the prescriptive requirements are not to be reduced by any form of alternative calculations such as FE analysis, unless explicitly stated.

Section 3 Verification of Compliance

1. General

1.1 Newbuilding

1.1.1

For newbuildings, the plans and documents submitted for approval, as indicated in **[2]**, are to comply with applicable requirements in these Rules, taking account of the relevant criteria, such as additional service features and classification notations assigned to the ship or the ship length.

1.1.2

When a ship is surveyed by the Society during construction, the Society:

a) Approves the plans and documentation submitted as required by the Rules.
b) Proceeds with the appraisal of the design of materials and equipment used in the construction of the ship and their inspection at works.
c) Carries out surveys or obtains appropriate evidence to satisfy itself that the scantlings and construction meet the Rule requirements in relation to the approved drawings.
d) Attends tests and trials provided for in the Rules.
e) Assigns the classification character of the Society's notation.

1.1.3

The Society defines in specific Rules which materials and equipment used for the construction of ships built under survey are, as a rule, subject to appraisal of their design and to inspection at works, and according to which particulars.

1.1.4

As part of his/her interventions during ship's construction, the surveyor:

a) Conducts an overall examination of the parts of the ship covered by the Rules.
b) Examines the construction methods and procedures when required by the Rules.
c) Checks selected items covered by the Rule requirements.
d) Attends tests and trials where applicable and deemed necessary.

1.1.5

Through all stages of ship construction, it is the builder's responsibility to promptly inform the Society of modifications or departures from approved plans. The builder is to ensure that deviations from the requirements of the Rules or approved plans are accepted by the Society.

2. Document to be submitted

2.1 Documentation and data requirements

2.1.1 Loading information

Loading information containing sufficient information to enable the master of the ship to maintain the ship within the stipulated operational limitations is to be provided on board the ship. The loading information is to include an approved loading manual and loading instrument complying with the requirements given in **Ch 1, Sec 5**.

2.1.2 Calculation data and results

Where calculations have been carried out in accordance with the procedures given in the Rules, one copy of the following is to be submitted for information as applicable:

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

The responsibility for error free specification and input of program data and the subsequent correct transposal of output resides with the designer.

Reference is made to **Ch 7, Sec 1, [4.1]** for required reporting of finite element analysis.

2.2 Submission of plans and supporting calculations

2.2.1 Plans and supporting calculations are to be submitted for approval

For the application of these Rules, the plans and supporting calculations to be submitted to the Society for approval are listed in **Table 1**. Plans are to be submitted electronically or physically. When physically submitted plans are to be submitted in triplicate, with one copy necessary for supporting documents and calculations. In addition, the Society may request the submission of information, other plans and documents deemed necessary for the review of the design.

Structural plans are to show scantling, details of connection of the various parts and are to specify the design materials including, in general, their grades, manufacturing processes, welding procedures and heat treatments.

For welding requirements, see **Ch 12, Sec 2** and **Ch 12, Sec 3**. In case there are deviations from the design basis, then these are to be documented and submitted to the Society.

2.2.2 Plans to be submitted for information

In addition to those in **[2.2.1]**, the following plans are to be submitted to the Society for information:

a) General arrangement.
b) Capacity plan, indicating the volume and position of the centre of gravity of all compartments and tanks.
c) Lines plan, when deemed necessary by the Society.
d) Hydrostatic curves.
e) Lightweight distribution.
f) Docking plan.
g) Arrangement of lifting appliances

Table 1 : Plans and supporting calculation to be submitted for approval

Plan or supporting calculation	Containing also information on
Midship section Transverse sections Shell expansion Decks and profiles Double bottom Pillar arrangements Framing plan Deep tank and ballast tank bulkheads, Standard construction details	Class characteristics Ship's main dimensions Minimum ballast draught Frame spacing Maximum service speed Design loads of container Steel grades Corrosion protection Openings in decks and shell and relevant compensations Boundaries of flat areas in bottom and sides Details of structural reinforcements and / or discontinuities Bilge keel with details of connections to hull structures Welding
Watertight subdivision bulkheads Watertight tunnels	Openings and their closing appliances, if any
Fore part structure	-
Aft part structure	-
Machinery space structures Foundations of propulsion machinery and boilers	Type, power and RPM of propulsion machinery Mass and centre of gravity of machinery and boilers
Superstructures and deckhouses Machinery space casing	Extension and mechanical properties of the aluminium alloy used (where applicable)
Hatch covers and hatch coamings	Design loads on hatch covers Sealing and securing arrangements, type and position of locking bolts Distance of hatch covers from the summer load waterline and from the fore end
Transverse thruster, if any, general arrangement, tunnel structure, connections of thruster with tunnel and hull structures	-
Bulwarks and freeing ports	Arrangement and dimensions of bulwarks and freeing ports on the freeboard deck and superstructure deck
Windows and side scuttles, arrangements and details	-
Scuppers and sanitary discharges	-
Mooring and towing arrangement	-
Supporting structure and foundations for shipboard fittings associated with mooring and towing operations	Design loads and directions of load actions, rated pull and holding load for mooring winches Reaction forces Details of connection of the foundations to the deck, including specifications for holding down bolts for mooring winches Material specifications and welding
Supporting structure and foundations for windlasses and chain stoppers	Design loads and directions of load actions Reaction forces Details of connection of the foundations to the deck, including specifications for holding down bolts for windlasses Material specifications and welding
Stern frame or sternpost, stern tube Propeller shaft boss and brackets$^{(1)}$	-
Plan of watertight doors and scheme of relevant closing devices	Closing devices Electrical diagrams of power control and position indication circuits

Plan or supporting calculation	Containing also information on
Plan of weathertight or outer doors and hatchways	–
Supporting structure for lifting appliances	Design loads (forces and moments) SWL and self weight of lifting appliances Maximum sea state in offshore operation, if any Connections to the hull structures
Supporting structure for life saving appliances	Design loads (forces and moments) SWL and self weight of lifting appliances Connections to the hull structure
Sea chests, stabiliser recesses, etc	–
Plan of manholes	–
Plan of access to and escape from spaces	–
Plan of ventilation including ventilators and tank vents	Use of spaces and location and height of air vent outlets of various compartments
Plan of tank testing	Testing procedures for the various compartments Height of pipes for testing
Equipment number calculation	Geometrical elements for calculation List of equipment Construction and breaking load of steel wires Material, construction, breaking load and relevant elongation of synthetic ropes
Anchoring arrangement	–
Hawse pipes	–
Loading manual and / or trim and stability booklet	–

(1) Where other steering or propulsion systems are adopted (e.g. steering nozzles or azimuth propulsion systems), the plans showing the relevant arrangement and structural scantlings are to be submitted.

2.2.3 Plans and instruments to be supplied onboard the ship

As a minimum, the following plans and instrument are to be supplied onboard:

a) One copy of the following plans indicating the newbuilding thickness for each structural item is to be supplied onboard the ship: plans of midship sections, construction profiles, shell expansion, transverse bulkheads, aft and fore part structures, machinery space structures, superstructures, deckhouses and casing.
b) One copy of the final approved loading manual, see **[2.1.1]**.
c) One copy of the final approved loading instrument, see **[2.1.1]**.
d) Welding.
e) 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.
f) Details and information on use of special materials, such as an aluminium alloy, used in the hull construction.
g) Towing and mooring arrangements plan.
h) Structural details for which post weld treatment methods are applied, showing the description of the details and their locations.

Other plans or instrument may be required by the Society.

3. Scope of approval

3.1 General

3.1.1

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

3.1.2

The documentation, plans and data requirements specified in **[2]** are to be submitted. The Society is to review such documentation to verify compliance with the requirements.

3.1.3

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

3.2 Requirements of international and national regulations

3.2.1 Responsibility

It is the responsibility of the designer to ensure that the design complies with the national and international regulations applicable to the ship.

The Society is not responsible for assessing compliance with international and national regulations as part of the general classification process. However, the Society may enter into an agreement with the flag administration of the ship under which they are explicitly instructed to review and approve a ship design for compliance with specified regulations.

4. Workmanship

4.1 Requirements to be complied with by the manufacturer

4.1.1

The manufacturing plant is to be provided with suitable equipment and facilities to enable proper handling of the materials, manufacturing processes and structural components. The manufacturing plant is to have at its disposal sufficiently qualified personnel. The Society is to be advised of the names and areas of responsibility of the supervisory and control personnel in charge of the project.

4.2 Quality control

4.2.1

As far as required and expedient, the manufacturer’s personnel has to examine all structural components both during manufacture and on completion, to verify that they are complete, that the dimensions are correct and that workmanship is satisfactory and meets the standard of good shipbuilding practice.

Upon inspection and corrections by the manufacturing plant, the structural components are to be shown to the surveyor of the Society for inspection, in suitable sections, normally unpainted condition and enabling proper access for inspection.

The Surveyor may reject components that have not been adequately checked by the plant and may demand their resubmission upon successful completion of such checks and corrections by the plant.

5. Structural details

5.1 Details in manufacturing documents

5.1.1

Significant details concerning quality and functional ability of the component concerned are to be entered in the manufacturing documents (e.g. workshop drawing). This includes not only scantlings but, where relevant, such items as surface conditions (e.g. finishing of flame cut edges and weld seams), and special methods of manufacture involved as well as inspection and acceptance requirements and where relevant permissible tolerances. When a standard is used (works or national standard), it is to be submitted to the Society. For weld joint details, see **Ch 12, Sec 2.**

If, due to missing or insufficient details in the manufacturing documents, the quality or functional ability of the component is doubtful, the Society may require appropriate improvements to be submitted by the manufacturer. This includes the provision of supplementary or additional parts (for example, reinforcements) even if these were not required at the time of plan approval.

6. Equivalence procedures

6.1 Rule applications

6.1.1

These Rules apply to ships of normal form, proportions, speed and structural arrangements. Relevant design parameters defining the assumptions made are given in **Ch 1, Sec 2, [2].**

6.1.2

Special consideration is to be given to the application of the Rules incorporating design parameters which are outside the design basis as specified in **Ch 1, Sec 2, [2]**, for example, increased fatigue life.

6.2 Novel designs

6.2.1

Ships of novel design, i.e. those of unusual form, proportions, speed and structural arrangements outside those specified in **Ch 1, Sec 2, [2.2]**, are specially considered according to the contents of **[6.2.2]** to **[6.2.4].**

6.2.2

Information is to be submitted to the Society to demonstrate that the structural safety of the novel design is at least equivalent to that intended by the Rules.

6.2.3

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

6.2.4

Dependent on the nature of the deviation, a systematic review may be required to document equivalence with the Rules.

6.3 Alternative calculation methods

6.3.1

Where indicated in specific sections of the Rules, alternative calculation methods to those shown in the Rules may be accepted provided it is demonstrated that the scantling and arrangements are of at least equivalent strength to those derived using the Rules.

Section 4 Symbols and Definitions

1. Primary symbols and units

1.1 General

1.1.1

Unless otherwise specified, the general symbols and their units used in these Rules are those defined in **Table 1**.

Table 1 : Primary symbols

Symbols	Meaning	Units
A	Area	m^2
	Sectional area of stiffeners and primary members	cm^2
C	Coefficient	-
F	Force and concentrated loads	kN
I	Hull girder inertia	m^4
	Inertia of stiffeners and primary members	cm^4
M	Bending moment	kNm
M	Mass	t
P	Pressure	kN/m^2
Q	Shear force	kN
T	Draught of ship, see **[3.1.5]**	m
Z	Hull girder section modulus	m^3
	Section modulus of stiffeners and primary supporting members	cm^3
a_i	Acceleration for the effect ‘i’	m/s^2
b	Width of attached plating	m
	Width of face plate of stiffeners and primary supporting members	mm
g	Gravity acceleration, taken equal to 9.81 m/s2	m/s^2
h	Height	m
	Web height of stiffeners and primary supporting members	mm
l	Length/span of stiffeners and primary supporting members	m
n	Number of items	-
r	Radius	mm
	Radius of curvature of plating or bilge radius	mm
t	Thickness	mm
x	X coordinate along longitudinal axis, see **[3.5]**	m
y	Y coordinate along transverse axis, see **[3.5]**	m
z	Z coordinate along vertical axis, see **[3.5]**	m
η	Permissible utilisation factor (usage factor)	-

Symbols	Meaning	Units
γ	Safety factor	-
δ	Deflection/displacement	mm
θ	Angle	deg
ρ	Density of seawater, taken equal to 1.025 t/m^3	t/m^3
σ	Normal stress	N/mm^2
τ	Shear stress	N/mm^2

2. Symbols

2.1 Ship's main data

2.1.1

Unless otherwise specified, symbols regarding ship's main data and their units used in these Rules are those defined in **Table 2**.

Table 2 : Ship's main data

Symbols	Meaning	Units
L	Rule length	m
L_{LL}	Freeboard length	m
L_{PP}	Length between perpendiculars	m
L_0	Rule length, L, but not to be taken less than 110 m	m
L_1	Rule length, L, but need not be taken greater than 250 m	m
L_2	Rule length, L, but need not be taken greater than 300 m	m
B	Moulded breadth of ship	m
D	Moulded depth of ship	m
T	Moulded draught	m
T_{SC}	Scantling draught	m
T_{BAL}	Ballast draught (minimum midship)	m
T_{Design}	Design draught	m
T_{LC}	Midship draught at considered loading condition	m
T_{FD}	Deepest equilibrium waterline in damage condition	m
T_F	Minimum draught at forward perpendicular for bottom slamming	m
T_{AE}	Minimum draught at aft end for stern slamming	m
Δ	Moulded displacement at draught T_{SC}	t
C_B	Block coefficient at draught T_{SC}	-
V	Maximum service speed	knot
x, y, z	X, Y, Z coordinates of the calculation point with respect to the reference coordinate system	m

2.2 Materials

2.2.1

Unless otherwise specified, symbols regarding materials and their units used in these Rules are those defined in **Table 3**.

Table 3 : Materials

Symbols	Meaning	Units
E	Young's modulus, see **Ch 3, Sec 1, [2]**	N/mm^2
G	Shear modulus, $G=\frac{E}{2(1+\upsilon)}$	N/mm^2
R_{eH}	Specified minimum yield stress, see **Ch 3, Sec 1, [2]**	N/mm^2
τ_{eH}	Specified shear yield stress, $\tau_{eH}=\frac{R_{eH}}{\sqrt{3}}$	N/mm^2
υ	Poisson's ratio, see **Ch 3, Sec 1, [2]**	-
k	Material factor, see **Ch 3, Sec 1, [2]**	-
R_m	Specified minimum tensile strength, see **Ch 3, Sec 1, [2]**	N/mm^2
R_Y	Nominal yield stress, taken equal to $235/k$	N/mm^2

2.3 Loads

2.3.1

Unless otherwise specified, symbols regarding loads and their units used in these Rules are those defined in **Table 4**.

Table 4 : Loads

Symbols	Meaning	Units
C_w	Wave coefficient	-
T_θ	Roll period	s
θ	Roll angle	deg
T_ϕ	Pitch period	s
ϕ	Pitch angle	deg
a_0	Common acceleration parameter	-
a_z	Vertical acceleration	m/s^2
a_y	Transverse acceleration	m/s^2
a_x	Longitudinal acceleration	m/s^2
f_P	Probability factor	-
k_r	Roll amplitude of gyration	m
GM	Metacentric height	m
λ	Wave length	m
S	Static load case	-

Symbols	Meaning	Units
$S+D$	Dynamic load case	–
P_{ex}	Total sea pressure, see **Ch 4, Sec 5, [1.1]**	kN/m^2
P_{in}	Total internal pressure due to liquid, see **Ch 4, Sec 6, [1]**, or due to container, see **Ch 4, Sec 6, [2]**	kN/m^2
P_s	Static sea pressure	kN/m^2
P_{ls}	Static tank pressure	kN/m^2
P_w	Dynamic wave pressure	kN/m^2
P_{ld}	Dynamic tank pressure	kN/m^2
P_D	Green sea deck pressure	kN/m^2
P_{slh-j}	Sloshing pressure, j=direction	kN/m^2
F_x	Total longitudinal force due to container load, see **Ch 4, Sec 5, [2.2]** and **[2.3]**	kN
F_y	Total transverse force due to container load, see **Ch 4, Sec 5, [2.2]** and **[2.3]**	kN
F_z	Total vertical force due to container load, see **Ch 4, Sec 5, [2.2]** and **[2.3]**	kN
P_{SL}	Bottom slamming pressure	kN/m^2
P_{FB}	Bow impact pressure	kN/m^2
P_{SS}	Stern slamming pressure	kN/m^2
P_{fs}	Static pressure in flooded conditions	kN/m^2
P_{fd}	Dynamic pressure in flooded conditions	kN/m^2
P_{ST}	Tank testing pressure (static)	kN/m^2
M_{sw-j}	Vertical still water bending moment, j = h, s, p (hog, sag, harbour)	kNm
Q_{sw}	Vertical still water shear force	kN
M_{wv-j}	Vertical wave bending moment, j = h, s (hog, sag)	kNm
Q_{wv}	Vertical wave shear force	kN
M_{wt}	Torsional wave moment	kNm
M_{wh}	Horizontal wave bending moment	kNm

2.4 Scantlings

2.4.1

Unless otherwise specified, symbols regarding scantlings and their units used in these Rules are those defined in **Table 5**.

Table 5 : Scantlings

Symbols	Meaning	Units
I_{y-n50}	Net vertical moment of inertia of hull girder	m^4
I_{z-n50}	Net horizontal moment of inertia of hull girder	m^4
Z_{D-n50}, Z_{B-n50}	Net vertical hull girder section moduli, at deck and bottom respectively	m^3
z_n	Vertical distance from BL to horizontal neutral axis	m
a	Length of EPP, as defined in **Ch 3, Sec 7, [2.1.1]**	mm

Symbols	Meaning	Units
b	Breadth of EPP, as defined in **Ch 3, Sec 7, [2.1.1]**	mm
s	Stiffener spacing (see **Ch 3, Sec 7, [1.2.1]**)	mm
S	Primary supporting member spacing (see **Ch 3, Sec 7, [1.2.2]**)	m
ℓ	Span of stiffeners or primary supporting member (see **Ch 3, Sec 7, [1]**)	m
ℓ_b	Bracket arm length	m
t	Net thickness with full corrosion reduction	mm
t_{n50}	Net thickness with half corrosion reduction	mm
t_c	Corrosion addition	mm
t_{gr}	Gross thickness	mm
t_{as_built}	As built thickness	mm
t_{gr_off}	Gross thickness offered	mm
t_{gr_req}	Gross thickness required	mm
t_{off}	Net thickness offered	mm
t_{req}	Net thickness required	mm
t_{vol_add}	Thickness for voluntary addition	mm
t_{res}	Reserve thickness	mm
t_{c1}, t_{c2}	Corrosion addition on each side of structural me	mm
h_w	Web height of stiffener or primary supporting member	mm
t_w	Web thickness of stiffener or primary supporting member	mm
b_f	Face plate width stiffener or primary supporting member	mm
h_{stf}	Height of stiffener	mm
t_f	Face plate/flange thickness of stiffener or primary supporting member	mm
t_p	Thickness of the plating attached to a stiffener or a primary supporting member	mm
d_e	Distance from the upper edge of the web to the top of the flange for L_3 profiles	mm
b_{eff}	Effective breadth of attached plating, in bending, for yield and fatigue	mm
A_{eff} or $A_{eff-n50}$	Net sectional area of stiffeners or primary supporting members, with attached plating (of width s)	cm^2
A_{shr} or $A_{shr-n50}$	Net shear sectional area of stiffeners or primary supporting members	cm^2
I_p	Net polar moment of inertia of stiffener about its connection to plating	cm^4
I	Net moment of inertia of the stiffener, with attached shell plating, about its neutral axis parallel to the plating	cm^4
Z or Z_{n50}	Net section modulus of a stiffener or primary supporting member with attached plating (of breadth b_{eff})	cm^3

3. Definition

3.1 Principal Particulars

3.1.1 L, Rule length

The Rule length L is the distance, in m, measured on the waterline at the scantling draught T_{SC} from the forward side of the stem to the centre of the rudder stock. L is to be not less than 96 % and need not exceed 97 % of the extreme length on the waterline at the scantling draught T_{SC}.

In ships without rudder stock (e.g. ships fitted with azimuth thrusters), the Rule length L is to be taken equal to 97 % of the extreme length on the waterline at the scantling draught T_{SC}.

In ships with unusual stem or stern arrangements, the Rule length is considered on a case-by-case basis.

3.1.2 L_{LL}, freeboard length

The freeboard length L_{LL}, in m, is to be taken as 96 % of the total length on a waterline at 85 % of the least moulded depth measured from the top of the keel, or as the length from the fore side of the stem to the axis of the rudder stock on that waterline, if that be greater.

For ships without a rudder stock, the length L_{LL} is to be taken as 96 % of the waterline at 85 % of the least moulded depth.

Where the stem contour is concave above the waterline at 85 % of the least moulded depth, both the forward end of the extreme length and the forward side of the stem are to be taken at the vertical projection to that waterline of the aftermost point of the stem contour (above that waterline), see Figure 1.

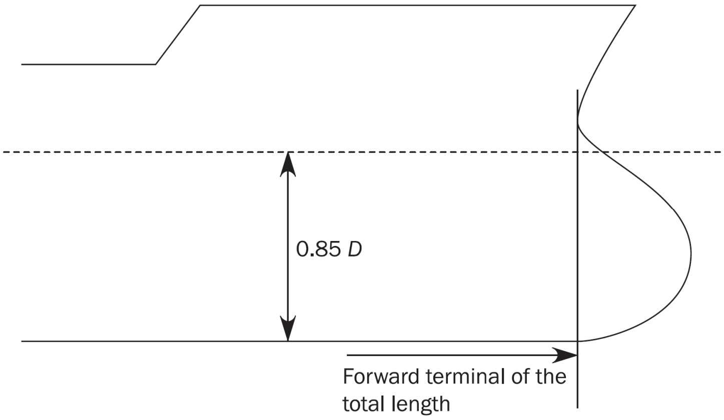


Figure 1 : Concave stem contour

3.1.3 Moulded breadth

The moulded breadth B is the greatest moulded breadth, in m, measured amidships at the scantling draught, T_{SC}.

3.1.4 Moulded depth

D, the moulded depth, is the vertical distance, in m, amidships, from the moulded baseline to the moulded deck line of the uppermost continuous deck measured at deck at side. On ships with a rounded gunwale, D is to be measured to the continuation of the moulded deck line.

3.1.5 Draughts

T, the draught in m, is the summer load line draught for the ship in operation, measured from the moulded baseline at midship. Note this may be less than the maximum permissible summer load waterline draught.

T_{SC} is the scantling draught, in m, at which the strength requirements for the scantlings of the ship are met and represents the full load condition. The scantling draught T_{SC} is to be not less than that corresponding to the assigned freeboard.

T_{BAL} is the minimum design normal ballast draught amidships, in m, at which the strength requirements for the scantlings of the ship are met. This normal ballast draught is the minimum draught of ballast conditions including ballast water exchange operation, if any, for any ballast conditions in the loading manual including both departure and arrival conditions.

3.1.6 Moulded displacement

Moulded displacement, in t, corresponds to the underwater volume of the ship, at a draught, in seawater with a density of 1.025 t/m^3.

3.1.7 Maximum service speed

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

3.1.8 Block coefficient

C_B, the block coefficient at the draught, T_{SC} is defined in the following equation:

$$C_B = \frac{\varDelta}{1.025 L B T_{SC}}$$

where:

$\varDelta$: Moulded displacement of the ship at draught T_{SC}.

$C_{B\text{-}BAL}$, the block coefficient at the draught, T_{BAL} is defined in the following equation:

$$C_{B-Bal} = \frac{\varDelta_{BAL}}{1.025 L B T_{BAL}}$$

where:

$\varDelta_{BAL}$: Moulded displacement of the ship at draught T_{BAL}.

3.1.9 Waterplane coefficient

C_{wp}, the Waterplane coefficient at the draught, T_{SC} is defined in the following equation:

$$C_{wp} = \frac{A_{wp}}{LB}$$

where:

A_{wp} : Waterplane area at draught T_{SC}.

C_{wp-Bal}, the Waterplane coefficient at the draught, T_{BAL} is defined in the following equation:

$$C_{wp-Bal} = \frac{A_{wp-Bal}}{LB}$$

where:

A_{wp-Bal} : Waterplane area at draught T_{BAL}.

3.1.10 Lightweight

The lightweight is the ship displacement, in t, complete in all respects, but without cargo, consumable, stores, passengers and crew and their effects, and without any liquids on board except that machinery and piping fluids, such as lubricants and hydraulics, are at operating levels.

3.1.11 Deadweight

The deadweight DWT is the difference, in t, between the displacement, at the summer draught in seawater of density ρ = 1.025 t/m^3, and the lightweight.

3.1.12 Fore end

The fore end (FE) of the rule length L, see **Figure 2**, is the perpendicular to the scantling draught waterline at the forward side of the stem.

3.1.13 Aft end

The aft end (AE) of the rule length L, see **Figure 2**, is the perpendicular to the scantling draught waterline at a distance L aft of the fore end.

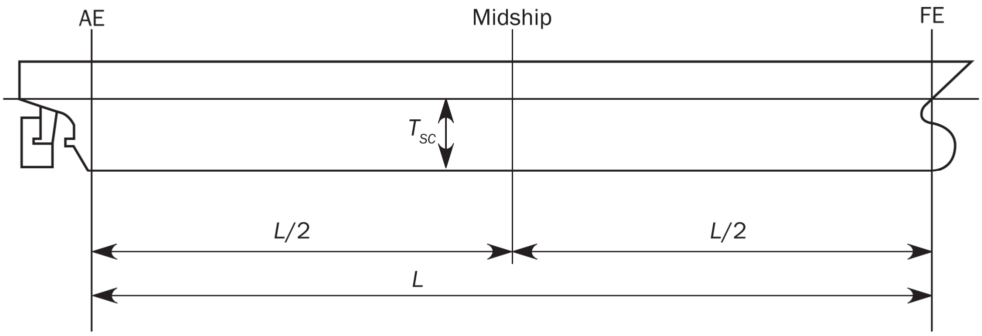


Figure 2 : Ends and midship

3.1.14 Midship

The midship is the perpendicular to the scantling draught waterline at a distance 0.5 L aft of the fore end.

3.1.15 Midship part

The midship part of a ship is the part extending 0.4 L amidships, unless otherwise specified.

3.1.16 Forward freeboard perpendicular

The forward freeboard perpendicular, FP_{LL}, is to be taken at the forward end of the length L_{LL} and is to coincide with the foreside of the stem on the waterline on which the length L_{LL} is measured.

3.1.17 After freeboard perpendicular

The after freeboard perpendicular, AP_{LL}, is to be taken at the aft end of the length L_{LL}.

3.2 Position 1 and Position 2

3.2.1 Position 1

Position 1 includes:

a) Exposed freeboard and raised quarter decks.
b) Exposed superstructure decks situated forward of 0.25 L_{LL} from FP_{LL}.

Note 1: In application of exposed deck, the details are as given in **Pt 4, Sec 2, 102** of the guidance.

3.2.2 Position 2

Position 2 includes:

a) Exposed superstructure decks situated aft of 0.25 L_{LL} from FP_{LL} and located at least one standard height of superstructure above the freeboard deck.
b) Exposed superstructure decks situated forward of 0.25 L_{LL} from FP_{LL} and located at least two standard heights of superstructure above the freeboard deck.

Note 1: In application of exposed deck, the details are as given in **Pt 4, Sec 2, 102** of the guidance.

3.3 Standard height of superstructure

3.3.1

The standard height of superstructure is defined in **Table 6**.

Table 6 : Standard height of superstructure

Freeboard length L_{LL}, in m	Standard height h_S, in m	
	Raised quarter deck	All other superstructures
$90 < L_{LL} \leq 125$	$0.3 + 0.012\,L_{LL}$	$1.05 + 0.01\,L_{LL}$
$L_{LL} > 125$	1.80	2.30

3.3.2

A tier is defined as a measure of the extent of a deckhouse. A deckhouse tier consists of a deck and external bulkheads. In general, the first tier is the tier situated on the freeboard deck.

3.4 Operation definition

3.4.1 Sheltered water

Sheltered waters are generally calm stretches of water when the wind force does not exceed 6 Beaufort scale, i.e. harbours, estuaries, roadsteads, bays, lagoons.

3.5 Reference coordinate system

3.5.1

The ship's geometry, motions, accelerations and loads are defined with respect to the following right-hand coordinate system, see **Figure 3**:

Origin : At the intersection among the longitudinal plane of symmetry of ship, the aft end of *L* and the baseline.

X axis : Longitudinal axis, positive forwards.

Y axis : Transverse axis, positive towards portside.

Z axis : Vertical axis, positive upwards.

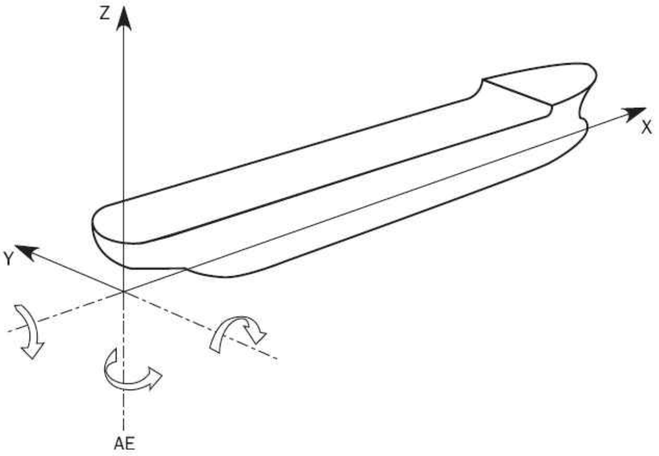


Figure 3 : Reference coordinate system

3.6 Naming convention

3.6.1 Structural nomenclature

Figure 4 to **Figure 6** show the common structural nomenclature used within these Rules.

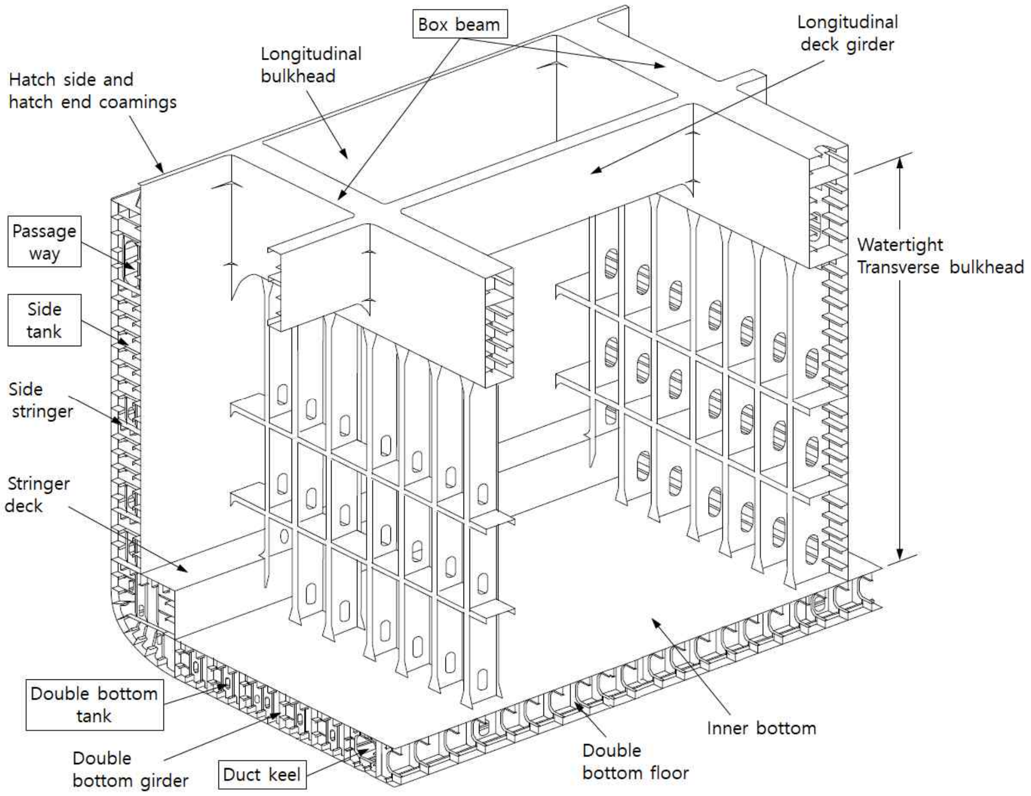


Figure 4 : Typical cargo hold configuration

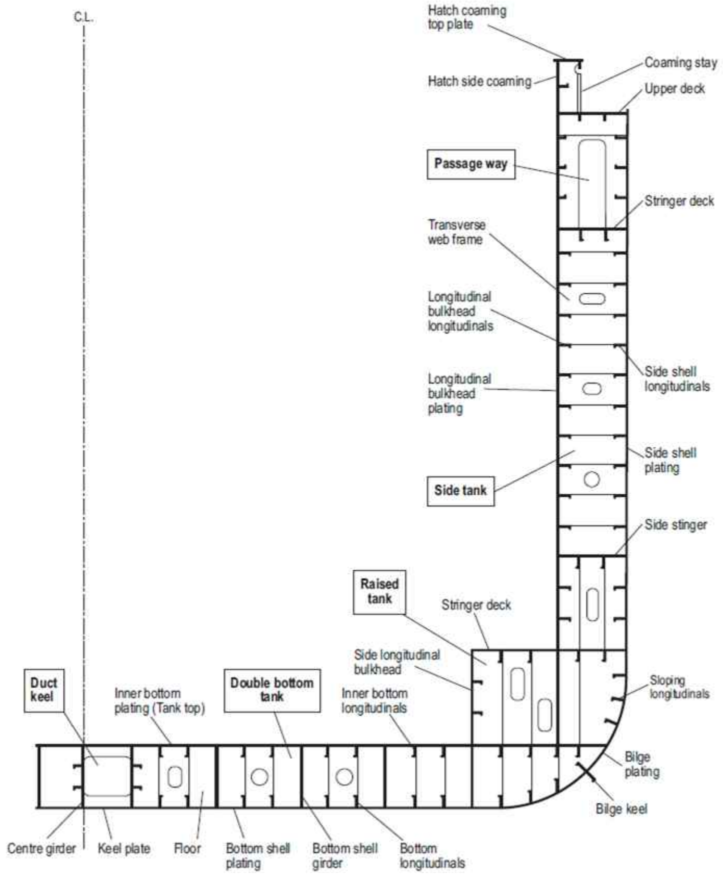


Figure 5 : Typical transverse section in way of cargo hold

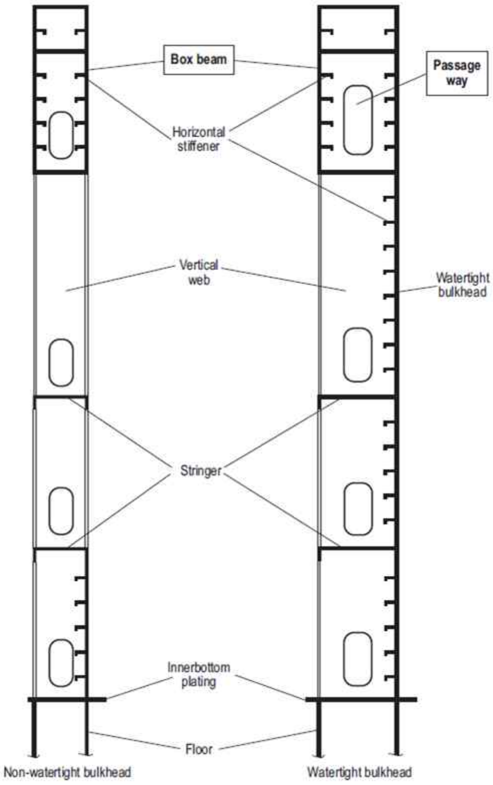


Figure 6 : typical transverse bulkheads

3.7 Glossary

3.7.1 Definitions of terms

Table 7 : Definition of terms

Terms	Definition
Accommodation deck	Deck used primarily for the accommodation of the crew
Accommodation ladder	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	First main transverse watertight bulkhead forward of the stern
Aft peak tank	Compartment in the narrow part of the stern, aft of the aft peak bulkhead
Anchor	Device 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
Ballast tank	Compartment used for the storage of water ballast
Bay	Area between adjacent transverse frames or transverse bulkheads
Bilge keel	Piece of plate set perpendicular to a ship's shell along the bilges to reduce the rolling motion

Terms	Definition
Bilge plating	Curved plating between the bottom shell and the side shell, to be taken as follows: • Within the cylindrical part of the ship: from the start of the curvature at the lower turn of bilge on the bottom to the end of the curvature at the upper turn of the bilge • Outside the cylindrical part of the ship: from the start of the curvature at the lower turn of the bilge on the bottom to the lesser of: – a point on the side shell located 0.2 *D* above the baseline / local centreline elevation – the end of the curvature at the upper turn of the bilge
Bilge strake	The lower strake of bilge plating
Boss	The boss of the propeller is the central part to which propeller blades are attached and through which the shaft end passes
Bottom shell	Shell envelope plating forming the predominantly flat bottom portion of the shell envelope, including the keel plate
Bow	Structural arrangement and form of the forward end of the ship
Bower anchor	Anchor carried at the bow of the ship
Bracket	Extra structural component used to increase the strength of a joint between two structural members
Bracket toe	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
Breasthook	Triangular plate bracket joining port and starboard side structural members at the stem
Bridge	Elevated superstructure having a clear view forward and at each side, and from which a ship is steered
Buckling panel	Elementary plate panel considered for the buckling analysis
Builder	The party contracted by the Owner to build a ship in compliance with the Rules
Bulb profile	Stiffener having an increase in steel mass on the outer end of the web instead of a separate flange
Bulkhead	Structural partition wall subdividing the interior of the ship into compartments
Bulkhead deck	Uppermost continuous deck up to which transverse watertight bulkheads and shell are to extend
Bulkhead structure	Transverse or longitudinal bulkhead plating with stiffeners and girders
Bulwark	Vertical plating immediately above the upper edge of the ship’s side surrounding the exposed deck(s)
Bunker	Compartment for the storage of fuel oil used by the ship's machinery
Cable	Rope or chain attached to the anchor
Camber	Upward rise of the weather deck from both sides towards the centreline of the ship
Container hold	Generic term for spaces intended to carry container
Carling	Stiffening member used to supplement the regular stiffening arrangement
Casing	Covering or bulkheads around any space for protection

Terms	Definition
Centreline girder	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	Compartment, usually at the forward end of the ship, used to store the anchor chain
Chain pipe	Section of pipe through which the anchor chain enters or leaves the chain locker
Chain stopper	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	Vertical boundary structure of a hatch or a skylight
Cofferdams	Spaces, between two bulkheads or decks, primarily designed as a safeguard against leakage from one compartment to another, see Ch 2, Sec 3, [1]
Collar plate	Patch used to close, partly or completely, a hole cut for a stiffener passing through a web plate
Collision bulkhead	The foremost main transverse watertight bulkhead
Companionway	Weathertight entrance leading from a deck to spaces below
Compartment	Internal space bounded by bulkheads or plating
Continually manned space	A space in which the continuous or prolonged presence of seafarers is necessary for normal operational periods. This includes spaces routinely occupied for a period of 20 minutes or more during normal operational periods.
Cargo hold region	See Ch 1, Sec 1, [2.4.3]
Cross deck	Area between cargo hatches
Deck	Horizontal structure element defining the upper or lower boundary of a compartment
Deckhouse	See Ch 1, Sec 1, [2.4.6]
Deck structure	Deck plating with stiffeners, girders and supporting pillars
Deck transverse	Transverse primary supporting member (PSM) of a deck
Deep tank	Any tank which extends between two decks or between the shell/inner bottom and the deck above or higher
Designer	The party who creates the documentation to be submitted to the Society for approval or for information. The designer can be the builder or a party contracted by the builder or the Owner to create this documentation
Discharges	Any piping leading through the ship's sides for conveying bilge water, circulating water, drains etc.
Docking bracket	Bracket located in the double bottom to locally strengthen the bottom structure for the purposes of docking
Double bottom structure	Inner bottom plating and all shell plating, stiffeners, primary supporting members and other elements located below
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	Structural member where the idealised beam comprises the web with top and bottom flanges formed by the attached plating

Terms	Definition
Duct keel	Keel built of plates in box form. It is used to house ballast and other piping leading forward which otherwise would have to run through the cargo hold and or ballast tanks.
Enclosed superstructure	Superstructure with bulkheads forward and/or aft fitted with weathertight doors and closing appliances
Engine room bulkhead	Transverse bulkhead located either directly forward or aft of the engine room
EPP	Elementary Plate Panel, the smallest plate element surrounded by structural members such as stiffeners, PSM, bulkheads, etc.
Face plate	Section of a stiffening member attached to the web and usually parallel to the plated surface
Flange	Section of a stiffening member attached to the web, or sometimes formed by bending the web over. It is usually parallel to the plated surface
Flat bar	Stiffener only made of a web
Floor	A bottom transverse member
Forecastle	Short superstructure situated at the bow
Fore peak	Area of the ship forward of the collision bulkhead
Fore peak deck	Short raised deck extending aft from the bow of the ship
Freeboard deck	Deck designated as such by the designer, in accordance with ICLL. Generally the uppermost complete deck exposed to weather and sea, with permanent means of closing for all the exposed openings
Freeing port	Opening in the bulwarks to allow water shipped on deck to run freely overboard
Girder	Collective term for primary supporting structural members
Gudgeon	Block with a hole in the centre to receive the pintle of a rudder; located on the stern post, it supports the rudder and allows it to swing
Gunwale	Upper edge of side shell
Gusset	Plate usually fitted to distribute forces at a strength connection between two structural members
Hatch cover	Cover fitted over a hatchway to prevent the ingress of water into the hold
Hatchway	Opening, generally rectangular, in a deck affording access to 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 fibre rope used for towing or mooring
HP	Bulb profile in accordance with the Holland Profile standard
IACS	International Association of Classification Societies
ICLL	IMO International Convention on Load Lines, 1966, as amended
IMO	International Maritime Organisation
Inner hull	The innermost plating forming a second layer to the hull of the ship
Intercostal	Non-continuous member between stiffeners or PSM

Terms	Definition
JIS	Japanese Industrial Standard
Keel	Main structural member or backbone of a ship running longitudinally along the centreline of the bottom. Usually a flat plate stiffened by a vertical plate on its centreline inside the shell
Knuckle	Discontinuity in a structural member
Lightening hole	Hole cut in a structural member to reduce its weight
Limber hole	Small drain hole cut in a frame or a plate to prevent water or oil from collecting
Local support members	Local stiffening members influencing only the structural integrity of a single panel, e.g. deck beams
Manhole	Round or oval hole cut in decks, tanks, etc, for the purpose of providing access
Margin plate	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
MARPOL	IMO International Convention for the Prevention of Pollution from Ships, 1973 and Protocol of 1978, as amended
Mid-hold	Middle hold(s) of the three cargo hold length FE model as defined in **Ch 7, Sec 2, [1.2.2]**
Normally unmanned space	A space not normally manned (without the continuous or prolonged presence of seafarers) during normal operational periods This includes spaces routinely occupied for a period of less than 20 minutes during normal operational periods.
Notch	Discontinuity in a structural member caused by welding
Oil fuel tank	Tank used for the storage of fuel oil
Outer shell	Same as shell envelope
Owner	The party who has assumed all the duties and responsibilities for registration and operation of the ship and who, assuming such responsibilities, has agreed to take over all the duties and responsibilities on delivery of the ship from the builder with valid certificates prepared for the operator
Pillar	Vertical support placed between decks, where the deck is not supported by the shell or a bulkhead
Pipe tunnel	Void space running between the inner bottom and the shell plating, and forming a protective space for bilge, ballast and other lines linking the engine room to the tanks
Plate panel	Unstiffened plate surrounded and supported by structural members such as stiffeners, PSM, bulkheads, etc. See also EPP
Plating	Sheet of steel supported by stiffeners, primary supporting members or bulkheads
Poop	Superstructure located at the extreme aft end of the ship
Primary supporting members (PSM)	Members of the beam, girder or stringer type, which provide 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.
Propeller post	The forward post of stern frame, which is bored for propeller shaft.
Rudder post	After post of stern frame to which the rudder is hung (also called stern post).

Terms	Definition
Scallop	Hole cut into a stiffening member to allow continuous welding of a plate seam
Scarfing bracket	Bracket used between two offset structural items
Scantlings	Physical dimensions of a structural item
Scupper	Any opening for carrying off water from a deck, either directly or through piping
Scuttle	Small opening in a deck or elsewhere, usually fitted with a cover, a lid or a door for access to a compartment
Sheer strake	Top strake of a ship's side shell plating
Shell envelope plating	Shell plating forming the effective hull girder exclusive of the strength deck plating
Side shell	Shell envelope plating forming the side portion of the shell envelope above the bilge plating
Single skin member	Structural member where the idealised beam comprises a web, a top flange formed by an attached plating and a bottom flange formed by a face plate
Skylight	Deck opening fitted with or without a glass port light and serving as a ventilator for engine room, quarters, etc.
SOLAS	IMO International Convention for the Safety of Life at Sea, 1974 as amended
Spaces	Separate compartments, including tanks
Stay	Bulwark or hatch coaming brackets
Stem	Piece of bar or plating at which the hull plating terminates at forward end
Stern	The after end of the vessel.
Stern frame	The heavy strength members attached to the after end of a hull to form the ship's stern. It includes rudder post, propeller post, and aperture for the propeller.
Stern tube	Tube through which the shaft passes to the propeller; it acts as an after bearing for the shafting. It may be lubricated with water or oil
Stiffener	Collective term for secondary supporting structural members
Strake	Course or row of shell, deck, bulkhead, or other plating
Strength deck	The uppermost continuous deck
Stringer	Horizontal girder linking vertical web frames
Stringer plate	Outside strake of deck plating
Superstructure	See **Ch 1, Sec 1, [2.4.6]**
SWL	Safe Working Load
Tank	Generic term for space intended to carry liquid such as seawater, fresh water, oil, liquid cargoes, FO, DO, etc.
Tank top	Horizontal plating forming the bottom of a cargo hold
Towing pennant	Long rope used to tow a ship
Transom	Structural arrangement and form of the aft end of the ship

Terms	Definition
Transverse ring	All transverse material appearing in a cross-section of the hull, in way of a double-bottom floor, a vertical web and a deck transverse girder
Transverse web frame	Primary transverse girder which joins the ship longitudinal structure
Tripping bracket	Bracket used to strengthen a structural member under compression against torsional forces
Trunk	Decked structure similar to a deckhouse but not provided with a lower deck
Tween deck	Space between two decks, placed between the upper deck and the tank top in the cargo hold
Void	Enclosed empty space in a ship
Wash bulkhead	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	Deck or section of deck exposed to the elements which has means of closing weathertight all hatches and openings
Weathertight	Weathertight means that, in any sea conditions, water will not penetrate into the ship
Web	Section of a stiffening member attached to the plated surface, usually perpendicular
Web frame	Transverse PSM, including deck transverse
Wind and water strakes	Strakes of the side shell plating between the ballast and the deepest load waterline
Windlass	Winch for lifting and lowering the anchor chain
Wing tank	Space bounded by the inner hull longitudinal bulkhead and the side shell

Section 5 Loading Manual and Loading Instrument

1. General requirements

1.1 Application

1.1.1

This Section contains minimum requirements for loading guidance information.

1.1.2

An approved loading manual and an approved loading instrument are to be supplied onboard.

1.1.3

A ship may in actual operation be loaded differently from the 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.

1.1.4

The requirements concerning the loading manual are given in **[2]** and those concerning the loading instruments in **[3]**.

1.2 Annual and class renewal survey

1.2.1

At each annual and class renewal survey, it is to be checked that the approved loading manual is available onboard.

1.2.2

The loading instrument is to be checked for accuracy at regular intervals by the ship's master by applying test loading conditions.

1.2.3

At each class renewal survey this checking is to be done in the presence of the surveyor.

2. Loading manuals

2.1 General requirements

2.1.1 Definition

The approved loading manual is to be based on the final data of the ship.

A loading manual is a document which describes:

a) The loading conditions on which the design of the ship has been based for seagoing and harbour / sheltered water, including permissible limits of still water bending moment and shear force.
b) The results of the calculations of still water bending moments, shear forces and where applicable limitations due to lateral loads,
c) The allowable local loading for the structure (e.g. hatch covers, decks, double bottom, etc), where applicable,
d) The relevant operational limitations.

2.1.2 Condition of approval

The approved loading manual is to be based on the final data of the ship.

Modifications resulting in changes to the main data of the ship (e.g. lightship weight, buoyancy distribution, tank volumes or usage, etc), require the loading manual to be updated and re-approved, and subsequently the loading computer system to be updated and re-approved. However, new loading guidance and an updated loading manual need not be resubmitted provided that the resulting draughts, still water bending moments and shear forces do not differ from the originally approved data by more than 2 %.

The loading manual is to be prepared in a language understood by the users. If this language is not English, a translation into English is to be included.

2.1.3 Loading conditions

The loading manual is to include the design (cargo and ballast) loading conditions, subdivided into departure and arrival conditions as appropriate, upon which the approval of the hull scantlings is based, as defined in **Ch 4, Sec 8**. The loading conditions are listed in **Ch 4, Sec 8, [2].**

2.1.4 Operational limitations

The loading manual is to describe relevant operational limitations:

a) Scantling draught,
b) Design minimum ballast draught at midships,
c) Design slamming ballast draught forward with forward double bottom ballast tanks filled,
d) Design slamming ballast draught forward with any of the forward double bottom ballast tanks empty,
e) Maximum allowable container weight,
f) Maximum container weight in any loading condition in the Loading Manual,
g) Maximum service speed,
h) Envelope results and permissible limits of still water bending moments and shear forces.

3. Loading instrument

3.1 General requirements

3.1.1 Definition

A loading computer system is a system, which is either analog or digital, by means of which it can be easily and quickly ascertained that, at specified read-out points, relevant operational limitations, such as the still water bending moments, shear forces, and lateral loads, where applicable, in any load or ballast condition do not exceed the specified permissible values.

The loading instrument is ship specific onboard equipment and the results of the calculations are only applicable to the ship for which it has been approved.

An approved loading instrument can not replace an approved loading manual.

3.1.2 Conditions of approval of loading instruments

The loading instrument is subject to approval based on the Rules of the individual Society. The approval is to include:

a) Verification of type approval, if any,
b) Verification that the final data of the ship has been used,
c) Acceptance of number and position of read-out points,
d) Acceptance of relevant limits for all read-out points,
e) Checking of proper installation and operation of the instrument onboard, in accordance with agreed test conditions, and that a copy of the operation manual is available.

Modifications resulting in changes to the main data of the ship (e.g. lightship weight, buoyancy distribution, tank volumes or usage, etc), require the loading manual to be updated and re-approved, and subsequently the loading instrument to be updated and re-approved. However, new loading guidance and an updated loading instrument need not be resubmitted provided that the resulting draughts, still water bending moments and shear forces do not differ from the originally approved data by more than 2%.

An operational manual is always to be provided for the loading instrument. The operation manual and the instrument output are to be prepared in a language understood by the users. If this language is not English, a translation into English is to be included.

The operation of the loading instrument is to be verified upon installation. It is to be checked that the agreed test conditions and the operation manual for the instrument is available onboard. ⚓

Chapter 2

General Arrangement

Section 1 Application

1. General

1.1 General

1.1.1

This chapter covers the general structural arrangement requirements for the ship.

Section 2 Subdivision Arrangement

1. Watertight bulkhead arrangement

1.1 Number and disposition of watertight bulkheads

1.1.1

All ships are to have at least the following transverse watertight bulkheads:

a) One collision bulkhead.
b) One aft peak bulkhead.
c) One bulkhead forward of the machinery space, and one bulkhead at the aft end of the machinery space which may be the aft peak bulkhead.

1.1.2

In the case of ships with an electrical propulsion plant, both the generator room and the engine room are to be enclosed by watertight bulkheads.

1.1.3

In addition to the requirements of **[1.1.1]** and **[1.1.2]**, the number and disposition of bulkheads are to be arranged to suit the requirements for subdivision, floodability and damage stability, and are to be in accordance with the requirements of national regulations.

1.1.4

For container ships not required to comply with subdivision requirements, bulkheads not less in number than indicated in **Table 1** are to be fitted.

Table 1 : Number of watertight bulkheads for container ships

Length in m	Total number of bulkhead	
	Ship with machinery room at aft body	Elsewhere
$90 \leq L < 102$	4	5
$102 \leq L < 123$	5	6
$123 \leq L < 143$	6	7
$143 \leq L < 165$	7	8
$165 \leq L < 186$	8	9
$186 \leq L$	to be considered individually	

1.1.5

The bulkheads in the cargo hold region are to be spaced at uniform intervals as far as practicable.

1.2 Deleted [2023]

2. Collision bulkhead

2.1 Extent and position of collision bulkhead

2.1.1

A collision bulkhead is to be fitted on all ships and is to extend to the freeboard deck. It is to be located between 0.05 L_{LL} or 10.0 m, whichever is less, and except as may be permitted by the Administration, 0.08 L_{LL} or 0.05 L_{LL} + 3.0 m, whichever is the greater, aft of the reference point, where the reference point is as defined in **[2.1.2]**.

2.1.2

For ships without bulbous bows the reference point is to be taken where the forward end of L_{LL} coincides with the forward side of stem, on the waterline which L_{LL} is measured. For ships with bulbous bows, it is to be measured from the forward end of L_{LL} a distance x forward; where x is to be taken as the lesser of the following:

a) Half the distance, from FP_{LL} to the extreme forward end of the bulb extension.
b) 0.015 L_{LL}.
c) 3.0 m.

2.2 Arrangement of collision bulkhead

2.2.1

In general, the collision bulkhead is to be in one plane; however, the bulkhead may have steps or recesses provided that they are within the limits prescribed in **[2.1.1]** and **[2.1.2]**.

2.2.2

Doors, manholes, permanent access openings or ventilation ducts are not to be cut in the collision bulkhead below the freeboard deck. Where the collision bulkhead is extended above 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.

3. Aft peak bulkhead

3.1 General

3.1.1

An aft peak bulkhead, enclosing the stern tube and rudder trunk in a watertight compartment, is to be provided. Where the shafting arrangements make enclosure of the stern tube in a watertight compartment impractical, alternative arrangements are specially considered.

3.1.2

The aft peak bulkhead may be stepped below the freeboard deck, provided that the degree of safety of the ship as regards subdivision is not thereby diminished.

3.1.3

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 are also subject to special consideration.

3.1.4

Provided that the aft peak bulkhead extends above the deepest load line, termination of the afterpeak bulkhead on a watertight deck lower than the freeboard deck can be accepted. In order to provide such a watertight deck a tight sealing of the rudder stock shall be fitted in way of this deck or above.

Section 3 Compartment Arrangement

1. Cofferdam

1.1 Definition

1.1.1

A cofferdam means an empty space arranged so that compartments on each side have no common boundary; a cofferdam may be located vertically or horizontally. As a rule, a cofferdam is to be kept gas-tight and is to be properly ventilated, provided with drainage arrangement, and of sufficient size to allow proper inspection, maintenance and safe evacuation.

1.2 Arrangement of cofferdams

1.2.1

Cofferdams are to be provided between compartments intended for liquid hydrocarbons (including fuel oil, lubricating oil) and those intended for fresh water (water for propelling machinery and boilers) as well as tanks intended for the carriage of liquid foam for fire extinguishing.

1.2.2

Furthermore, tanks carrying fresh water for human consumption are to be separated from other tanks containing substances hazardous to human health by cofferdams or other means as approved by the Society.

Note 1: Normally, tanks for fresh water and water ballast are considered non-hazardous.

1.2.3

Where a corner to corner situation occurs, tanks are not considered to be adjacent.

1.2.4

The cofferdams specified in **[1.2.1]** may be waived when deemed impracticable or unreasonable by the Society in relation to the characteristics and dimensions of the spaces containing such tanks, provided that:

- the thickness of common boundary plates of adjacent tanks is increased, with respect to the thickness obtained according to **Ch 6**, **Sec 4**, by 2 mm in the case of tanks carrying fresh water or boiler feed water, and by 1 mm in all other cases,
- the sum of the throats of the weld fillets at the edges of these plates is not less than the thickness of the plates themselves,
- the structural test is carried out with a test pressure increased by 1 m with respect to **Pt 1**, **Ch 1**, **Sec 3**, **306**.

2. Double bottom

2.1 General

2.1.1

A double bottom need not be fitted in way of watertight tanks, including dry tanks of moderate size provided the safety of the ship is not impaired in the event of bottom or side damage as regulated in **SOLAS II-1, Reg 9.**

2.2 Extent of double bottom

2.2.1

A double bottom is to be fitted extending from the collision bulkhead to the aft peak bulkhead, as far as this is practicable and compatible with the design and proper working of the ship.

2.2.2

Where double bottom is required to be fitted, the inner bottom is to be continued out to the ship side in such a manner as to protect the bottom to the turn of the bilge in areas where double side spaces are not provided.

2.3 Height of double bottom

2.3.1

Unless otherwise specified, the height of the double bottom is not to be less than the lesser of:

$B/20$ or 2.0 m, however not less than 0.76 m measured vertically from the plane parallel with keel line to inner bottom.

2.4 Small wells in double bottom tank

2.4.1

Small wells constructed in the double bottom are not to extend in depth more than necessary. A well extending to the outer bottom, may, however, be permitted at the after end of the shaft tunnel of the ship. Other wells may be permitted by the Society if it is satisfied that the arrangements give protection equivalent to that afforded by a double bottom that complies with **[2.1]**.

3. Deleted [2023]

4. Deleted [2023]

5. Deleted [2023]

6. Ballast Tank

6.1 Capacity and disposition of ballast tanks

6.1.1

All ships are to have ballast tanks of sufficient capacity that the ship may operate safely on ballast voyage.

Section 4 Access Arrangement

1. Closed spaces

1.1 General

1.1.1

All enclosed spaces are to be accessible for easy inspection. Special measures for inspection and maintenance are to be put in place for small closed spaces for which the design causes impracticality for the access.

2. Cargo area and forward space

2.1 General

All tanks are to be accessible for easy inspection. ⚓

Chapter 3

Structural Design Principles

Section 1 Materials

1. General

1.1 Standard of material

1.1.1

Materials used during construction are to comply with **Pt 2, Ch 1**.

1.1.2

Other materials than those covered under **[1.1.1]** may be accepted, provided their specification (e.g. manufacture, chemical composition, mechanical properties, welding) is submitted to the Society for approval.

1.2 Testing of materials

1.2.1

Materials are to be tested in compliance with the applicable requirements of **Pt 2, Ch 1**.

1.3 Manufacturing process

1.3.1

The requirements of this section presume that welding and other cold or hot manufacturing processes are carried out in compliance with current sound working practice defined in the Rules and / or documents of the individual Society which incorporate **IACS UR W** and the applicable requirements of **Pt 2, Ch 1**.

In particular:

a) Parent material and welding processes are to be within the limits stated for the specified type of material for which they are intended.
b) Specific preheating may be required before welding.
c) Welding or other cold or hot manufacturing processes may need to be followed by an adequate heat treatment.

2. Hull structural steel

2.1 General

2.1.1 Young's modulus and Poisson's ratio

The Young's modulus for Carbon steel materials is equal to 206,000 $\mathrm{N/mm^2}$ and the Poisson's ratio equal to 0.3.

2.1.2 Steel material grades and mechanical properties

Steel having a specified minimum yield stress of 235 $\mathrm{N/mm^2}$ is regarded as normal strength hull structural steel and is denoted by 'MS' for mild steel. Steel having a higher specified minimum yield stress is regarded as higher strength hull structural steel and is denoted 'HT' for high tensile steel.

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.

Table 1 gives the mechanical characteristics of steels generally used in the construction of ships.

Table 1 : Mechanical properties of hull steels

Steel grades for plates with $t_{as-built} \leq 100\ \mathrm{mm}$	R_{eH}, specified minimum yield stress, in $\mathrm{N/mm^2}$	R_m, specified tensile strength, in $\mathrm{N/mm^2}$
A-B-D-E	235	400 - 520
AH32 – DH32 – EH32 – FH32	315	440 - 570
AH36 – DH36 – EH36 – FH36	355	490 - 630
AH40 – DH40 – EH40 – FH40	390	510 - 660
AH47 – DH47 – EH47 – FH47	460	570-720

2.1.3

Higher strength steels other than those indicated in **Table 1** are considered by the Society on a case-by-case basis.

2.1.4 High tensile steel

When steels with a specified minimum yield stress R_{eH} other than 235 $\mathrm{N/mm^2}$ are used, hull girder strength and hull scantlings are to be determined by taking into account the material factor, k defined in **[2.2]**.

2.1.5 Onboard documents

It is required to keep onboard a plan indicating the steel types and grades adopted for the hull structures. Where steels other than those indicated in **Table 1** are used, their mechanical and chemical properties, as well as any workmanship requirements or recommendations, are to be available onboard together with the above plan.

2.2 Material factor, k

2.2.1

Unless otherwise specified, the material factor, k of normal and higher strength steel for hull girder strength and scantling purposes is to be taken as defined in **Table 2**, as a function of the specified minimum yield stress R_{eH}. For intermediate values of R_{eH}, k is obtained by linear interpolation.

Steels with a specified minimum yield stress R_{eH}, greater than 460 $\mathrm{N/mm^2}$ are considered by the Society on a case by-case basis.

Table 2 : Material factor, k

R_{eH}, specified minimum yield stress, in $\mathrm{N/mm^2}$	k
235	1.00
315	0.78
355	0.72
390	0.68(1)
460	0.62
(1) 0.66 for material factor provided that a fatigue assessment of the structure is performed to verify compliance with the requirements of **Ch 9**.	

2.3 Steel grades

2.3.1

Materials in the various strength members are not to be of lower grade than those corresponding to the material classes and grades specified in **Table 3** to **Table 6**. General requirements are given in **Table 3**, while additional minimum requirements for ships greater than 150 m or 250 m in length are given respectively in **Table 4** and **Table 5**. The material grade requirements for hull members of each class depending on the thickness are defined in **Table 6**.

2.3.2

For strength members not mentioned in **Table 3** to **Table 5**, grade A / AH may be used, upon agreement of the Society.

2.3.3

Plating materials for stern frames and shaft brackets are, in general, not to be of lower grades than those corresponding to Class II.

Table 3 : Material classes and grades

Structural member category		Within 0.4 L amidships	Outside 0.4 L and within 0.6 L amidships	Outside 0.6 L amidships
Secondary	• Longitudinal bulkhead strakes, other than those belonging to the primary category • Deck plating exposed to weather, other than that belonging to the primary or special category • Side plating	I	A / AH	A / AH
Primary	• Bottom plating, including keel plate • Strength deck plating, excluding that belonging to the special category • Continuous longitudinal plating of strength members above strength deck, excluding hatch coamings • Uppermost strake in longitudinal bulkhead	II	A / AH	A / AH
Special	• Sheerstrake at strength deck(1) • Stringer plate in strength deck(1) • Deck strake at longitudinal bulkhead, excluding deck plating in way of inner-skin bulkhead of double hull ships(1)	III	II	I
	• Strength deck plating at outboard corners of cargo hatch openings	III	II Min. class III within cargo region	I Min. class III within cargo region
	• Bilge strake in ships with double bottom over the full breadth and with length less than 150 m	II	II	I
	• Bilge strake in other ships(1)	III	II	I
	• Longitudinal hatch coamings of length greater than 0.15 L, including coaming top plate and flange • End brackets and deckhouse transition of longitudinal cargo hatch coamings	III not to be less than grade D/DH	II not to be less than grade D/DH	I not to be less than grade D/DH

(1) Single strakes required to be of class III within 0.4 L amidships are to have breadths not less than (800 + 5 L) mm, but need not be greater than 1,800 mm, unless limited by the geometry of the ship's design.

Table 4 : Minimum material grades for ships greater than 150 m in length

Structural member category	Material grade
• Longitudinal plating of strength deck where contributing to the longitudinal strength	Grade B/AH within 0.4 *L* amidships
• Continuous longitudinal plating of strength members above strength deck	Grade B/AH within 0.4 *L* amidships
• Single side strakes for ships without inner continuous longitudinal bulkhead(s) between bottom and the strength deck	Grade B/AH within cargo region

Table 5 : Minimum material grades for ships greater than 250 m in length

Structural member category(1)	Material grade
• Shear strake at strength deck	Grade E/EH within 0.4 *L* amidships
• Stringer plate in strength deck	Grade E/EH within 0.4 *L* amidships
• Bilge strake	Grade D/DH within 0.4 *L* amidships
(1) Single strakes required to be of grade E/EH and within 0.4 *L* amidships are to have breadths not less than (800 + 5 *L*) mm, but need not be greater than 1,800 mm, unless limited by the geometry of the ship's design.	

Table 6 : Material grade requirements for classes I, II, III

As-built thickness, in mm	Class I		Class II		Class III	
	MS steel	HT steel	MS steel	HT steel	MS steel	HT steel
$t \leq 15$	A	AH	A	AH	A	AH
$15 < t \leq 20$	A	AH	A	AH	B	AH
$20 < t \leq 25$	A	AH	B	AH	D	DH
$25 < t \leq 30$	A	AH	D	DH	D	DH
$30 < t \leq 35$	B	AH	D	DH	E	EH
$35 < t \leq 40$	B	AH	D	DH	E	EH
$40 < t \leq 50$	D	DH	E	EH	E	EH

2.4 Through thickness property

2.4.1

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, in accordance with **Pt 2, Ch 1**. These steels are to be designated on the approved plan by the required steel strength grade followed by the letter Z (e.g. EH36Z).

2.5 Stainless steel

2.5.1

The reduction of strength of stainless steel with increasing temperature is to be taken into account in the calculation of the material factor, k and in the material Young's modulus, E.

Stainless steels are to be in accordance with **Pt 3, Ch 1, 401**.

3. Steels for forging and casting

3.1 General

3.1.1

Mechanical and chemical properties of steels for forging and casting to be used for structural members are to comply with the applicable requirements of **Pt 2, Ch 1.**

3.1.2

Steels of structural members intended to be welded are to have mechanical and chemical properties deemed appropriate for this purpose by the Society on a case-by-case basis.

3.1.3

The steels used are to be tested in accordance with the applicable requirements of **Pt 2, Ch 1.**

3.2 Steels for forging

3.2.1

Rolled bars may be accepted in lieu of forged products, after consideration by the Society on a case-by-case basis. In such case, compliance with the applicable requirements of the Rules for Materials of the Society, relevant to the quality and testing of rolled parts accepted in lieu of forged parts, may be required.

3.3 Steels for casting

3.3.1

Cast parts intended for stems and stern frames in general may be made of C and C-Mn weldable steels, having specified minimum tensile strength, $R_m = 400\ \mathrm{N/mm^2}$, in accordance with the applicable requirements of **Pt 2, Ch 1** for Materials.

3.3.2

The welding of cast parts to main plating contributing to hull strength members is considered by the Society on a case-by-case basis.

The Society may require additional properties and tests for such casting, in particular impact properties which are appropriate to those of the steel plating on which the cast parts are to be welded and non-destructive examinations.

4. Aluminium alloys

4.1 General

4.1.1

The use of aluminium alloys in superstructures, deckhouses, hatch covers, helicopter platforms, or other local components is to be specially considered. A specification of the proposed alloys and their proposed method of fabrication is to be submitted for approval.

Material requirements and scantlings are to comply with **Pt 2, Ch 1** for Materials. Series 5000 aluminium -magnesium alloys or series 6000 aluminium-magnesium-silicon alloys are to be used.

4.1.2

In the case of structures subjected to low service temperatures or intended for other specific applications, the alloys to be employed are to be agreed by the Society.

4.1.3

Unless otherwise agreed, the Young's modulus for aluminium alloys is equal to 70,000 $\mathrm{N/mm^2}$ and the Poisson's ratio equal to 0.33.

4.1.4

Details of the proposed method of joining any aluminium and steel structures are to be submitted for approval.

4.2 Extruded plating

4.2.1

Extrusions with built-in plating and stiffeners, referred to as extruded plating, may be used.

4.2.2

In general, the application of extruded plating is limited to decks, bulkheads, superstructures and deckhouses. Other uses may be permitted by the Society on a case-by-case basis.

4.2.3

Extruded plating is to be oriented so that the stiffeners are parallel to the direction of main stresses.

4.2.4

Connections between extruded plating and primary members are to be given special attention.

4.3 Mechanical properties of weld joints

4.3.1

Welding heat input lowers locally the mechanical strength of aluminium alloys hardened by work hardening (series 5000 other than condition O or H111) or by heat treatment (series 6000).

4.3.2

The as-welded properties of aluminium alloys of series 5000 are in general those of condition O or H111. Higher mechanical characteristics may be considered, provided they are duly justified.

4.3.3

The as-welded properties of aluminium alloys of series 6000 are to be agreed by the Society.

4.4 Material factor, k

4.4.1

The material factor, k for aluminium alloys is to be obtained from the following formula:

$$k = \frac{235}{R'_{lim}}$$

where:

R'_{lim} : Minimum guaranteed yield stress of the parent metal in welded condition $R'_{p0.2}$, in $\mathrm{N/mm^2}$, but not to be taken greater than 70 % of the minimum guaranteed tensile strength of the parent metal in welded condition R'_m, in $\mathrm{N/mm^2}$.

$R'_{p0.2}$: Minimum guaranteed yield stress, in $\mathrm{N/mm^2}$, of material in welded condition.

$R'_{p0.2} = \eta_1 R_{p0.2}$

R'_m : Minimum guaranteed tensile strength, in $\mathrm{N/mm^2}$, of material in welded condition.

$R'_m = \eta_2 R_m$

$R_{p0.2}$: Minimum guaranteed yield stress, in $\mathrm{N/mm^2}$, of the parent metal in delivery condition.

R_m : Minimum guaranteed tensile strength, in $\mathrm{N/mm^2}$, of the parent metal in delivery condition.

η_1, η_2 : Specified in **Table 7**.

Table 7 : Aluminium alloys – Coefficients for welded construction

Aluminium alloy	η_1	η_2
Alloys without work-hardening treatment (series 5000 in annealed condition O or annealed flattened condition H111)	1.0	1.0
Alloys hardened by work hardening (series 5000 other than condition O or H111)	$R'_{p0.2} / R_{p0.2}$	R'_m / R_m
Alloys hardened by heat treatment (series 6000) (1)	$R'_{p0.2} / R_{p0.2}$	0.6
(1) When no information is available, coefficient η_1 is to be taken equal to the metallurgical efficiency coefficient β as defined in **Table 8**.		

Table 8 : Aluminium alloys – Metallurgical efficiency coefficient β

Aluminium alloy	Temper condition	As-built thickness, in mm	β
6005A (Open sections)	T5 or T6	$t \leq 6.0$	0.45
		$t > 6.0$	0.40
6005A (Closed sections)	T5 or T6	All	0.50
6061 (Sections)	T6	All	0.53
6082 (Sections)	T6	All	0.45

4.4.2

In the case of welding of two different aluminium alloys, the material factor, k to be considered for the scantlings is the greater material factor of the aluminium alloys of the assembly.

4.5 Others

4.5.1

Aluminium fittings in cofferdams are to be avoided.

4.5.2

The underside of heavy portable aluminium structures such as gangways, is to be protected by means of a hard plastic or wood cover, or other approved means, in order to avoid the creation of smears. Such protection is to be permanently and securely attached to the structures.

5. Other materrials and products

5.1 General

5.1.1

Other materials and products such as parts made of iron castings, where allowed, products made of copper and copper alloys, rivets, anchors, chain cables, cranes, masts, derrick posts, derricks, accessories and wire ropes are to comply with the applicable requirements of **Pt 2, Ch 1** for Materials.

5.1.2

The use of plastics or other special materials not covered by these Rules is to be considered by the Society on a case-by-case basis. In such cases, the requirements for the acceptance of the materials concerned are to be agreed by the Society.

5.2 Iron cast parts

5.2.1

As a rule, the use of grey iron, malleable iron or spheroidal graphite iron cast parts with combined ferritic/perlitic structure is allowed only to manufacture low stressed elements of secondary importance.

5.2.2

Ordinary iron cast parts may not be used for windows or sidescuttles; Iron cast part used for windows or sidescuttles are to be in accordance with **Pt 4, Ch 8, 804** and **904**.

Section 2 Net Scantling Approach

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4**

t : Net thickness in mm.

t_c : Corrosion addition in mm.

t_{gr} : Gross thickness in mm.

h_{stf} : Height of stiffener or primary supporting member in mm.

h_w : Web height of stiffener or primary supporting member in mm.

t_w : Web thickness of stiffener or primary supporting member in mm.

b_f : Face plate width of stiffener or primary supporting member in mm.

t_f : Face plate thickness of stiffener or primary supporting member in mm.

t_p : Thickness of the plating attached to a stiffener or to a primary supporting member in mm.

d_e : Distance in mm, from the upper edge of the web to the top of the flange for L3 profiles, see **Figure 3**.

d_f : Distance in mm, for extension of flange for L2 profiles, see **Figure 3**.

$t_{as-built}$: As-built thickness, in mm, taken as the actual thickness provided at the newbuilding stage.

t_{gr-off} : Gross offered thickness, in mm, as defined in **[1.2.2]**.

t_{gr-req} : Gross required thickness, in mm, as defined in **[1.2.1]**.

t_{off} : Net offered thickness, in mm, as defined in **[1.2.3]**.

t_{dm} : Design production margin, in mm, taken as the thickness difference between offered gross thickness and required gross thickness (equal also to the difference between offered net and required net thickness) as a result of scantlings applied by the designer or builder to suit design or production situation. This difference in thickness is not to be considered as an additional corrosion margin.

t_{req} : Net required thickness, in mm, as required in **[1.3.1]**.

$t_{vol-add}$: Thickness for voluntary addition, in mm, taken as the thickness voluntarily added as the owner's extra margin or builder's extra margin for corrosion wastage in addition to t_c.

t_{res} : Reserve thickness, in mm, taken equal to 0.5 mm.

t_{c1}, t_{c2} : Corrosion addition on one side of the considered structural member, in mm, as defined in **Ch 3, Sec 3, Table 1**.

1. General

1.1 Application

1.1.1 Net thickness approach

The net thickness, t, of a structural element is required for structural strength in compliance with the design basis. The corrosion addition, t_c, for a structural element is derived independently from the net scantling requirements as shown in **Figure 1**. This approach clearly separates the net thickness from the thickness added to address the corrosion that is likely to occur during the ship-in-operation phase.

1.1.2 Local and global corrosion

The net thickness approach distinguishes between local and global corrosion. Local corrosion is defined as uniform corrosion of local structural elements, such as a single plate or stiffener. Global corrosion is defined as the average corrosion of larger areas, such as primary supporting members and the hull girder.

1.1.3 Exceptions in gross scantling

Items that are directly determined in terms of gross scantlings do not follow the net scantling approach, i.e. they already include additions for corrosion but without any owner's extra margin. Gross scantling requirements are identified with the suffix "gr" and examples are:

a) Scantlings of superstructures and deckhouses as given in **Ch 11, Sec 1**.

b) Scantlings of massive pieces made of steel forgings and steel castings.

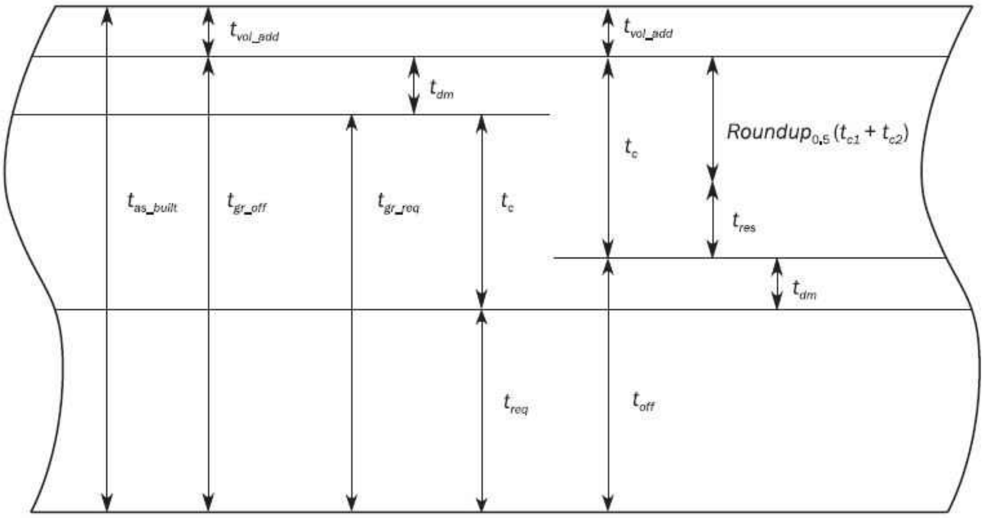


Figure 1 : Net scantling approach scheme

1.2 Gross and net scantling definitions

1.2.1 Gross required thickness

The gross required thickness, t_{gr-req}, is the thickness obtained by adding the corrosion addition as defined in **Ch 3, Sec 3** to the net required thickness, as follows:

$$t_{gr-req} = t_{req} + t_c$$

1.2.2 Gross offered thickness

The gross offered thickness, t_{gr-off}, is the gross thickness provided at the newbuilding stage, which is obtained by deducting any thickness for voluntary addition from the as-built thickness, as follows:

$$t_{gr-off} = t_{as-built} - t_{vol-add}$$

1.2.3 Net offered thickness

The net offered thickness, t_{off}, is obtained by subtracting the corrosion addition from the gross offered thickness, as follows:

$$t_{off} = t_{gr-off} - t_c = t_{as-built} - t_{vol-add} - t_c$$

1.3 Scantling compliance

1.3.1

The net required thickness, t_{req}, is obtained by rounding the net thickness calculated according to the Rules to the nearest half millimetre. For example:

a) For $10.75 \le t < 11.25\,\mathrm{mm}$, the Rule required net thickness is 11.0 mm.

b) For $11.25 \le t < 11.75\,\mathrm{mm}$, the Rule required net thickness is 11.5 mm.

1.3.2

Scantling compliance in relation to the Rules is as follow:

a) The net offered thickness of plating is to be equal to or greater than the net required thickness of plating.

b) The required net section modulus, moment of inertia and shear area properties of local supporting members are to be calculated using the net thickness of the attached plate, web and flange. The net sectional dimensions of local supporting members are defined in **Figure 2** and **Figure 3**. The required section modulus and web net thickness apply to areas clear of the end brackets.

c) The offered net sectional properties of primary supporting members and the hull girder are to be equal to or greater than the required net sectional properties which are to be based on the gross offered scantling with a reduction of the applicable corrosion addition, as specified in **Table 1**, applied to all component structural members.

d) The strength assessment methods prescribed are to be assessed by applying the corrosion reduction specified in **Table 1** to the offered gross scantlings. Half of the applied corrosion addition specified in **Table 1** is to be deducted from both sides of the structural members being considered.

e) Corrosion additions are not to be taken less than those given in **Ch 3, Sec 3, [1.2]**.

Any additional thickness specified by the owner or the builder is not to be included when considering the compliance with the Rules.

Table 1 : Assessment for corrosion applied to the gross scantlings

Structural requirement	Property / analysis type	Applied corrosion addition
Minimum thickness (all members including PSM)	Thickness	t_c
Local strength (plates and stiffeners)	Thickness / sectional properties	t_c
	Stiffness / proportions / Buckling capacity	t_c
Primary supporting members (prescriptive)	Sectional properties	$0.5t_c$
	Stiffness / proportions of web and flange Buckling capacity	t_c
Strength assessment by FEM	Cargo hold (stress determination)	0.0
	Buckling capacity	$t_c^{(1)}$
	Local fine mesh	0.0
Hull girder strength	Sectional properties	$0.5t_c$
	Buckling capacity	t_c
Hull girder ultimate strength	Sectional properties	$0.5t_c$
	Buckling / collapse capacity	$0.5t_c$
Fatigue assessment (simplified stress analysis)	Hull girder section properties Local support member	$0.5t_c$
Fatigue assessment (FE Stress analysis)	Coarse mesh FE model Very fine mesh portion	0.0

(1) $t_c = t_{c1} + t_{c2}$

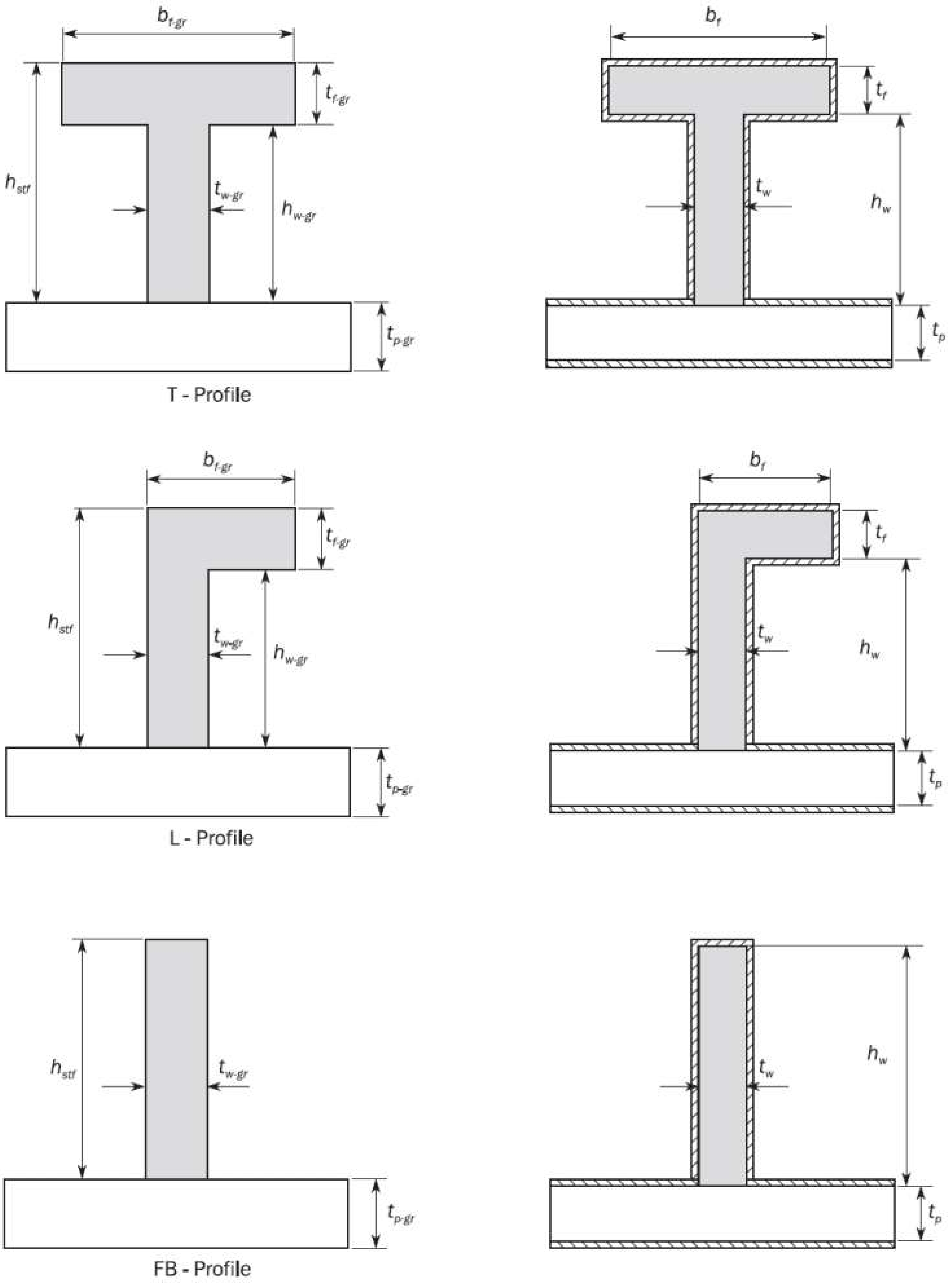
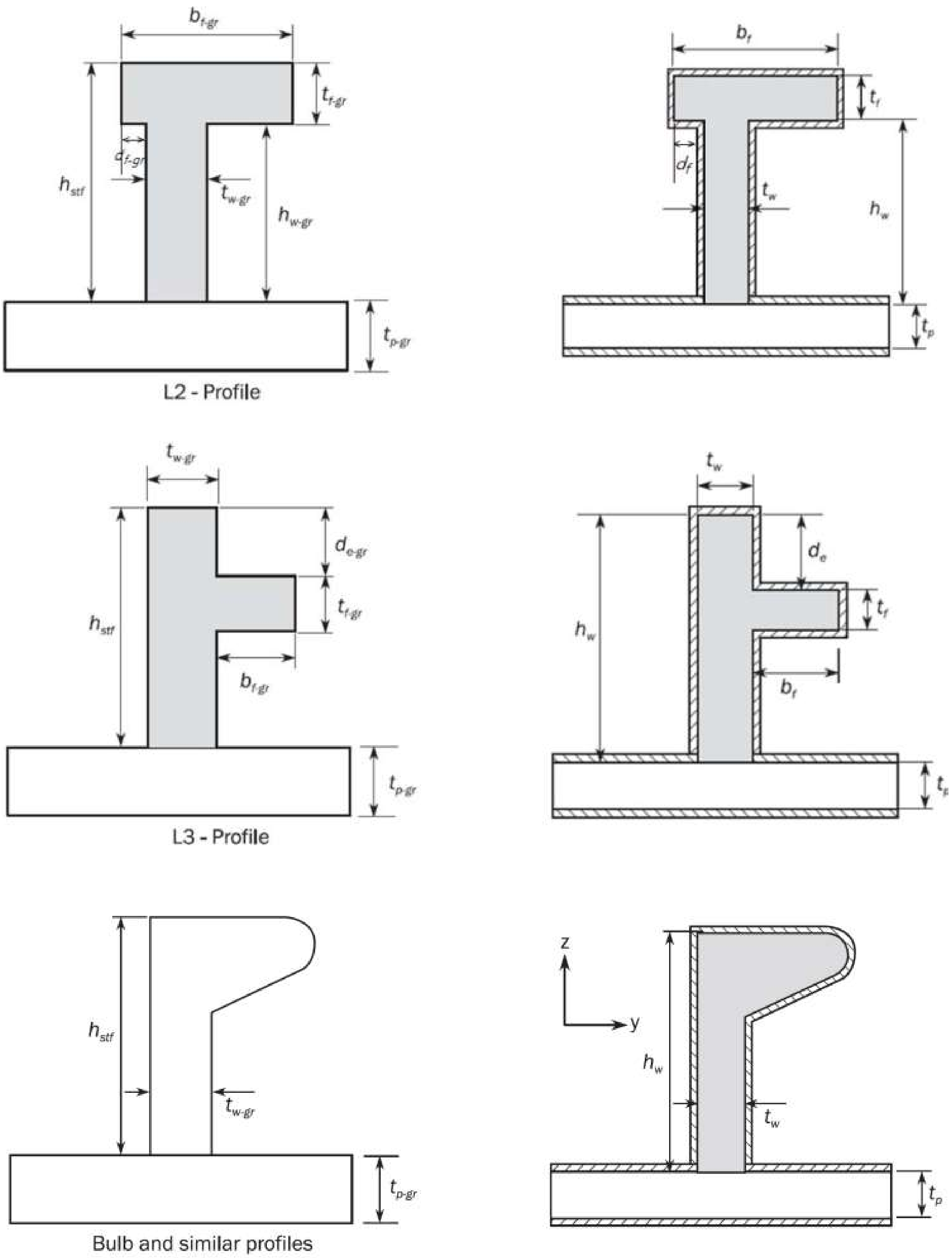


Figure 2 : Net sectional properties of local supporting members (T, L and FB-profile)



L2 - Profile

L3 - Profile

Bulb and similar profiles

Figure 3 : Net sectional properties of local supporting members (L2, L3 and Bulb-Profile)

The net cross-sectional area, the moment of inertia about the y-axis and the associated neutral axis position are to be determined applying a corrosion magnitude of 0.5 t_c deducted from the surface of the profile cross-section.

Section 3 Corrosion Additions

Symbols

t_c : Corrosion addition, in mm.

t_{c1}, t_{c2} : Corrosion addition, in mm, on one side of the considered structural member, as defined in **Table 1**.

t_{res} : Reserve thickness, taken as 0.5 mm.

1. General

1.1 Applicability

1.1.1

The corrosion additions given in these Rules are applicable to carbon-manganese steels, stainless steels, stainless clad steels and aluminium alloys. Corrosion addition for the exposed carbon steel side of stainless clad structure is to be as required in **Table 1** for the corresponding compartment.

The corrosion additions for other materials are to be in accordance with the requirements of the Society.

1.2 Corrosion addition determination

1.2.1

The corrosion addition for each of the two sides of a structural member, t_{c1} or t_{c2}, is specified in **Table 1**.

The total corrosion addition, t_c, in mm, for both sides of the structural member is obtained by the following formula:

$$t_c = t_{c1} + t_{c2} + t_{res}$$

For an internal member within a given compartment, the total corrosion addition, t_c, is obtained from the following formula:

$$t_c = 2t_{c1} + t_{res}$$

where t_{c1} is the value specified in **Table 1** for one side exposure to that compartment.

The total corrosion addition, t_c, in mm, for compartment boundaries and internal members made from stainless steel, or aluminium is to be taken as:

$$t_c = t_{res} = 0.5$$

In case of stainless clad steel, the corrosion additions, t_{c1}, for the carbon steel side and t_{c2}, for the stainless steel side are respectively to be taken as:

a) t_{c1} as specified for the corresponding compartment in **Table 1**

b) t_{c2} = 0.0

Table 1 : Corrosion addition for one side of a structural member

Compartment type		t_{c1} or t_{c2}
Ballast water tank, bilge tank, drain storage tank, chain locker$^{(1)}$		1.0
Exposed to atmosphere$^{(5)}$		0.5
Exposed to sea water$^{(5)}$		0.5
Fuel oil, methanol fuel and lube oil tank		0.5
Fresh water tank		0.5
Void spaces$^{(2)(3)(4)}$	Spaces not normally accessed, e.g. access only via bolted manhole openings, pipe tunnels, etc.	0.0
Dry spaces$^{(3)(4)}$	Internals of machinery spaces, store rooms, steering gear space, etc.	0.0
Container holds$^{(5)}$		0.5
Accommodation spaces		0.0
Compartments other than those mentioned above		0.5

(1) 1.0 mm is to be added to the plate surface within 3.0 m above the upper surface of the chain locker bottom.
(2) For the determination of the corrosion addition of the outer shell plating, the pipe tunnel is considered as for a ballast water tank.
(3) For bottom plate of void spaces and dry spaces, t_{c1} or t_{c2} is to be taken equal to 0.5 mm.
(4) For the hull girder strength assessment according to **Ch 5,** t_{c1} or t_{c2} is to be taken equal to 0.5 mm.
(5) For the hull girder strength assessment according to **Ch 5,** t_{c1} or t_{c2} is to be taken equal to 1.0 mm.

1.2.2 Stiffener

The corrosion addition of a stiffener is determined according to the location of its connection to the attached plating.

1.2.3

When a local structural member / plate is affected by more than one value of corrosion addition considering compartment type excluding extended parts only due to reasons for workmanship, the most onerous value is to be applied to the entire strake.

1.2.4 Corrosion addition limit

Considering the renewal criteria specified in **Ch 13, Sec 2**, the total corrosion addition, t_c in mm, need not to be taken more than 20 % of gross offered thickness, t_{gr-off} in mm. The corrosion addition satisfy the following condition:

$t_c \leq 0.2\, t_{gr-off}$ with nearest half millimetre

For examples;

0.75 ≤ t_c 〈 1.25mm, the corrosion addition, t_c, is 1.0mm.

1.25 ≤ t_c 〈 1.75mm, the corrosion addition, t_c, is 1.5mm.

Section 4 Corrosion Protection

1. General

1.1 Structures to be protected

1.1.1 Dedicated seawater ballast tanks

All dedicated seawater ballast tanks are to have an efficient corrosion prevention system.

1.1.2 Narrow spaces

Narrow spaces are generally to be filled by an efficient protective product, particularly at the ends of the ship where inspections and maintenance are not easily practicable due to their inaccessibility.

Section 5 Limit States

1. General

1.1 Limit states

1.1.1 Definition

A limit state is defined as a state beyond which the structure no longer satisfies the requirements. The following categories of limit states are relevant for structures:

a) Serviceability limit state (SLS), which corresponds to conditions beyond which specified requirements are no longer met.
b) Ultimate limit state (ULS), which corresponds to the maximum load carrying-capacity or, in some cases, to the maximum applicable strain or deformation, under intact (undamaged) conditions.
c) Fatigue limit state (FLS), which corresponds to degradation due to effect of time varying (cyclic) loading.
d) Accidental limit state (ALS), which concerns the ability of the structure to resist accident situations.

1.1.2 Serviceability limit state

Serviceability limit state, which concerns the normal use, includes:

a) Local damage which may reduce the working life of the structure or affect the efficiency or appearance of structural members or non-structural elements.
b) Unacceptable deformations which affect the efficient use and appearance of structural or non-structural elements or the functioning of safety equipment.

In the context of serviceability limit state, the term ‘appearance’ is concerned with such criteria as high deflection and extensive cracking, rather than aesthetics.

1.1.3 Ultimate limit state

Ultimate limit state, which corresponds to the maximum load-carrying capacity, or in some cases, the maximum applicable strain or deformation, includes:

a) Attainment of the maximum resistance capacity of sections, members or connections by rupture or excessive deformations or instability (buckling).
b) Excessive yielding, transforming the structure or part of it into a plastic mechanism.

1.1.4 Fatigue limit state

Fatigue limit states assess that the fatigue capacity of structural members due to cyclic loads is greater than the design fatigue life.

1.1.5 Accidental limit state

Accidental limit states are concerned with the ability of the structure to resist accident situations or abnormal events. As described in **Pt 7, Ch 5,** this limit states are concerned with the collision loads imposed on a liquefied natural gas fuel containment system and its supporting structure in intact (undamaged) conditions as follows:

- 0.5g in the forward direction in full condition.
- 0.25g in the aft direction in full condition.

where, “g” is gravitational acceleration.

Flooded conditions of any compartment without progression of the flooding to another compartment are considered. The limit states are concerned with the following in intact (undamaged) conditions with accidental or abnormal loads, or in damaged conditions with environmental loads the ship meets during a limited time frame:

- The safety of life.
- Environment.

- Property (ship and cargo).

Accidental limit state includes:

- Loss of structural strength without loss of containment.
- Loss of structural strength and loss of containment.

1.2 Failure modes

1.2.1

A number of possible failure modes may be relevant for the various parts of the ship structure. For each failure mode, one or more limit states may be relevant. The failure modes to be considered for the assessment of ship structural safety with relation to the limit states are shown in **Table 1**.

Table 1 : Failure modes in relation to the limit states to be considered

Possible failure modes to be considered	Limit states[1]			
	SLS	ULS	FLS	ALS
Yielding	Y	Y	–	Y
Plastic collapse	–	Y	–	Y
Buckling	Y	Y	–	Y
Rupture	–	Y	–	Y
Fatigue cracking	–	–	Y	–
Brittle fracture[2]	–	–	–	–

[1] “Y” indicates that the structural assessment is to be carried out.

[2] Controlled by the material rule requirement of steel grade

1.2.2 Yielding

The yielding failure mode is the mode in which plastic strain locally occurs in the structural members to be considered under combined in-plane and normal stresses. Local plastic strain is controlled in SLS, ULS and ALS by checking that the stresses caused in the structural members remains below a permissible value.

1.2.3 Plastic collapse

The plastic collapse failure mode usually appears in the local structural members under large lateral impact pressure. In this failure mode, permanent lateral deflection in the local structural members occurs, but does not influence the global strength. This mode is controlled in ULS and ALS by using conventional plastic design method.

1.2.4 Buckling

The buckling failure mode is the instability phenomena of structural members under compressive loads. When the stress in structural members just attains the elastic buckling stress, elastic (reversible) buckling occurs during the compressive load. This buckling failure mode is controlled in SLS. By further increasing the compressive load, stress redistribution occurs due to buckling of the weakest structural member and the stress in some structural members reaches the yield stress. This buckling failure mode with large elastic deflection is controlled in ULS or ALS. When compression is unloaded, no consequence of failure due to buckling is seen.

On the other hand, plastic (irreversible) buckling occurs when the stress in structural members exceeds the yield stress. As a result, the substantial permanent deflections due to plastic buckling appear. This irreversible buckling failure mode is controlled only in ULS or ALS for global hull girder strength.

1.2.5 Rupture

The rupture failure mode is the mode in which breaking occurs in the structural members to be considered under large tensile stress beyond the yield stress of the material. This failure mode is controlled in ULS or ALS, but the assessment of this failure mode is covered by controlling the yielding failure.

1.2.6 Brittle fracture

Brittle fracture is dependent upon the material, temperature and thickness. Therefore, this mode is controlled by the material rule requirement of steel grade.

1.2.7 Fatigue cracking

This failure mode is different from the failure modes mentioned above and is controlled in FLS.

2. Criteria

2.1 General

2.1.1

Criteria are prescribed in the Rules to check the relevant limit states for the various structural elements. The strength assessments included in the Rules are defined in terms of yield check, buckling check, ultimate strength check, and fatigue check as indicated in **Table 2**.

Table 2 : Structural assessment

Structural Elements(1)		Yielding check	Buckling check	Ultimate strength check	Fatigue check
Local Structures	Stiffeners	Y	Y	Y(2)	Y
	Plating	Y	Y	Y(3)	–
Primary supporting members		Y	Y	Y(2)	Y
Hull girder		Y	Y(4)	Y	–

(1) “Y” indicates that the structural assessment is to be carried out.
(2) The ultimate strength check is included in the buckling check.
(3) The ultimate strength check of plating is included in the yielding check formula of plating.
(4) The buckling check of stiffeners and plating taking part in hull girder strength is performed against stress due to hull girder bending moment and hull girder shear force.

2.2 Serviceability limit states

2.2.1 Hull girder

For the yielding check of the hull girder, the stress corresponds to a load at 10^{-8} probability level.

2.2.2 Plating

For the yielding check and buckling check of platings constituting a primary supporting member, the stress corresponds to a load at 10^{-8} probability level.

2.2.3 Stiffeners

For the yielding check of stiffeners, the stress corresponds to a load at 10^{-8} probability level.

2.3 Ultimate limit states

2.3.1 Hull girder

The ultimate strength of the hull girder is to be checked against the hull girder loads at 10^{-8} probability level, amplified with the partial safety factor.

2.3.2 Plating

The ultimate strength of the plating between stiffeners and primary supporting members is to be checked against theloads at 10^{-8} probability level.

2.3.3 Stiffeners

The ultimate strength of stiffeners is to be checked against the loads at 10^{-8} probability level.

2.4 Fatigue limit state

2.4.1 Structural details

The fatigue life of representative welded structural details such as connections of stiffeners and primary supporting members is to be assessed from long term distribution loads based on loads at 10^{-2} probability level.

2.5 Accidental limit state

2.5.1 Bulkhead structure

The fore and aft cofferdam transverse bulkheads in liquefied natural gas fuel tank boundary, are to be assessed for regarding bow/stern collision loads in accordance with **Ch 6** and **Ch 7** for yielding criteria.

2.5.2 Plating, stiffeners and PSM

The plating, stiffeners and PSM are to be assessed in flooded conditions in accordance with **Ch 6** and **Ch 7** for yielding criteria.

3. Strength check against impact loads

3.1 General

3.1.1

Structural response against impact loads such as forward bottom slamming, bow impact and stern slamming depends on the loaded area, magnitude of loads and structural grillage.

3.1.2

The ultimate strength of structural members that constitute the grillage, i.e. platings between stiffeners and primary supporting members and stiffeners with attached plating, is to be checked against the maximum impact loads acting on them.

Section 6 Structural Detail Principles

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

1. Application

1.1 General

1.1.1

If not specified otherwise, the requirements of this section apply to the hull structure except superstructures and deckhouses.

2. General principles

2.1 Structural continuity

2.1.1 General

Attention is to be paid to the structural continuity, in particular in the following areas:

a) In way of changes in the framing system.
b) At end connections of primary supporting members or ordinary stiffeners.
c) In way of the transition zones between cargo hold region and fore part, aft part and machinery space.
d) In way of side and end bulkheads of superstructures.

At the termination of a structural member, structural continuity is to be maintained by the fitting of suitable supporting structure. Abrupt changes in transverse section properties of longitudinal members are to be avoided. Smooth transitions are to be provided.

On double hull ships, where the machinery space is located between two holds, the inner side is, in general, to be continuous within the machinery space. Where the machinery space is situated aft, the inner hull is to extend as far abaft as possible and be tapered at the ends.

2.1.2 Longitudinal members

Longitudinal members are to be arranged in such a way that continuity of strength is maintained.

Longitudinal members contributing to the hull girder longitudinal strength are to extend continuously as far as practicable towards the ends of the ship.

2.1.3 Primary supporting members

Primary supporting members are to be arranged in such a way that continuity of strength is maintained. Abrupt changes of web height or cross section are to be avoided.

2.1.4 Stiffeners

Stiffeners are to be arranged in such a way that continuity of strength is maintained. Stiffeners contributing to the hull girder longitudinal strength are to be continuous when crossing primary supporting members within the 0.4 L amidships and as far as practicable outside 0.4 L amidships. Where stiffeners are terminated in way of large openings, foundations and partial girders, compensation is to be arranged to provide structural continuity in way of the end connection.

2.1.5 Plating

Where plates with different thicknesses are joined, the change in the as-built plate thickness is not to exceed 50 % of the larger plate thickness in the load carrying direction. This also applies to strengthening by local inserts, e.g. insert plates in double bottom girders, floors and inner bottom.

2.1.6 Weld joints

Weld joints are to be avoided in areas with high stress concentration.

2.2 Local reinforcements

2.2.1 Reinforcements at knuckles

a) Knuckles are in general to be stiffened to achieve out-of-plane stiffness by fitting ordinary stiffeners or equivalent means in line with the knuckle.
b) Whenever a knuckle in a main member (shell, longitudinal bulkhead etc) is arranged, stiffening in the form of webs, brackets or profiles is to be connected to the members to which they are to transfer the load (in shear).
c) 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.
d) Generally, the distance between the knuckle and the support stiffening in line with the knuckle is not to be greater than 50 mm. Otherwise, fatigue analysis according to **Ch 9** is to be submitted by the designer.

2.2.2 Reinforcement of deck structure in way of concentrated loads

The deck structure is to be reinforced in way of concentrated loads, such as anchor windlass, deck machinery, cranes, masts and derrick posts.

2.2.3 Reinforcement under container corners and in way of fixed cargo securing devices and cell guides

Local reinforcement of the hull structure and hatch covers is to be provided under container corners and in way of fixed cargo securing devices and cell guides, if fitted.

The forces applying on the fixed cargo securing devices are to be indicated by the designer.

2.2.4 Reinforcement by insert plates

Insert plates are to be made of materials with, at least, the same specified minimum yield stress and the same grade as the plates to which they are welded. See also **[2.1.5]**.

2.3 Connection of longitudinal members not contributing to the hull girder longitudinal strength

2.3.1

Where the hull girder stress at the strength deck or at the bottom as defined in **Ch 5, Sec 1, [2.2.2]** is higher than the permissible stress as defined in **Ch 5, Sec 1, [3.4.1]** for normal strength steel, longitudinal members not contributing to the hull girder longitudinal strength and welded to the strength deck or bottom plating and bilge plating, such as gutter bars, strengthening of deck openings, bilge keel, are to be made of steel with the same specified minimum yield stress as the strength deck or bottom structure steel.

2.3.2

The requirement in **[2.3.1]** is also applicable to non-continuous longitudinal stiffeners welded on the web of a primary structural member contributing to the hull girder longitudinal strength such as hatch coamings, stringers and girders or on the inner bottom are to be made of steel with the same specified minimum yield stress as attached plate when the hull girder stress on those members is higher than the permissible stress as defined in **Ch 5, Sec 1, [3.4.1]** for normal strength steel.

3. Stiffeners

3.1 General

3.1.1

All types of stiffeners(excluding web stiffeners) are to be connected at their ends. However, in special cases such as isolated areas of the ship where end connections cannot be applied, sniped ends may be permitted. Requirements for the various types of connections(bracketed, bracketless or sniped ends) are given in **[3.2]** to **[3.4]**.

3.1.2

Where the angle between the web plate of the stiffener and the attached plating is less than 50 °, as shown on **Figure 1**, a tripping bracket is to be fitted. If the angle between the web plate of an unsymmetrical stiffener and the attached plating is less than 50 °, the face plate of the stiffener is to be fitted on the side of the open angle.

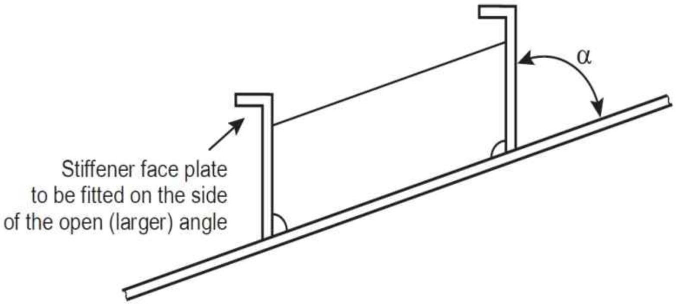


Figure 1 : Stiffener on attached plating with an angle less than 50 °

3.2 Bracketed end connections of non-continuous stiffeners

3.2.1

Where continuity of strength of longitudinal members is provided by brackets, the alignment of the brackets on each side of the primary supporting member is to be ensured, 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.

3.2.2

At bracketed end connections, continuity of strength is to be maintained at the stiffener connection to the bracket and at the connection of the bracket to the supporting member.

3.2.3

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

3.2.4 Net web thickness

The net bracket web thickness, t_b in mm, is to comply with the following:

$t_b \geq (2 + f_{bkt}\sqrt{Z})\sqrt{\dfrac{R_{eH-stf}}{R_{eH-bkt}}}$ and need not be greater than 13.5 mm.

where:

f_{bkt} : Coefficient taken as:

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

f_{bkt} = 0.3 for brackets without flange or edge stiffener.

Z : Net required section modulus, of the stiffener, in cm^3. In the case of two stiffeners connected, Z is the smallest net required section modulus of the two connected stiffeners.

R_{eH-stf} : Specified minimum yield stress of the stiffener material, in $\mathrm{N/mm}^2$.

R_{eH-bkt} : Specified minimum yield stress of the bracket material, in $\mathrm{N/mm}^2$.

3.2.5 Brackets at the ends of non-continuous stiffeners

Brackets at the ends of non-continuous stiffeners Brackets are to be fitted at the ends of non-continuous stiffeners, with arm lengths, ℓ_{bkt} in mm, taken as:

$$\ell_{bkt} = C_{bkt}\sqrt{\frac{Z}{t_b}}$$

ℓ_{bkt} is not to be taken less than:

ℓ_{bkt} = 1.8 h_{stf} 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 item (c) in **Figure 2.**

ℓ_{bkt} = 2.0 h_{stf} for other cases, see items (a), (b) and (d) in **Figure 2.**

where:

C_{bkt} : Coefficient taken as:

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

C_{bkt} = 70 for brackets without flange or edge stiffener.

Z : Net required section modulus, for the stiffener, in cm^3, as defined in **[3.2.4].**

t_b : Minimum net bracket thickness, in mm, as defined in **[3.2.4].**

For connections similar to item (b) in **Figure 2**, but not lapped, the bracket arm length is to comply with $\ell_{bkt} \geq 2.0\,h_{stf}$.

For connections similar to items (c) and (d) in **Figure 2** where the smaller stiffener is connected to a primary supporting member or bulkhead, the bracket arm length is not to be less than two times of h_{stf}.

3.2.6 Brackets with different arm lengths

The lengths of the arms, measured from the plating to the toe of the bracket, are to be such that the sum of them is greater than 2 ℓ_{bkt} and each arm not to be less than 0.8 ℓ_{bkt}, where ℓ_{bkt} is as defined in **[3.2.5].**

3.2.7 Edge stiffening of bracket

Where an edge stiffener is required, the web height of the edge stiffener, h_w in mm, is not to be less than:

$h_w = 45\left(1 + \dfrac{Z}{2000}\right)$ but not less than 50 mm.

where:

Z : Net section modulus, of the stiffener, in cm^3, as defined in **[3.2.4].**

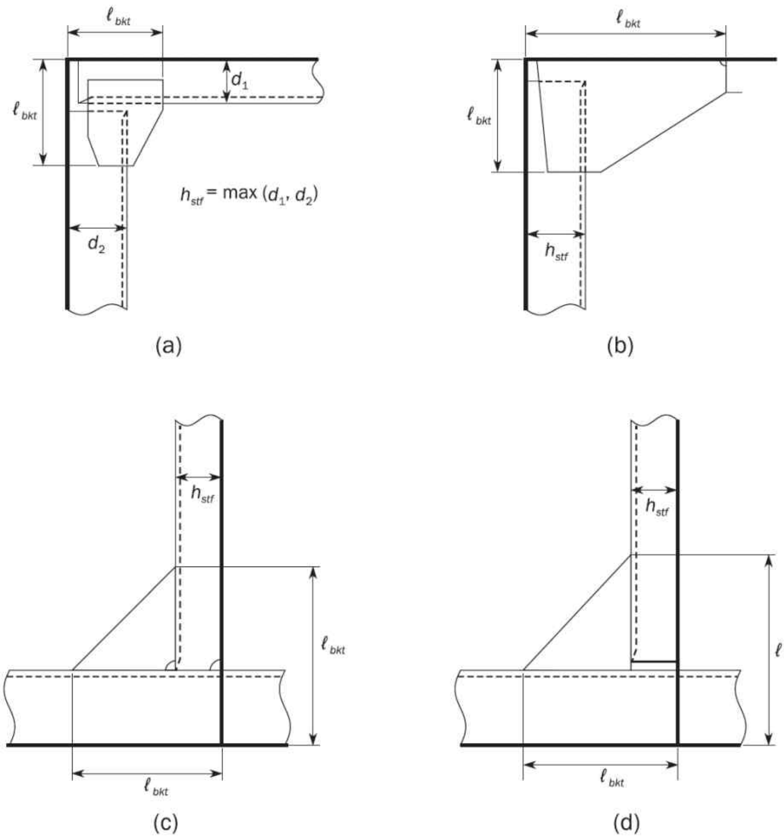


Figure 2 : Bracket arm length of non-continuous stiffeners

3.3 Bracketless connections

3.3.1

The design of bracketless connections is to be such as to provide adequate resistance to rotation and displacement of the connection.

3.4 Sniped ends

3.4.1

Sniped ends may be used where dynamic loads are small, provided the net thickness of plating supported by the stiffener, t_p in mm, is not less than:

$$t_p = c_1 \sqrt{(1000\,\ell - \frac{s}{2}) \frac{s\,P\,k}{10^6}}$$

where:

P : Design pressure for the stiffener for the design load set being considered, in $\mathrm{kN/m^2}$.

c_1 : Coefficient for the design load set being considered, to be taken as:

c_1 = 1.2	for acceptance criteria set AC-S.
c_1 = 1.0	for acceptance criteria set AC-SD, AC-A and AC-T.

In general, sniped stiffeners are not to be used on structures at the following locations:

- In the vicinity of engines and generators in the machinery space
- Propeller impulse zone in the stern area
- On the shell envelope under impact pressure

3.4.2

Bracket toes and sniped stiffeners ends are to be terminated close to the adjacent member. The distance is not to exceed 40 mm unless the bracket or member is supported by another member on the opposite side of the plating. Tapering of the sniped end is not to be more than 30 °, where it is not practical to comply with this requirement, alternative arrangements are specially considered. 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 15 mm.

4. Primary support members

4.1 General

4.1.1

Primary supporting members web stiffeners, tripping brackets and end brackets are to comply with **[4.2]** to **[4.4]**. Where the structural arrangement is such that these requirements cannot be complied with, adequate alternative arrangement has to be demonstrated by the designer.

4.2 Web stiffening arrangement

4.2.1

Web stiffeners arranged on primary supporting members are to be arranged in such a way that they ensure adequate strength.

4.3 Tripping bracket arrangement

4.3.1

Tripping brackets (see **Figure 3**) are generally to be fitted:

a) At every fourth spacing of ordinary stiffeners, with an interval of about 3 m.
b) At the toe of end brackets.
c) At ends of continuous curved face plates.
d) In way of concentrated loads.
e) Near the change of section.

4.3.2

Where the width of the symmetrical face plate is greater than 400 mm, backing brackets are to be fitted in way of the tripping brackets.

4.3.3

Where the face plate of the primary supporting member exceeds 180 mm on either side of the web, a tripping bracket is to support the face plate.

4.3.4 Arm length

The arm length of tripping brackets is not to be less than the greater of the following values, in m:

a) $d = 0.38\,b$

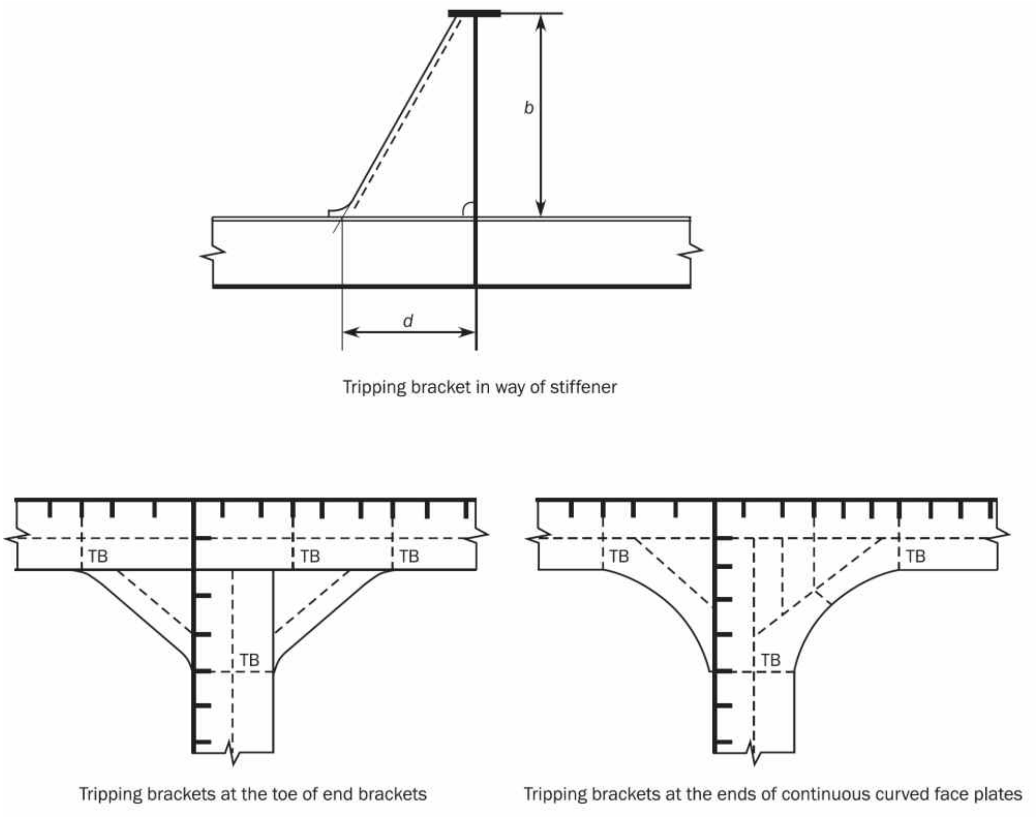
b) $d = 0.85\,b\sqrt{\dfrac{s_t}{t}}$

where:

b : Height, in m, of tripping brackets, shown in **Figure 3**.

s_t : Spacing, in m, of tripping brackets.

t : Net thickness, in mm, of tripping brackets.



Tripping bracket in way of stiffener

Tripping brackets at the toe of end brackets

Tripping brackets at the ends of continuous curved face plates

Figure 3 : Primary supporting member: Tripping bracket arrangement

4.4 Bracketed end connections

4.4.1 General

Brackets or equivalent structure are to be provided at ends of primary supporting members.

End brackets are generally to be soft-toed.

Bracketless connections may be applied provided that there is adequate support of adjoining face plates.

4.4.2 Scantling of end brackets

In general, the arm length of brackets connecting PSMs, as shown in **Figure 4**, is not to be less than the web depth of the member and need not be taken greater than 1.5 times this web depth.

The bracket thickness is, in general, not to be less than that of the adjoining PSM web plate.

The scantling of the end brackets is to be such that the section modulus of the primary supporting member with end bracket, excluding face plate where it is sniped, is not less than that of the primary supporting member at mid-span.

The net cross-sectional area, A_f in cm^2, of the bracket face plates is to be such that:

$A_f = \ell_b t_b$

where:

ℓ_b : Length of the bracket edge, in m, see **Figure 4**. For curved brackets, the length of the bracket edge may be taken as the length of the tangent at the midpoint of the edge.

t_b : Minimum net bracket web thickness, in mm, as defined in **[3.2.4].**

Moreover, the net thickness of the face plate is to be not less than that of the bracket web.

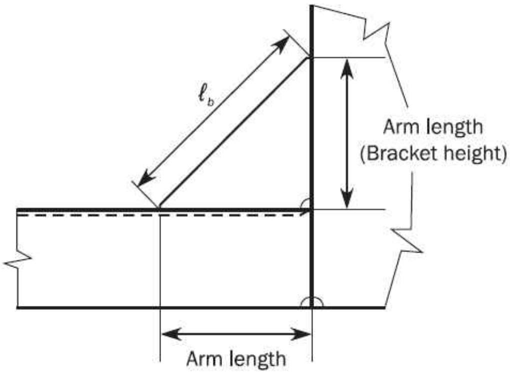


Figure 4 : Dimension of brackets

4.4.3 Arrangement of end brackets

Where the length of free edge of bracket, ℓ_b, is greater than 1.5 m, the web of the bracket is to be stiffened as follows:

a) The net sectional area, in cm^2, of web stiffeners is to be not less than 16.5 ℓ, where ℓ is the span, in m, of the stiffener.

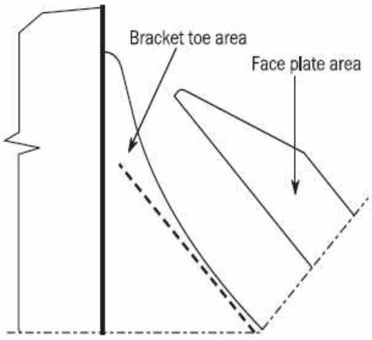
b) Tripping flat bars are to be fitted. Where the width of the symmetrical face plate is greater than 400 mm, additional backing brackets are to be fitted.

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 is to be maintained close to the mid-point of the bracket and gradually tapered to the smaller face plates. Butts in face plates are to be kept well clear of the bracket toes.

Where a wide face plate abuts a narrower one, the taper is not to be greater than 1 to 4.

The toes of brackets are not to land on unstiffened plating. The toe height is not to be greater than the thickness of the bracket toe, but need not be less than 15 mm. In general, the end brackets of primary supporting members are to be soft-toed. Where primary supporting members are constructed of higher strength steel, particular attention is to be paid to the design of the end bracket toes in order to minimise stress concentrations.

Where a face plate is welded onto the edge or welded adjacent to the edge of the end bracket (see **Figure 5**), the face plate is to be sniped and tapered at an angle not greater than 30 °.



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 5 : Bracket face plate adjacent to the edge

5. Intersection of stiffeners and primary supporting members

5.1 Cut-outs

5.1.1

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

5.1.2

The total depth of cut-outs without collar plate is to be not greater than 50 % of the depth of the primary supporting member.

5.1.3

Cut-outs in high stress areas are to be fitted with full collar plates, see **Figure 6**.

$R \geq 0.2\,b$ but not less than 25 mm.

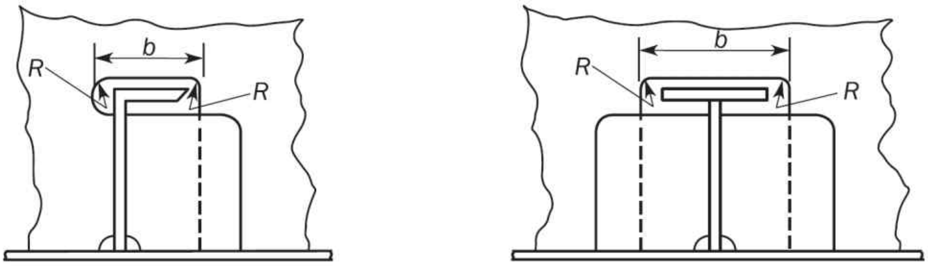
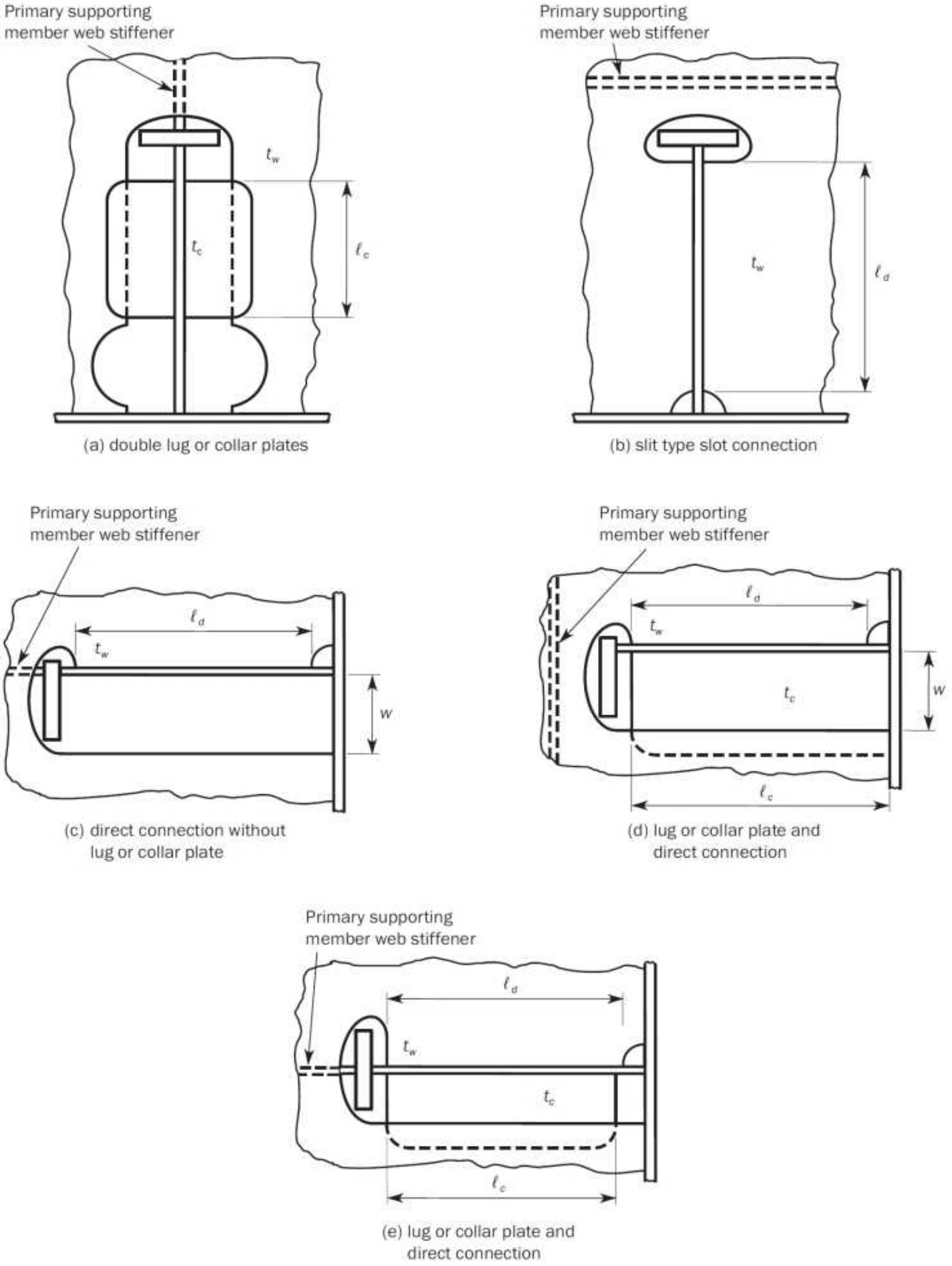


Figure 6 : Full collar plates

5.1.4

Lug type collar plates are to be fitted in cut-outs where required for compliance with the requirements of **[5.2]**, and in areas of high stress concentrations, e.g. in way of primary supporting member toes. See **Figure 7** for typical lug arrangements.



(a) double lug or collar plates

(b) slit type slot connection

(c) direct connection without lug or collar plate

(d) lug or collar plate and direct connection

(e) lug or collar plate and direct connection

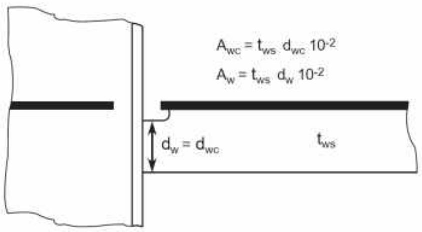
The details shown in this figure are only used to illustrate symbols and definitions and are not intended to represent design guidance.

Figure 7 : Symmetric and asymmetric cut-outs

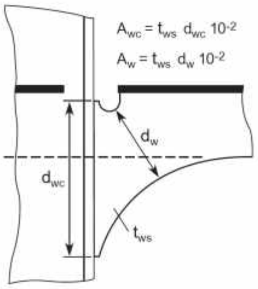
5.1.5

Cut-outs are to have rounded corners and the corner radii, R, are to be as large as practicable, with a minimum of 20 % of the breadth, b, of the cut-out or 25 mm, whichever is greater. The corner radii, R, does not need to be greater than 50 mm, see **Figure 6.** Consideration is to be given to other shapes on the basis of maintaining equivalent strength and minimising stress concentration.

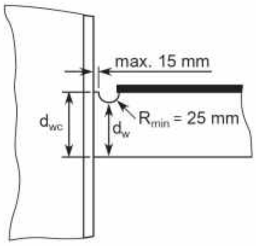
Note 1: Except where specific dimensions are noted for the details of the keyhole in way of the soft heel, the details shown in this figure are only used to illustrate symbols and definitions and are not intended to represent design guidance or recommendations.



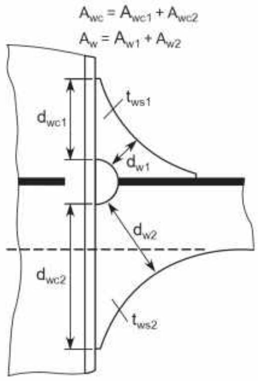
(a) Straight heel no bracket



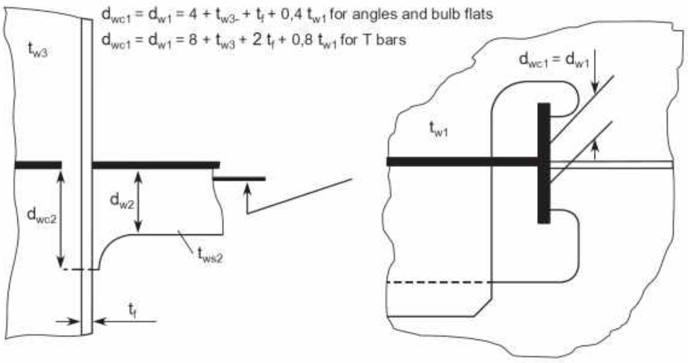
(b) Soft toe and soft heel



(c) Keyhole in way of soft heel



(d) Symmetrical soft toe brackets



(e) Primary supporting member web welded directly to stiffener flange

t_{ws}, t_{ws1}, t_{ws2} : Net thickness of the primary supporting member web stiffener / backing bracket, in mm.

d_w, d_{w1}, d_{w2} : Minimum depth of the primary supporting member web stiffener / backing bracket, in mm.

d_{wc}, d_{wc1}, d_{wc2} : Length of connection between the primary supporting member web stiffener / backing bracket and the stiffener, in mm.

t_f : Net thickness of the flange in mm. For bulb profile, t_f is to be obtained as defined in Sec 7 [1.4.1].

Figure 8 : Primary supporting member web stiffener details

5.2 Connection of stiffeners to PSM

5.2.1 General

For connection of stiffeners to PSM in case of lateral pressure, **[5.2.2]** and **[5.2.3]** are to be applied.

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

5.2.2

The load, W_1 in kN, transmitted through the shear connection is to be taken as follows.

a) If the web stiffener is connected to the intersecting stiffener:

$$W_1 = W\left(\alpha_a + \frac{A_1}{4\,f_c\,A_w + A_1}\right)$$

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

$$W_1 = W$$

where:

W : Total load, in kN, transmitted through the stiffener connection to the PSM taken equal to:

$$W = \frac{P_1\,s_1\left(S_1 - \frac{s_1}{2000}\right) + P_2\,s_2\left(S_2 - \frac{s_2}{2000}\right)}{2\,\sin\varphi_{w1}\,\sin\varphi_{w2}}\,10^{-3}$$

P_1, P_2 : Design pressure applied on the stiffener for the design load set being considered, in $\mathrm{kN/m^2}$, on each side of the considered connection. For bottom slamming or bow impact loads, P_1 and P_2 are 50 % of the design pressure as defined in **Ch 4, Sec 5, [3.2]**, **[3.3]** and **[3.4]** respectively.

S_1, S_2 : Spacing between the considered and the adjacent PSM on each side of the considered connection, in m.

s_1, s_2 : Spacing of the stiffener, in mm, on each side of the considered connection.

α_a : Panel aspect ratio, not to be taken greater than 0.25.

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

$$S = \frac{S_1 + S_2}{2}$$

$$s = \frac{s_1 + s_2}{2}$$

φ_{w1} : Angle between primary supporting member and attached plating, in $\deg$, as defined in **Ch 3, Sec 7, Symbols** and **Ch 10, Sec 1, Figure 5**.

φ_{w2} : Angle between stiffener and attached plating, in $\deg$, as defined in **Ch 3, Sec 7, Symbols** and **Ch 3, Sec 7, Figure 12**.

A_1 : Effective net shear area, in $\mathrm{cm^2}$, of the connection, to be taken equal to:

$$A_1 = A_{1d} + A_{1c}$$

In case of a slit type slot connections area, A_1, is given by:

$$A_1 = 2A_{1d}$$

In case of a typical double lug or collar plate connection area, A_1, is given by:

$$A_1 = 2A_{1c}$$

A_{1d} : Net shear connection area, in $\mathrm{cm^2}$, excluding lug or collar plate, as given by:

$$A_{1d} = \ell_d\,t_w\,10^{-2}$$

ℓ_d : Length of direct connection between stiffener and PSM web, in mm.

t_w : Net web thickness of the primary supporting member, in mm.

A_{1c} : Net shear connection area, in $\mathrm{cm^2}$, with lug or collar plate, given by:

$$A_{1c} = f_1\,\ell_c\,t_c\,10^{-2}$$

ℓ_c : Length of connection between lug or collar plate and PSM, in mm.

t_c : Net thickness of lug or collar plate, not to be taken greater than the net thickness of the adjacent PSM web, in mm.

f_1 : Shear stiffness coefficient, taken as:

$f_1 = 1.0$ for stiffeners of symmetrical cross section.

$f_1 = 140 / w$ not to be taken greater than 1.0, for stiffeners of asymmetrical cross section.

w : 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 7.**

A_w : Effective net cross sectional area, in cm^2, of the PSM web stiffener in way of the connection including backing bracket where fitted, as shown in **Figure 8.** If the PSM web stiffener incorporates a soft heel ending or soft heel and soft toe ending, A_w is to be measured at the throat of the connection, as shown in **Figure 8**.

f_c : Collar load factor taken equal to:

For intersecting stiffeners of symmetrical cross section:

$f_c = 1.85$ for $A_w \le 14$

$f_c = 1.85 - 0.0441(A_w - 14)$ for $14 < A_w \le 31$

$f_c = 1.1 - 0.013(A_w - 31)$ for $31 < A_w \le 58$

$f_c = 0.75$ for $A_w > 58$

For intersecting stiffeners of asymmetrical cross section:

$$f_c = 0.68 + 0.0172\frac{\ell_s}{A_w}$$

ℓ_s : Connection length equal to:

For a single lug or collar plate connection to the PSM:

$\ell_s = \ell_c$

For a single sided direct connection to the PSM:

$\ell_s = \ell_d$

In the case of a lug or collar plus a direct connection:

$\ell_s = 0.5(\ell_c + \ell_d)$

5.2.3

The load, W_2, in kN, transmitted through the PSM web stiffener is to be taken as:

- If the web stiffener is connected to the intersecting stiffener:

$$W_2 = W\left(1 - \alpha_a - \frac{A_1}{4 f_c A_W + A_1}\right)$$

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

W_2 = 0.0

The values of A_w, A_{wc} and A_1 are to be such that the calculated stresses satisfy the following criteria:

- For the connection to the PSM web stiffener not in way of the weld : $\sigma_w \le \sigma_{perm}$
- For the connection to the PSM web stiffener in way of the weld : $\sigma_{wc} \le \sigma_{perm}$
- For the shear connection to the PSM web : $\tau_w \le \tau_{perm}$

where:

W : Load, in kN, as defined in **[5.2.2].**

f_c : Collar load factor as defined in **[5.2.2].**

α_a : Panel aspect ratio, as defined in **[5.2.2].**

A_1 : Effective net shear area, in cm^2, as defined in **[5.2.2].**

A_w : Effective net cross sectional area, in cm^2, as defined in **[5.2.2].**

σ_w : Direct stress, in $\mathrm{N/mm^2}$, in the PSM web stiffener at the minimum bracket area away from the weld connection:

$$\sigma_w = \frac{10\,W_2}{A_w}$$

σ_{wc} : Direct stress, in $\mathrm{N/mm^2}$, in the PSM web stiffener in way of the weld connection:

$$\sigma_{wc} = \frac{10\,W_2}{A_{wc}}$$

τ_w : Shear stress, in $\mathrm{N/mm^2}$, in the shear connection to the PSM web:

$$\tau_w = \frac{10\,W_1}{A_1}$$

A_{wc} : Effective net area, in $\mathrm{cm^2}$, of the PSM web stiffener in way of the weld as shown in **Figure 8**.

σ_{perm} : Permissible direct stress given in **Table 1** for AC-S, AC-SD, AC-I, AC-A and AC-T, in $\mathrm{N/mm^2}$.

τ_{perm} : Permissible shear stress given in **Table 1** for AC-S, AC-SD, AC-I, AC-A and AC-T, in $\mathrm{N/mm^2}$.

Table 1 : Permissible stresses for connection between stiffeners and PSMs

Item	Direct stress, σ_{perm}, in $\mathrm{N/mm^2}$			shear stress, τ_{perm}, in $\mathrm{N/mm^2}$		
	Acceptance criteria set			Acceptance criteria set		
	AC-S	AC-SD	AC-I AC-A AC-T	AC-S	AC-SD	AC-I AC-A AC-T
PSM web stiffener	$0.83R_{eH}{}^{(2)}$	R_{eH}	R_{eH}	-	-	-
PSM web stiffener to intersecting stiffener in way of weld connection: • Double continuous fillet • Partial penetration weld	$0.58R_{eH}{}^{(2)}$ $0.83R_{eH}{}^{(1)(2)}$	$0.70R_{eH}{}^{(2)}$ $R_{eH}{}^{(1)}$	R_{eH} R_{eH}	- -	- -	- -
PSM stiffener to intersecting stiffener in way of lapped welding	$0.50R_{eH}$	$0.60R_{eH}$	R_{eH}	-	-	-
Shear connection including lugs or collar plates: • Single sided connection • Double sided connection	- -	- -	- -	$0.71\tau_{eH}$ $0.83\tau_{eH}$	$0.85\tau_{eH}$ τ_{eH}	τ_{eH} τ_{eH}

(1) The root face is not to be greater than one third of the gross thickness of the PSM stiffener.
(2) Permissible stresses may be increased by 5 % where a soft heel is provided in way of the heel of the PSM web stiffener.

5.2.4

Where a backing bracket is fitted in addition to the PSM web stiffener, it is to be aligned with the web stiffener. The arm length of the backing bracket is not to be less than the depth of the web stiffener. The net cross sectional area through the throat of the bracket is to be included in the calculation of A_w as shown in **Figure 8.**

5.2.5

Lapped connections of PSM web stiffeners or tripping brackets to stiffeners are not permitted in the cargo hold region.

5.2.6

Where built-up stiffeners have their face plate welded to the side of the web, a symmetrical arrangement of connection to the PSM is to be fitted. This may be achieved by fitting backing brackets on the opposite side of the PSM or bulkhead. In way of the cargo hold region, the PSM web stiffener and backing brackets are to be butt welded to the intersecting stiffener web.

5.2.7

Where the web stiffener of the PSM is parallel to the web of the intersecting stiffener, but not connected to it, the offset PSM web stiffener is to be located in close proximity to the slot edge as shown in **Figure 9.** The ends of the offset web stiffeners are to be suitably tapered and softened.

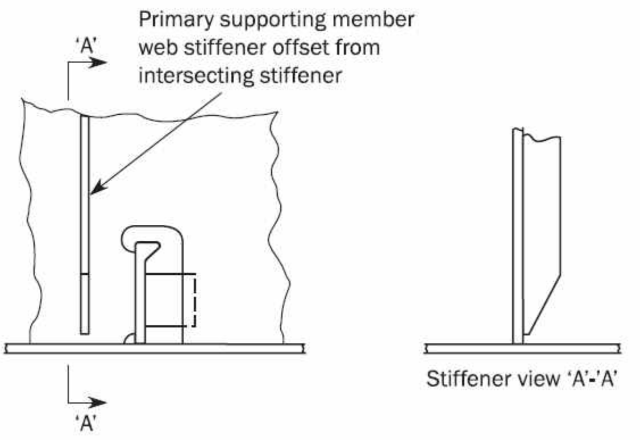


Figure 9 : Offset PSM web stiffeners

5.2.8

The size of the fillet welds is to be calculated according to **Ch 12, Sec 3, [2.5]** based on the weld factors given in **Table 2.** For the welding in way of the shear connection the size is not to be less than that required for the PSM web plate for the location under consideration.

Table 2 : Weld factors for connection between stiffeners and PSMs

Item	Weld factor
PSM stiffener to intersecting stiffener	0.6 $\sigma_{wc} / \sigma_{perm}$
Shear connection inclusive of lug or collar plate, including the web stiffener of the PSM is not connected to the intersection stiffener	0.6 τ_w / τ_{perm}

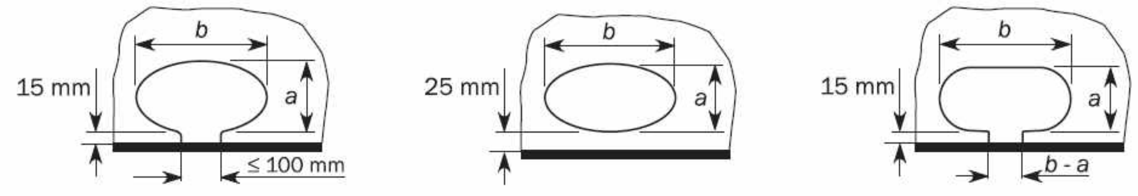
τ_w : Shear stress, in $\mathrm{N/mm^2}$, as defined in **[5.2.3]**.
σ_{wc} : Stress, in $\mathrm{N/mm^2}$, as defined in **[5.2.3].**
τ_{perm} : Permissible shear stress, in $\mathrm{N/mm^2}$, see **Table 1.**
σ_{perm} : Permissible direct stress, in $\mathrm{N/mm^2}$, see **Table 1.**
W : Load, in kN, as defined in **[5.2.2].**
A_1 : Effective net shear area, in $\mathrm{cm^2}$, as defined in **[5.2.2].**
A_w : Effective net cross sectional area, in $\mathrm{cm^2}$, as defined in **[5.2.2].**

6. Openings

6.1 Openings and scallops in stiffeners

6.1.1

Figure 10 shows examples of air holes, drain holes and scallops. In general, the ratio of a/b, as defined in **Figure 10**, 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.



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

Figure 10 : Examples of air holes, drain holes and scallops

6.1.2

Openings and scallops are to be kept at least 200 mm 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 50 mm measured along the length in the opposite direction, see **Figure 11**. In areas where the shear stress is less than 60 % of the permissible stress, alternative arrangements may be accepted.

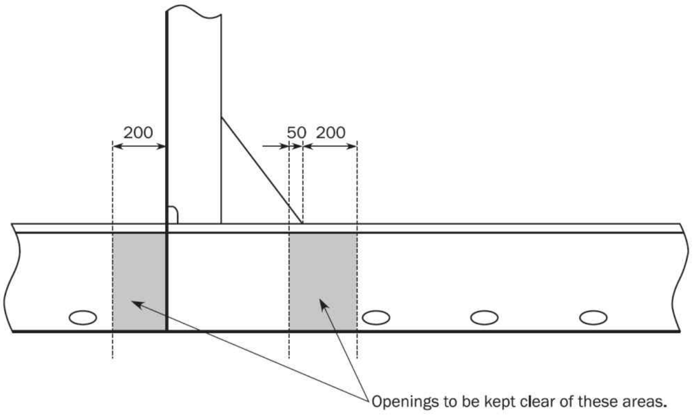


Figure 11 : Location of air and drain holes

6.1.3

Closely spaced scallops or drain holes, i.e. where the distance between scallops / drain holes is less than twice the width b as shown in **Figure 10,** are not permitted in stiffeners contributing to the longitudinal strength.

For other stiffeners, closely spaced scallops / drain holes are not permitted within 20 % of the stiffener span measured from the end of the stiffener. Widely spaced air or drain holes may be permitted provided that they are of elliptical shape or equivalent to minimise stress concentration and are cut clear of the welds.

6.2 Openings in primary supporting members

6.2.1 General

Manholes, lightening holes and other similar openings are to be avoided in way of concentrated loads and areas of high shear. In particular, 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) Floors or double bottom girders close to their span ends.

b) Primary supporting member webs in way of end bracket toes.

c) Above the heads and below the heels of pillars.

Where openings are arranged, the shape of openings is to be such that the stress concentration remains within acceptable limits. Openings are to be well rounded with smooth edges.

6.2.2 Manholes and lightening holes

Web openings as indicated below do not require reinforcement

- In single skin sections, having depth not exceeding 25 % of the web depth and located so that the edges are not less than 40 % of the web depth from the face plate.
- In double skin sections, having depth not exceeding 50 % of the web depth and located so that the edges are well clear of cut outs for the passage of stiffeners.

The length of openings is not to be greater than:

- At the mid-span of primary supporting members : the distance between adjacent openings.
- At the ends of the span : 25 % of the distance between adjacent openings.

For openings cut in single skin sections, the length of opening is not to be greater than the web depth or 60 % of the stiffener spacing, whichever is greater.

The ends of the openings are to be equidistant from the cut outs for stiffeners.

Where lightening holes are cut in the brackets, the distance from the circumference of the hole to the free flange of brackets is not to be less than the diameter of the lightening hole.

Openings not complying with this requirement are to be reinforced according to **[6.2.3].**

6.2.3 Reinforcements around openings

Manholes and lightening holes are to be stiffened according to this requirement, except where alternative arrangements are demonstrated as satisfactory, in accordance with the analysis methods described in **Ch 7**.

On members contributing to longitudinal strength, stiffeners are to be fitted along the free edges of the openings parallel to the vertical and horizontal axis of the opening. Stiffeners may be omitted in one direction if the shortest axis is less than 400 mm and in both directions if length of both axes is less than 300 mm. Edge reinforcement may be used as an alternative to stiffeners, see **Figure 12**.

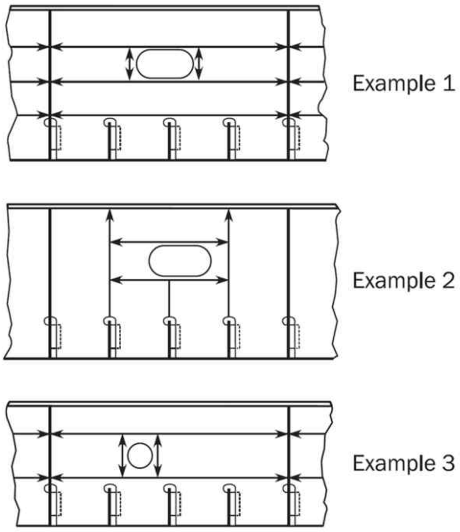


Figure 12 : Web plate with openings

In the case of large openings in the web of PSMs (e.g. where a pipe tunnel is fitted in the double bottom), the secondary stresses in PSMs are to be considered for the reinforcement of these openings.

Where no FE analysis is performed, this may be carried out by assigning an equivalent net shear sectional area to the PSM obtained, in cm^2, according from the following formula:

$$A_{s-n50} = \frac{A_{1-n50}}{1+\dfrac{32\,\ell_{shr}^2\,A_{1-n50}}{I_{1-n50}}} + \frac{A_{2-n50}}{1+\dfrac{32\,\ell_{shr}^2\,A_{2-n50}}{I_{2-n50}}}$$

where:

I_{1-n50}, I_{2-n50} : Net moments of inertia, in cm^4, of deep webs (1) and (2), respectively, with attached plating around their neutral axes parallel to the plating.

A_{1-n50}, A_{2-n50} : Net shear sectional areas, in cm^2, of deep webs (1) and (2), respectively, taking account of the web height reduction by the depth of the cut out for the passage of the ordinary stiffeners, if any.

ℓ_{shr} : Shear span, in m, of deep webs (1) and (2) as defined in **Ch 3, Sec 7, [1.1.2].**

Deep web (1) and (2) are defined in **Figure 13.**

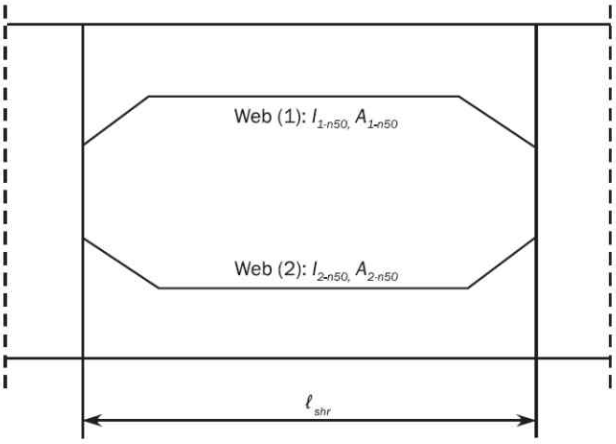


Figure 13 : Large openings in the web of primary supporting members

6.3 Openings in the strength deck

6.3.1 General

Openings in the strength deck are to be kept to a minimum and spaced as far as practicable from one another and from the ends of superstructures. Openings are to be located as far as practicable from high stress regions such as side shell platings, hatchway corners, or hatch side coamings.

6.3.2 Small opening location

Openings are generally to be located outside the limits as shown in **Figure 14** in dashed area, defined by:

a) The bent area of a rounded sheer strake, if any, or the side shell.

b) $e = 0.25(B - b)$ from the edge of opening.

c) $c = 0.074\ell + 0.1b$ or $0.25b$, whichever is greater.

where:

b : Width, in m, of the hatchway considered, measured in the transverse direction, see **Figure 14.**

ℓ : Width, in m, in way of the corner considered, of the cross deck strip between two consecutive hatchways, measured in the longitudinal direction, see **Figure 14.**

Transverse distance between the above limits and openings or between hatchways and openings as shown in **Figure 14** is not to be less than:

- $g_2 = 2a_2$ for circular openings
- $g_1 = a_1$ for elliptical openings

Transverse distance between openings as shown in **Figure 15** is not to be less than:

- $2(a_1 + a_2)$ for circular openings
- $1.5(a_1 + a_2)$ for elliptical openings

where:

a_1 : Transverse dimension of elliptical openings, or diameter of circular openings.

a_2 : Transverse dimension of elliptical openings, or diameter of circular openings.

a_3 : Longitudinal dimension of elliptical openings, or diameter of circular openings.

Longitudinal distance between openings is not to be less than:

- $(a_1 + a_3)$ for circular openings.
- $0.75(a_1 + a_3)$ for elliptical openings and for an elliptical opening in line with a circular one.

If the opening arrangements do not comply with these requirements, the hull girder longitudinal strength assessment is to be carried out by subtracting such opening areas, see **Ch 5, Sec 1, [1.2.11].**

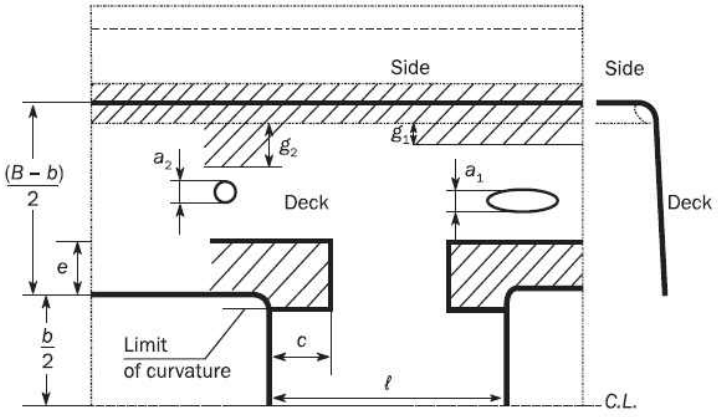


Figure 14 : Position of openings in strength deck

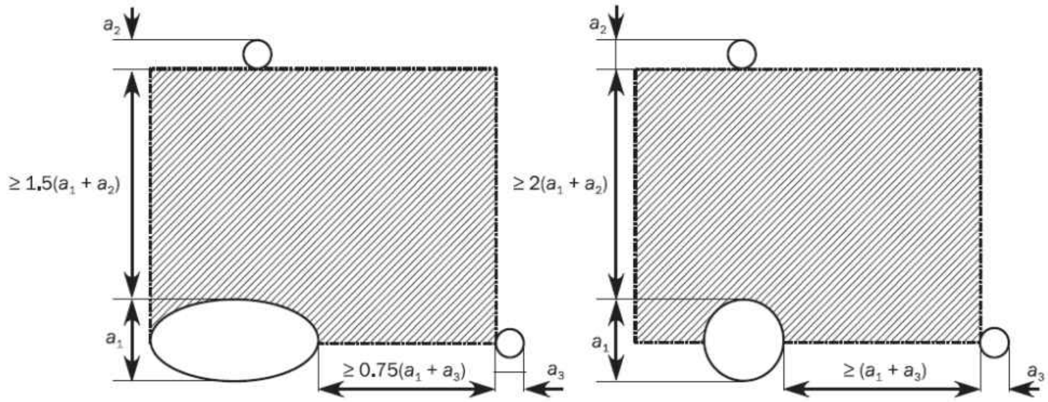


Figure 15 : Elliptical and circular openings in strength deck

7. Double bottom structure

7.1 General

7.1.1 Framing system

For ships greater than 120 m in length, the bottom shell and the inner bottom are to be longitudinally framed within the cargo hold region. Where it is not practicable to apply the longitudinal framing system to fore and aft parts of the cargo hold region due to the hull form, transverse framing may be accepted on a case-by-case basis subject to appropriate brackets and other arrangements being incorporated to provide structural continuity in way of changes to the framing system.

7.1.2 Variation in height of double bottom

Any variation in the height of the double bottom is to be made gradually and over an adequate length; the knuckles of inner bottom plating are to be located in way of plate floors. Where such arrangement is not possible, suitable longitudinal structures such as partial girders, longitudinal brackets, fitted across the knuckle are to be arranged.

7.1.3 Breadth of inner bottom

Breadth of inner bottom, in m, is to be measured at mid-length of the cargo hold as shown in **Figure 16.**

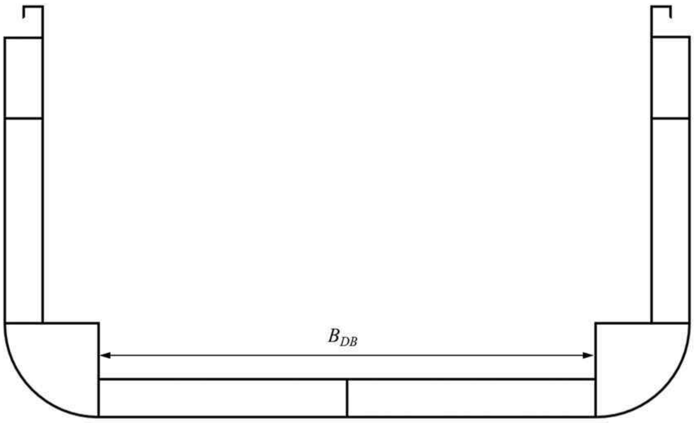


Figure 16 : Breadth of inner bottom

7.1.4 Drainage of tank top

Where wells are provided for the drainage, such wells are not to extend for more than one-half height of the double bottom. The vertical distance from the bottom of such a well to a plane coinciding with the keel line shall not be less 500 mm.

7.1.5 Cell guides

The structure of the bottom and inner bottom on which cell guides rest is to be adequately stiffened with doublers, brackets or other equivalent reinforcements.

7.1.6 Duct keel

Where a duct keel is arranged, the centre girder may be replaced by two girders spaced, no more than 3 m apart. Otherwise, for a spacing wider than 3 m, the two girders are to be provided with support of adjacent structure and subject to the Society's approval. The structures in way of the floors are to provide sufficient continuity of the latter.

7.2 Keel plate

7.2.1

Keel plating is to extend over the flat of bottom for the full length of the ship.

The width of the keel, in m, is not to be less than $0.8 + L/200$, without being taken greater than 2.3 m.

7.3 Girders

7.3.1 Centre girder

When fitted, the centre girder is to extend within the cargo hold region and is to extend forward and aft as far as practicable. Structural continuity of the centre girder is to be maintained within the full length of the ship.

Where double bottom compartments are used for the carriage of fuel oil, fresh water or ballast water, the centre girder is to be watertight, except for the case such as narrow tanks at the end parts or when other watertight girders are provided within $0.25\,B$ from the centreline.

7.3.2 Side girders

The side girders are to extend within the parallel part of the cargo hold region and are to extend forward and aft of the cargo hold region as far as practicable.

7.4 Floors

7.4.1 Web stiffeners

Floors are to be provided with web stiffeners in way of longitudinal ordinary stiffeners. Where the web stiffeners are not welded to the longitudinal stiffeners, design standard as given in **Ch 9, Sec 6, [2]** applies unless fatigue strength assessment for the cut out and connection of longitudinal stiffener is carried out.

7.5 Bilge keel

7.5.1 Material

The material of the bilge keel and ground bar is to be of the same yield stress as the material to which they are attached.

In addition, when the bilge keel extends over a length more than $0.15\,L$, the material of the bilge keel and ground bar is to be of the same grade as the material to which they are attached.

7.5.2 Design

The design of single web bilge keels is to be such that failure to the web occurs before failure of the ground bar. This may be achieved by ensuring the web thickness of the bilge keel does not exceed that of the ground bar.

Bilge keels of a different design, from that shown in **Figure 17**, are to be specially considered by the Society.

7.5.3 Ground bars

Bilge keels are not to be welded directly to the shell plating. A ground bar, or doubler, is to be fitted on the shell plating as shown in **Figure 17** and **Figure 18.** In general, the ground bar is to be continuous.

The gross thickness of the ground bar is not to be less than the gross thickness of the bilge plating or 14.0 mm, whichever is the lesser.

7.5.4 End details

The ground bar and bilge keel ends are to be tapered or rounded. Tapering is to be gradual with a minimum ratio of 3:1, see items (a), (b), (d) and (e) in **Figure 18 / Figure 19.** Rounded ends are to be as shown in item (c) of **Figure 18.** Cut-outs on the bilge keel web, within zone ‘A’ (see items (b) and (e) of **Figure 18 / Figure 19**) are not permitted.

The end of the bilge keel web is to be not less than 50 mm and not greater than 100 mm from the end of the ground bar, see items (a) and (d) of **Figure 18 / Figure 19.**

Ends of the bilge keel and ground bar are to be supported by either transverse or longitudinal members inside the hull, as indicated as follows:

a) Transverse support member is to be fitted at mid length between the end of the bilge keel web and the end of the ground bar, see items (a), (b) and (c) of **Figure 18**.
b) Longitudinal stiffener is to be fitted in line with the bilge keel web, it is to extend to at least the nearest transverse member forward and aft of zone ’A’ (see items (b) and (e) of **Figure 18 / Figure 19**).

Alternative end arrangements may be accepted, provided that they are considered equivalent.

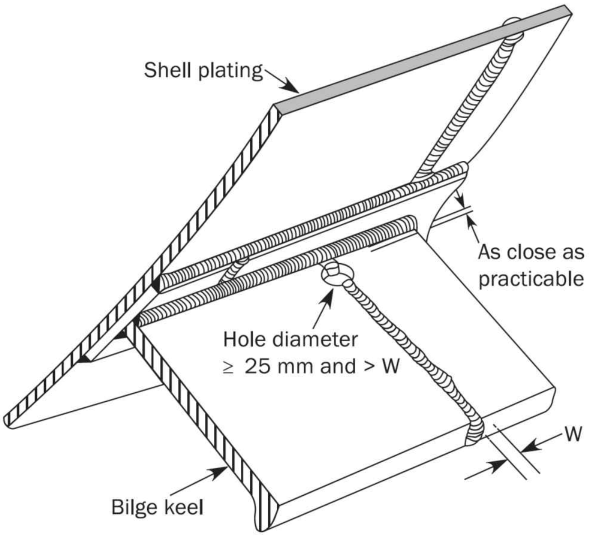


Figure 17 : Bilge keel construction

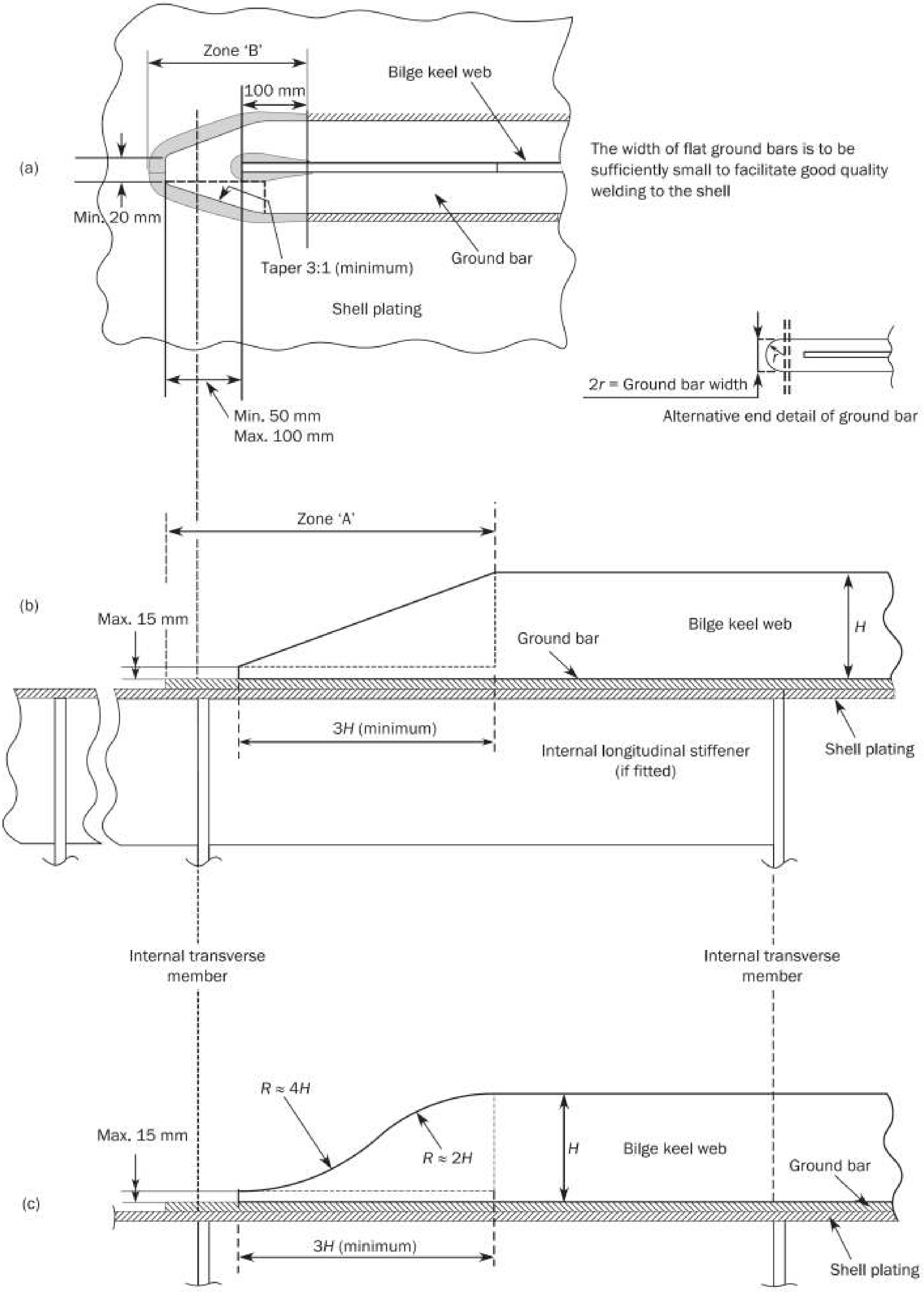


Figure 18 : Bilge keel end design (continued)

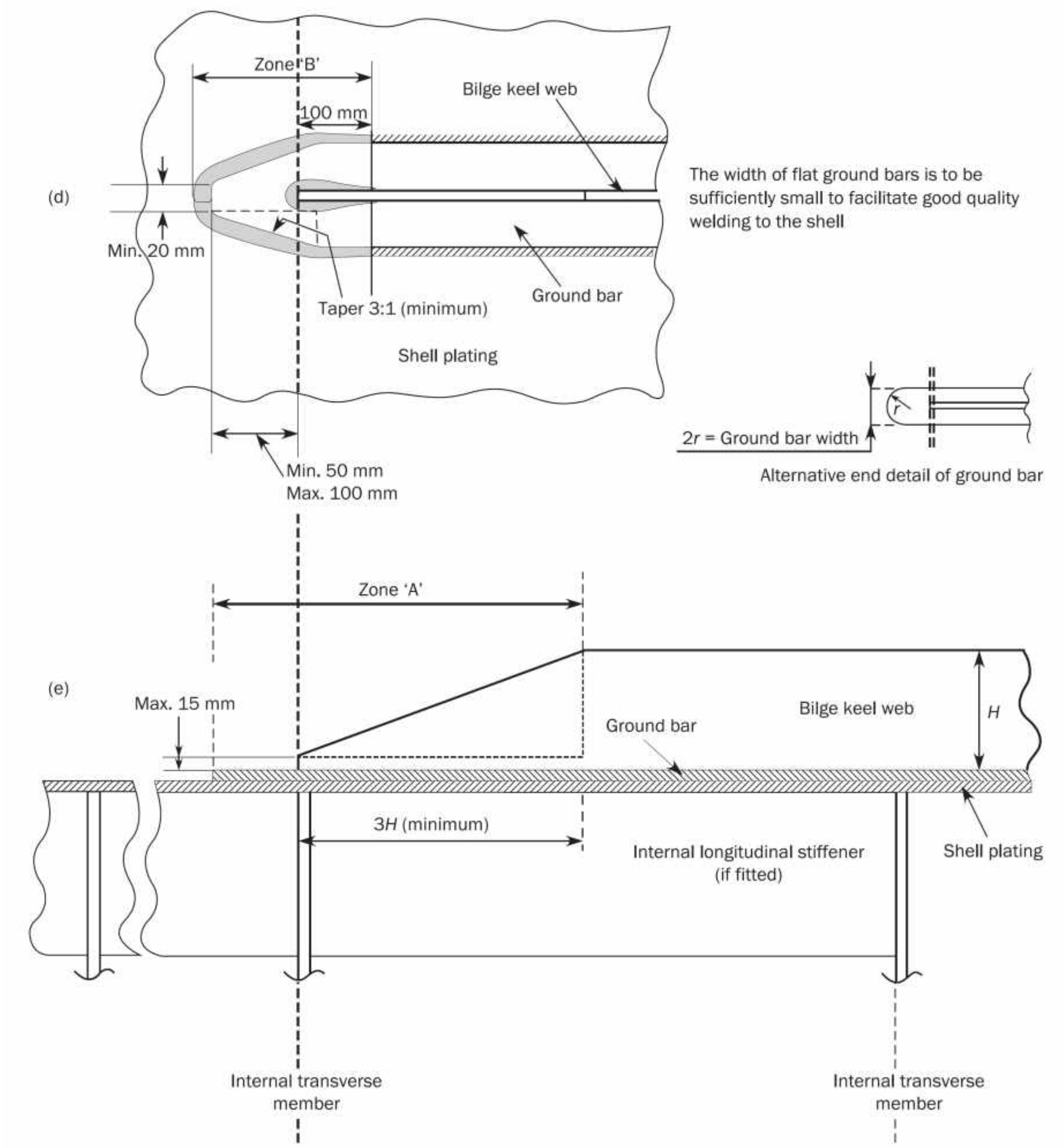


Figure 19 : Bilge keel end design (continued)

7.6 Docking

7.6.1 General

The drydocking arrangement itself is not covered in these Rules.

The bottom structure is to withstand the forces imposed by drydocking the ship.

7.6.2 Docking brackets

Docking brackets connecting the centreline girder to the bottom plating, are to be connected to the adjacent bottom longitudinals.

8. Double side sturcture

8.1 General

8.1.1

Side shell and inner hull are generally to be longitudinally framed. Where the side shell is longitudinally framed, the inner hull bulkheads are to be longitudinally framed.

8.2 Structural arrangement

8.2.1 Primary supporting members

Side web frames are to be fitted in line with the bottom web frames. Alternative framing arrangements may be considered by the Society on a case by case basis.

8.2.2 Longitudinal stiffeners

The longitudinal stiffeners on side shell and inner hull, where fitted, are to be continuous within the length of the parallel part of the cargo hold region. They are to be effectively connected to the transverse web frames and bulkheads of the double side structure.

Longitudinal framing of the side shell is to extend outside the cargo hold region, as far forward as practicable.

8.2.3 Transverse stiffeners

The transverse stiffeners on side shell and inner hull, where fitted, are to be continuous or fitted with bracket end connections. At their upper and lower ends, the shell and inner hull transverse stiffeners are to be connected by brackets to the supporting stringer plates.

8.2.4 Sheer strake

Sheer strakes are to have breadths, in m, not less than $0.8 + L/200$, measured vertically, but need not be greater than $1.8\,\mathrm{m}$. The sheer strake may be either welded to the stringer plate or rounded. If the sheer strake is rounded, its radius, in mm, is to be not less than $17\,t_s$, where t_s is the net thickness, in mm, of the sheer strake.

The upper edge of the welded sheer strake is to be rounded, smooth and free of notches. Fixtures, such as bulwarks and eye plates, are not to be directly welded on the upper edge of the sheer strake, except in fore and aft parts. Drainage openings with a smooth transition in the longitudinal direction may be permitted.

Longitudinal seam welds of rounded sheer strake are to be located outside the bent area at a distance not less than 5 times the maximum net thickness of the sheer strake.

The welding of deck fittings to rounded sheer strakes is to be avoided within $0.6\,L$ amidships.

The transition from a rounded sheer strake to an angled sheer strake associated with the arrangement of superstructures is to be designed to avoid any discontinuities.

9. Deck structure

9.1 Structural arrangement

9.1.1 Framing system

Deck areas contributing to the longitudinal strength are to be longitudinally framed.

9.1.2 Stringer plate

Stringer plates are to have breadths not less than $0.8+L/200\ \mathrm{m}$, measured parallel to the deck, but need not be greater than 1.8 m.

Rounded stringer plates, where adopted, are to comply with the requirements in **[8.2.4].**

9.1.3 Connection of deckhouses and superstructures

Connection of deckhouses and superstructures to the strength deck are to be designed such that loads are transmitted into the under deck supporting structure.

9.1.4 Longitudinal hatch coaming

The width of the longitudinal hatch coaming flanges is to be such as to accommodate the hatch covers and their securing arrangements. The end connections of the longitudinal hatch coamings are to ensure a proper transmission of stresses from the hatch coaming to the supporting structure.

9.2 Deck scantlings

9.2.1 Deck and hatch cover reinforcements

The deck and hatch cover structures are to be reinforced taking into account the loads transmitted by the container corners and cell guides.

9.2.2 Hatch corners

The stress concentrations in way of the hatch corners are to be checked, in particular in the top part (hatch coaming, upper deck and stringers under deck).

9.2.3 Hatch corner curvature radii

The hatch corner curvature radius, r in mm, as shown in **Figure 20** is not to be taken less than:

$r = C_{\sec}\, C_{thick}\, C_{material}\, C_{L2}\, C_{location}\, 10^3$ with $r \geq r_{\min}$

where:

$r_{\min}$: Minimum curvature radius of hatch corner

$r_{\min} = 250$ for $0.25 \leq x/L \leq 0.75$

$r_{\min} = 200$ for other cases

$C_{\sec}$: Coefficient of section property in longitudinal direction

$$C_{\sec} = \frac{M_{sw} + M_{wv}}{Z_{deck}\,\dfrac{235}{1.24k}\,10^3} \bullet \frac{1}{C_{dis}}$$

M_{sw} : Permissible hogging and sagging vertical still water bending moment in seagoing operation, in kNm, at the hull transverse section considered,

M_{wv} : Vertical wave bending moment in seagoing condition, in kNm, in seagoing operation at the hull transverse section considered

Z_{deck} : Section modulus at strength deck, in m^3

C_{dis} : Correction factor in longitudinal direction

$C_{dis} = 0.5$ for $x/L = 0.0$

$C_{dis} = 1.0$ for $0.25 \leq x/L \leq 0.75$

$C_{dis} = 0.5$ for $x/L = 1.0$

Intermediate values are obtained by linear interpolation.

C_{thick} : Correction factor for plate thickness effect

$$C_{thick} = \frac{t_{deck}}{t_{insert}} \quad \text{with } 0.667 \le C_{thick} \le 1.0$$

t_{deck} : Gross thickness of the strength deck plate, in mm, see **Figure 20**

t_{insert} : Gross thickness of the insert plate, in mm, see **Figure 20**

$C_{material}$: Correction factor of material

$$C_{material} = \sqrt{\frac{R_{eH-deck}}{R_{eH-insert}}}$$

$R_{eH-deck}$: Specified minimum yield stress of strength deck plate, in $\mathrm{N/mm^2}$

$R_{eH-insert}$: Specified minimum yield stress of insert plate, in $\mathrm{N/mm^2}$

C_{L2} : Correction factor along the ship length

$$C_{L2} = \sqrt{\frac{\mathrm{L}_2}{2000}}$$

$C_{location}$: Correction factor of hatch corner location

$$C_{location} = 1.0 + \frac{\sqrt{b_{hatch}}}{\ell_{hatch}}$$

b_{hatch} : Breadth of hatch opening at considered location, in m

ℓ_{hatch} : Length of hatch opening at considered location, in m

The size of insert plates, in mm, at hatch corner as defined in **Figure 20** is not to be taken less than:

$a \ge a_{\min}$

$b \ge b_{\min}$

where:

$a_{\min}$= 350

$b_{\min}$: End of curvature radius of hatch corner(R.E.) + 100 mm

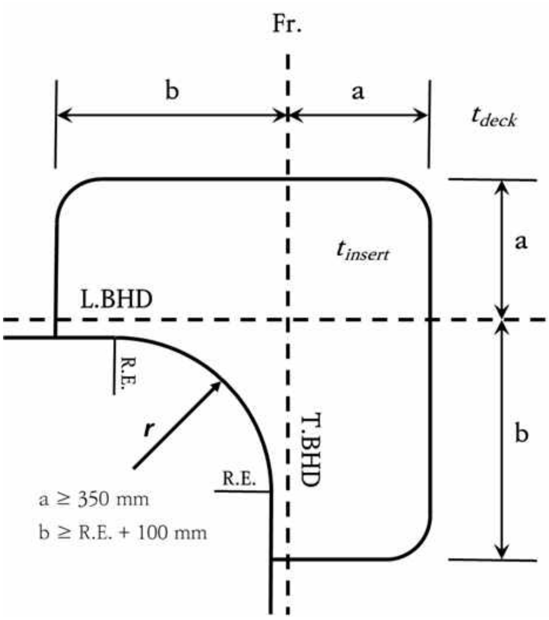


Figure 20 : Curvature radius of hatch corner

10. Bulkhead structure

10.1 Application

10.1.1

The requirements of this article apply to longitudinal and transverse bulkheads.

10.2 Cargo hold bulkheads

10.2.1 General

Watertight transverse bulkheads are to be fitted in line with a double bottom floor.

10.2.2 Primary supporting members

The vertical primary supporting members of the transverse bulkheads are to be fitted in line with bottom girders. Their flanges are to be in line with a double bottom floor.

The strength of the connection between these members and the bottom structure is to be assessed.

10.2.3 Reinforcements in way of cell guides

When cell guides are fitted on transverse or longitudinal bulkheads which form boundaries of the hold, such structures are to be reinforced, taking into account the loads transmitted by the cell guides.

10.3 Plane bulkheads

10.3.1 General

Plane bulkheads may be horizontally or vertically stiffened. The horizontally framed bulkheads are made of horizontal stiffeners supported by vertical primary supporting members. The vertically framed bulkheads are made of vertical stiffeners supported by horizontal stringers, if needed.

10.3.2 End connection of stiffeners

The crossing of stiffeners through a watertight bulkhead is to be watertight. End connections of stiffeners are to be bracketed. For isolated areas where bracketed end connections cannot be applied due to hull lines, other arrangements including sniped ends are acceptable.

Sniped ends may be used for stiffeners on bulkheads subject to hydrostatic pressure, provided they comply with **[3.4]**.

10.4 Corrugated bulkheads

10.4.1 Construction

The main dimensions b_{f-cg}, R, b_{w-cg}, d_{cg}, t_f, t_w, s_{cg} of corrugated bulkheads are defined in **Figure 21**.

The corrugation angle φ is not to be less than 55°.

When welds in a direction parallel to the bend axis are provided in the zone of the bend, the welding procedures are to be submitted to the Society for approval.

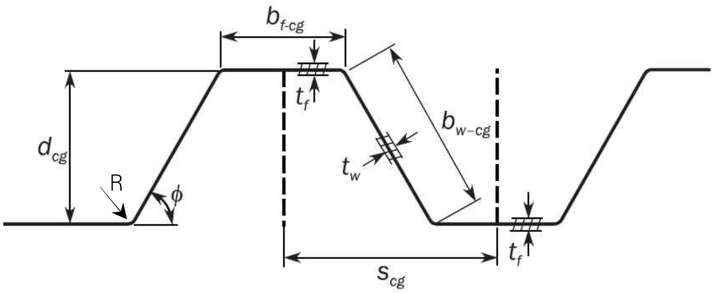


Figure 21 : Dimensions of a corrugated bulkhead

10.4.2 Corrugated bulkhead depth

The depth of the corrugation, d_{cg}, in mm, is not to be less than:

$$d_{cg} = \frac{1000\ell_c}{C}$$

where:

ℓ_c : Mean span of considered corrugation, in m, as defined in **[10.4.4]**.

C : Coefficient to be taken as:

C = 15

10.4.3 Actual section modulus of corrugations

The net section modulus of a corrugation may be obtained, in cm^3, from the following formula:

$$Z = \left[\frac{d_{cg}(3b_{f-cg}t_f + b_{w-cg}t_w)}{6}\right]10^{-3}$$

where:

t_f, t_w : Net thickness of the plating of the corrugation, in mm, shown in **Figure 21**.

d_{cg}, b_{f-cg}, b_{w-cg} : Dimensions of the corrugation, in mm, shown in **Figure 21**.

Where the web continuity is not ensured at ends of the bulkhead, the net section modulus of a corrugation is to be obtained, in cm^3, from the following formula:

$$Z = 0.5b_{f-cg}t_f\,d_{cg}\,10^{-3}$$

10.4.4 Span of corrugations

The span ℓ_c of the corrugations is to be taken as the distance shown in **Figure 22**.

For the definition of ℓ_c, the bottom of the upper stool is not to be taken more than a distance from the deck at the centre line equal to:

- 3 times the depth of corrugation, for non rectangular stool.
- 2 times the depth of corrugation, for rectangular stool.

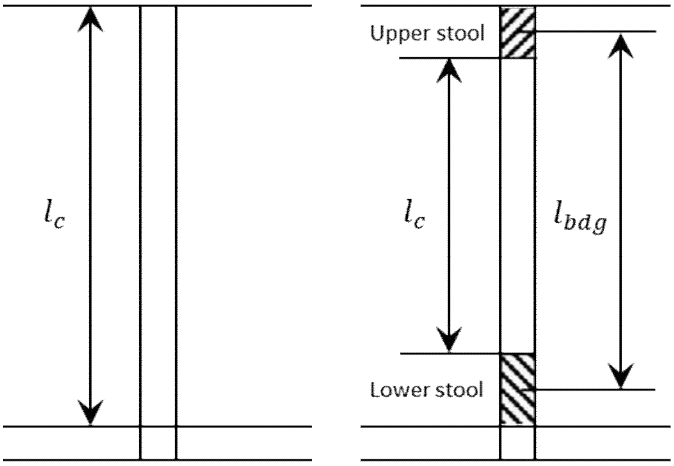


Figure 22 : Span of the corrugations

10.4.5 Structural arrangements

Where corrugated bulkheads are cut in way of primary supporting members, corrugations on each side of the primary member are to be aligned with each other.

10.4.6 Bulkhead end supports

The strength continuity of corrugated bulkheads is to be maintained at the ends of corrugations.

Where a bulkhead is provided with a lower stool, floors or girders are to be fitted in line with both sides of the lower stool. Where a bulkhead is not provided with a lower stool, floors or girders are to be fitted in line with both flanges of the vertically corrugated transverse bulkhead.

The supporting floors or girders are to be connected to each other by suitably designed shear plates.

At deck, if no upper stool is fitted, transverse or longitudinal stiffeners are to be fitted in line with the corrugation flanges.

When the corrugation flange connected to the adjoining boundary structures (i.e. inner hull, side shell, longitudinal bulkhead, trunk, etc) is smaller than 50% of the width of the typical corrugation flange, an advanced analysis of the connection is required.

10.5 Watertight bulkheads of trunks and tunnels

10.5.1

Watertight bulkheads of trunks, tunnels, duct keels and ventilators are to be of the same strength as watertight bulkheads at corresponding levels. The means used for making them watertight, and the arrangements adopted for closing their openings, are to be to the satisfaction of the Society.

11. Pillars

11.1 General

11.1.1

Wherever possible, pillars are to be fitted in the same vertical line. If not possible, effective means are to be provided for transmitting the pillar loads to the supports below. Effective arrangements are to be made to distribute the loads at the heads and the heels of all the pillars. Where pillars support eccentric loads, they are to be strengthened to withstand the additional bending moment applied on them.

11.1.2

Pillars are to be provided in line with the double bottom girders or as close thereto as practicable, and the structure above and below the pillars is to be of sufficient strength to provide effective distribution of the load.

Where pillars connected to the inner bottom are not located in way of the intersection of floors and girders, partial floors or girders, or equivalent structures, are to be fitted as necessary to support the pillars.

11.1.3

Pillars provided in tanks are to be of solid or open section type.

11.2 Connections

11.2.1

Heads and heels of the pillars are to be secured by thick doubling plates and brackets, as necessary. Alternative arrangements for doubling plates may be accepted, provided they are considered equivalent, as deemed appropriate by the Society. Where the pillars are likely to be subjected to tensile loads, heads and heels of the pillars are to be efficiently secured to withstand the tensile loads and the doubling plates are to be replaced by insert plates.

The net thickness of the doubling plates, when fitted, is to be not less than 1.5 times the net thickness of the pillar. Pillars are to be attached at their heads and heels by continuous welding.

Section 7 Structural Idealisation

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4**.

φ_w : Angle, in $\deg$, between the stiffener or primary supporting member web and the attached plating, see **Figure 12** for stiffener and **Ch 10, Sec 1, Figure 4** for primary supporting member. φ_w is to be taken equal to 90 $\deg$ if the angle is between 75 and 105 $\deg$ including 75 and 105 $\deg$.

ℓ_{bdg} : Effective bending span, in m, as defined in **[1.1.2]** for stiffeners and **[1.1.6]** for primary supporting members.

ℓ_{shr} : Effective shear span, in m, as defined in **[1.1.3]** for stiffeners and **[1.1.7]** for primary supporting members.

ℓ : Full length of stiffener or of primary supporting member, in m, between their supports.

s : Stiffener spacing, in mm, as defined in **[1.2]**.

S : Primary supporting member spacing, in m, as defined in **[1.2]**.

a : Length, in mm, of EPP as defined in **[2.1.1]**.

b : Breadth, in mm, of EPP as defined in **[2.1.1]**.

h_{stf} : Stiffener height, including the face plate, in mm.

t_p : Net thickness of attached plate, in mm.

t_w : Net web thickness, in mm. For bulb profiles, see **[1.4.1]**.

b_f : Breadth of flange, in mm, see **Ch 3, Sec 2**, **Figure 2**. For bulb profiles, see **[1.4.1]**.

t_f : Net thickness of flange, in mm.

PSM : Primary Supporting Member.

EPP : Elementary Plate Panel.

LCP : Load Calculation Point.

1. Structural idealisation of stiffeners and primary support members

1.1 Effective spans

1.1.1 General

Where arrangements differ from those defined in this article, span definition may be specially considered.

1.1.2 Effective bending span of stiffeners

The effective bending span ℓ_{bdg} of stiffeners is to be measured as shown in **Figure 1** for single skin structures and **Figure 2** for double skin structures.

If the web stiffener is sniped at the end or not attached to the stiffener under consideration, the effective bending span is to be taken as the full length between PSMs unless a backing bracket is fitted, see **Figure 1**.

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

In single skin structures, the effective bending span of a stiffener supported by a bracket or by a web stiffener on one side only of the primary supporting member web, is to be taken as the total span between primary supporting members as shown in item (a) of **Figure 1**. If brackets are fitted on both sides of the primary supporting member, the effective bending span is to be taken as in items (b), (c) and (d) of **Figure 1**.

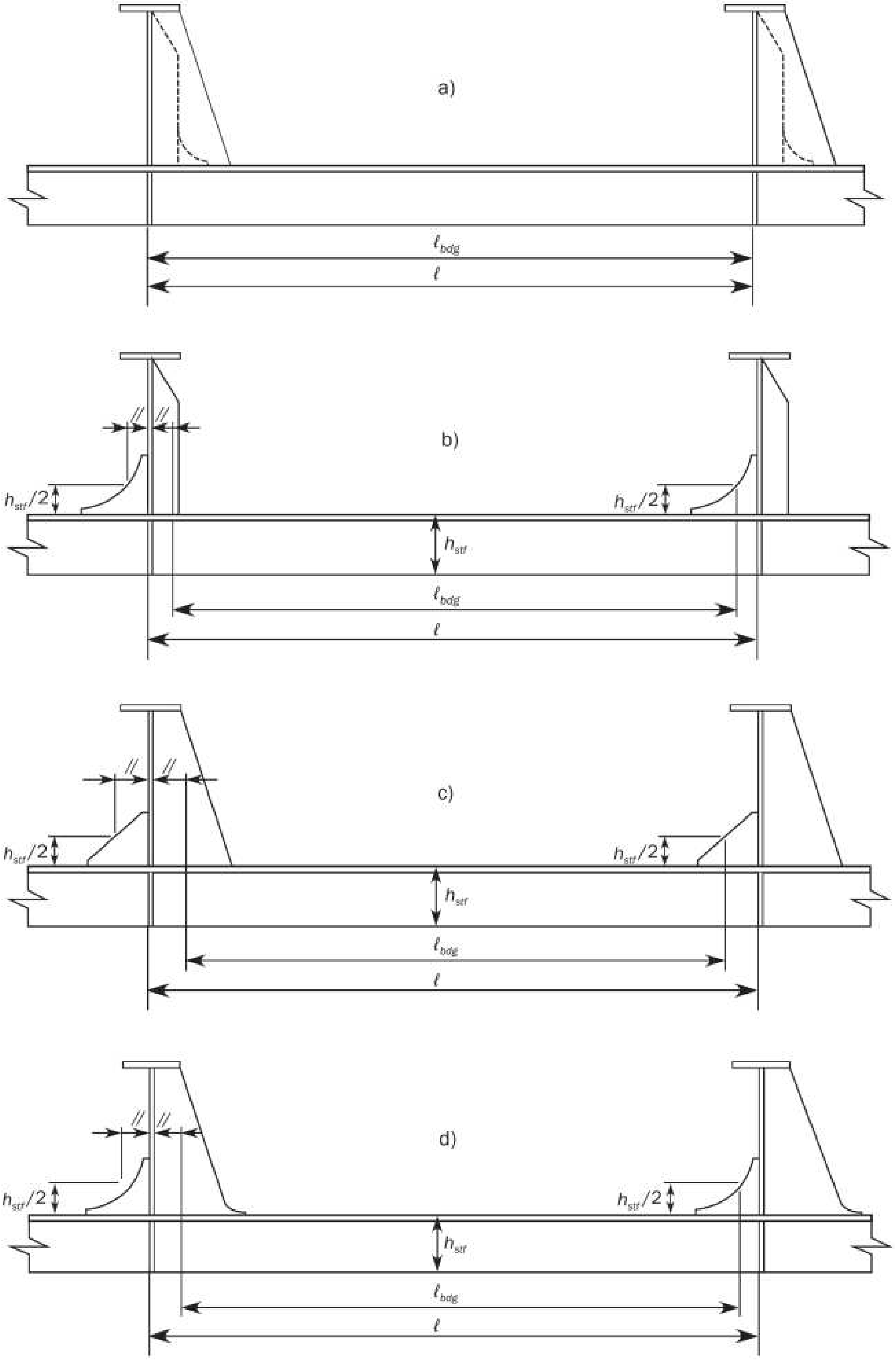


Figure 1 : Effective bending span of stiffeners supported by web stiffeners (Single skin construction)

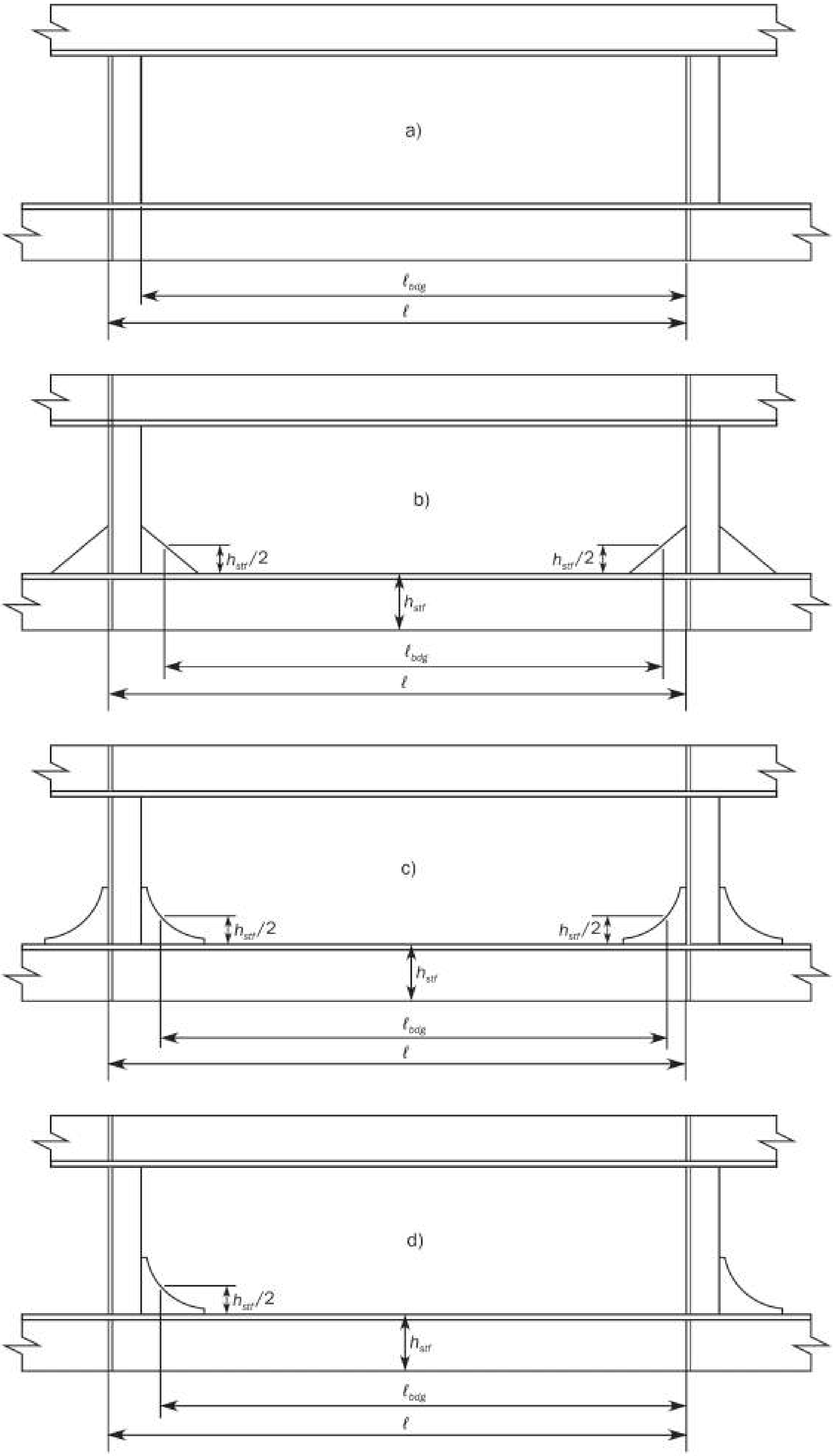


Figure 2 : Effective bending span of stiffeners supported by web stiffeners (Double skin construction)

Where the face plate of the stiffener is continuous along the edge of the bracket, the effective bending span is to be taken to the position where the depth of the bracket is equal to one quarter of the depth of the stiffener, see **Figure 3**.

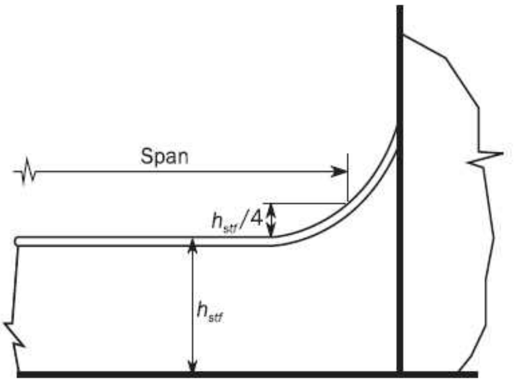


Figure 3 : Effective bending span for local support members with continuous face plate along bracket edge

1.1.3 Effective shear span of stiffeners

The effective shear span, ℓ_{shr} in m, of stiffeners is to be measured as shown in **Figure 4** for single skin structures and **Figure 5** for double skin structures.

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.

If brackets are fitted at both the flange or free edge of the stiffener, and to the attached plating on the side opposite to the stiffener the effective shear span may be reduced using the longer effective bracket arm.

Regardless of support detail, the full length of the stiffener may be reduced by a minimum of $s/4000$ m at each end of the member, hence the effective shear span ℓ_{shr}, is not to be taken greater than:

$$\ell_{shr} \le \ell - \frac{s}{2000}$$

For curved and / or long brackets (high length / height ratio), the effective bracket length is to be taken as the maximum inscribed 1:1.5 right angled triangle as shown in item (c) of both **Figure 4** and **Figure 5.**

Where the face plate of the stiffener is continuous along the curved edge of the bracket, the bracket length to be considered for determination of the span point location is not to be taken greater than 1.5 times the length of the bracket arm as shown in **Figure 6.**

1.1.4 Effect of hull form shape on span of stiffeners

For curved stiffeners, the span is defined as the chord length between span points to be measured at the flange for stiffeners with a flange, and at the free edge for flat bar stiffeners. The calculation of the effective span is to be in accordance with requirements given in **[1.1.2]** and **[1.1.3].**

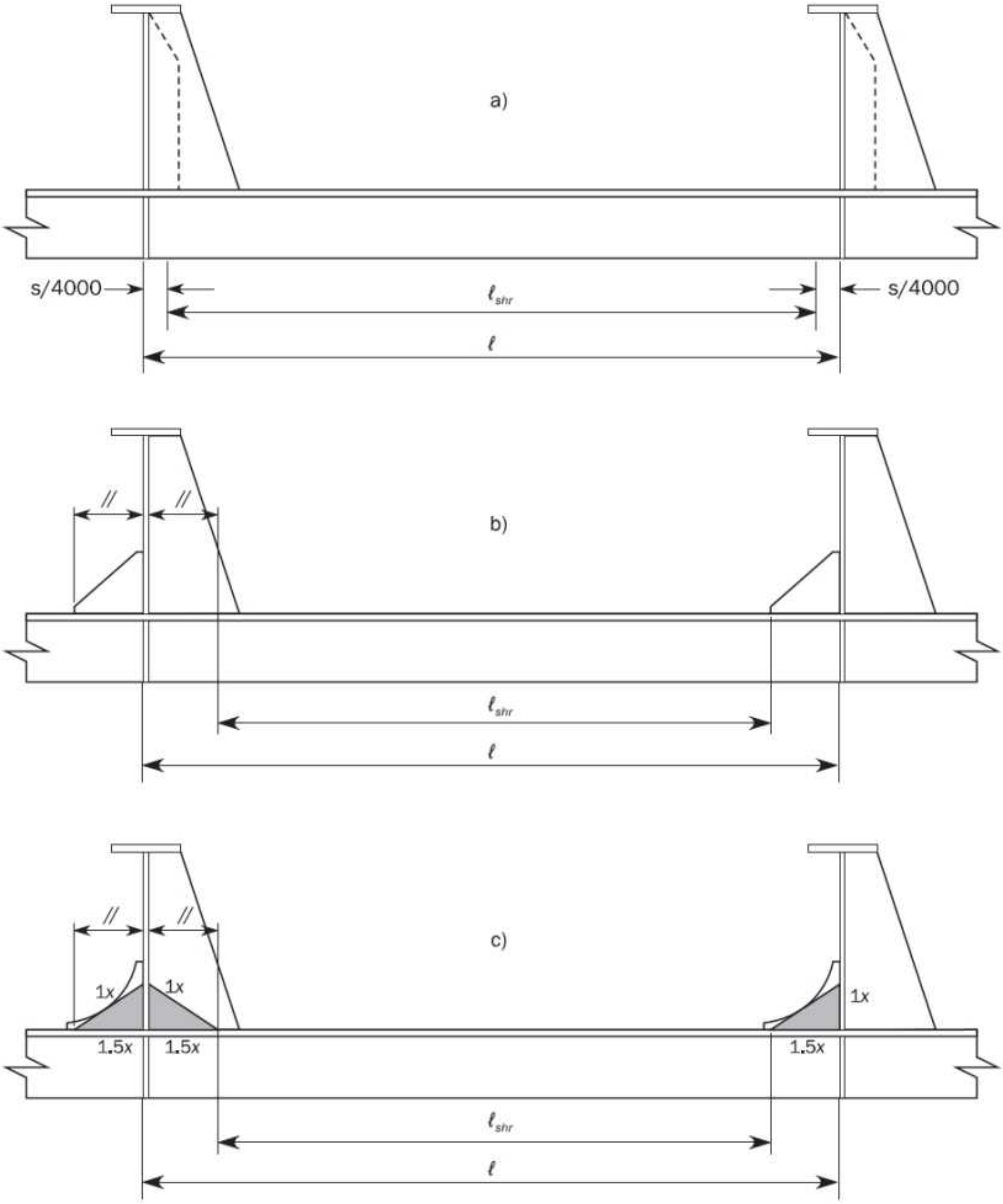


Figure 4 : Effective shear span of stiffeners supported by web stiffeners (single skin construction)

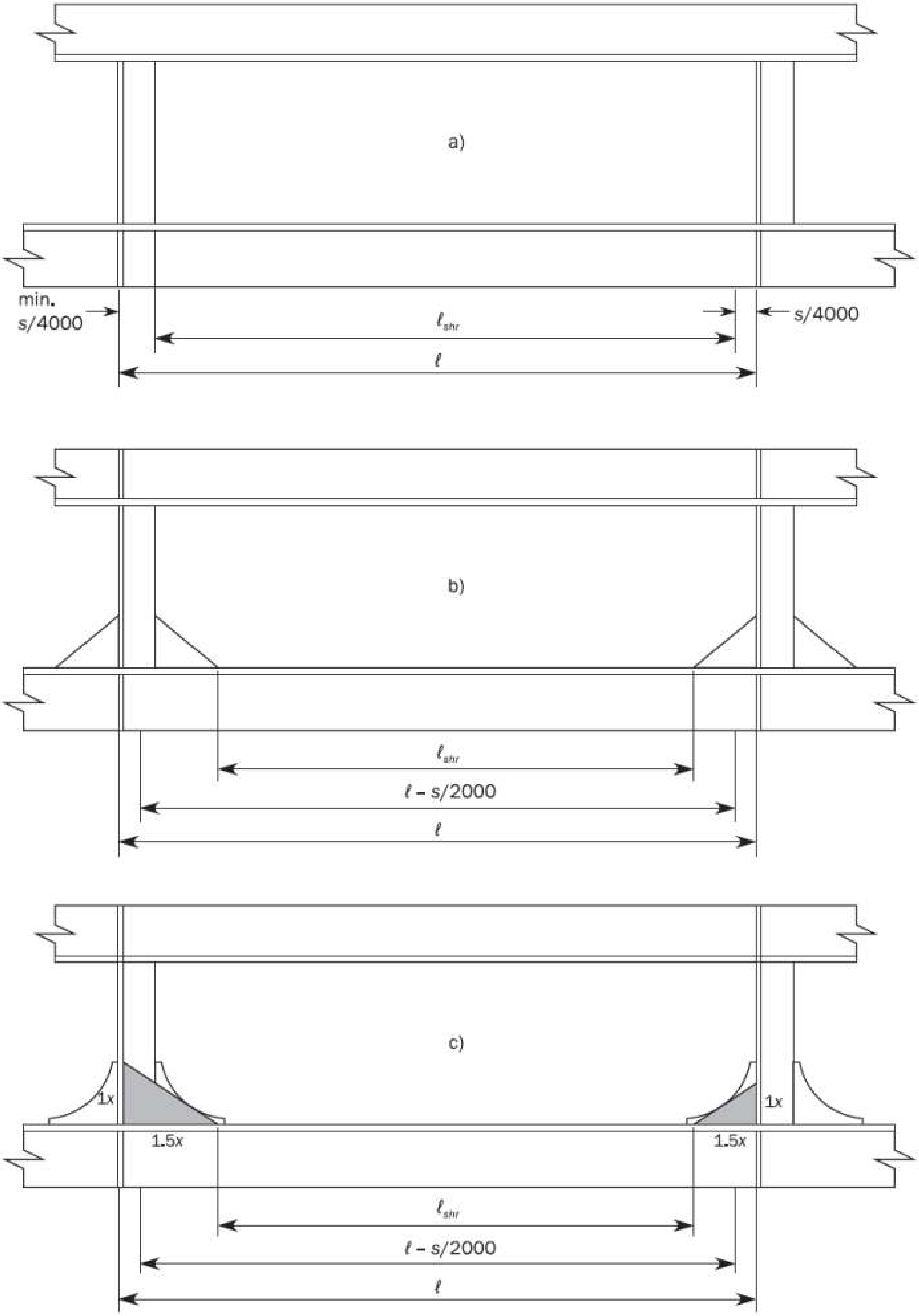


Figure 5 : Effective shear span of stiffeners supported by web stiffeners (double skin construction)

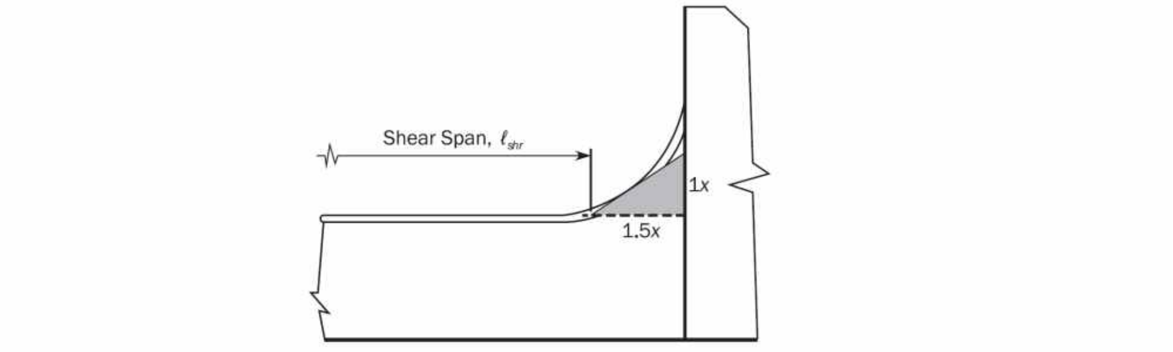


Figure 6 : Effective shear span for local support members with continuous face plate along bracket edge

1.1.5 Effective bending span of primary supporting members

The effective bending span ℓ_{bdg} of a primary supporting member without end bracket is to be taken as the length of the primary supporting member between supports.

The effective bending span ℓ_{bdg} of a primary supporting member may be taken as less than the full length of the primary supporting member between supports, provided suitable end brackets are fitted:

The effective bending span ℓ_{bdg} in m, of a primary supporting member with end brackets is taken between points where the depth of the bracket is equal to half the web height of the primary supporting member as shown in **Figure 7 (b)**. The effective bracket used to define these span points is to be taken as given in **[1.1.7]**.

In case of brackets where the face plate of the member is continuous along the face of the bracket, as shown in **Figure 7 (a)**, **(c)** and **(d)**, the effective bending span ℓ_{bdg} in m, is taken between points where the depth of the bracket is equal to one quarter the web height of the primary supporting member. The effective bracket used to define these span points is to be taken as given in **[1.1.7]**.

For straight brackets with a length to height ratio greater than 1.5, the span point is to be taken to the effective bracket; otherwise the span point is to be taken to the fitted bracket.

For curved brackets, for span positions above the tangent point between fitted bracket and effective bracket, the span point is to be taken to the fitted bracket; otherwise, the span point is to be taken to the effective bracket.

For arrangements where the primary supporting member face plate is carried on to the bracket and backing brackets are fitted, the span point need not be taken greater than to the position where the total depth reaches twice the depth of the primary supporting member. Arrangements with small and large backing brackets are shown in **Figure 7 (e)** and **(f)**.

For arrangements where the height of the primary supporting member is maintained and the face plate width is increased towards the support, the effective bending span ℓ_{bdg} may be taken to a position where the face plate breadth reaches twice the nominal breadth.

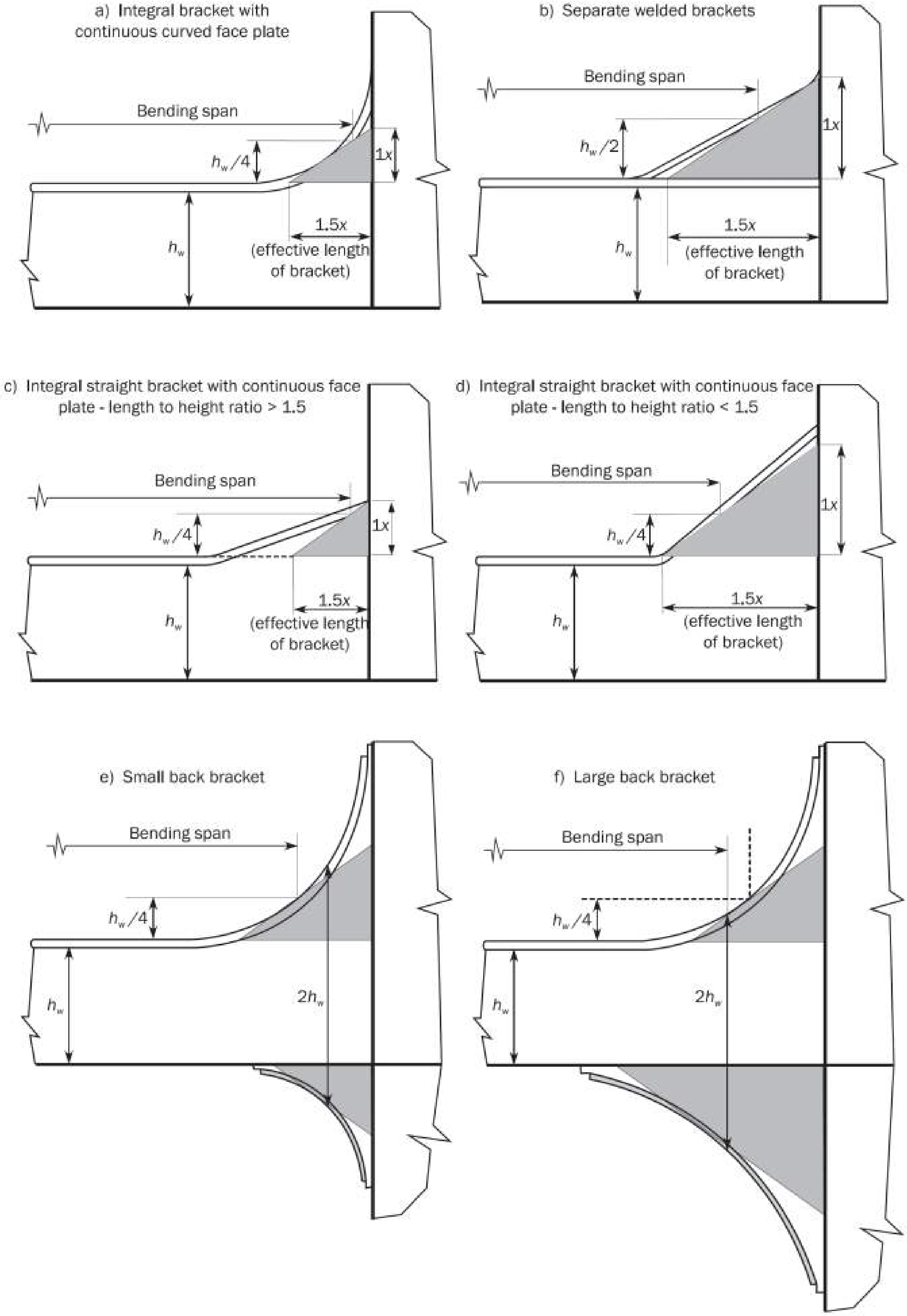
1.1.6 Effective shear span of primary supporting members

The effective shear span of the primary supporting member may be reduced compared to effective bending span, and taken between the toes of the effective brackets supporting the member, where the toes of effective brackets are as shown in **Figure 8**. The effective bracket used to define the toe point is given in **[1.1.7]**.

For arrangements where the effective backing bracket is larger than the effective 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 item **(f)** of **Figure 8**.

1.1.7 Effective bracket definition

The effective bracket is defined as the maximum size of right angled triangular bracket with a length to height ratio of 1.5 that fits inside the fitted bracket. See **Figure 7** for examples.


a) Integral bracket with continuous curved face plate

b) Separate welded brackets

c) Integral straight bracket with continuous face plate - length to height ratio > 1.5

d) Integral straight bracket with continuous face plate - length to height ratio < 1.5

e) Small back bracket

f) Large back bracket

Figure 7 : Effective bending span of primary supporting member

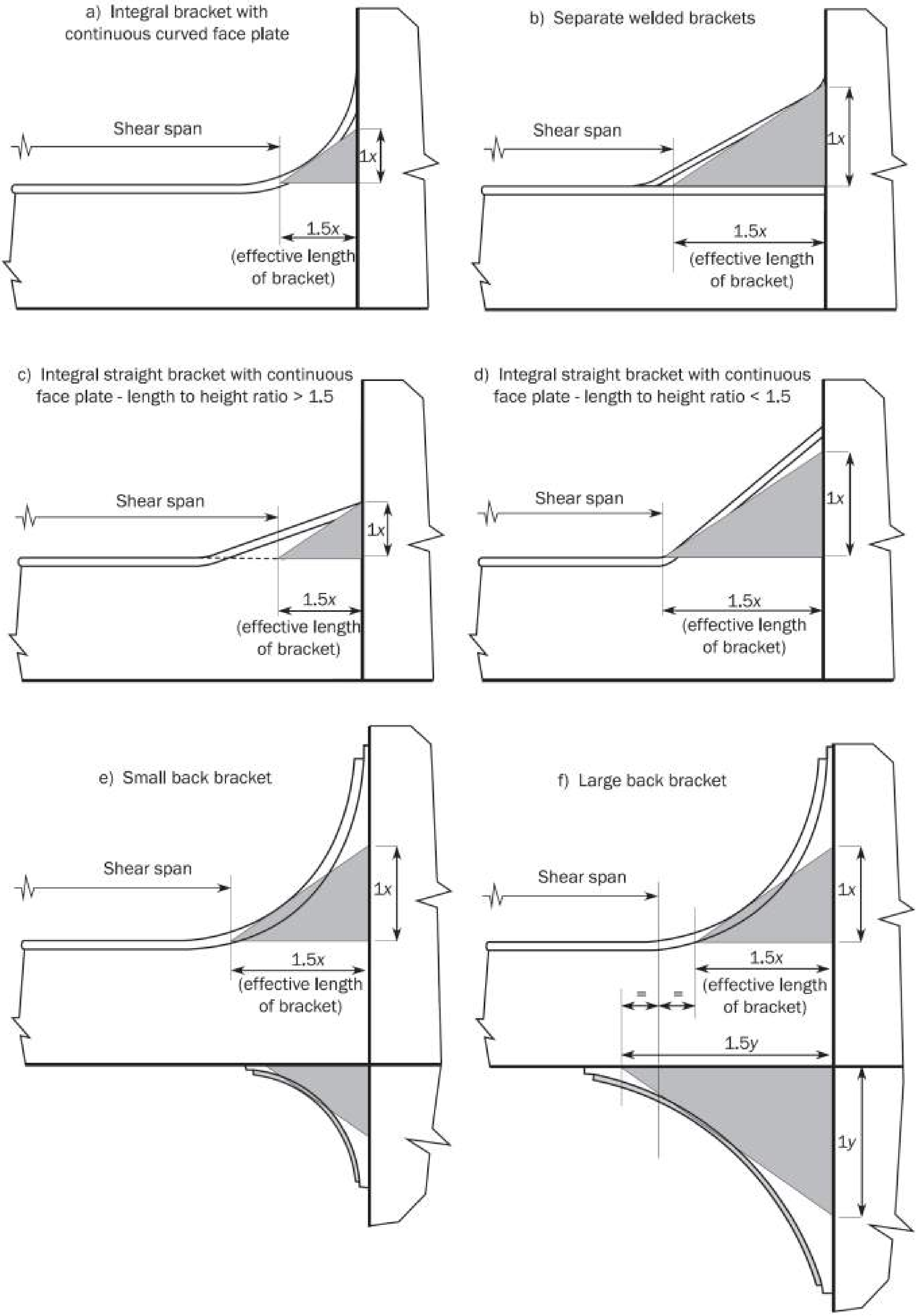


Figure 8 : Effective shear span of primary supporting member

1.2 Spacing and load supporting breadth

1.2.1 Stiffeners

Stiffeners spacing, s in mm, for the calculation of the effective attached plating of stiffeners is to be taken as the mean spacing between stiffeners and taken equal to, see **Figure 9**.

$$s = \frac{b_1 + b_2 + b_3 + b_4}{4}$$

where:

b_1, b_2, b_3, b_4 : Spacings between stiffeners at ends, in mm.

In general, the loading breadth supported by stiffener is to be taken equal to s.

1.2.2 Primary supporting member

Primary supporting member spacing, S, for the calculation of the effective attached plating of primary supporting members is to be taken as the mean spacing between adjacent primary supporting members, and taken equal to, see **Figure 9**.

$$S = \frac{b_1 + b_2 + b_3 + b_4}{4}$$

where:

b_1, b_2, b_3, b_4 : Spacings between primary supporting members at ends, in m.

In general, the loading breadth supported by a primary supporting member is to be taken equal to S.

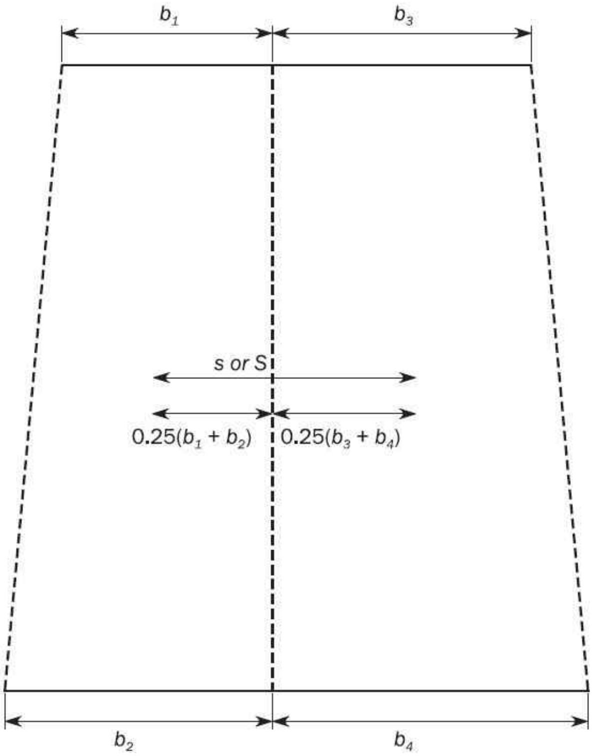


Figure 9 : Spacing of plating

1.2.3 Spacing of curved plating

For curved plating, the stiffener spacing, s or the primary supporting member spacing, S is to be measured on the mean chord between members.

1.3 Effective breadth

1.3.1 Stiffeners

The effective breadth, b_{eff} in mm, of the attached plating to be considered in the actual net section modulus for the yielding check of stiffeners is to be obtained from the following formulae:

a) Where the plating extends on both sides of the stiffener:

$b_{eff} = 200\ell$, or $b_{eff} = s$

whichever is lesser.

b) Where the plating extends on one side of the stiffener (i.e. stiffeners bounding openings):

$b_{eff} = 100\ell$, or $b_{eff} = 0.5s$

whichever is lesser.

However, where the attached plate net thickness is less than 8.0 mm, the effective breadth is not to be taken greater than 600 mm.

The effective breadth, b_{eff} in mm, of the attached plating to be considered for the buckling check of stiffeners is given in **Ch 8, Sec 5, [2.3.5]**.

1.3.2 Primary supporting members

The effective breadth of attached plating, b_{eff} in m, for calculating the section modulus and / or moment of inertia of a primary supporting member is to be taken as:

$$b_{eff} = S \cdot \min\left[\frac{1.12}{1+\dfrac{1.75}{\left(\dfrac{\ell_{bdg}}{S\sqrt{3}}\right)^{1.6}}};1.0\right] \qquad \text{for} \quad \frac{\ell_{bdg}}{S\sqrt{3}} \geq 1.0$$

$$b_{eff} = 0.407\frac{\ell_{bdg}}{\sqrt{3}} \qquad \text{for} \quad \frac{\ell_{bdg}}{S\sqrt{3}} < 1.0$$

1.3.3 Effective area of curved face plate and attached plating of primary supporting members

The effective net area given in a) and b) is only applicable to curved face plates and curved attached plating of primary supporting members. This is not applicable for the area of web stiffeners parallel to the face plate.

The effective net area is applicable to primary supporting members for the following calculations:

- Actual net section modulus used for comparison with the scantling requirements in **Ch 6**.
- Actual effective net area of curved face plates, modelled by beam elements, used in **Ch 7**.

a) The effective net area, $A_{eff-n50}$, in mm^2, is to be taken as:

$A_{eff-n50} = C_f t_{f-n50} b_f$

where:

C_f : Flange efficiency coefficient is to be obtained from the following formula but not to be greater than 1.0:

- $C_f = C_{f1}\dfrac{1.285}{\beta k_1}$ for symmetrical face plates.
- $C_f = 0.18 + \dfrac{0.08}{\beta^2}$ for unsymmetrical face plate.
- $C_f = C_{f1}\dfrac{1.285}{\beta}$ for attached plating of box girders.

C_{f1} : Coefficient taken equal to:

- For symmetrical face plates,

$$C_{f1} = \frac{(\sinh k_1\beta \ \cosh k_1\beta \ + \sin k_1\beta \ \cos k_1\beta)}{(\cosh k_1\beta)^2 + (\cos k_1\beta)^2}$$

- For attached plating of box girders with two webs,

$$C_{f1} = \frac{0.78\,(\sinh\beta + \sin\beta)(\cosh\beta - \cos\beta)}{(\sinh\beta\,)^2 + \sin^2\,\beta}$$

- For attached plating of box girders with multiple webs,

$$C_{f1} = \frac{1.56\,(\cosh\beta - \cos\beta)}{\sinh\beta + \sin\beta}$$

k_1 : Coefficient calculated as:

- $k_1 = 1.4 + 1.25(1.4 - \beta)^3$ for $\beta < 1.4$
- $k_1 = 1.4$ for $\beta \geq 1.4$

β : Coefficient calculated as:

$$\beta \ = \frac{1.285\,b_1}{\sqrt{r_f t_{f-n50}}} \ , \text{ in rad.}$$

b_1 : Breadth, in mm, to be taken equal to:

- $b_1 = 0.5(b_f - t_{w-n50})$ for symmetrical face plates
- $b_1 = b_f$ for unsymmetrical face plates
- $b_1 = s_w - t_{w-n50}$ for attached plating of box girders

s_w : Spacing of supporting webs for box girders, in mm.

t_{f-n50} : Net flange thickness, in mm. For calculation of C_f and β of unsymmetrical face plates, t_{f-n50} is not to be taken greater than t_{w-n50}.

t_{w-n50} : Net web plate thickness, in mm.

r_f : Radius of curved face plate or attached plating, in mm, see **Figure 10** at mid thickness.

b_f : Breadth of face plate or attached plating, in mm, see **Figure 10**.

b) The effective net area, in mm^2, of curved face plates supported by radial brackets, or attached plating supported by cylindrical stiffeners, is given by:

$$A_{eff-n50} = \left(\frac{3\,r_f t_{f-n50} + C_f\,s_r^2}{3\,r_f t_{f-n50} + s_r^2}\right) t_{f-n50}\,b_f$$

where:

s_r : Spacing of tripping brackets or web stiffeners or stiffeners normal to the web plating, in mm, see **Figure 10**.

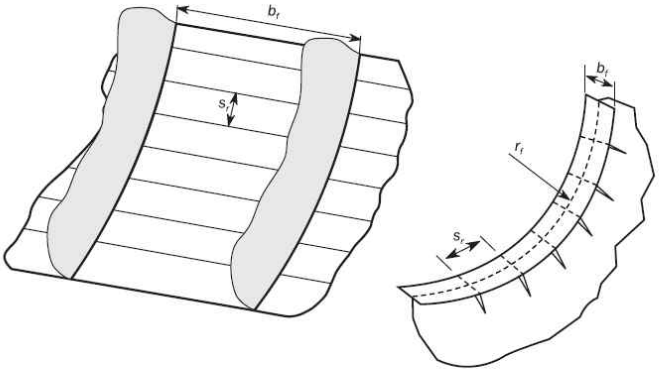


Figure 10 : Curved shell panel and face plate

1.4 Geometrical properties of stiffeners and primary supporting members

1.4.1 Stiffener profile with a bulb section

The properties of bulb profile sections are to be determined by direct calculations.

Where direct calculation of properties is not possible, a bulb section may be taken equivalent to a built-up section. The net dimensions of the equivalent built-up section are to be obtained, in mm, from the following formulae.

$$h_W = h'_W - \frac{h'_W}{9.2} + 2$$

where:

$$b_f = \alpha\left(t'_W + \frac{h'_W}{6.7} - 2\right)$$

$$t_f = \frac{h'_W}{9.2} - 2$$

$$t_w = t'_w$$

h'_w, t'_w : Net height and thickness of a bulb section, in mm, as shown in **Figure 11**.

α : Coefficient equal to:

$\alpha = 1.1 + \frac{(120 - h'_w)^2}{3000}$ for $h'_w \leq 120$

$\alpha = 1.0$ for $h'_w > 120$

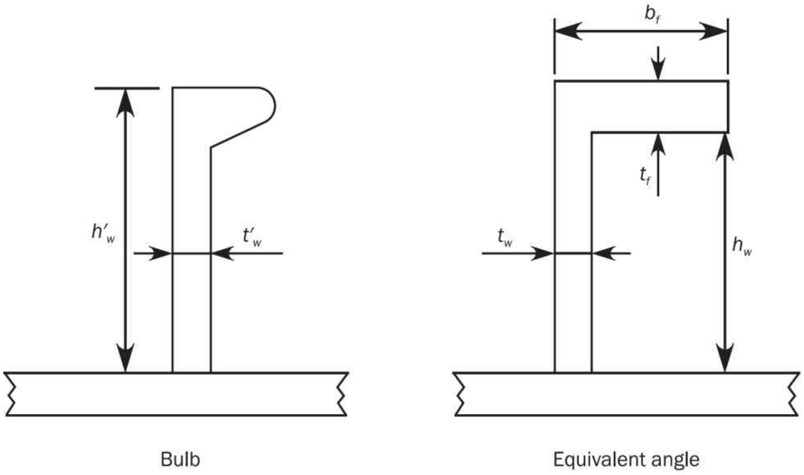


Figure 11 : Dimensions of stiffeners

1.4.2 Net elastic shear area of stiffeners

The net elastic shear area, A_{shr}, in cm^2, of stiffeners is to be taken as:

$$A_{shr} = d_{shr} t_w 10^{-2}$$

d_{shr} : Effective shear depth of stiffener, in mm, as defined in **[1.4.3]**.

t_w : Net web thickness of the stiffener, in mm, as defined in **Ch 3, Sec 2, Figure 2**.

1.4.3 Effective shear depth of stiffeners

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

$$d_{shr}=(h_{stf}-0.5t_{c-stf}+t_p+0.5t_{c-pl})\sin\varphi_w$$

where:

h_{stf} : Height of stiffener, in mm, as defined in **Ch 3, Sec 2, Figure 2.**

t_p : Net thickness of the stiffener attached plating, in mm, as defined in **Ch 3, Sec 2, Figure 2.**

t_{c-stf} : Corrosion addition, in mm, of considered stiffener as given in **Ch 3, Sec 3**.

t_{c-pl} : Corrosion addition, in mm, of attached plate of the stiffener considered as given in **Ch 3, Sec 3**.

1.4.4 Elastic net section modulus of stiffeners

The elastic net section modulus, Z in cm^3 and the net moment of inertia, I in cm^4, of stiffeners is to be taken as:

$$Z=Z_{stf}\sin\varphi_w$$

$$I=I_{st}\sin^2\varphi_w$$

where:

Z_{stf} : Net section modulus of the stiffener, in cm^3, considered perpendicular to its attached plate, i.e. with φ_w = 90 deg.

I_{st} : Net moment of inertia of the stiffener, in cm^4, considered perpendicular to its attached plate, i.e. with φ_w = 90 deg.

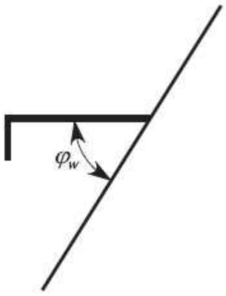


Figure 12 : Angle between stiffener web and attached plating

1.4.5 Effective net plastic shear area of stiffeners

The net plastic shear area, A_{shr-pl} of stiffeners, in cm^2, which is used for assessment against impact loads is to be taken as:

$$A_{shr-pl}=A_{shr}$$

where:

A_{shr} : Net elastic shear area, in cm^2, as defined in **[1.4.2].**

1.4.6 Effective net plastic section modulus of stiffeners

The effective net plastic section modulus, Z_{pl}, of stiffeners, in cm^3, which is used for assessment against impact loads, is to be taken as:

$$Z_{pl} = \frac{f_w h_w t_w (h_w + e_{pN})}{2000} + \frac{(2\gamma - 1)\, A_f (h_{f-ctr} + e_{pN})}{1000} + \frac{(h_w t_w + A_f) e_{pN}}{1000} \quad \text{for } 75^o \le \varphi_w \le 105^o$$

$$Z_{pl} = \frac{f_w h_w t_w (h_w + e_{pN}) \sin\varphi_w}{2000} + \frac{(2\gamma - 1)\, A_f ((h_{f-ctr} + e_{pN}) \sin\varphi_w - b_{f-ctr} \cos\varphi_w)}{1000} \quad \text{for } \varphi_w < 75^o \text{ or } \varphi_w > 105^o$$

where

f_w : Web shear stress factor, taken equal to:

- f_w = 0.75 for flanged profile cross sections with n = 1 or 2
- f_w = 1.0 for flanged profile cross sections with n = 0
- f_w = 1.0 for flat bar stiffeners

n : Number of plastic hinges at end supports of each member, taken equal to: 0, 1 or 2.

A plastic hinge at end support may be considered where:

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

h_w : Depth of stiffener web, in mm, taken equal to:

- For T, L (rolled and built-up) profiles and flat bar, as defined in **Ch 3, Sec 2, Figure 2.**
- For L2 and L3 profiles as defined in **Ch 3, Sec 2, Figure 3.**
- For bulb profiles, to be taken as defined in **[1.4.1].**

γ : Coefficient equal to:

$$\gamma = \frac{\sqrt{3 + 2\beta}}{2}$$

e_{pN} : Coefficient taken equal to:

$$e_{pN} = \frac{(A_f + h_w t_w)}{2s} \le \frac{t_p}{2}$$

β : Coefficient equal to:

- For L profiles without a mid-span tripping bracket:

  $$\beta = \frac{t_w^2 f_b l_{shr}^2}{80 b_f^2 t_f h_{f-ctr}} 10^6 + \frac{t_w}{2b_f}$$

  Without being taken greater than 0.5.
- For other cases:

  $\beta = 0.5$

A_f : Net cross sectional area of flange, in mm^2:

- $A_f = 0.0$ for flat bar stiffeners.
- $A_f = b_f t_f$ for other stiffeners.

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

- $b_{f-ctr} = 0.5(b_f - t_w)$ for rolled angle profiles and bulb profiles.
- $b_{f-ctr} = 0.0$ for T profiles.

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

- $h_{f-ctr} = h_w + 0.5t_f$ for profiles with flange of rectangular shape except for L3 profiles.
- $h_{f-ctr} = h_{stf} - d_e - 0.5t_f$ for L3 profiles as defined in **Ch 3, Sec 2, Figure 3.**

d_e : Distance from upper edge of web to the top of the flange, in mm, for L3 profiles, see **Ch 3, Sec 2, Figure 3.**

f_b : Coefficient taken equal to:

- f_b = 0.8 for flanges continuous through the primary supporting member, with end bracket(s).
- f_b = 0.7 for flanges sniped at the primary supporting member or terminated at the support without aligned structure on the other side of the support, and with end bracket(s).
- f_b = 1.0 for other stiffeners.

t_f : Net flange thickness, in mm.

- t_f = 0.0 for flat bar stiffeners.
- For bulb profiles t_f is defined in **[1.4.1].**

1.4.7 Primary supporting member web not perpendicular to attached plating

Where the primary supporting member web is not perpendicular to the attached plating, the actual net shear area, in cm^2, and the actual net section modulus, in cm^3, can be obtained from the following formulae:

a) Actual net shear area:

$$A_{sh-n50} = A_{sh\text{-}0\text{-}n50} \sin\varphi_w$$

b) Actual net section modulus:

$$Z_{n50} = Z_{perp-n50} \sin\varphi_w$$

where:

$A_{sh-0-n50}$: Actual net shear area, in cm^2, of the primary supporting member assumed to be perpendicular to the attached plating, to be taken equal to:

$$A_{sh-0-n50} = (h_{eff} + t_{f-n50} + t_{p-n50})\, t_{w-n50}\, 10^{-2}$$

$Z_{perp-n50}$: Actual section modulus, in cm^3, with its attached plating of the primary supporting member assumed to be perpendicular to the attached plating.

1.4.8 Shear area of primary supporting members with web openings

The effective web height, h_{eff} in mm, to be considered for calculating the effective net shear area, A_{sh-n50} is to be taken as the lesser of:

$$h_{eff} = h_w$$

$$h_{eff} = h_{w3} + h_{w4}$$

$$h_{eff} = h_{w1} + h_{w2} + h_{w4}$$

where:

h_w : Web height of primary supporting member, in mm.

h_{w1}, h_{w2}, h_{w3}, h_{w4} : Dimensions as shown in **Figure 13.**

where an opening is located at a distance less than $h_w/3$ from the cross-section considered, h_{eff} is to be taken as the smaller of the net height and the net distance through the opening. See **Figure 13.**

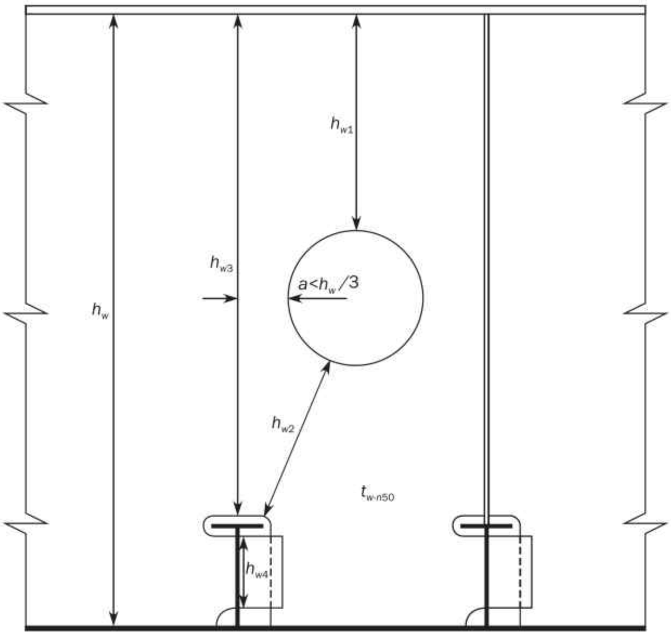


Figure 13 : Effective shear area in way of web openings

1.4.9 Stiffener flange width

In case the stiffener flange thickness requirement in **Ch 8, Sec 2, [3.1.1] b)** is not fulfilled, the effective free flange outstand, used in strength assessment including the calculation of actual net section modulus, is to be taken as $b_{f-out-max}$ defined in **Ch 8, Sec 2, [3.1.1]**.

2. Plates

2.1 Idealisation of EPP

2.1.1 EPP

An elementary plate panel (EPP) is the unstiffened part of the plating between stiffeners and / or primary supporting members. The plate panel length, a, and breadth, b, of the EPP are defined respectively as the longest and shortest plate edges, as shown in **Figure 14.**

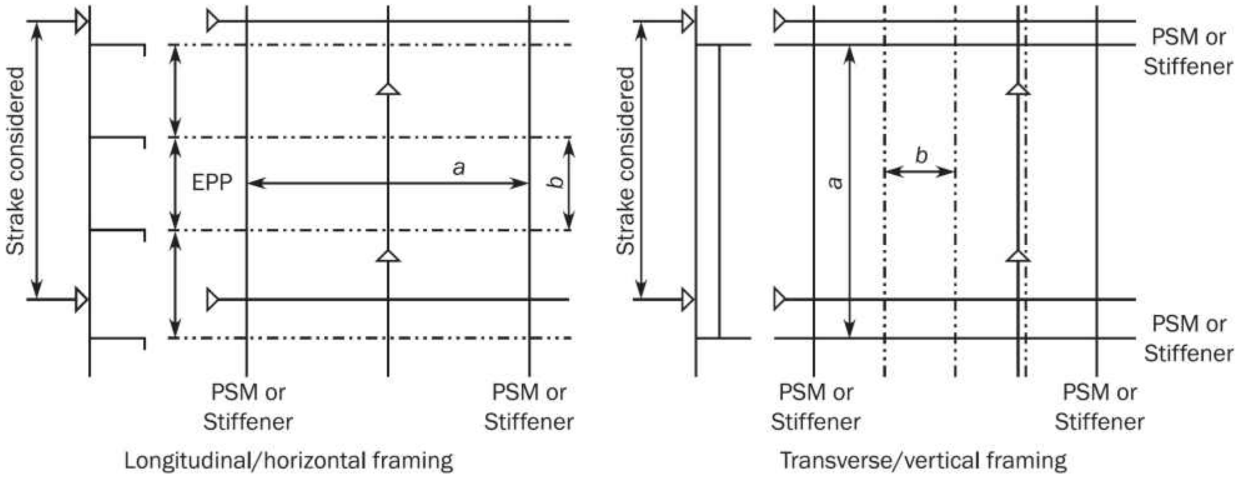


Figure 14 : Elementary Plate Panel (EPP) definition

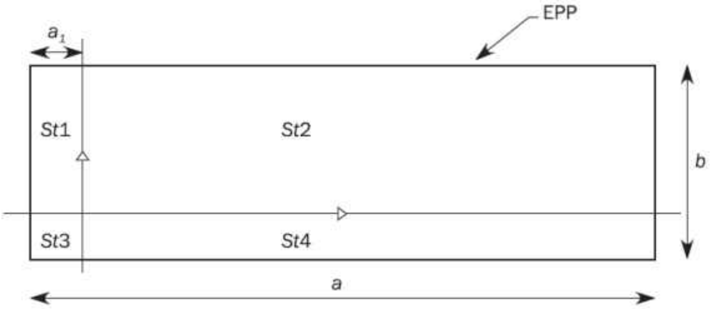
2.1.2 Strake required thickness

The required thickness of a plate strake is to be taken as the greatest value required for each EPP within that strake. The requirements given in **Table 1** are to be applied for the selection of strakes to be considered as shown in **Figure 15**.

The maximum corrosion addition within a strake is to be applied according to **Ch 3, Sec 3, [1.2.3]**.

Table 1 : Strake considered in a given EPP

	$a / b > 2$	$a / b \le 2$
$a_1 > b/2$	All strakes (St1, St2, St3, St4)	All strakes (St1, St2, St3, St4)
$a_1 \le b/2$	Strakes St2 and St4	All strakes (St1, St2, St3, St4)



a_1 : Distance, in mm, measured inside the considered strake in the direction of the long edge of the EPP, between the strake boundary weld seam and the EPP edge.

Figure 15 : Strake considered in a given EPP

2.1.3

For direct strength assessment, the EPP is idealised with the mesh arrangement in the finite element model.

2.2 Load calculation point

2.2.1 Yielding

For the yielding check, the local pressure and hull girder stress, used for the calculation of the local scantling requirements are to be taken at the Load Calculation Point (LCP) having coordinates *x*, *y* and *z* as defined in **Table 2.**

Table 2 : LCP coordinates for yielding

LCP coordinates	General(1)		Horizontal plating		Vertical transverse structure	
	Longitudinal framing (**Figure 16**)	Transverse framing (**Figure 17**)	Longitudinal framing	Transverse framing	Horizontal framing (**Figure 18**)	Vertical framing (**Figure 19**)
x coordinate	Mid-length of the EPP		Mid-length of the EPP		Corresponding to *y* and *z* values	
y coordinate	Corresponding to *x* and *z* coordinates		Outboard *y* value of the EPP		Outboard *y* value of the EPP, taken at *z* level(2)	
z coordinate	Lower edge of the EPP	The greater of lower edge of the EPP or lower edge of the strake	Corresponding to *x* and *y* values		Lower edge of the EPP	The greater of lower edge of the EPP or lower edge of the strake

(1) All structures other than horizontal platings or vertical transverse structures

(2) For transom plate, the y coordinate of the load calculation point is to be taken corresponding to *y* value at side shell at *z* level of the load calculation point, for the external dynamic pressure calculation.

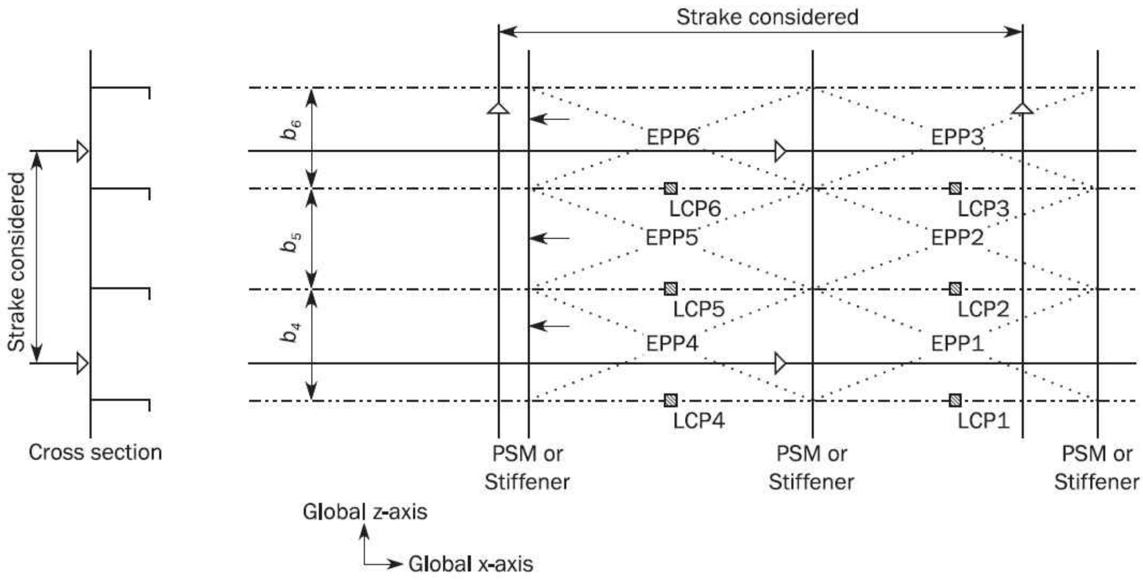


Figure 16 : Load calculation point for longitudinal framing

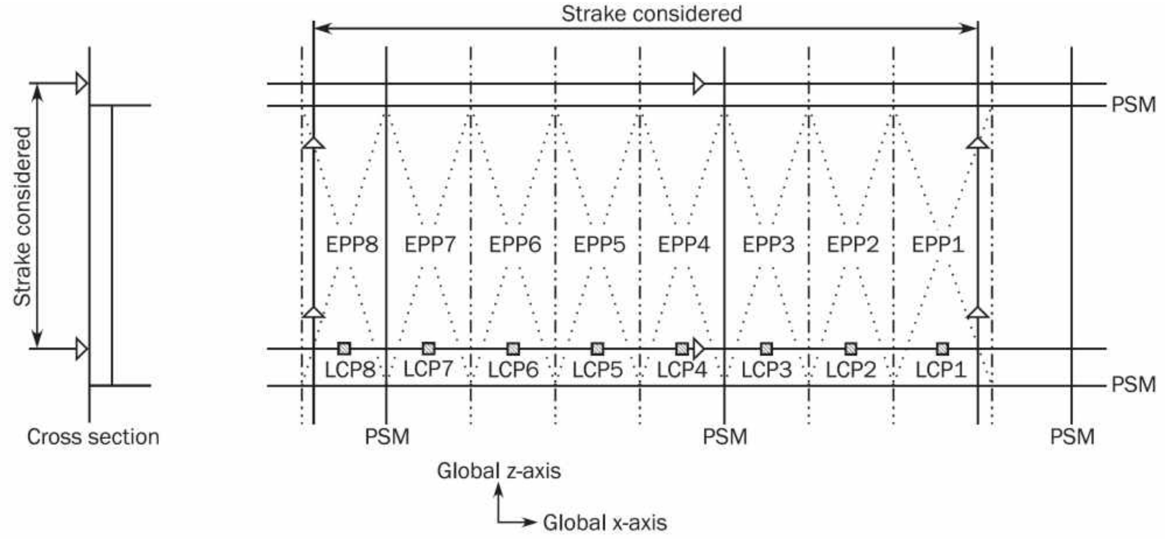


Figure 17 : Load calculation point for transverse framing

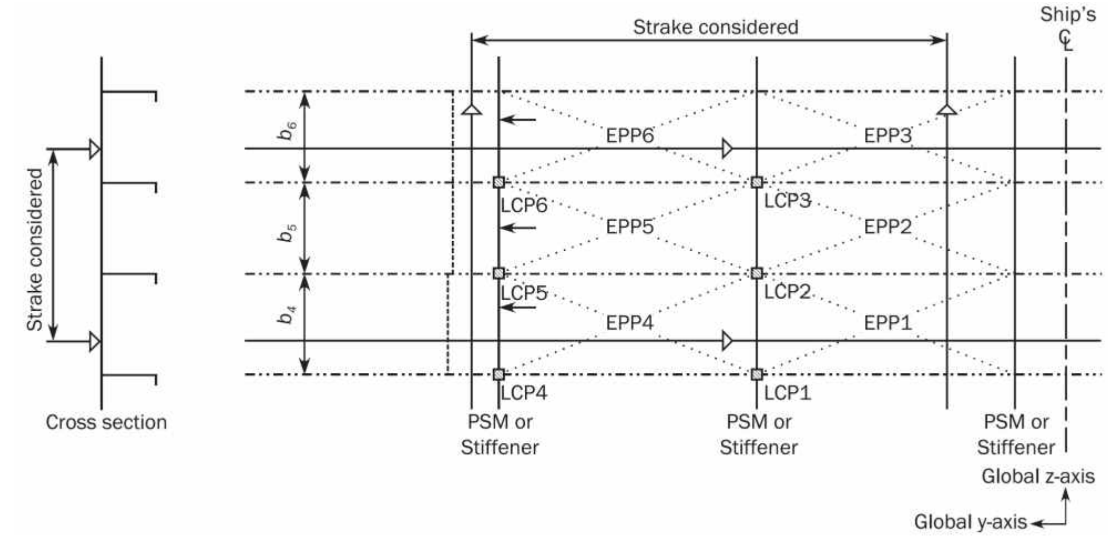


Figure 18 : Load calculation point for horizontal framing on transverse vertical structure

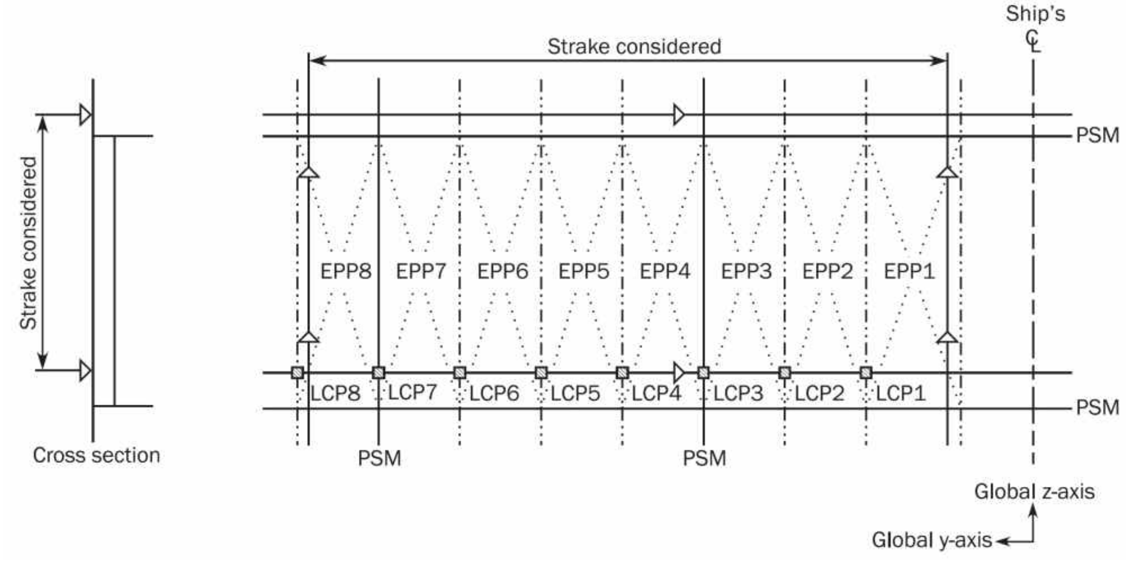


Figure 19 : Load calculation point for vertical framing on transverse vertical structure

2.2.2 Buckling

For the prescriptive buckling check of the EPP according to **Ch 8, Sec 2**, the LCP for the pressure and for the hull girder stresses are defined in **Table 3.**

For the FE buckling check, **Ch 8, Sec 4** is applicable.

Table 3 : LCP coordinates for plate buckling

LCP coordinates	LCP for pressure	LCP for hull girder stresses (**Figure 20**)		
		Bending stresses[1]		Shear stresses
		Non horizontal plate	Horizontal plate	
x coordinate	Same coordinates as LCP for yielding See **Table 2**	Mid-length of the EPP		
y coordinate		Corresponding to x and z values	Outboard and inboard ends of the EPP (points A1 and A2)	Mid-point of EPP (point B)
z coordinate		Both upper and lower ends of the EPP (points A1 and A2)	Corresponding to x and y values	

[1] The bending stress for curved plate panel is the mean value of the stresses calculated at points A1 and A2.

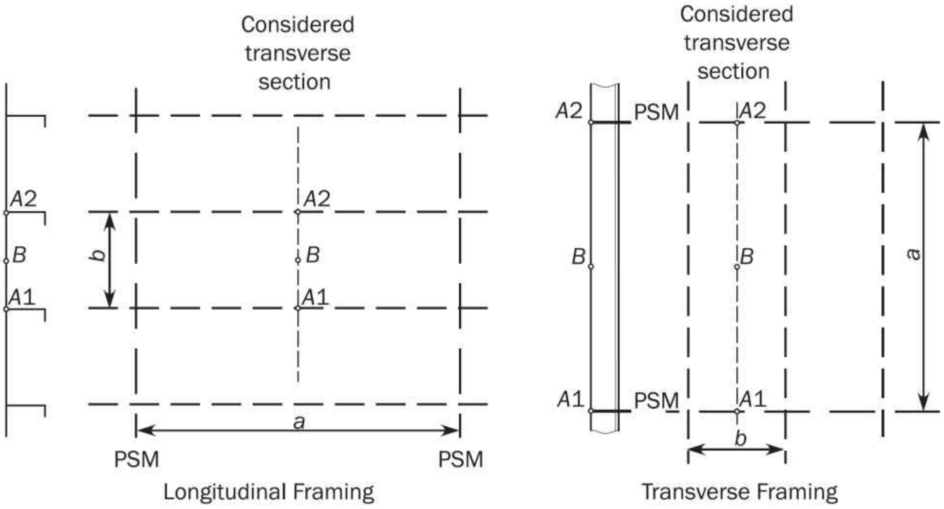


Figure 20 : LCP for plate buckling – hull girder stresses

3. Stiffeners

3.1 Reference point

3.1.1

The requirements of section modulus for stiffeners relate to the reference point giving the minimum section modulus. This reference point is generally located as shown in **Figure 21** for typical profiles.

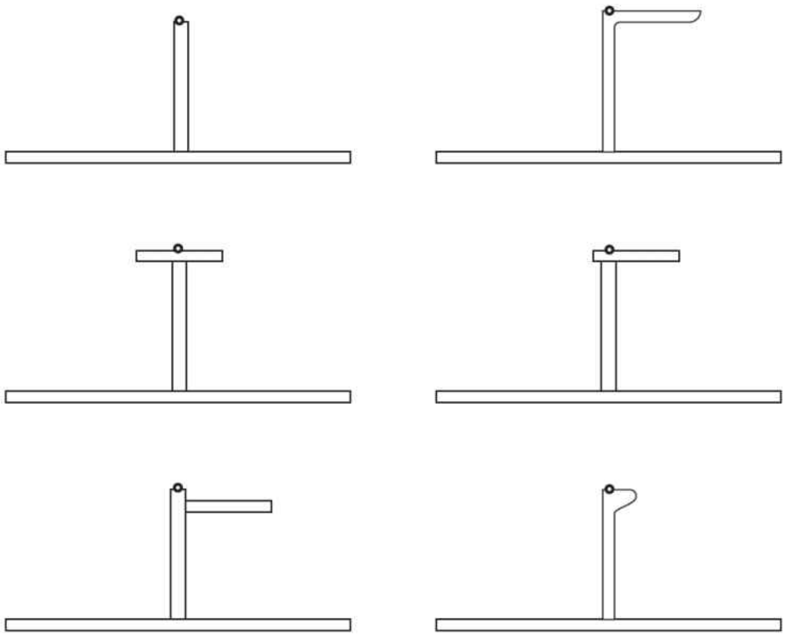


Figure 21 : Reference point for calculation of section modulus and hull girder stress for local scantling assessment

3.2 Load calculation points

3.2.1 LCP for Pressure

The load calculation point for the pressure is located at:

a) Middle of the full length, ℓ, of the considered stiffener.

b) The intersection point between the stiffener and its attached plate.

For stiffeners located on transom plate, the y coordinate of the load calculation point is to be taken corresponding to y value at side shell at z level of the load calculation point, for the external dynamic pressure calculation.

3.2.2 LCP for hull girder bending stress

The load calculation point for the hull girder bending stresses is defined as follows:

a) For prescriptive yielding verification according to **Ch 6** and **Ch 10, Sec 4**:
  - At the middle of the full length, ℓ, of the considered stiffener.
  - At the reference point given in **Figure 21.**

b) For prescriptive buckling requirements according to **Ch 8**:
  - At the middle of the full length, ℓ, of the considered stiffener.
  - At the intersection point between the stiffener and its attached plate.

3.2.3 Non-horizontal stiffeners

The lateral pressure, P is to be calculated as the maximum between the value obtained at middle of the full length, ℓ, and the value obtained from the following formulae:

a) when the upper end of the vertical stiffener is below the lowest zero pressure level.

$$P = \frac{P_u + P_L}{2}$$

b) when the upper end of the vertical stiffener is at or above the lowest zero pressure level, see **Figure 22**.

$$P = \frac{\ell_1}{\ell}\frac{P_L}{2}$$

where:

ℓ_1 : Distance, in m, between the lower end of vertical stiffener and the lowest zero pressure level.

P_u : Lateral pressures at the upper end of the vertical stiffener span ℓ.

P_L : Lateral pressures at the lower end of the vertical stiffener span ℓ.

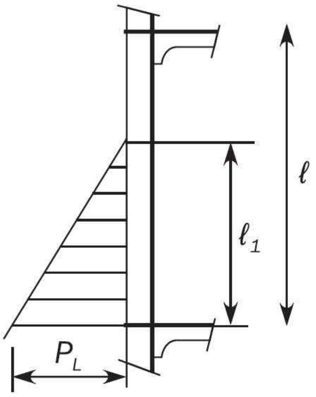


Figure 22 : Definition of pressure for vertical stiffeners

4. Primary Support Members

4.1 Load calculation point

4.1.1

The load calculation point is located at the middle of the full length, ℓ, at the attachment point of the primary supporting member with its attached plate. However, for primary supporting members in the cargo hold region the requirements in **Ch 6, Sec 6, [2]**, as applicable.

For primary supporting members located on transom plate, the y coordinate of the load calculation point is to be taken corresponding to *y* value at side shell at *z* level of load calculation point for the external dynamic pressure calculation. ⚓

Chapter 4

Loads

Section 1 Introduction

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

S : Static load case

$S+D$: Static plus dynamic load case

1. General

1.1 Application

1.1.1 Scope

This chapter provides the design load for strength and fatigue assessments.

The load combinations are to be derived for the design load scenarios specified in **Sec 7.** This section uses the concept of design load scenarios to specify consistent design load sets which cover the appropriate operating modes.

1.1.2 Equivalent Design Wave EDW

The dynamic loads associated with each dynamic load case are based on the Equivalent Design Wave (EDW) concept. The EDW concept applies a consistent set of dynamic loads to the ship such that specified dominant load response is equivalent to the required long term response value.

1.1.3 Probability level for strength and fatigue assessments

In this chapter, the assessments are to be understood as follows:

- Strength assessment means the assessment for the strength criteria excluding fatigue, for the loads corresponding to the probability level of 10^{-8} for the ballast water exchange, for harbour conditions and for flooded conditions.
- Fatigue assessment means the assessment for the fatigue criteria for the loads corresponding to the probability level of 10^{-2}.

1.1.4 Dynamic load components

All dynamic load components are to be concurrent values calculated for each dynamic load case.

1.1.5 Loads for strength assessment

The strength assessment is to be undertaken for all design load scenarios and the final assessment is to be made on the most onerous strength requirement.

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

The static loads are defined in the following sections:

- Still water hull girder loads in **Sec 4**.
- External loads in **Sec 5**.
- Internal loads in **Sec 6**.

The EDWs for the strength assessment and the dynamic load combination factors for global loads are listed in **Sec 2, [2].**

The dynamic load components are defined in the following sections:

- Dynamic hull girder load components in **Sec 4**.
- External loads in **Sec 5.**
- Internal loads in **Sec 6.**

1.1.6 Loads for fatigue assessment

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

The static loads are defined in the following sections:

- Still water hull girder loads in **Sec 4.**
- External loads in **Sec 5.**
- Internal loads in **Sec 6.**

The EDWs for the fatigue assessment are listed in **Sec 2, [2].**

The dynamic load components are defined in the following sections:

- Dynamic hull girder load components in **Sec 4.**
- External loads in **Sec 5.**
- Internal loads in **Sec 6.**

1.2 Definitions

1.2.1 Coordinate system

The coordinate system is defined in **Ch 1, Sec 4, [3.5.1].**

1.2.2 Sign convention for ship motions

The ship motions are defined with respect to the ship"s centre of gravity (COG) as shown in **Figure 1,** where:

- Positive surge is translation in the X-axis direction (positive forward).
- Positive sway is translation in the Y-axis direction (positive towards port side of ship).
- Positive heave is translation in the Z-axis direction (positive upwards).
- Positive roll motion is positive rotation about a longitudinal axis through the COG (starboard down and port up).
- Positive pitch motion is positive rotation about a transverse axis through the COG (bow down and stern up).
- Positive yaw motion is positive rotation about a vertical axis through the COG (bow moving to port and stern to starboard).

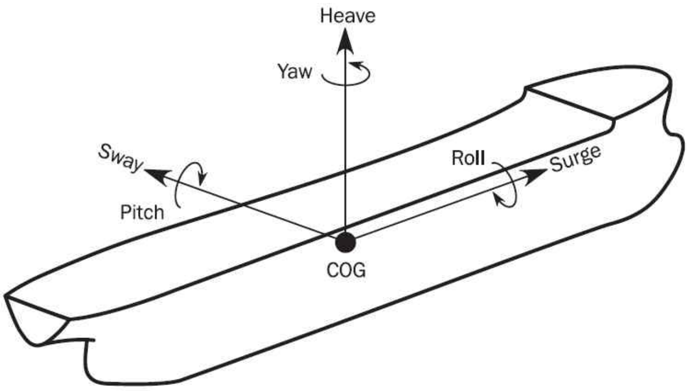


Figure 1 : Definition of positive motions

1.2.3 Sign convention for hull girder loads

The sign conventions of vertical bending moments, vertical shear forces, horizontal bending moments and torsional moments at any ship transverse section are as shown in **Figure 2,** namely:

- The vertical bending moments M_{sw} and M_{wv} are positive when they induce tensile stresses in the strength deck (hogging bending moment) and negative when they induce tensile stresses in the bottom (sagging bending moment).
- The vertical shear forces Q_{sw}, Q_{wv} are positive in the case of downward resulting forces acting aft of the transverse section and upward resulting forces acting forward of the transverse section under consideration.
- The horizontal bending moment M_{wh} is positive when it induces tensile stresses in the starboard side and negative when it induces tensile stresses in the port side.
- The torsional moment M_{wt} is positive in the case of resulting moment acting aft of the transverse section following negative rotation around the X-axis, and of resulting moment acting forward of the transverse section following positive rotation around the X-axis.

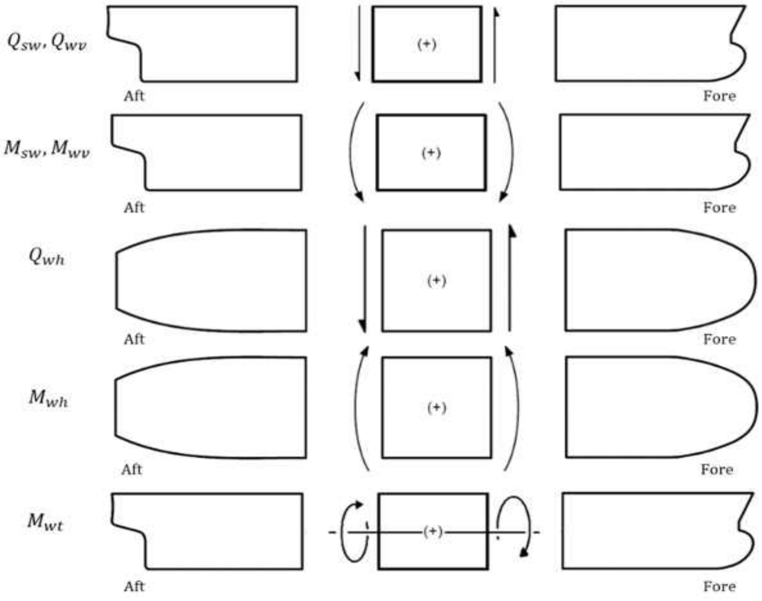


Figure 2 : Sign conventions for shear forces Q_{sw}, Q_{wv}, Q_{wh} and bending moments M_{sw}, M_{wv}, M_{wh} and M_{wt}

Section 2 Dynamic Load Cases

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

a_{surge}, $a_{pitch-x}$, a_{sway}, a_{roll-y}, a_{heave}, a_{roll-z}, $a_{pitch-z}$: Acceleration components, as defined in **Sec 3.**

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

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

f_T : Ratio between draught at a loading condition and scantling draught, as defined in **Sec 3.**

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

$f_{lp} = 1.0$ for $f_{xL} \le 0.5$

$f_{lp} = -1.0$ for $f_{xL} > 0.5$

f_{lp-OST} : Factor for the longitudinal distribution of the torsional moment for the OST load case, to be taken as:

$f_{lp-OST} = 1.0$ for $f_{xL} \le 0.45$

$f_{lp-OST} = -8.5 f_{xL} + 4.825$ for $0.45 < f_{xL} \le 0.65$

$f_{lp-OST} = -0.7$ for $f_{xL} > 0.65$

f_{lp-OSA} : Factor for the longitudinal distribution of the torsional moment for the OSA load case, to be taken as:

$f_{lp-OSA} = -0.8$ for $f_{xL} \le 0.3$

$f_{lp-OSA} = \frac{11}{3} f_{xL} - 1.9$ for $0.3 < f_{xL} \le 0.6$

$f_{lp-OSA} = 0.3$ for $f_{xL} > 0.6$

WS : Weather side, side of the ship exposed to the incoming waves.

LS : Lee side, sheltered side of the ship away from the incoming waves.

M_{WV} : Vertical wave bending moment, in kNm, defined in **Sec 4.**

Q_{WV} : Vertical wave shear force, in kN, defined in **Sec 4.**

M_{WH} : Horizontal wave bending moment, in kNm, defined in **Sec 4.**

Q_{WH} : Horizontal wave shear force, in kN, defined in **Sec 4.**

M_{WT} : Torsional wave bending moment, in kNm, defined in **Sec 4.**

C_{WV} : Load combination factor to be applied to the vertical wave bending moment.

C_{QV} : Load combination factor to be applied to the vertical wave shear force.

C_{WH} : Load combination factor to be applied to the horizontal wave bending moment.

C_{WT} : Load combination factor to be applied to the wave torsional moment.

C_{XS} : Load combination factor to be applied to the surge acceleration.

C_{XP} : Load combination factor to be applied to the longitudinal acceleration due to pitch.

C_{XG} : Load combination factor to be applied to the longitudinal acceleration due to pitch motion.

C_{YS} : Load combination factor to be applied to the sway acceleration.

C_{YR} : Load combination factor to be applied to the transverse acceleration due to roll.

C_{YG} : Load combination factor to be applied to the transverse acceleration due to roll motion.

C_{ZH} : Load combination factor to be applied to the heave acceleration.

C_{ZR} : Load combination factor to be applied to the vertical acceleration due to roll.

C_{ZP} : Load combination factor to be applied to the vertical acceleration due to pitch.

θ : Roll angle, in deg, as defined in **Sec 3, [2.1.1].**

ϕ : Pitch angle, in deg, as defined in **Sec 3, [2.1.2].**

1. General

1.1 Definition of dynamic load cases

1.1.1

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

- HSM load cases :
  HSM-1 and HSM-2: Head sea EDWs that minimise and maximise the vertical wave bending moment amidships respectively.
- HSA load cases:
  HSA-1 and HSA-2: Head sea EDWs that maximise and minimise the head sea vertical acceleration at FP respectively.
- FSM load cases:
  FSM-1 and FSM-2: Following sea EDWs that minimise and maximise the vertical wave bending moment amidships respectively.
- BSR load cases:
  BSR-1P and BSR-2P: Beam sea EDWs that minimise and maximise the roll motion downward and upward on the port side respectively with waves from the port side.

  BSR-1S and BSR-2S: Beam sea EDWs that maximise and minimise the roll motion downward and upward on the starboard side respectively with waves from the starboard side.
- BSP load cases:
  BSP-1P and BSP-2P: Beam sea EDWs that maximise and minimise the hydrodynamic pressure at the waterline amidships on the port side respectively.

  BSP-1S and BSP-2S: Beam sea EDWs that maximise and minimise the hydrodynamic pressure at the waterline amidships on the starboard side respectively.
- OST load cases:
  OST-1P and OST-2P: Oblique sea EDWs that minimise and maximise the torsional moment at 0.25L from the AE with waves from the port side respectively.

  OST-1S and OST-2S: Oblique sea EDWs that maximise and minimise the torsional moment at 0.25L from the AE with waves from the starboard side respectively.
- OSA load cases:
  OSA-1P and OSA-2P: Oblique sea EDWs that maximise and minimise the pitch acceleration with waves from the port side respectively.

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

Note 1: 1 and 2 denote the maximum or the minimum dominate load component for each EDW.
Note 2: P and S denote that the weather side is on port side and on starboard side respectively.

BSP load cases are not to be used for ballast conditions.

HSA and OSA load cases are not to be used for fatigue assessment.

1.2 Application

1.2.1

The dynamic load cases described in this section are to be used for determining the dynamic loads required by the design load scenarios described in **Sec 7.** These dynamic load cases are to be applied to the following structural assessments:

a) Strength assessment:
  - For plating, ordinary stiffeners and primary supporting members by prescriptive methods.
  - For the direct strength method (FE analysis) assessment of structural members.

b) Fatigue assessment:
  - For structural details covered by simplified stress analysis.
  - For structural details covered by FE stress analysis.

2. Dynamic load cases for strength assessment

2.1 Description of dynamic load cases

2.1.1

Table 1 to **Table 3** describe the ship motions responses and the global loads corresponding to each dynamic load case to be considered for the strength assessment.

Table 1 : Ship responses for HSM, HSA and FSM load cases - Strength assessment

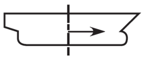
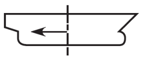
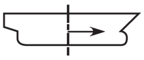
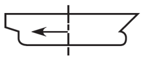
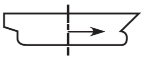
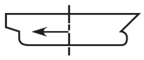
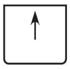
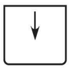
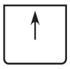
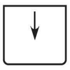
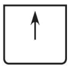
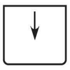
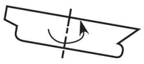
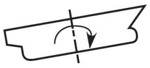
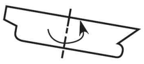
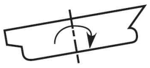
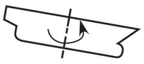
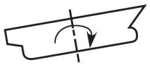
Load case	HSM-1	HSM-2	HSA-1	HSA-2	FSM-1	FSM-2
EDW	HSM		HSA		FSM	
Heading	Head		Head		Following	
Effect	Max. bending moment		Max. vertical acceleration		Max. bending moment	
VWBM	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging
VWSF	Negative-aft Positive-fore	Positive-aft Negative-fore	Negative-aft Positive-fore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

Table 2 : Ship responses for BSR and BSP load cases - Strength assessment

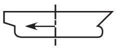
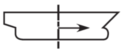
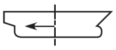
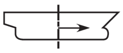
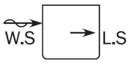
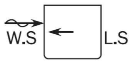
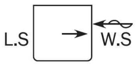
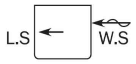
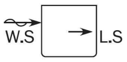
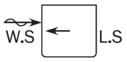
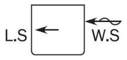
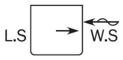
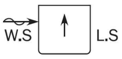
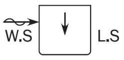
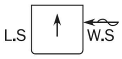
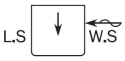
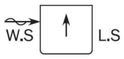
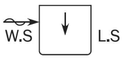
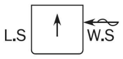
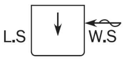
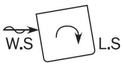
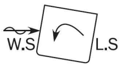
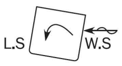
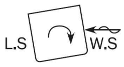
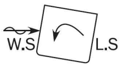
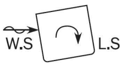
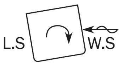
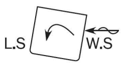
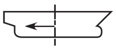
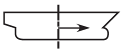
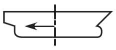
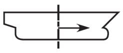
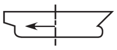
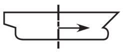
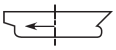
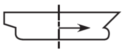
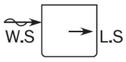
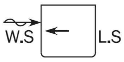
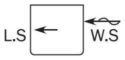
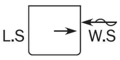
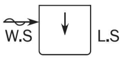
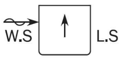
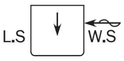
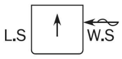
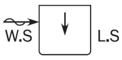
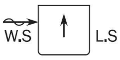
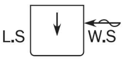
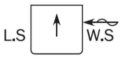
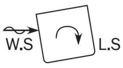
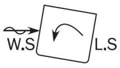
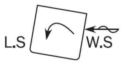
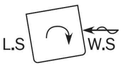
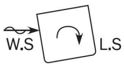
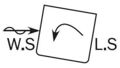
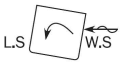
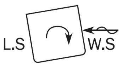
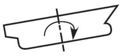
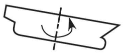
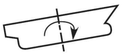
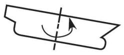
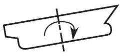
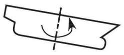
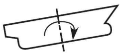
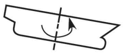
Load case	BSR-1P	BSR-2P	BSR-1S	BSR-2S	BSP-1P	BSP-2P	BSP-1S	BSP-2S
EDW	BSR		BSR		BSP		BSP	
Heading	Beam				Beam			
Effect	Max. roll				Max. pressure at waterline			
VWBM	-	-	-	-	Sagging	Hogging	Sagging	Hogging
VWSF	-	-	-	-	Negative-aft Positive-fore	Positive-aft Negative-fore	Negative-aft Positive-fore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

Table 3 : Ship responses for OST and OSA load cases – Strength assessment

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

2.2 Load combination factors

2.2.1

The load combinations factors, LCFs for the global loads and inertia load components for strength assessment are defined in:

Table 4 : LCFs for HSM, HSA and FSM load cases.

Table 5 : LCFs for BSR and BSP load cases.

Table 6 : LCFs for OST and OSA load cases.

Table 4 : Load combination factors, LCFs for HSM, HSA and FSM load cases – Strength assessment

Load component		LCF	HSM-1	HSM-2	HSA-1	HSA-2	FSM-1	FSM-2
Hull girder loads	M_{WV}	C_{WV}	-1.0	1.0	-0.9	0.9	-1.0	1.0
	Q_{WV}	C_{QW}	$-f_{lp}$	f_{lp}	$-f_{lp}$	f_{lp}	$-0.85f_{lp}$	$0.85f_{lp}$
	M_{WH}	C_{WH}	0.0	0.0	0.0	0.0	0.0	0.0
	Q_{WH}	C_{QH}	0.0	0.0	0.0	0.0	0.0	0.0
	M_{WT}	C_{WT}	0.0	0.0	0.0	0.0	0.0	0.0
Longitudinal accelerations	a_{surge}	C_{XS}	$-0.4f_T+0.6$	$0.4f_T-0.6$	$-0.4f_T+1$	$0.4f_T-1$	$-0.5f_T+0.5$	$0.5f_T-0.5$
	$a_{pitch-x}$	C_{XP}	-0.5	0.5	-1.0	1.0	-0.1	0.1
	$gsin\varphi$	C_{XG}	0.45	-0.45	0.95	-0.95	0.1	-0.1
Transverse accelerations	a_{sway}	C_{YS}	0.0	0.0	0.0	0.0	0.0	0.0
	a_{roll-y}	C_{YR}	0.0	0.0	0.0	0.0	0.0	0.0
	$gsin\theta$	C_{YG}	0.0	0.0	0.0	0.0	0.0	0.0
Vertical accelerations	a_{heave}	C_{ZH}	0.2	-0.2	$0.4f_T-0.1$	$-0.4f_T+0.1$	0.1	-0.1
	a_{roll-z}	C_{ZR}	0.0	0.0	0.0	0.0	0.0	0.0
	$a_{pitch-z}$	C_{ZP}	-0.5	0.5	-1.0	1.0	-0.1	0.1

Table 5 : Load combination factors, LCFs for BSR and BSP load cases – Strength assessment

Load component		LCF	BSR-1P	BSR-2P	BSR-1S	BSR-2S
Hull girder loads	M_{WV}	C_{WV}	0.0	0.0	0.0	0.0
	Q_{WV}	C_{QW}	0.0	0.0	0.0	0.0
	M_{WH}	C_{WH}	0.05	-0.05	-0.05	0.05
	Q_{WH}	C_{QH}	0.0	0.0	0.0	0.0
	M_{WT}	C_{WT}	0.0	0.0	0.0	0.0
Longitudinal accelerations	a_{surge}	C_{XS}	0.0	0.0	0.0	0.0
	$a_{pitch-x}$	C_{XP}	0.0	0.0	0.0	0.0
	$gsin\varphi$	C_{XG}	0.0	0.0	0.0	0.0
Transverse accelerations	a_{sway}	C_{YS}	$-0.7f_T+0.6$	$0.7f_T-0.6$	$0.7f_T-0.6$	$-0.7f_T+0.6$
	a_{roll-y}	C_{YR}	1.0	-1.0	-1.0	1.0
	$gsin\theta$	C_{YG}	-1.0	1.0	1.0	-1.0
Vertical accelerations	a_{heave}	C_{ZH}	$-0.8f_T+0.9$	$0.8f_T-0.9$	$-0.8f_T+0.9$	$0.8f_T-0.9$
	a_{roll-z}	C_{ZR}	1.0	-1.0	-1.0	1.0
	$a_{pitch-z}$	C_{ZP}	0.0	0.0	0.0	0.0

Load component		LCF	BSP-1P	BSP-2P	BSP-1S	BSP-2S
Hull girder loads	M_{WV}	C_{WV}	$-0.5f_T+0.25$	$0.5f_T-0.25$	$-0.5f_T+0.25$	$0.5f_T-0.25$
	Q_{WV}	C_{QW}	$(0.25f_T-0.5)f_{lp}$	$(-0.25f_T+0.5)f_{lp}$	$(0.25f_T-0.5)f_{lp}$	$(-0.25f_T+0.5)f_{lp}$
	M_{WH}	C_{WH}	0.15	-0.15	-0.15	0.15
	Q_{WH}	C_{QH}	$-0.1f_{lp}$	$0.1f_{lp}$	$0.1f_{lp}$	$-0.1f_{lp}$
	M_{WT}	C_{WT}	0.0	0.0	0.0	0.0
Longitudinal accelerations	a_{surge}	C_{XS}	-0.1	0.1	-0.1	0.1
	$a_{pitch-x}$	C_{XP}	0.0	0.0	0.0	0.0
	$gsin\varphi$	C_{XG}	0.0	0.0	0.0	0.0
Transverse accelerations	a_{sway}	C_{YS}	-1.0	1.0	1.0	-1.0
	a_{roll-y}	C_{YR}	$-0.58f_T+0.18$	$0.58f_T-0.18$	$0.58f_T-0.18$	$-0.58f_T+0.18$
	$gsin\theta$	C_{YG}	0.1	-0.1	-0.1	0.1
Vertical accelerations	a_{heave}	C_{ZH}	$0.5f_T+0.4$	$-0.5f_T-0.4$	$0.5f_T+0.4$	$-0.5f_T-0.4$
	a_{roll-z}	C_{ZR}	$-0.58f_T+0.18$	$0.58f_T-0.18$	$0.58f_T-0.18$	$-0.58f_T+0.18$
	$a_{pitch-z}$	C_{ZP}	0.0	0.0	0.0	0.0

Table 6 : Load combination factors, LCFs for OST and OSA load cases - Strength assessment

Load component		LCF	OST-1P	OST-2P	OST-1S	OST-2S
Hull girder loads	M_{WV}	C_{WV}	$-0.2f_T-0.3$	$0.2f_T+0.3$	$-0.2f_T-0.3$	$0.2f_T+0.3$
	Q_{WV}	C_{QW}	$-0.35f_{lp}$	$0.35f_{lp}$	$-0.35f_{lp}$	$0.35f_{lp}$
	M_{WH}	C_{WH}	-1.0	1.0	1.0	-1.0
	Q_{WH}	C_{QH}	$(1.1f_T-0.4)f_{lp}$	$(-1.1f_T+0.4)f_{lp}$	$(-1.1f_T+0.4)f_{lp}$	$(1.1f_T-0.4)f_{lp}$
	M_{WT}	C_{WT}	$-f_{lp-OST}$	f_{lp-OST}	f_{lp-OST}	$-f_{lp-OST}$
Longitudinal accelerations	a_{surge}	C_{XS}	-0.25	0.25	-0.25	0.25
	$a_{pitch-x}$	C_{XP}	0.6	-0.6	0.6	-0.6
	$gsin\varphi$	C_{XG}	-0.4	0.4	-0.4	0.4
Transverse accelerations	a_{sway}	C_{YS}	0.0	0.0	0.0	0.0
	a_{roll-y}	C_{YR}	$1.4f_T-0.7$	$-1.4f_T+0.7$	$-1.4f_T+0.7$	$1.4f_T-0.7$
	$gsin\theta$	C_{YG}	$-0.4f_T+0.1$	$0.4f_T-0.1$	$0.4f_T-0.1$	$-0.4f_T+0.1$
Vertical accelerations	a_{heave}	C_{ZH}	-0.15	0.15	-0.15	0.15
	a_{roll-z}	C_{ZR}	$1.4f_T-0.7$	$-1.4f_T+0.7$	$-1.4f_T+0.7$	$1.4f_T-0.7$
	$a_{pitch-z}$	C_{ZP}	0.6	-0.6	0.6	-0.6

Load component		LCF	OSA-1P	OSA-2P	OSA-1S	OSA-2S
Hull girder loads	M_{WV}	C_{WV}	$-0.3f_T+0.75$	$0.3f_T-0.75$	$-0.3f_T+0.75$	$0.3f_T-0.75$
	Q_{WV}	C_{QW}	$(-0.3f_T+0.75)f_{lp}$	$(0.3f_T-0.75)f_{lp}$	$(-0.3f_T+0.75)f_{lp}$	$(0.3f_T-0.75)f_{lp}$
	M_{WH}	C_{WH}	$-0.4f_T+1.1$	$0.4f_T-1.1$	$0.4f_T-1.1$	$-0.4f_T+1.1$
	Q_{WH}	C_{QH}	$(0.4f_T-1.1)f_{lp}$	$(-0.4f_T+1.1)f_{lp}$	$(-0.4f_T+1.1)f_{lp}$	$(0.4f_T-1.1)f_{lp}$
	M_{WT}	C_{WT}	$-f_{lp-OSA}$	f_{lp-OSA}	f_{lp-OSA}	$-f_{lp-OSA}$
Longitudinal accelerations	a_{surge}	C_{XS}	$0.2f_T-0.45$	$-0.2f_T+0.45$	$0.2f_T-0.45$	$-0.2f_T+0.45$
	$a_{pitch-x}$	C_{XP}	1.0	-1.0	1.0	-1.0
	$gsin\varphi$	C_{XG}	-0.6	0.6	-0.6	0.6
Transverse accelerations	a_{sway}	C_{YS}	$-0.2f_T$	$0.2f_T$	$0.2f_T$	$-0.2f_T$
	a_{roll-y}	C_{YR}	0.2	-0.2	-0.2	0.2
	$gsin\theta$	C_{YG}	0.1	-0.1	-0.1	0.1
Vertical accelerations	a_{heave}	C_{ZH}	$-0.4f_T+0.1$	$0.4f_T-0.1$	$-0.4f_T+0.1$	$0.4f_T-0.1$
	a_{roll-z}	C_{ZR}	0.2	-0.2	-0.2	0.2
	$a_{pitch-z}$	C_{ZP}	1.0	-1.0	1.0	-1.0

3. Dynamic load cases for fatigue assessment

3.1 Description of dynamic load cases

3.1.1

Table 7 to **Table 9** describe the ship motions responses and the global loads corresponding to each dynamic load case to be considered for the fatigue assessment.

Table 7 : Ship responses for HSM and FSM load cases – Fatigue assessment

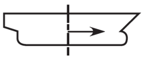
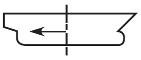
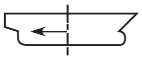
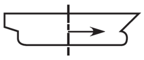
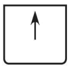
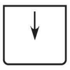
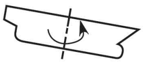
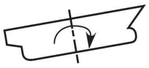
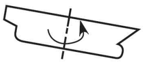
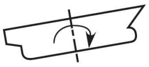
Loadcase	HSM-1	HSM-2	FSM-1	FSM-2
EDW	HSM		FSM	
Heading	Head		Following	
Effect	Max. bending moment		Max. bending moment	
VWBM	Sagging	Hogging	Sagging	Hogging
VWSF	Negative-aft Positive-fore	Positive-aft Negative-fore	Negative-aft Positive-fore	Positive-aft Negative-fore
HWBM	-	-	-	-
HWSF	-	-	-	-
TM	-	-	-	-
Surge	To stern	To bow	To bow	To stern
a_{surge}				
Sway	-	-	-	-
a_{sway}	-	-	-	-
Heave	Down	Up	-	-
a_{heave}			-	-
Roll	-	-	-	-
a_{roll}	-	-	-	-
Pitch	Bow down	Bow up	Bow down	Bow up
a_{pitch}				

Table 8 : Ship responses for BSR and BSP load cases – Fatigue assessment

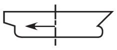
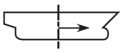
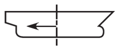
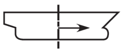
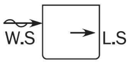
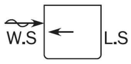
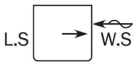
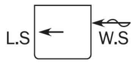
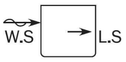
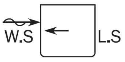
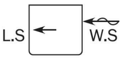
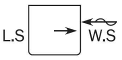
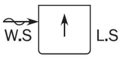
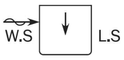
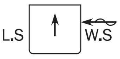
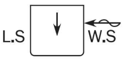
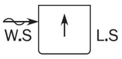
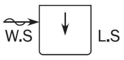
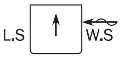
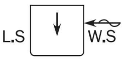
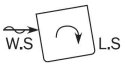
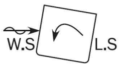
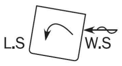
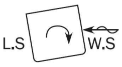
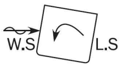
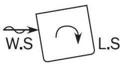
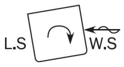
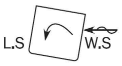
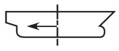
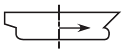
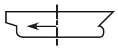
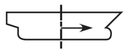
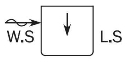
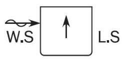
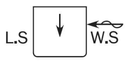
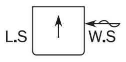
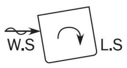
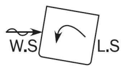
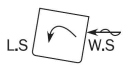
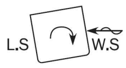
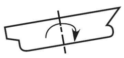
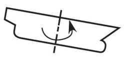
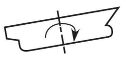
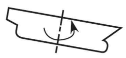
Load case	BSR-1P	BSR-2P	BSR-1S	BSR-2S	BSP-1P	BSP-2P	BSP-1S	BSP-2S
EDW	BSR		BSR		BSP		BSP	
Heading	Beam				Beam			
Effect	Max. roll				Max. pressure at waterline			
VWBM	–	–	–	–	Sagging	Hogging	Sagging	Hogging
VWSF	–	–	–	–	Negative-aft Positive-fore	Positive-aft Negative-fore	Negative-aft Positive-fore	Positive-aft Negative-fore
HWBM	Stbd tensile	Port tensile	Port tensile	Stbd tensile	Stbd tensile	Port tensile	Port tensile	Stbd tensile
HWSF	–	–	–	–	Negative-aft Positive-fore	Positive-aft Negative-fore	Positive-aft Negative-fore	Negative-aft Positive-fore
TM	–	–	–	–	–	–	–	–
Surge	–	–	–	–	To bow	To stern	To bow	To stern
a_{surge}	–	–	–	–				
Sway	To portside or to starboard		To starboard or to portside		To portside	To starboard	To starboard	To portside
a_{sway}	 or 		 or 					
Heave	Down	Up	Down	Up	Down	Up	Down	Up
a_{heave}								
Roll	Portside down	Portside up	Starboard down	Starboard up	Portside up	Portside down	Starboard up	Starboard down
a_{roll}								
Pitch	–	–	–	–	–	–	–	–
a_{pitch}	–	–	–	–	–	–	–	–

Table 9 : Ship responses for OST load cases - Fatigue assessment

Loadcase	OST-1P	OST-2P	OST-1S	OST-2S
EDW	OST			
Heading	Oblique			
Effect	Max. torsional moment			
VWBM	Sagging	Hogging	Sagging	Hogging
VWSF	Negative-aft Positive-fore	Positive-aft Negative-fore	Negative-aft Positive-fore	Positive-aft Negative-fore
HWBM	Port tensile	Stbd tensile	Stbd tensile	Port tensile
HWSF	Positive-aft Negative-fore	Negative-aft Positive-fore	Negative-aft Positive-fore	Positive-aft Negative-fore
TM	Negative-aft Positive-fore	Positive-aft Negative-fore	Positive-aft Negative-fore	Negative-aft Positive-fore
Surge	To bow	To stern	To bow	To stern
a_{surge}				
Sway	–	–	–	–
a_{sway}	–			–
Heave	Up	Down	Up	Down
a_{heave}				
Roll	Portside down	Portside up	Starboard down	Starboard up
a_{roll}				
Pitch	Bow up	Bow down	Bow up	Bow down
a_{pitch}				

3.2 Load combination factors

3.2.1

The load combinations factors, LCFs for the global loads and inertia load components for fatigue assessment are defined in:

Table 10 : LCFs for HSM and FSM load cases.

Table 11 : LCFs for BSR and BSP load cases.

Table 12 : LCFs for OST load cases.

Table 10 : Load combination factors, LCFs for HSM and FSM load cases - Fatigue assessment

Load component		LCF	HSM-1	HSM-2	FSM-1	FSM-2
Hull girder loads	M_{WV}	C_{WV}	-1.0	1.0	-1.0	1.0
	Q_{WV}	C_{QW}	$-f_{lp}$	f_{lp}	$-(-0.15f_T+0.95)f_{lp}$	$(-0.15f_T+0.95)f_{lp}$
	M_{WH}	C_{WH}	0.0	0.0	0.0	0.0
	Q_{WH}	C_{QH}	0.0	0.0	0.0	0.0
	M_{WT}	C_{WT}	0.0	0.0	0.0	0.0
Longitudinal accelerations	a_{surge}	C_{XS}	$-0.4f_T+0.6$	$0.4f_T-0.6$	$-0.65f_T+0.6$	$0.65f_T-0.6$
	$a_{pitch-x}$	C_{XP}	$-0.35f_T-0.5$	$0.35f_T+0.5$	-0.05	0.05
	$gsin\varphi$	C_{XG}	$0.35f_T+0.4$	$-0.35f_T-0.4$	0.1	-0.1
Transverse accelerations	a_{sway}	C_{YS}	0.0	0.0	0.0	0.0
	a_{roll-y}	C_{YR}	0.0	0.0	0.0	0.0
	$gsin\theta$	C_{YG}	0.0	0.0	0.0	0.0
Vertical accelerations	a_{heave}	C_{ZH}	$0.4f_T-0.1$	$-0.4f_T+0.1$	0.0	0.0
	a_{roll-z}	C_{ZR}	0.0	0.0	0.0	0.0
	$a_{pitch-z}$	C_{ZP}	$-0.35f_T-0.5$	$0.35f_T+0.5$	-0.05	0.05

Table 11 : Load combination factors, LCFs for BSR and BSP load cases – Fatigue assessment

Load component		LCF	BSR-1P	BSR-2P	BSR-1S	BSR-2S
Hull girder loads	M_{WV}	C_{WV}	0.0	0.0	0.0	0.0
	Q_{WV}	C_{QW}	0.0	0.0	0.0	0.0
	M_{WH}	C_{WH}	0.05	-0.05	-0.05	0.05
	Q_{WH}	C_{QH}	0.0	0.0	0.0	0.0
	M_{WT}	C_{WT}	0.0	0.0	0.0	0.0
Longitudinal accelerations	a_{surge}	C_{XS}	0.0	0.0	0.0	0.0
	$a_{pitch-x}$	C_{XP}	0.0	0.0	0.0	0.0
	$gsin\varphi$	C_{XG}	0.0	0.0	0.0	0.0
Transverse accelerations	a_{sway}	C_{YS}	$-0.8f_T+0.75$	$0.8f_T-0.75$	$0.8f_T-0.75$	$-0.8f_T+0.75$
	a_{roll-y}	C_{YR}	$-1.35f_T+1.75$	$1.35f_T-1.75$	$1.35f_T-1.75$	$-1.35f_T+1.75$
	$gsin\theta$	C_{YG}	-1.0	1.0	1.0	-1.0
Vertical accelerations	a_{heave}	C_{ZH}	$0.75f_T-0.8$	$0.8-0.75f_T$	$0.8-0.75f_T$	$0.75f_T-0.8$
	a_{roll-z}	C_{ZR}	$-1.35f_T+1.75$	$1.35f_T-1.75$	$1.35f_T-1.75$	$-1.35f_T+1.75$
	$a_{pitch-z}$	C_{ZP}	0.0	0.0	0.0	0.0

Load component		LCF	BSP-1P	BSP-2P	BSP-1S	BSP-2S
Hull girder loads	M_{WV}	C_{WV}	$-0.65f_T+0.4$	$0.65f_T-0.4$	$-0.65f_T+0.4$	$0.65f_T-0.4$
	Q_{WV}	C_{QW}	$(-0.65f_T+0.4)f_{lp}$	$(0.65f_T-0.4)f_{lp}$	$(-0.65f_T+0.4)f_{lp}$	$(0.65f_T-0.4)f_{lp}$
	M_{WH}	C_{WH}	0.15	-0.15	-0.15	0.15
	Q_{WH}	C_{QH}	$-0.1f_{lp}$	$0.1f_{lp}$	$0.1f_{lp}$	$-0.1f_{lp}$
	M_{WT}	C_{WT}	0.0	0.0	0.0	0.0
Longitudinal accelerations	a_{surge}	C_{XS}	0.0	0.0	0.0	0.0
	$a_{pitch-x}$	C_{XP}	0.0	0.0	0.0	0.0
	$gsin\varphi$	C_{XG}	0.0	0.0	0.0	0.0
Transverse accelerations	a_{sway}	C_{YS}	$-2.4f_T+1.5$	$2.4f_T-1.5$	$2.4f_T-1.5$	$-2.4f_T+1.5$
	a_{roll-y}	C_{YR}	$-3.3f_T+3.0$	$3.3f_T-3.0$	$3.3f_T-3.0$	$-3.3f_T+3.0$
	$gsin\theta$	C_{YG}	$2.6f_T-2.5$	$-2.6f_T+2.5$	$-2.6f_T+2.5$	$2.6f_T-2.5$
Vertical accelerations	a_{heave}	C_{ZH}	$0.55f_T+0.2$	$-0.55f_T-0.2$	$0.55f_T+0.2$	$-0.55f_T-0.2$
	a_{roll-z}	C_{ZR}	$-3.3f_T+3.0$	$3.3f_T-3.0$	$3.3f_T-3.0$	$-3.3f_T+3.0$
	$a_{pitch-z}$	C_{ZP}	0.0	0.0	0.0	0.0

Table 12 : Load combination factors, LCFs for OST load cases – Fatigue assessment

Load component		LCF	OST-1P	OST-2P	OST-1S	OST-2S
Hull girder loads	M_{WV}	C_{WV}	$-0.8f_T+0.5$	$0.8f_T-0.5$	$-0.8f_T+0.5$	$0.8f_T-0.5$
	Q_{WV}	C_{QW}	$(-0.8f_T+0.5)f_{lp}$	$(0.8f_T-0.5)f_{lp}$	$(-0.8f_T+0.5)f_{lp}$	$(0.8f_T-0.5)f_{lp}$
	M_{WH}	C_{WH}	$-1.3f_T+0.3$	$1.3f_T-0.3$	$1.3f_T-0.3$	$-1.3f_T+0.3$
	Q_{WH}	C_{QH}	$(0.11f_T+0.05)f_{lp}$	$(-0.11f_T-0.05)f_{lp}$	$(-0.11f_T-0.05)f_{lp}$	$(0.11f_T+0.05)f_{lp}$
	M_{WT}	C_{WT}	$-f_{lp-OST}$	f_{lp-OST}	f_{lp-OST}	$-f_{lp-OST}$
Longitudinal accelerations	a_{surge}	C_{XS}	$0.1f_T-0.2$	$-0.1f_T+0.2$	$0.1f_T-0.2$	$-0.1f_T+0.2$
	$a_{pitch-x}$	C_{XP}	$-0.26f_T+0.24$	$0.26f_T-0.24$	$-0.26f_T+0.24$	$0.26f_T-0.24$
	$g sin\varphi$	C_{XG}	$0.26f_T-0.24$	$-0.26f_T+0.24$	$0.26f_T-0.24$	$-0.26f_T+0.24$
Transverse accelerations	a_{sway}	C_{YS}	0.0	0.0	0.0	0.0
	a_{roll-y}	C_{YR}	$3.4f_T-2.9$	$-3.4f_T+2.9$	$-3.4f_T+2.9$	$3.4f_T-2.9$
	$g sin\theta$	C_{YG}	$-2.5f_T+2.4$	$2.5f_T-2.4$	$2.5f_T-2.4$	$-2.5f_T+2.4$
Vertical accelerations	a_{heave}	C_{ZH}	$1.3f_T-1.2$	$-1.3f_T+1.2$	$1.3f_T-1.2$	$-1.3f_T+1.2$
	a_{roll-z}	C_{ZR}	$3.4f_T-2.9$	$-3.4f_T+2.9$	$-3.4f_T+2.9$	$3.4f_T-2.9$
	$a_{pitch-z}$	C_{ZP}	$-0.26f_T+0.24$	$0.26f_T-0.24$	$-0.26f_T+0.24$	$0.26f_T-0.24$

Section 3 Ship Motions and Accelerations

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

a_0 : Acceleration parameter, to be taken as:

$$a_0 = (1.31 - 0.43C_B)\left(\frac{4.2}{\sqrt{L}} + \frac{16}{L} - \frac{150}{L^2}\right)$$

T_θ : Roll period, in s, as defined in **[2.1.1].**

θ : Roll angle, in deg, as defined in **[2.1.1].**

T_ϕ : Pitch period, in s, as defined in **[2.1.2].**

ϕ : Pitch angle, in deg, as defined in **[2.1.2].**

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

$$R = \frac{1}{2}(0.35B + 1.4T_{LC})$$

C_{XG}, C_{XS}, C_{XP}, C_{YG}, C_{YS}, C_{YR}, C_{ZH}, C_{ZR} and C_{ZP} : Load combination factors, as defined in **Sec 2.**

a_{roll-y} : Transverse acceleration due to roll, in $\mathrm{m/s^2}$, as defined in **[3.3.2].**

$a_{pitch-x}$: Longitudinal acceleration due to pitch, in $\mathrm{m/s^2}$, as defined in **[3.3.1].**

a_{roll-z} : Vertical acceleration due to roll, in $\mathrm{m/s^2}$, as defined in **[3.3.3].**

$a_{pitch-z}$: Vertical acceleration due to pitch, in $\mathrm{m/s^2}$, as defined in **[3.3.3].**

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

$$f_T = \frac{T_{LC}}{T_{SC}}$$ but is not to be taken less than 0.5.

T_{LC} : Draught, in m, amidships for the considered load case.

x, y, z : X, Y and Z coordinates, in m, of the considered point with respect to the coordinate system, as defined in **Sec 1, [1.2.1].**

f_{ps} : Coefficient for strength assessments which is dependant on the applicable design load scenario specified in **Sec 7,** and to be taken as:

f_{ps} = 1.0 for the extreme sea loads design load scenario.

f_{ps} = 0.8 for the ballast water exchange design load scenario.

f_{ps} = 0.8 for the accidental design load scenario at sea.

f_{ps} = 0.4 for the harbour/sheltered water design load scenario.

f_R : Coefficient related to the operational profile, to be taken as:

f_R = 0.85

1. General

1.1 Definition

1.1.1

The ship motions and accelerations are assumed to be sinusoidal. The motion values defined by the formulae in this section are single amplitudes, i.e. half of the 'crest to trough' height.

2. Ship motions and accelerations

2.1 Ship motions

2.1.1 Roll motion

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

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

The roll angle, θ in deg, to be taken as:

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

where:

f_p : Coefficient to be taken as:

$f_p = f_{ps}$	for strength assessment.
$f_p = 0.1\left[(-8f_T + 10) - B \times 10^{-2}\right]$	for fatigue assessment.

f_{BK} : To be taken as:

$f_{BK} = 1.2$	for ships without bilge keel.
$f_{BK} = 1.0$	for ships with bilge keel.

k_r : Roll radius of gyration, in m, in the considered loading condition. The values in **Table 1** is to be adopted unless provided in the loading manual.

GM : Metacentric height, in m, in the considered loading condition. The values in **Table 1** is to be adopted unless provided in the loading manual.

Table 1 : k_r and GM values

Loading condition(1)	T_{LC}	k_r	GM
Full load condition	T_{SC}	$0.35B$	$0.06B$
Ballast condition	T_{BAL}	$0.45B$	$0.16B$

(1) For flooded loading conditions, the values of k_r and GM, unless provided in the loading manual, are to be taken as those for the full load condition.

2.1.2 Pitch motion

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

$$T_\phi = \sqrt{\frac{2\pi L}{g}}$$

where:

The pitch angle, ϕ in deg, is to be taken as:

$$\phi = 1350 f_R f_p L^{-0.94}\left\{1.0 + \left(\frac{15}{\sqrt{gL}}\right)^{1.6}\right\}$$

where:

f_p : Coefficient to be taken as:

$f_p = f_{ps}$	for strength assessment.
$f_p = 0.92\left[(0.36 - 0.1 f_T) - (11.6 - 5.17 f_T) L \times 10^{-9.34}\right]$	for fatigue assessment.

2.2 Ship accelerations at the centre of gravity

2.2.1 Surge acceleration

The longitudinal acceleration due to surge, in $\mathrm{m/s^2}$, is to be taken as:

$$a_{surge} = 0.32 f_R f_p a_0 g$$

where:

f_p : Coefficient to be taken as:

$f_p = f_{ps}$	for strength assessment.
$f_p = 0.9\left[0.4 - (12 f_T - 0.6) L \times 10^{-4.26}\right]$	for fatigue assessment.

2.2.2 Sway acceleration

The transverse acceleration due to sway, in $\mathrm{m/s^2}$, is to be taken as:

$$a_{sway} = 0.56 f_R f_p a_0 g$$

where:

f_p : Coefficient to be taken as:

$f_p = f_{ps}$	for strength assessment.
$f_p = 0.9\left[0.3 - (0.56 f_T - 2) B \times 10^{-3.7}\right]$	for fatigue assessment.

2.2.3 Heave acceleration

The vertical acceleration due to heave, in $\mathrm{m/s^2}$, is to be taken as:

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

where:

f_p : Coefficient to be taken as:

$f_p = f_{ps}$	for strength assessment.
$f_p = 0.9\left[(0.35 + 0.15 f_T) - 5L \times 10^{-4}\right]$	for fatigue assessment.

2.2.4 Roll acceleration

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

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

where:

θ : Roll angle using f_p equal to 1.0

f_p : Coefficient to be taken as:

$f_p = f_{ps}$ for strength assessment.

$f_p = 0.3\left[(-5f_T + 10) - B \times 10^{-2}\right]$ for fatigue assessment.

2.2.5 Pitch acceleration

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

$$a_{pitch} = f_p\left(\frac{3.1}{\sqrt{gL}} + 1.4\right)\phi \frac{\pi}{180}\left(\frac{2\pi}{T_\phi}\right)^2$$

where:

ϕ : Pitch angle using f_p equal to 1.0

f_p : Coefficient to be taken as:

$f_p = f_{ps}$ for strength assessment.

$f_p = 1.0$ for fatigue assessment.

3. Accelerations at any position

3.1 General

3.1.1

The accelerations used to derive the inertial loads at any position are defined with respect to the ship fixed coordinate system. Hence the acceleration values defined in **[3.2]** and **[3.3]** include the gravitational acceleration components due to the instantaneous roll and pitch angles.

3.1.2

The accelerations to be applied for the dynamic load cases defined in **Sec 2** are given in **[3.2]**.

3.1.3

The envelope accelerations as defined in **[3.3]** are provided for advisory purposes and may be used for other design purpose when the maximum design acceleration values are required, for example, crane foundations, machinery foundations, etc.

3.2 Accelerations for dynamic load cases

3.2.1 General

The accelerations to be applied for the dynamic load cases defined in **Sec 2** are given in **[3.2.2]** to **[3.2.4]**.

3.2.2 Longitudinal acceleration

The longitudinal acceleration at any position for each dynamic load case, in $\mathrm{m/s^2}$, is to be taken as:

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

3.2.3 Transverse acceleration

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

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

3.2.4 Vertical acceleration

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

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

3.3 Envelope accelerations

3.3.1 Longitudinal acceleration

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

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

where:

$a_{pitch-x}$: Longitudinal acceleration due to pitch, in $\mathrm{m/s^2}$.

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

3.3.2 Transverse acceleration

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

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

where:

a_{roll-y} : Transverse acceleration due to roll, in $\mathrm{m/s^2}$.

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

3.3.3 Vertical acceleration

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

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

where:

$a_{pitch-z}$: Vertical acceleration due to pitch, in $\mathrm{m/s^2}$.

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

a_{roll-z} : Vertical acceleration due to roll, in $\mathrm{m/s^2}$.

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

Section 4 Hull Girder Loads

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

x : X coordinate, in m, of the calculation point with respect to the reference coordinate system defined in **Sec 1, [1.2.1].**

f_{xL} : Ratio as defined in **Sec 2.**

f_β : Heading correction factor, to be taken as:

a) For strength assessment:

f_β = 1.0 in general

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

b) For fatigue assessment:

f_β = 1.0

f_{ps} : Coefficient, as defined in **Sec 3**.

f_R : Coefficient, as defined in **Sec 3**.

C_w : Wave coefficient, to be taken as:

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

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

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

C_{wp} : Waterplane coefficient at scantling draught to be taken as:

$$C_{wp} = \frac{A_{wp}}{LB}$$

A_{wp} : Waterplane area at scantling draught, in m^2

HSM, HSA, FSM, BSR, BSP, OST, OSA : Dynamic load cases, as defined in **Sec 2.**

1. Application

1.1 General

1.1.1

The hull girder loads for the static (S) design load scenarios is to be taken as the still water loads defined in **[2].**

1.1.2

The total hull girder loads for the static plus dynamic (S+D) design load scenarios are to be derived for each dynamic load case and are to be taken as the sum of the still water loads defined in **[2]** and the dynamic loads defined in **[3.7]**.

2. Vertical still water hull girder loads

2.1 Application

2.1.1 General

The designer is to provide the permissible still water bending moment and shear force for seagoing and harbour/sheltered water operations.

The permissible still water hull girder loads are to be given at each transverse bulkhead in the cargo hold region, at the middle of cargo compartments, at the collision bulkhead, at the engine room forward bulkhead and at the midpoint between the forward and aft engine room bulkheads. The permissible hull girder bending moments and shear forces at any other position may be obtained by linear interpolation.

Still water bending moments, M_S in kNm, and still water shear forces, F_S in kN, are to be calculated at each section along the ship length for design loading conditions as specified in **[2.1.2]**.

2.1.2 Design loading conditions

In general, the design cargo and ballast loading conditions, based on amount of bunker, fresh water and stores at departure and arrival, are to be considered for the M_S and F_S calculations. Where the amount and disposition of consumables at any intermediate stage of the voyage are considered more severe, calculations for such intermediate conditions are to be submitted in addition to those for departure and arrival conditions. Also, where any ballasting and/or de-ballasting is intended during voyage, calculations of the intermediate condition just before and just after ballasting and/or de-ballasting any ballast tank are to be submitted and where approved included in the loading manual for guidance.

The permissible vertical still water bending moments M_{Smax} and M_{Smin} and the permissible vertical still water shear forces F_{Smax} and F_{Smin} in seagoing conditions at any longitudinal position are to envelop:

- The maximum and minimum still water bending moments and shear forces for the seagoing loading conditions defined in the loading manual.
- The maximum and minimum still water bending moments and shear forces specified by the designer

The loading manual should include the relevant loading conditions, which envelop the still water hull girder loads for seagoing conditions.

2.2 Vertical still water bending moment

2.2.1 Still water bending moment

When the still water bending moments are not defined in the loading manual, the permissible still water bending moment, M_{sw-h}, in kNm, in hogging condition, is to be taken as:

Hogging conditions:

$$M_{sw-h} = f_{sw}(190\, C_w\, L^2 B(C_B + 0.7)10^{-3} - M_{wv-h-mid})$$

where:

$M_{wv-h-mid}$: Vertical wave bending moment for strength assessment in hogging condition, as defined in **[3.2]** using f_p and f_m equal to 1.0.

f_{sw} : Distribution factor along the ship length. To be taken as, see **Figure 1**:

f_{sw} = 0.0 for $f_{xL} = 0.0,\ f_{xL} = 1.0$

f_{sw} = 0.15 for $f_{xL} = 0.1$

f_{sw} = 1.0 for $0.3 \le f_{xL} \le 0.7$

f_{sw} = 0.15 for $f_{xL} = 0.9$

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

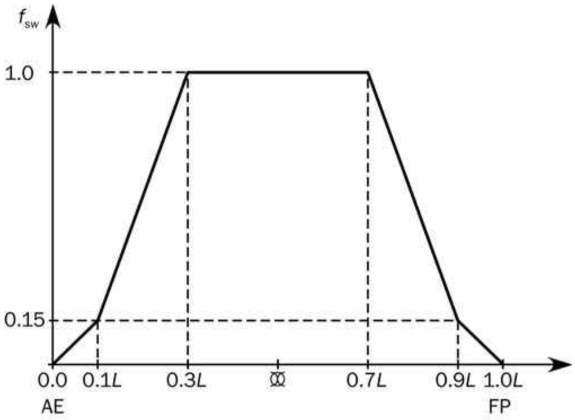


Figure 1 : Distribution factor f_{sw}

2.2.2 Permissible vertical still water bending moment in seagoing condition

The permissible vertical still water bending moments, M_{sw-h} and M_{sw-s} in seagoing condition at any longitudinal position are to envelop:

- The most severe still water bending moments calculated, in hogging and sagging conditions, respectively, for the seagoing loading conditions defined in **Sec 8**.
- The most severe still water bending moments for the seagoing loading conditions defined in the loading manual.

2.2.3 Permissible vertical still water bending moment in harbour / sheltered water

The permissible vertical still water bending moments in the harbour / sheltered water M_{sw-p-h} and M_{sw-p-s} at any longitudinal position are to envelop:

- The most severe still water bending moments, in hogging and sagging conditions, respectively, for the harbour / sheltered water loading conditions defined in **Sec 8**.
- The most severe still water bending moments for the harbour / sheltered water loading conditions defined in the loading manual.
- The permissible still water bending moment defined in **[2.2.2]**.

2.2.4 Permissible vertical still water bending moment in flooded condition at sea

The permissible vertical still water bending moments in flooded condition M_{sw-f} at any longitudinal position are to envelop:

- The most severe still water bending moments, in hogging and sagging conditions, respectively, for the intact and flooded seagoing loading conditions defined in **Sec 8**.
- The most severe still water bending moments for the intact and flooded seagoing loading conditions defined in the loading manual.
- The permissible still water bending moment defined in **[2.2.2]**.

2.2.5 Permissible vertical still water bending moment in tank testing condition

The permissible vertical still water bending moments in tank testing condition M_{sw-t} at any longitudinal position are to envelop:

- The most severe still water bending moments for the tank testing conditions defined in the tank testing procedure.
- When the still water bending moments are not defined in the tank testing procedure, the permissible still water bending moment may be taken the values as defined in **[2.2.2]**.

2.3 Vertical still water shear force

2.3.1 Permissible still water shear force in seagoing condition

The permissible vertical still water shear forces, Q_{sw}, in seagoing condition at any longitudinal position are to envelop:

- The most severe still water shear forces, positive or negative, for the seagoing loading conditions defined in **Sec 8**.
- The most severe still water shear forces for the seagoing loading conditions defined in the loading manual.

2.3.2 Permissible still water shear force in harbour / sheltered water

The permissible vertical still water shear forces, Q_{sw-p}, in the harbour / sheltered water at any longitudinal position are to envelop:

- The most severe still water shear forces, positive or negative, for the harbour / sheltered water loading conditions defined in **Sec 8**.
- The most severe still water shear forces for the harbour / sheltered water loading conditions defined in the loading manual.
- The permissible still water shear force defined in **[2.3.1]**.

2.3.3 Permissible still water shear force in flooded condition at sea

The permissible vertical still water shear forces, Q_{sw-f}, in flooded condition at any longitudinal position are to envelop:

- The most severe still water shear forces, positive or negative, for the flooded seagoing loading conditions defined in **Sec 8**.
- The most severe still water shear forces for the flooded seagoing loading conditions defined in the loading manual.
- The permissible still water shear force defined in **[2.3.1]**.

2.3.4 Permissible still water shear force in tank testing condition

The permissible vertical still water shear forces, Q_{sw-t}, in tank testing condition at any longitudinal position are to envelop:

- The most severe still water shear forces for the tank testing conditions defined in the tank testing procedure.
- When the still water shear forces are not defined in the tank testing procedure, the permissible still water shear force may be taken the values as defined in **[2.3.1]**.

2.4 Torsional still water moment

2.4.1

The value and distribution of still water moment torsional, M_{st}, are to be specified by designer and are not to be less than minimum design value to still water torsional moment. The minimum design value of still water torsional moment, M_{st}, in kNm, at any position along the ship is defined as:

$$M_{st} = 0.11 B W_{total-cont} (1 - L/500)$$

where:

$W_{total-cont}$: maximum total container weight of vessel, in ton

$$W_{total-cont} = n \cdot W_{cont}$$

n : Number of containers corresponding to W_{cont}

W_{cont} : Maximum weight of 20 ft container in the loading manual, in ton

3. Dynamic hull girder loads

3.1 Wave parameter

3.1.1

The wave parameter is defined as follows:

$$C = 1 - 1.50\left(1 - \sqrt{\frac{L}{L_{ref}}}\right)^{2.2} \qquad \text{for } L \le L_{ref}$$

$$C = 1 - 0.45\left(\sqrt{\frac{L}{L_{ref}}} - 1\right)^{1.7} \qquad \text{for } L > L_{ref}$$

where:

L_{ref} : Reference length, in m, to be taken as:

$L_{ref} = 315\, C_{wp}^{-1.3}$ for the determination of vertical wave bending moments according to **[3.2].**

$L_{ref} = 330\, C_{wp}^{-1.3}$ for the determination of vertical wave shear forces according to **[3.3].**

3.2 Vertical wave bending moment

3.2.1

The distribution of the vertical wave induced bending moments, M_{wv} in kNm, along the ship length is given in **Figure 2**, where:

$$M_{wv-Hog} = 1.5\, f_R f_p L^3 C\, C_{wp} \left(\frac{B}{L}\right)^{0.8} f_{NL-Hog}$$

$$M_{wv-Sag} =- 1.5\, f_R f_p L^3 C\, C_{wp} \left(\frac{B}{L}\right)^{0.8} f_{NL-Sag}$$

where:

f_p : Coefficient to be taken as:

$f_p = f_{ps}$ for strength assessment.

$f_p = 0.9\left[0.27 - (16 - 16 f_T) L \times 10^{-5}\right]$ for fatigue assessment.

f_{NL-Hog} : Non-linear correction for hogging, to be taken as:

$f_{NL-Hog} = 0.3 \dfrac{C_B}{C_{wp}} \sqrt{T_{SC}}$, for strength assessment, not to be taken greater than 1.1.

$f_{NL-Hog} = 1.0$, for fatigue assessment

f_{NL-Sag} : Non-linear correction for sagging, to be taken as:

$f_{NL-Sag} = 4.5 \dfrac{1 + 0.2 f_{Bow}}{C_{wp} \sqrt{C_B} L^{0.3}}$, for strength assessment, not to be taken less than 1.0.

$f_{NL-Sag} = 1.0$, for fatigue assessment

f_{Bow} : Bow flare shape coefficient, to be taken as:

$$f_{Bow} = \frac{A_{DK} - A_{WL}}{0.2 L z_f}$$

A_{DK} : Projected area in horizontal plane of uppermost deck, in m^2 including the forecastle deck, if any, extending from 0.8 L forward (see **Figure 3**). Any other structures, e.g. plated bulwark, are to be excluded.

A_{WL} : Waterplane area, in m^2, at scantling draught T_{SC}, extending from 0.8 L forward.

z_f : Vertical distance, in m, from the waterline at scantling draught T_{SC} to the uppermost deck (or forecastle deck), measured at FE (see **Figure 3**). Any other structures, e.g. plated bulwark, are to be excluded.

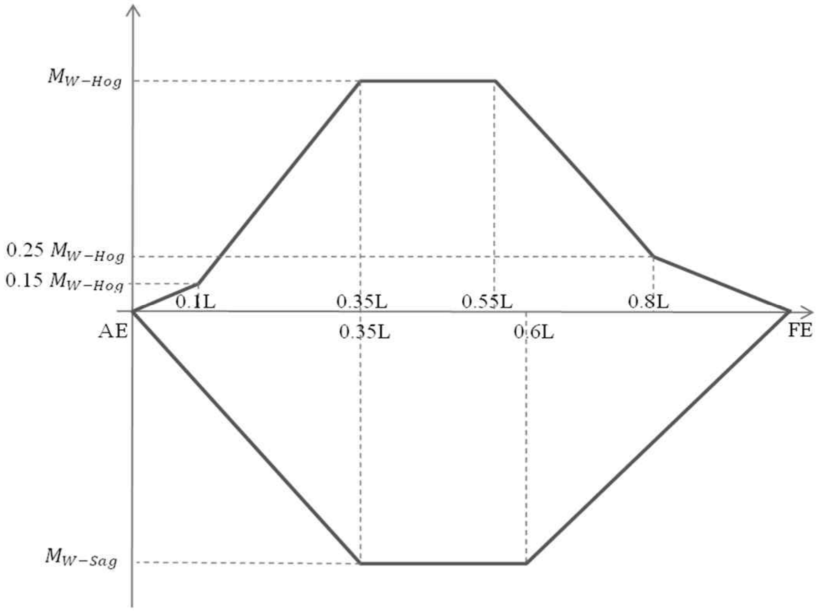


Figure 2 : Distribution of vertical wave bending moment M_{wv} along the ship length

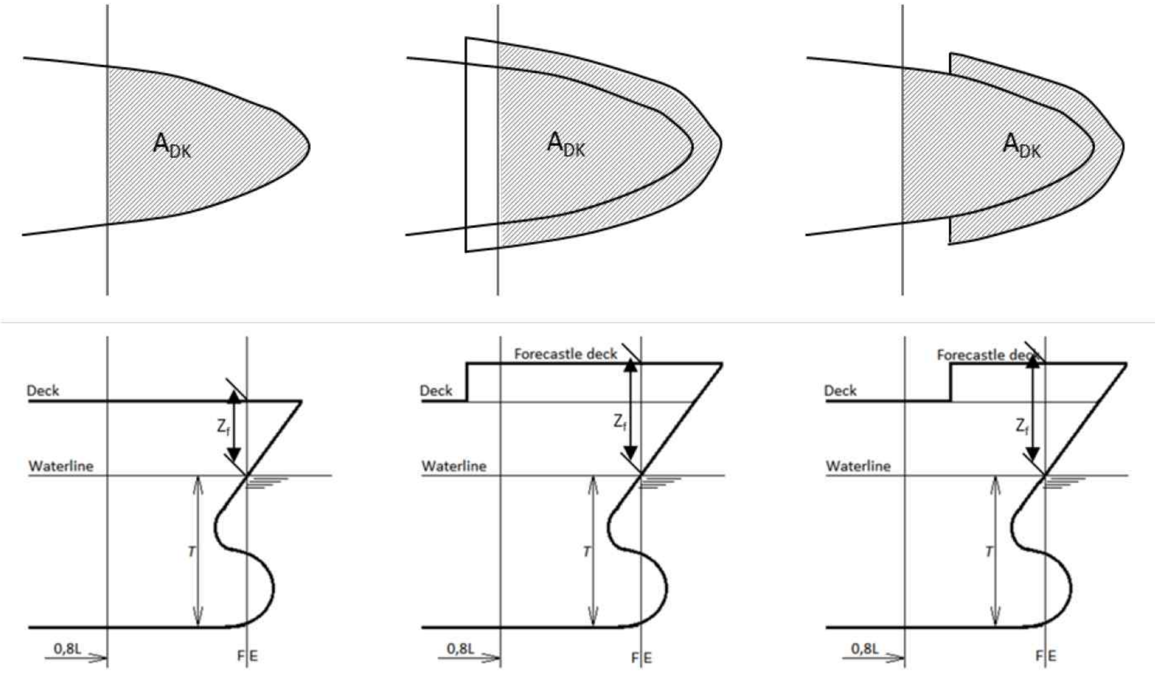


Figure 3 : Projected area A_{DK} and vertical distance z_f

3.3 Vertical wave shear force

3.3.1

The distribution of the vertical wave induced shear forces, Q_{wv} in kN, along the ship length is given in **Figure 4**, where:

$$Q_{wv}{}^{Aft}_{Hog} = 5.2 f_R f_p L^2 C C_{wp} \left(\frac{B}{L}\right)^{0.8} (0.3 + 0.7 f_{NL-Hog})$$

$$Q_{wv}{}^{Fore}_{Hog} = -5.7 f_R f_p L^2 C C_{wp} \left(\frac{B}{L}\right)^{0.8} f_{NL-Hog}$$

$$Q_{wv}{}^{Aft}_{Sag} = -5.2 f_R f_p L^2 C C_{wp} \left(\frac{B}{L}\right)^{0.8} (0.3 + 0.7 f_{NL-Sag})$$

$$Q_{wv}{}^{Fore}_{Sag} = 5.7 f_R f_p L^2 C C_{wp} \left(\frac{B}{L}\right)^{0.8} (0.25 + 0.75 f_{NL-Sag})$$

$$Q_{wv}{}^{Mid} = 4.0 f_R f_p L^2 C C_{wp} \left(\frac{B}{L}\right)^{0.8}$$

Intermediate values are obtained by linear interpolation.

where:

f_p : Coefficient to be taken as:

$f_p = f_{ps}$ for strength assessment.

$f_p = 0.9\left[0.4 - (12 - 12 f_T) L \times 10^{-5}\right]$ for fatigue assessment.

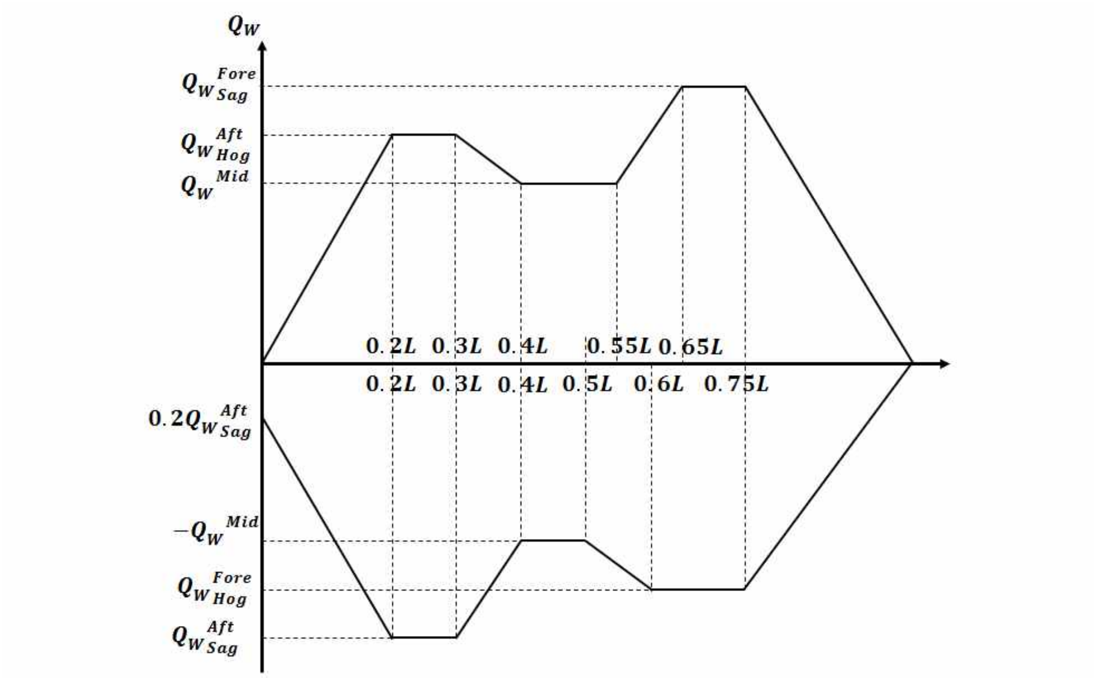


Figure 4 : Distribution of vertical wave shear force Q_{wv} along the ship length

3.4 Horizontal wave bending moment

3.4.1

The horizontal wave bending moment at any longitudinal position, in kNm, is to be taken as:

$$M_{wh}=0.25\, f_R\, f_p\, L^2 T_{LC}\, C_w\left(\frac{1.2L}{1000}+1\right) f_{m-H}$$

where:

f_{m-H} : Distribution factor along the ship length, to be taken as(see **Figure 5**):

$f_{m-H}=0.0$ for $f_{xL}=0.0,\ f_{xL}=1.0$

$f_{m-H}=1.0$ for $0.4 \le f_{xL} \le 0.65$

Intermediate values are obtained by linear interpolation.

f_p : Coefficient to be taken as:

$f_p=f_{ps}$ for strength assessment.

$f_p=0.9\left[(0.08+0.16 f_T)+(25-20 f_T)L \times 10^{-5}\right]$ for fatigue assessment.

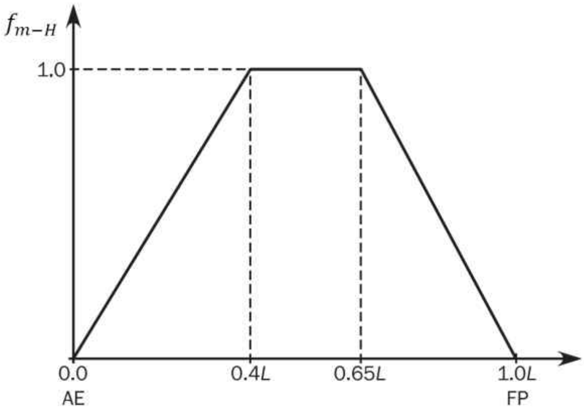


Figure 5 : Distribution of horizontal wave bending moment f_{m-H} along the ship length

3.5 Horizontal wave shear force

3.5.1

The horizontal wave shear force at any longitudinal position with respect to the ship baseline, in kNm, is to be taken as:

$$Q_{wh}=f_R\, f_p\, L\, T_{LC}\, C_B\, C_w\left(\frac{17L}{10000}+1.27\right) f_{q-H}$$

where:

f_{q-H} : Distribution factor along the ship length, to be taken as (see **Figure 6**):

$f_{q-H}=0.0$ for $f_{xL}=0.0,\ f_{xL}=1.0$

$f_{q-H}=1.0$ for $0.2 \le f_{xL} \le 0.35$

$f_{q-H}=0.8$ for $0.5 \le f_{xL} \le 0.55$

$f_{q-H}=1.0$ for $0.7 \le f_{xL} \le 0.85$

Intermediate values are obtained by linear interpolation.

f_p : Coefficient to be taken as:

$f_p = f_{ps}$ for strength assessment.

$f_p = 0.9\left[(0.11 + 0.13 f_T) + (0.2 - f_T) L \times 10^{-5}\right]$ for fatigue assessment.

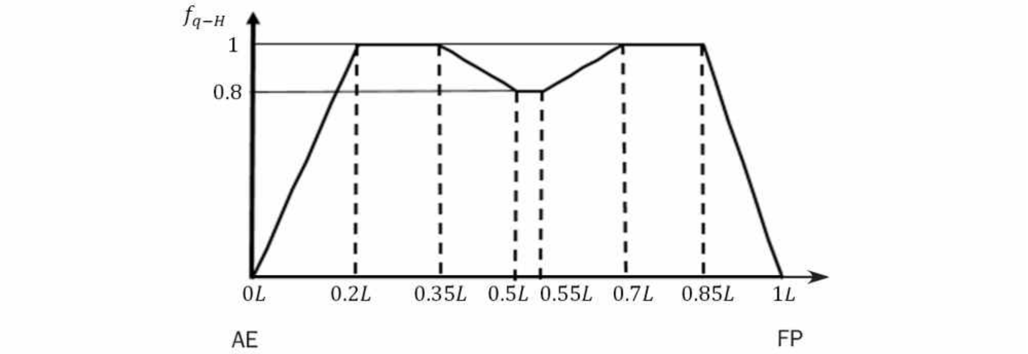


Figure 6 : Distribution of horizontal shear force f_{q-H} along the ship length

3.6 Wave torsional moment

3.6.1

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

$$M_{wt} = f_R f_p L B C_w T_{LC}\left(\frac{5B}{1000} + 0.44\right) f_{m-T} f_{sc}$$

where:

f_p : Coefficient to be taken as:

$f_p = f_{ps}$ for strength assessment.

$f_p = 0.9\left[0.55 + (50 - 60 f_T) B \times 10^{-4}\right]$ for fatigue assessment.

f_{m-T} : Distribution factor along the ship length, to be taken as (see **Figure 7**):

$f_{m-T} = 0.0$ for $f_{xL} = 0.0$, $f_{xL} = 1.0$

$f_{m-T} = 1.0$ for $0.2 \le f_{xL} \le 0.35$

$f_{m-T} = 0.6$ for $0.45 \le f_{xL} \le 0.55$

$f_{m-T} = 0.03 C_w + 0.5$ for $0.65 \le f_{xL} \le 0.8$

Intermediate values are obtained by linear interpolation.

f_{sc} : Shear center factor along the ship length, to be taken as:

$$f_{sc} = 1 - \frac{z_{sc}}{D}$$

z_{sc} : Z coordinates of shear center, in m, at the middle of the mid-hold.

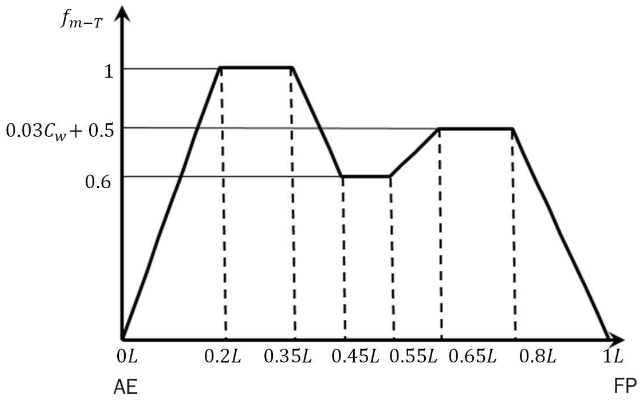


Figure 7 : Distribution of wave torsional moment f_{m-T} along the ship length

3.7 Hull girder loads for dynamic load cases

3.7.1 General

The dynamic hull girder loads to be applied for the dynamic load cases defined in **Sec 2**, are given in **[3.7.2]** to **[3.7.5]**.

3.7.2 Vertical wave bending moment

The vertical wave bending moment, M_{wv-LC} in kNm, to be used for each dynamic load case in **Sec 2**, is defined in **Table 1**.

Table 1 : Vertical wave bending moment for dynamic load cases

Load combination factor	M_{wv-LC}
$C_{WV} \geq 0$	$f_\beta\, C_{WV} M_{wv-Hog}$
$C_{WV} < 0$	$f_\beta\, C_{WV} \mid M_{wv-Sag} \mid$

where:

C_{WV} : Load combination factor for vertical wave bending moment, to be taken as specified in **Sec 2.**

M_{wv-Hog}, M_{wv-Sag} : Hogging and sagging vertical wave bending moment taking account of the considered design load scenario, as defined in **[3.2].**

3.7.3 Vertical wave shear force

The vertical wave shear force, Q_{wv-LC} in kN, to be used for each dynamic load case in **Sec 2,** is defined in **Table 2**.

Table 2 : Vertical wave shear force for dynamic load cases

Load combination factor	Q_{wv-LC}
$C_{QW} \geq 0$	$f_\beta \, C_{QW} \, Q_{wv}{}_{Hog}^{Aft}$ $f_\beta \, C_{QW} \, Q_{wv}{}_{Sag}^{Fore}$
$C_{QW} < 0$	$f_\beta \, C_{QW} \left\| Q_{wv}{}_{Hog}^{Fore} \right\|$ $f_\beta \, C_{QW} \left\| Q_{wv}{}_{Sag}^{Aft} \right\|$

where:

C_{QW} : Load combination factor for vertical wave shear force, to be taken as specified in **Sec 2.**

Q_{wv-pos}, Q_{wv-neg} : Vertical wave shear force taking account of the considered design load scenario, as defined in **[3.3].**

3.7.4 Horizontal wave bending moment

The horizontal wave bending moment, M_{wh-LC} in kNm, to be used for each dynamic load case defined in **Sec 2**, is to be taken as:

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

where:

C_{WH} : Load combination factor for horizontal wave bending moment, to be taken as specified in **Sec 2.**

M_{wh} : Horizontal wave bending moment taking account of the appropriate design load scenario, as defined in **[3.4].**

3.7.5 Horizontal wave shear force

The horizontal wave shear force, Q_{wh} in kN, to be used for each dynamic load case in **Sec 2,** is defined in **Table 3.**

Table 3 : Horizontal wave shear force for dynamic load cases

Load combination factor	Q_{wh-LC}
$C_{QH} \geq 0$	$f_\beta \, C_{QH} \, Q_{wh}$
$C_{QH} < 0$	$f_\beta \, C_{QH} \left\| Q_{wh} \right\|$

where:

C_{QH} : Load combination factor for horizontal wave shear force, to be taken as specified in **Sec 2.**

Q_{wh} : Horizontal wave shear force taking account of the considered design load scenario, as defined in **[3.5]**

3.7.6 Wave torsional moment

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

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

where:

C_{WT} : Load combination factor for wave torsional moment, to be taken as specified in **Sec 2.**

M_{wt} : Wave torsional moment taking account of the appropriate design load scenario, as defined in **[3.6].**

Section 5 External Loads

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

λ : Wave length, in m.

B_x : Moulded breadth at the waterline, in m, at the considered cross section.

x, y, z : X, Y and Z coordinates, in m, of the load point with respect to the reference coordinate system defined in **Sec 1, [1.2.1].**

f_{xL} : Ratio as defined in **Sec 2.**

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

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

$f_{yB} = 0$ when $B_x = 0$.

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

$f_{yB1} = \dfrac{|2y|}{B}$, but not greater than 1.0.

f_T : Ratio as defined in **Sec 3.**

f_{zT} : Ratio between Z-coordinate of the load point and f_T, to be taken as:

$f_{zT} = \dfrac{z}{T_{LC}}$, but not greater than 1.0.

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

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

$P_{W,WL}$: Wave pressure at the waterline, $\mathrm{kN/m^2}$, for the considered dynamic load case.

$P_{W,WL} = P_W$ for $y = B_x/2$ and $z = T_{LC}$

f_{ps} : Coefficient for strength assessment, as defined in **Sec 3.**

f_R : Coefficient, as defined in **Sec 3**.

T_θ : Roll period, in s, as defined in **Sec 3, [2.1.1].**

θ : Roll angle, in deg, as defined in **Sec 3, [2.1.1]**.

f_β : Coefficient defined in **Sec 4**.

C_w : Coefficient defined in **Sec 4**.

z_{SD} : Z coordinate, in m, of the midpoint of stiffener span, or of the middle of the plate field.

1. Sea pressure

1.1 Total pressure

1.1.1

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

$P_{ex} = P_s$, but not less than 0.0

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

$P_{ex} = P_S + P_W$, but not less than 0.0

where:

P_S : Hydrostatic pressure, in $\mathrm{kN/m^2}$, is defined in **[1.2].**

P_W : Wave pressure, in $\mathrm{kN/m^2}$, is defined in **[1.3].**

1.2 Hydrostatic pressure

1.2.1

The hydrostatic pressure, P_S at any load point, in $\mathrm{kN/m^2}$, is obtained from **Table 1.** See also **Figure 1.**

Table 1 : Hydrostatic pressure, P_S

Location	Hydrostatic pressure, P_S, in $\mathrm{kN/m^2}$
$z \le T_{LC}$	$\rho g (T_{LC} - z)$
$z > T_{LC}$	0.0

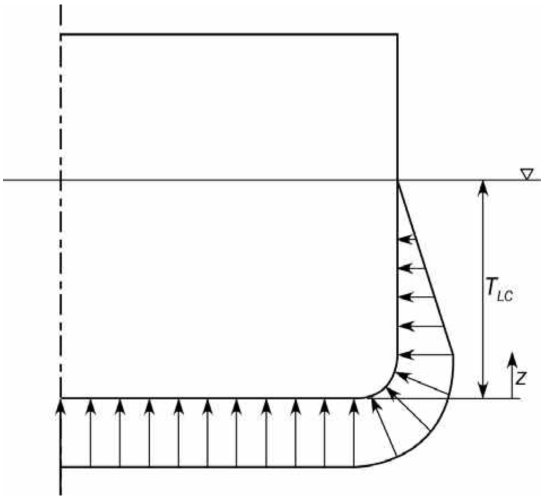


Figure 1 : Hydrostatic pressure, P_S

1.3 External dynamic pressures for strength assessment

1.3.1 General

The hydrodynamic pressures for each dynamic load case defined in **Sec 2, [2]** are defined in **[1.3.2]** to **[1.3.8]**.

1.3.2 Hydrodynamic pressures for HSM load cases

The hydrodynamic pressures, P_W, for HSM-1 and HSM-2 load cases, at any load point, in $\mathrm{kN/m^2}$, are to be obtained from **Table 2**.

Table 2 : Hydrodynamic pressures for HSM load cases

	Wave pressure, in $\mathrm{kN/m^2}$		
Load case	$Z \leq T_{LC}$	$T_{LC} < Z \leq h_w + T_{LC}$	$Z > h_W + T_{LC}$
HSM-1	$P_W = \max(-P_{HSM}, \rho g(z - T_{LC}))$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
HSM-2	$P_W = \max(P_{HSM}, \rho g(z - T_{LC}))$		

where:

$P_{HSM} = f_R f_{ps} f_{nl} f_\beta f_{yz} P_a f_a f_{p-HSM}$

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

a) For extreme sea loads design load scenario:

$f_{nl} = 0.7$ at $f_{xL} = 0.0$

$f_{nl} = 0.9$ at $0.3 \leq f_{xL} < 0.7$

$f_{nl} = 0.6$ at $f_{xL} = 1.0$

b) For ballast water exchange design load scenario:

$f_{nl} = 0.85$ at $f_{xL} = 0.0$

$f_{nl} = 0.95$ at $0.3 \leq f_{xL} < 0.7$

$f_{nl} = 0.80$ at $f_{xL} = 1.0$

Intermediate values are obtained by linear interpolation.

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

$$f_{yz} = \frac{1}{3}(0.5 f_{yB} f_{BG} + 1.4 f_{zT} f_{WL} + 1.1 f_{CL})$$

f_{WL} : Pressure amplitude coefficient at water line, but not less than 1.0

a) For full load condition and $B > 35\mathrm{m}$:

$f_{WL} = 2.59 - 0.15 P_a$

b) For ballast load condition or $B \leq 35\mathrm{m}$:

$f_{WL} = 2.0 - 0.085 P_a$

f_{BG} : Pressure amplitude coefficient at bilge, but not less than 1.0

a) For full load condition and $B > 35\mathrm{m}$:

$f_{BG} = 2.5 - 0.15 P_a$

b) For ballast load condition or $B \leq 35\mathrm{m}$:

$f_{BG} = 2.22 - 0.13 P_a$

f_{CL} : Pressure amplitude coefficient at bottom centerline, but not less than 1.0

a) For full load condition and $B > 35\text{m}$:

$$f_{CL} = 2.21 - 0.13P_a$$

b) For ballast load condition or $B \leq 35\text{m}$:

$$f_{CL} = 1.75 - 0.08P_a$$

P_a : Pressure amplitude coefficient in mid-ship position, to be taken as:

a) For full load condition and $B > 35\text{m}$:

$$P_a = \frac{B}{10} + \frac{L}{80}$$

b) For ballast load condition or $B \leq 35\text{m}$:

$$P_a = \frac{L}{B} + \frac{200}{L}$$

f_a : Wave amplitude coefficient to be taken as:

$$f_a = 0.85C_w\sqrt{\frac{\lambda + 25}{L}}$$

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

$$\lambda = 0.5(1 + f_T)L$$

f_{p-HSM} : Pressure distribution coefficient in the longitudinal direction of the ship, to be taken as:

$$f_{p-HSM} = k_a k_p$$

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

$$k_a = k_{a-WL} f_{zT} + k_{a-CL}(1 - f_{zT})$$

Intermediate values are obtained by linear interpolation.

Table 3 : k_{a-WL} values for HSM load case

f_{xL}	0.0	$-\frac{1}{9}f_T + \frac{47}{180}$	$-\frac{1}{9}f_T + \frac{37}{90}$	$-\frac{1}{9}f_T + \frac{32}{45}$	$-\frac{1}{45}f_T + \frac{158}{225}$	1.0
k_{a-WL}	$-\frac{20}{9}f_T + \frac{29}{9}$	0.3	1.0	1.0	0.3	$\frac{20}{9}f_T + \frac{16}{9}$

Table 4 : k_{a-CL} values for HSM load case

f_{xL}	0.0	$-\frac{1}{9}f_T + \frac{14}{45}$	$-\frac{1}{9}f_T + \frac{37}{90}$	$-\frac{1}{9}f_T + \frac{32}{45}$	$-\frac{4}{45}f_T + \frac{173}{225}$	1.0
k_{a-CL}	$-\frac{34}{9}f_T + \frac{547}{90}$	0.3	1.0	1.0	0.5	$\frac{40}{9}f_T + \frac{347}{90}$

k_p : Phase coefficient in the longitudinal direction of the ship, to be taken as:

$$k_p = k_{p-WL} f_{zT} + k_{p-CL}(1 - f_{zT})$$

Intermediate values are obtained by linear interpolation.

Table 5 : k_{p-WL} values for HSM load case

f_{xL}	0.0	0.15	0.22	0.25	0.35	0.65	0.7	0.75	1.0
k_{p-WL}	$-\frac{16}{9}f_T+\frac{62}{45}$	$-f_T$	$\frac{41}{15}f_T-\frac{751}{300}$	$3f_T-\frac{49}{20}$	0.0	1.0	$-\frac{26}{9}f_T+\frac{17}{9}$	-1.0	-0.8

Table 6 : k_{p-CL} values for HSM load case

f_{xL}	0.0	$-\frac{8}{45}f_T+\frac{313}{900}$	$-\frac{1}{9}f_T+\frac{37}{90}$	$-\frac{1}{9}f_T+\frac{32}{45}$	$-\frac{1}{9}f_T+\frac{73}{90}$	1.0
k_{p-CL}	$-\frac{10}{9}f_T+\frac{10}{9}$	-1.0	1.0	1.0	-1.0	-0.75

1.3.3 Hydrodynamic pressure for HSA load cases

The hydrodynamic pressures, P_W, for HSA-1 and HSA-2 load cases at any load point, in $\mathrm{kN/m^2}$, are to be obtained from **Table 7.**

Table 7 : Hydrodynamic pressures for HSA load cases

	Wave pressure, in $\mathrm{kN/m^2}$		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
HSA-1	$P_W = \max\left(P_{HSA},\ \rho g(z - T_{LC})\right)$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
HSA-2	$P_W = \max\left(-P_{HSA},\ \rho g(z - T_{LC})\right)$		

where:

$P_{HSA} = f_R f_{ps} f_{nl} f_\beta f_{yz} P_a f_a f_{p-HSA}$

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

a) For extreme sea loads design load scenario:

$f_{nl} = 0.7$ at $f_{xL} = 0.0$

$f_{nl} = 0.9$ at $0.3 \le f_{xL} < 0.7$

$f_{nl} = 0.6$ at $f_{xL} = 1.0$

b) For ballast water exchange design load scenario

$f_{nl} = 0.85$ at $f_{xL} = 0.0$

$f_{nl} = 0.95$ at $0.3 \le f_{xL} < 0.7$

$f_{nl} = 0.80$ at $f_{xL} = 1.0$

Intermediate values are obtained by linear interpolation.

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

$$f_{yz} = \frac{1}{3}\left(0.5 f_{yB} + 1.4 f_{zT} + 1.1\right)$$

P_a : Pressure amplitude coefficient in mid-ship position, to be taken as:

a) For full load condition and $B > 35\mathrm{m}$:

$$P_a = \frac{B}{10} + \frac{L}{80}$$

b) For ballast load condition or $B \leq 35\mathrm{m}$:

$$P_a = \frac{L}{B} + \frac{200}{L}$$

f_a : Wave amplitude coefficient to be taken as:

$$f_a = 0.8 C_w \sqrt{\frac{L + \lambda - 125}{L}}$$

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

$\lambda = 0.5(1 + f_T)L$

f_{p-HSA} : Pressure distribution coefficient in the longitudinal direction of the ship, to be taken as:

$f_{p-HSA} = k_a k_p$

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

$k_a = k_{a-WL} f_{zT} + k_{a-CL}(1 - f_{zT})$

Intermediate values are obtained by linear interpolation.

Table 8 : k_{a-WL} values for HSA load case

f_{xL}	0.0	$-\frac{2}{9} f_T + \frac{67}{180}$	$-\frac{2}{9} f_T + \frac{47}{90}$	0.6	$-\frac{1}{9} f_T + \frac{73}{90}$	1.0
k_{a-WL}	$-\frac{8}{3} f_T + \frac{11}{3}$	0.3	1.0	1.0	0.25	$\frac{10}{9} f_T + \frac{26}{9}$

Table 9 : k_{a-CL} values for HSA load case

f_{xL}	0.0	$-\frac{1}{9} f_T + \frac{14}{45}$	$-\frac{2}{9} f_T + \frac{47}{90}$	0.6	$-\frac{1}{9} f_T + \frac{73}{90}$	1.0
k_{a-CL}	$-4 f_T + \frac{31}{5}$	0.3	1.0	1.0	0.45	$\frac{10}{9} f_T + \frac{62}{9}$

k_p : Phase coefficient in the longitudinal direction of the ship, to be taken as:

$k_p = k_{p-WL} f_{zT} + k_{p-CL}(1 - f_{zT})$

Intermediate values are obtained by linear interpolation.

Table 10 : k_{p-WL} values for HSA load case

f_{xL}	0.0	$-\frac{2}{9} f_T + \frac{353}{900}$	$-\frac{2}{9} f_T + \frac{47}{90}$	$-\frac{4}{45} f_T + \frac{133}{180}$	$-\frac{2}{9} f_T + \frac{83}{90}$	1.0
k_{p-WL}	$\frac{10}{9} f_T - \frac{68}{45}$	1.0	-0.7	-0.7	0.9	1.0

Table 11 : k_{p-CL} values for HSA load case

f_{xL}	0.0	0.15	$-\frac{2}{9}f_T+\frac{19}{45}$	$-\frac{2}{9}f_T+\frac{47}{90}$	$-\frac{4}{45}f_T+\frac{133}{180}$	$-\frac{2}{9}f_T+\frac{83}{90}$	1.0
k_{p-CL}	$\frac{4}{9}f_T-\frac{103}{90}$	$\frac{8}{9}f_T-\frac{8}{9}$	1.0	-0.7	-0.7	0.9	1.0

1.3.4 Hydrodynamic pressure for FSM load cases

The hydrodynamic pressures, P_W, for FSM-1 and FSM-2 load cases, at any load point, in $\mathrm{kN/m^2}$, are to be obtained from **Table 12.**

Table 12 : Hydrodynamic pressures for FSM load cases

	Wave pressure, in $\mathrm{kN/m^2}$		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
FSM-1	$P_W = \max\left(-P_{FSM},\ \rho g\left(z - T_{LC}\right)\right)$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
FSM-2	$P_W = \max\left(P_{FSM},\ \rho g\left(z - T_{LC}\right)\right)$		

where:

$P_{FSM} = f_R f_{ps} f_{nl} f_\beta f_{yz} P_a f_a f_{p-FSM}$

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

a) For extreme sea loads design load scenario:

$$f_{nl} = 0.9$$

b) For ballast water exchange design load scenario:

$$f_{nl} = 0.95$$

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

$$f_{yz} = \frac{1}{3}\left(0.5 f_{yB} + 1.2 f_{zT} + 1.3\right)$$

P_a : Pressure amplitude coefficient in mid-ship position, to be taken as:

$$P_a = 0.5\frac{L}{B} + \frac{50}{L} + 2.3$$

f_a : Wave amplitude coefficient to be taken as:

$$f_a = 0.85 C_w \sqrt{\frac{\lambda + 25}{L}}$$

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

$$\lambda = 0.5(1 + 1.5 f_T)L$$

f_{p-FSM} : Pressure distribution coefficient in the longitudinal direction of the ship, to be taken as:

$$f_{p-FSM} = k_a k_p$$

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

$k_a = k_{a-WL} f_{zT} + k_{a-CL}(1 - f_{zT})$

Intermediate values are obtained by linear interpolation.

Table 13 : k_{a-WL} values for FSM load case

f_{xL}	0.0	$-\frac{2}{9}f_T + \frac{67}{180}$	$-\frac{2}{9}f_T + \frac{17}{36}$	$-\frac{1}{9}f_T + \frac{32}{45}$	$-\frac{1}{9}f_T + \frac{73}{90}$	1.0
k_{a-WL}	$-\frac{20}{9}f_T + \frac{67}{18}$	0.4	1.0	1.0	0.5	$\frac{4}{9}f_T + \frac{106}{45}$

Table 14 : k_{a-CL} values for FSM load case

f_{xL}	0.0	$-\frac{7}{45}f_T + \frac{16}{45}$	$-\frac{2}{9}f_T + \frac{17}{36}$	$-\frac{1}{9}f_T + \frac{32}{45}$	$-\frac{4}{45}f_T + \frac{683}{900}$	1.0
k_{a-CL}	$-\frac{40}{9}f_T + \frac{125}{18}$	0.2	1.0	1.0	0.4	5.0

k_p : Phase coefficient in the longitudinal direction of the ship, to be taken as:

$k_p = k_{p-WL} f_{zT} + k_{p-CL}(1 - f_{zT})$

Intermediate values are obtained by linear interpolation.

Table 15 : k_{p-WL} values for FSM load case

f_{xL}	0.0	$-\frac{8}{45}f_T + \frac{67}{225}$	$-\frac{2}{9}f_T + \frac{17}{36}$	$-\frac{1}{9}f_T + \frac{32}{45}$	$-\frac{1}{9}f_T + \frac{31}{36}$	1.0
k_{p-WL}	$-\frac{5}{9}f_T - \frac{7}{36}$	-1.0	1.0	1.0	-1.0	-0.7

Table 16 : k_{p-CL} values for FSM load case

f_{xL}	0.0	$-\frac{8}{45}f_T + \frac{161}{450}$	$-\frac{2}{9}f_T + \frac{19}{45}$	0.65	$-\frac{1}{9}f_T + \frac{73}{90}$	1.0
k_{p-CL}	-0.6	-1.0	1.0	1.0	-1.0	-0.7

1.3.5 Hydrodynamic pressure for BSR load cases

The wave pressures, P_W, for BSR-1 and BSR-2 load cases, at any load point, in $\mathrm{kN/m^2}$, are to be obtained from **Table 17.**

Table 17 : Hydrodynamic pressures for BSR load cases

	Wave pressure, in $\mathrm{kN/m^2}$		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
BSR-1P	$P_W = \max\left(P_{BSR}, \rho g(z - T_{LC})\right)$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
BSR-2P	$P_W = \max\left(-P_{BSR}, \rho g(z - T_{LC})\right)$		
BSR-1S	$P_W = \max\left(P_{BSR}, \rho g(z - T_{LC})\right)$		
BSR-2S	$P_W = \max\left(-P_{BSR}, \rho g(z - T_{LC})\right)$		

where:

For BSR-1P and BSR-2P load cases, to be taken as:

$$P_{BSR} = f_\beta f_{nl}\left(10\, y \sin\theta + 0.48 f_{ps} C_W \sqrt{\frac{L_0 + \lambda - 125}{L}}\,(f_{yB1} + 1)\right)$$

For BSR-1S and BSR-2S load cases, to be taken as:

$$P_{BSR} = f_\beta f_{nl}\left(-10\, y \sin\theta + 0.48 f_{ps} C_W \sqrt{\frac{L_0 + \lambda - 125}{L}}\,(f_{yB1} + 1)\right)$$

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

$$f_{nl} = 1.0$$

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

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

1.3.6 Hydrodynamic pressure for BSP load cases

The wave pressure, P_W, for BSP-1 and BSP-2 load cases, at any load point, in $\mathrm{kN/m^2}$, are to be obtained from **Table 18.**

Table 18 : Hydrodynamic pressures for BSP load cases

	Wave pressure, in $\mathrm{kN/m^2}$		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
BSP-1P	$P_W = \max\left(P_{BSP}, \rho g(z - T_{LC})\right)$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
BSP-2P	$P_W = \max\left(-P_{BSP}, \rho g(z - T_{LC})\right)$		
BSP-1S	$P_W = \max\left(P_{BSP}, \rho g(z - T_{LC})\right)$		
BSP-2S	$P_W = \max\left(-P_{BSP}, \rho g(z - T_{LC})\right)$		

Table 19 : Factor application for BSP load cases

Transverse position	BSP-1P, BSP-2P	BSP-1S, BSP-2S
$y \geq 0$	(S)	(P)
$y < 0$	(P)	(S)

where:

$P_{BSP} = f_R f_{ps} f_{nl} f_\beta f_{yz} P_a f_a f_{p-BSP}$

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

a) For extreme sea loads design load scenario:

$f_{nl} = 0.6$ at $f_{xL} = 0.0$

$f_{nl} = 0.8$ at $0.3 \leq f_{xL} < 0.7$

$f_{nl} = 0.6$ at $f_{xL} = 1.0$

b) For ballast water exchange design load scenario:

$f_{nl} = 0.6$ at $f_{xL} = 0.0$

$f_{nl} = 0.8$ at $0.3 \leq f_{xL} < 0.7$

$f_{nl} = 0.6$ at $f_{xL} = 1.0$

Intermediate values are obtained by linear interpolation.

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

$f_{yz}(P) = 0.25 f_{zT} + 0.6 f_{yB1} + 0.15$

$f_{yz}(S) = 0.5 f_{zT} + 0.35 f_{yB1} + 0.15$

P_a : Pressure amplitude coefficient in mid-ship position, to be taken as:

$P_a(P) = 11$

$P_a(S) = 25$

f_a : Wave amplitude coefficient to be taken as:

$$f_a = \left(0.8 C_w \sqrt{\frac{L + \lambda - 125}{L}}\right)\left(\frac{L}{600(2 - f_T)}\right) + 5C_b$$

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

$\lambda = 90 + 0.3B$

f_{p-BSP} : Pressure distribution coefficient in the longitudinal direction of the ship, to be taken as:

$f_{p-BSP} = 1.0$

1.3.7 Hydrodynamic pressure for OST load cases

The wave pressures, P_W, for OST-1 and OST-2 load cases, at any load point are to be obtained, in $\mathrm{kN/m^2}$, from **Table 20.**

Table 20 : Hydrodynamic pressures for OST load cases

	Wave pressure, in $\mathrm{kN/m^2}$		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
OST-1P	$P_W = \max\,(P_{OST},\, \rho g\,(z - T_{LC}))$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
OST-2P	$P_W = \max\,(-P_{OST},\, \rho g\,(z - T_{LC}))$		
OST-1S	$P_W = \max\,(P_{OST},\, \rho g\,(z - T_{LC}))$		
OST-2S	$P_W = \max\,(-P_{OST},\, \rho g\,(z - T_{LC}))$		

Table 21 : Factor application for OST load cases

Transverse position	OST-1P, OST-2P	OST-1S, OST-2S
$y \ge 0$	(S)	(P)
$y < 0$	(P)	(S)

where:

$P_{OST} = f_R\, f_{ps}\, f_{nl}\, f_\beta\, f_{yz}\, P_a\, f_a\, f_{p-OST}$

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

$f_{nl} = 0.8$

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

$f_{yz}(P) = 0.06 f_{zT} + 0.09 f_{yB} + 0.15$

$f_{yz}(S) = 0.72 f_{zT} + 0.28 f_{yB} + 0.15$

P_a : Pressure amplitude coefficient in mid-ship position, to be taken as:

$P_a = 20.0$

f_a : Wave amplitude coefficient to be taken as:

$$f_a = 0.6 C_w \sqrt{\frac{L + \lambda - 125}{L}}$$

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

$\lambda = 0.45L$

f_{p-OST} : Pressure distribution coefficient in the longitudinal direction of the ship, to be taken as:

$f_{p-OST} = k_a\, k_p$

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

$k_a = k_{a-WL} f_{zT} + k_{a-CL}(1 - f_{zT})$

Intermediate values are obtained by linear interpolation.

Table 22 : k_{a-WL} values for OST load case

Transverse position	OST-1P, OST-2P		OST-1S, OST-2S	
	f_{xL}	k_{a-WL}	f_{xL}	k_{a-WL}
$y \geq 0$	0.0	1.0	0.0	$3-2f_T$
	0.2	$0.6f_T+0.4$	0.15	f_T
	0.4	$0.4f_T+0.6$	0.3	$2-f_T$
	0.5	1.0	0.5	1.0
	0.6	1.0	0.65	$1.4f_T-0.4$
	0.8	f_T	0.8	f_T
	1.0	$1.4-0.4f_T$	1.0	3.0
$y < 0$	0.0	$3-2f_T$	0.0	1.0
	0.15	f_T	0.2	$0.6f_T+0.4$
	0.3	$2-f_T$	0.4	$0.4f_T+0.6$
	0.5	1.0	0.5	1.0
	0.65	$1.4f_T-0.4$	0.6	1.0
	0.8	f_T	0.8	f_T
	1.0	3.0	1.0	$1.4-0.4f_T$

Table 23 : k_{a-CL} values for OST load case

f_{xL}	0.0	0.2	0.8	1.0
k_{a-CL}	$7-5f_T$	1.0	1.0	$6-2f_T$

k_p : Phase coefficient in the longitudinal direction of the ship, to be taken as:

$$k_p = k_{p-WL} f_{zT} + k_{p-CL}(1 - f_{zT})$$

Intermediate values are obtained by linear interpolation.

Table 24 : k_{p-WL} values for OST load case

Transverse position	OST-1P, OST-2P		OST-1S, OST-2S	
	f_{xL}	k_{p-WL}	f_{xL}	k_{p-WL}
$y \geq 0$	0.0	1.0	0.0	$1.5 - f_T$
	0.1	1.0	0.1	$2.5 - 3f_T$
	0.15	1.0	0.15	$2.4 - 2.8f_T$
	0.2	1.0	0.2	$1.1 - 1.4f_T$
	0.4	-1.0	0.4	$2.06 - 2.36f_T$
	$0.1f_T + 0.55$	-1.0	0.45	$2.53 - 3.06f_T$
			0.55	$3 - 4f_T$
	$0.1f_T + 0.75$	1.0	0.65	$3 - 4f_T$
			0.8	$2 - 3f_T$
	1.0	$0.5 - f_T$	1.0	$-0.6f_T - 0.4$
$y < 0$	0.0	$1.5 - f_T$	0.0	1.0
	0.1	$2.5 - 3f_T$	0.1	1.0
	0.15	$2.4 - 2.8f_T$	0.15	1.0
	0.2	$1.1 - 1.4f_T$	0.2	1.0
	0.4	$2.06 - 2.36f_T$	0.4	-1.0
	0.45	$2.53 - 3.06f_T$	$0.1f_T + 0.55$	-1.0
	0.55	$3 - 4f_T$		
	0.65	$3 - 4f_T$	$0.1f_T + 0.75$	1.0
	0.8	$2 - 3f_T$		
	1.0	$-0.6f_T - 0.4$	1.0	$0.5 - f_T$

Table 25 : k_{p-CL} values for OST load case

f_{xL}	0.0	$0.35 - 0.1f_T$	$0.5 - 0.2f_T$	$0.2f_T + 0.55$	0.8	1.0
k_{p-CL}	1.0	$1.4 - 0.8f_T$	-1.0	-1.0	$2.5 - 3f_T$	-0.5

1.3.8 Hydrodynamic pressure for OSA load cases

The wave pressures, P_W, for OSA-1 and OSA-2 load cases, at any load point, in $\mathrm{kN/m^2}$, are to be obtained from **Table 26.**

Table 26 : Hydrodynamic pressures for OSA load cases

	Wave pressure, in $\mathrm{kN/m^2}$		
Load case	$z \leq T_{LC}$	$T_{LC} < z \leq h_W + T_{LC}$	$z > h_W + T_{LC}$
OSA-1P	$P_W = \max\left(P_{OSA},\ \rho g(z - T_{LC})\right)$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
OSA-2P	$P_W = \max\left(-P_{OSA},\ \rho g(z - T_{LC})\right)$		
OSA-1S	$P_W = \max\left(P_{OSA},\ \rho g(z - T_{LC})\right)$		
OSA-2S	$P_W = \max\left(-P_{OSA},\ \rho g(z - T_{LC})\right)$		

Table 27 : Factor application for OSA load cases

Transverse position	OSA-1P, OSA-2P	OSA-1S, OSA-2S
$y \geq 0$	(S)	(P)
$y < 0$	(P)	(S)

where:

$P_{OSA} = f_R f_{ps} f_{nl} f_\beta f_{yz} P_a f_a f_{p-OSA}$

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

a) For extreme sea loads design load scenario:

$f_{nl} = 0.5$ at $f_{xL} = 0.0$

$f_{nl} = 0.8$ at $0.3 \leq f_{xL} < 0.7$

$f_{nl} = 0.6$ at $f_{xL} = 1.0$

b) For ballast water exchange design load scenario:

$f_{nl} = 0.75$ at $f_{xL} = 0.0$

$f_{nl} = 0.90$ at $0.3 \leq f_{xL} < 0.7$

$f_{nl} = 0.80$ at $f_{xL} = 1.0$

Intermediate values are obtained by linear interpolation.

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

$f_{yz}(P) = 0.6 f_{zT} + (0.32 f_T - 0.16) f_{yB} + 0.24$

$f_{yz}(S) = 0.85 f_{zT} + 0.21 f_{yB} + 0.24$

P_a : Pressure amplitude coefficient in mid-ship position, to be taken as:

$$P_a = \left(\frac{2300}{L} + 0.4L^{0.3}\right)(2f_T - 1) + 12(1 - f_T)$$

f_a : Wave amplitude coefficient to be taken as:

$$f_a = 0.6C_w\sqrt{\frac{L + \lambda - 125}{L}}$$

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

$\lambda = 0.3(f_T + 1)L$

f_{p-OSA} : Pressure distribution coefficient in the longitudinal direction of the ship, to be taken as:

$f_{p-OSA} = k_a k_p$

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

$k_a = k_{a-WL} f_{zT} + k_{a-CL}(1 - f_{zT})$

Intermediate values are obtained by linear interpolation.

Table 28 : k_{a-WL} values for OSA load case

Transverse position	OSA-1P, OSA-2P		OSA-1S, OSA-2S	
	f_{xL}	k_{a-WL}	f_{xL}	k_{a-WL}
$y \geq 0$	0.0	$-f_T + 1$	0.0	$2f_T$
	0.1	$-0.4f_T + 0.7$	0.1	$3f_T - 1$
	0.2	$1.2f_T - 0.6$	0.2	$3f_T - 1$
	0.3	$-0.2f_T + 1.1$	0.3	$3f_T - 1$
	0.4	1.0	0.4	f_T
	0.5	1.0	0.5	1.0
	0.6	f_T	0.6	1.5
	0.7	f_T	0.7	2.0
	0.8	$0.8f_T + 0.4$	0.8	$0.6f_T + 0.9$
	0.9	$0.4f_T + 1$	0.9	2.0
	1.0	$f_T + 1$	1.0	3.0
$y < 0$	0.0	$2f_T$	0.0	$-f_T + 1$
	0.1	$3f_T - 1$	0.1	$-0.4f_T + 0.7$
	0.2	$3f_T - 1$	0.2	$1.2f_T - 0.6$
	0.3	$3f_T - 1$	0.3	$-0.2f_T + 1.1$
	0.4	f_T	0.4	1.0
	0.5	1.0	0.5	1.0
	0.6	1.5	0.6	f_T
	0.7	2.0	0.7	f_T
	0.8	$0.6f_T + 0.9$	0.8	$0.8f_T + 0.4$
	0.9	2.0	0.9	$0.4f_T + 1$
	1.0	3.0	1.0	$f_T + 1$

Table 29 : k_{a-CL} values for OSA load case

f_{xL}	0.0	0.1	0.2	0.6	0.7	0.8	0.9	1.0
k_{a-CL}	4.0	2.0	1.0	1.0	$2f_T$	$3f_T+0.5$	$3f_T+2.5$	$3f_T+4.5$

k_p : Phase coefficient in the longitudinal direction of the ship, to be taken as:

$k_p = k_{p-WL} f_{zT} + k_{p-CL}(1 - f_{zT})$

Intermediate values are obtained by linear interpolation.

Table 30 : k_{p-WL} values for OSA load case

Transverse position	OSA-1P, OSA-2P		OSA-1S, OSA-2S	
	f_{xL}	k_{p-WL}	f_{xL}	k_{p-WL}
$y \geq 0$	0.0	f_T	0.0	0.5
	0.1	$2f_T-1$	0.1	0.5
	0.2	$4f_T-3$	0.2	$f_T-0.5$
	0.3	$0.4f_T+0.6$	0.3	$2.2f_T-1.7$
	0.4	$1.1-0.2f_T$	0.4	$3f_T-2.5$
	0.5	$1.1-0.4f_T$	0.5	$0.4f_T-0.9$
	0.6	$1.2-1.2f_T$	0.6	$-0.6f_T-0.4$
	0.7	$-0.6f_T-0.2$	0.7	$-0.6f_T-0.4$
	0.8	$0.2f_T-1.1$	0.8	-1.0
	0.9	-1.0	0.9	$0.4f_T-1.2$
	1.0	-1.0	1.0	$0.4f_T-1.2$
$y < 0$	0.0	0.5	0.0	f_T
	0.1	0.5	0.1	$2f_T-1$
	0.2	$f_T-0.5$	0.2	$4f_T-3$
	0.3	$2.2f_T-1.7$	0.3	$0.4f_T+0.6$
	0.4	$3f_T-2.5$	0.4	$1.1-0.2f_T$
	0.5	$0.4f_T-0.9$	0.5	$1.1-0.4f_T$
	0.6	$-0.6f_T-0.4$	0.6	$1.2-1.2f_T$
	0.7	$-0.6f_T-0.4$	0.7	$-0.6f_T-0.2$
	0.8	-1.0	0.8	$0.2f_T-1.1$
	0.9	$0.4f_T-1.2$	0.9	-1.0
	1.0	$0.4f_T-1.2$	1.0	-1.0

Table 31 : k_{p-CL} values for OSA load case

f_{xL}	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0
k_{p-CL}	$0.9 - 0.4 f_T$	$0.9 - 0.4 f_T$	$2 f_T - 1$	$2 f_T - 1$	f_T	$1.2 - 0.4 f_T$	$2.5 - 3 f_T$	$-0.6 f_T - 0.2$	-1.0	-1.0

1.3.9 Envelope of dynamic pressure

The envelope of dynamic pressure at any point, $P_{ex-\max}$, is to be taken as the greatest pressure obtained from any of the load cases determined by **[1.3.2]** to **[1.3.8]**.

1.4 External dynamic pressures for fatigue assessments

1.4.1 General

The external pressure P_{ex} at any load point of the hull for the fatigue static plus dynamic (F:S+D) design load scenario, is to be derived for each fatigue dynamic load case and is to be taken as:

$P_{ex} = P_S + P_W$ but not less than 0.

where:

P_S : Hydrostatic pressure, in kN/m^2, is defined in **[1.2]**.

P_W : Hydrodynamic pressure, in kN/m^2, is defined in **[1.4.2]** to **[1.4.6]**.

1.4.2 Hydrodynamic pressures for HSM load cases

The hydrodynamic pressures, P_W, for HSM-1 and HSM-2 load cases, at any load point, in kN/m^2, are to be obtained from **Table 32**.

Table 32 : Hydrodynamic pressures for HSM load cases

	Wave pressure, in kN/m^2		
Load case	$Z \le T_{LC}$	$T_{LC} < Z \le h_w + T_{LC}$	$Z > h_W + T_{LC}$
HSM-1	$P_W = \max(-P_{HSM}, \rho g(z - T_{LC}))$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
HSM-2	$P_W = \max(P_{HSM}, \rho g(z - T_{LC}))$		

where:

$P_{HSM} = f_R f_\beta f_{yz} P_a f_a f_{p-HSM}$

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

$f_{yz} = 0.28 f_{zT} + 0.01 f_{yB} + 0.52$

P_a : Pressure amplitude coefficient in mid-ship position, to be taken as:

a) For full load condition and $B > 35\text{m}$:

$$P_a = \frac{B}{10} + \frac{L}{80}$$

b) For ballast load condition or $B \le 35\text{m}$:

$$P_a = \frac{L}{B} + \frac{200}{L}$$

f_a : Wave amplitude coefficient to be taken as:

$$f_a = 0.14 C_w \sqrt{\frac{L_0 + \lambda - 50}{L}}$$

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

$$\lambda = 0.5(1.34 + 0.56 f_T) L$$

f_{p-HSM} : Pressure distribution coefficient in the longitudinal direction of the ship, to be taken as:

$$f_{p-HSM} = k_a k_p$$

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

$$k_a = k_{a-WL} f_{zT} + k_{a-CL}(1 - f_{zT})$$

Intermediate values are obtained by linear interpolation.

Table 33 : k_{a-WL} values for HSM load case

f_{xL}	0.0	0.6	1.0
k_{a-WL}	1.0	1.0	$10 f_T - 5$

Table 34 : k_{a-CL} values for HSM load case

f_{xL}	0.0	0.15	0.3	0.6	0.8	1.0
k_{a-CL}	$3 - 1.5 f_T$	$1.5 - 1.1 f_T$	1.0	1.0	$4 f_T - 1$	$10 f_T - 1$

k_p : Phase coefficient in the longitudinal direction of the ship, to be taken as:

$$k_p = k_{p-WL} f_{zT} + k_{p-CL}(1 - f_{zT})$$

Intermediate values are obtained by linear interpolation.

Table 35 : k_{p-WL} values for HSM load case

f_{xL}	0.0	0.12	0.18	0.55	0.6	1.0
k_{p-WL}	-0.3	-1.0	1.0	1.0	-1.0	-1.0

Table 36 : k_{p-CL} values for HSM load case

f_{xL}	0.0	0.15	0.25	0.5	0.75	1.0
k_{p-CL}	$2.5 - 2.5 f_T$	-1.0	1.0	1.0	-1.0	-1.0

1.4.3 Hydrodynamic pressure for FSM load cases

The hydrodynamic pressures, P_W, for FSM-1 and FSM-2 load cases, at any load point, in $\mathrm{kN/m^2}$, are to be obtained from **Table 37**.

Table 37 : Hydrodynamic pressures for FSM load cases

	Wave pressure, in $\mathrm{kN/m^2}$		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
FSM-1	$P_W = \max\left(-P_{FSM},\ \rho g\left(z - T_{LC}\right)\right)$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
FSM-2	$P_W = \max\left(P_{FSM},\ \rho g\left(z - T_{LC}\right)\right)$		

where:

$P_{FSM} = f_R\, f_\beta\, f_{yz}\, P_a\, f_a\, f_{p-FSM}$

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

$f_{yz} = 0.04 f_{zT} + 0.02 f_{yB} + 0.04$

P_a : Pressure amplitude coefficient in mid-ship position, to be taken as:

$$P_a = 0.5\frac{L}{B} + \frac{50}{L} + 2.3$$

f_a : Wave amplitude coefficient to be taken as:

$$f_a = 0.15 C_w \sqrt{\frac{L_0 + \lambda + 222}{L}}$$

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

$\lambda = 0.5(1.56 + 0.4 f_T)L$

f_{p-FSM} : Pressure distribution coefficient in the longitudinal direction of the ship, to be taken as:

$f_{p-FSM} = k_a\, k_p$

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

$k_a = k_{a-WL}\, f_{zT} + k_{a-CL}\left(1 - f_{zT}\right)$

Intermediate values are obtained by linear interpolation.

Table 38 : k_{a-WL} values for FSM load case

f_{xL}	0.0	0.15	0.3	0.6	0.7	1.0
k_{a-WL}	$2.3 - 1.4 f_T$	$1.5 - f_T$	1.0	1.0	0.55	$3 - 1.2 f_T$

Table 39 : k_{a-CL} values for FSM load case

f_{xL}	0.0	0.2	0.3	0.6	0.7	1.0
k_{a-CL}	$5.5 - 3.7 f_T$	$1.5 - 1.1 f_T$	1.0	1.0	$0.7 - 0.4 f_T$	$4.0 - 0.1 f_T$

k_p : Phase coefficient in the longitudinal direction of the ship, to be taken as:

$$k_p = k_{p-WL} f_{zT} + k_{p-CL}(1 - f_{zT})$$

Intermediate values are obtained by linear interpolation.

Table 40 : k_{p-WL} values for FSM load case

f_{xL}	0.0	0.15	0.3	0.6	0.8	1.0
k_{p-WL}	-0.9	-1.0	1.0	1.0	-1.0	-0.75

Table 41 : k_{p-CL} values for FSM load case

f_{xL}	0.0	0.2	0.25	0.65	0.75	1.0
k_{p-CL}	-0.65	-1.0	1.0	1.0	-1.0	-0.65

1.4.4 Hydrodynamic pressure for BSR load cases

The wave pressures, P_W, for BSR-1 and BSR-2 load cases, at any load point, in $\mathrm{kN/m^2}$, are to be obtained from **Table 42**.

Table 42 : Hydrodynamic pressures for BSR load cases

	Wave pressure, in $\mathrm{kN/m^2}$		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
BSR-1P	$P_W = \max(P_{BSR}, \rho g(z - T_{LC}))$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
BSR-2P	$P_W = \max(-P_{BSR}, \rho g(z - T_{LC}))$		
BSR-1S	$P_W = \max(P_{BSR}, \rho g(z - T_{LC}))$		
BSR-2S	$P_W = \max(-P_{BSR}, \rho g(z - T_{LC}))$		

where:

For BSR-1P and BSR-2P load cases, to be taken as:

$$P_{BSR} = f_\beta \left(10 y \sin\theta + 0.015 C_W \sqrt{\frac{L_0 + \lambda - 125}{L}} (f_{yB1} + 1) \right)$$

For BSR-1S and BSR-2S load cases, to be taken as:

$$P_{BSR} = f_\beta \left(-10 y \sin\theta + 0.015 C_W \sqrt{\frac{L_0 + \lambda - 125}{L}} (f_{yB1} + 1) \right)$$

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

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

1.4.5 Hydrodynamic pressure for BSP load cases

The wave pressure, P_W, for BSP-1 and BSP-2 load cases, at any load point, in $\mathrm{kN/m^2}$, are to be obtained from **Table 43**.

Table 43 : Hydrodynamic pressures for BSP load cases

	Wave pressure, in $\mathrm{kN/m^2}$		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
BSP-1P	$P_W = \max\,(P_{BSP},\ \rho g\,(z - T_{LC}))$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
BSP-2P	$P_W = \max\,(-P_{BSP},\ \rho g\,(z - T_{LC}))$		
BSP-1S	$P_W = \max\,(P_{BSP},\ \rho g\,(z - T_{LC}))$		
BSP-2S	$P_W = \max\,(-P_{BSP},\ \rho g\,(z - T_{LC}))$		

Table 44 : Factor application for BSP load cases

Transverse position	BSP-1P, BSP-2P	BSP-1S, BSP-2S
$y \ge 0$	(S)	(P)
$y < 0$	(P)	(S)

where:

$P_{BSP} = f_R f_\beta f_{yz} P_a f_a f_{p-BSP}$

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

$f_{yz}(P) = 0.5 f_{zT} + 0.77 f_{yB1}$

$f_{yz}(S) = 0.5 f_{zT} + 0.55 f_{yB1}$

P_a : Pressure amplitude coefficient in mid-ship position, to be taken as:

$P_a(P) = 11$

$P_a(S) = 25$

f_a : Wave amplitude coefficient to be taken as:

$$f_a = \left(0.8 C_w \sqrt{\frac{L + \lambda - 125}{L}}\right)\left(\frac{0.22L}{1200(5 - 4f_T)}\right) + 1.5 C_b$$

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

$\lambda = 55 + 2.0B$

f_{p-BSP} : Pressure distribution coefficient in the longitudinal direction of the ship, to be taken as:

$f_{p-BSP} = 1.0$

1.4.6 Hydrodynamic pressure for OST load cases

The wave pressures, P_W, for OST-1 and OST-2 load cases, at any load point are to be obtained, in $\mathrm{kN/m^2}$, from **Table 45.**

Table 45 : Hydrodynamic pressures for OST load cases

	Wave pressure, in $\mathrm{kN/m^2}$		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
OST-1P	$P_W = \max\,(P_{OST},\ \rho g(z - T_{LC}))$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
OST-2P	$P_W = \max\,(-P_{OST},\ \rho g(z - T_{LC}))$		
OST-1S	$P_W = \max\,(P_{OST},\ \rho g(z - T_{LC}))$		
OST-2S	$P_W = \max\,(-P_{OST},\ \rho g(z - T_{LC}))$		

Table 46 : Factor application for OST load cases

Transverse position	OST-1P, OST-2P	OST-1S, OST-2S
$y \ge 0$	(S)	(P)
$y < 0$	(P)	(S)

where:

$P_{OST} = f_R f_\beta f_{yz} P_a f_a f_{p-OST}$

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

$f_{yz}(P) = 0.1 f_{zT} + 0.2 f_{yB} + 0.15$

$f_{yz}(S) = 0.8 f_{zT} + 0.3 f_{yB} + 0.15$

P_a : Pressure amplitude coefficient in mid-ship position, to be taken as:

$P_a = 20.0$

f_a : Wave amplitude coefficient to be taken as:

$$f_a = 0.11 C_w \sqrt{\frac{L + \lambda - 125}{L}}$$

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

$\lambda = 0.45(3.16 - 2.27 f_T) L$

f_{p-OST} : Pressure distribution coefficient in the longitudinal direction of the ship, to be taken as:

$f_{p-OST} = k_a k_p$

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

$k_a = k_{a-WL} f_{zT} + k_{a-CL}(1 - f_{zT})$

Intermediate values are obtained by linear interpolation.

Table 47 : k_{a-WL} values for OST load case

Transverse position	OST-1P, OST-2P		OST-1S, OST-2S	
	f_{xL}	k_{a-WL}	f_{xL}	k_{a-WL}
$y \geq 0$	0.0	$0.05+0.55f_T$	0.0	$3.1f_T-1.9$
	0.15	$1.3f_T-0.3$	0.12	$0.25+0.15f_T$
	0.3	1.0	0.35	$2.0f_T-0.4$
	0.6	1.0	0.6	$1.8-1.2f_T$
	0.8	$1.3f_T-0.3$	0.8	$1.8f_T-0.8$
	1.0	$2.5f_T-0.9$	1.0	$10f_T-7.0$
$y < 0$	0.0	$3.1f_T-1.9$	0.0	$0.05+0.55f_T$
	0.12	$0.25+0.15f_T$	0.15	$1.3f_T-0.3$
	0.35	$2.0f_T-0.4$	0.3	1.0
	0.6	$1.8-1.2f_T$	0.6	1.0
	0.8	$1.8f_T-0.8$	0.8	$1.3f_T-0.3$
	1.0	$10f_T-7.0$	1.0	$2.5f_T-0.9$

Table 48 : k_{a-CL} values for OST load case

f_{xL}	0.0	0.25	0.35	0.6	0.7	1.0
k_{a-CL}	$8.5-7.0f_T$	$3.3-2.6f_T$	1.0	1.0	$2.0-1.3f_T$	$12.0-8f_T$

k_p : Phase coefficient in the longitudinal direction of the ship, to be taken as:

$$k_p = k_{p-WL} f_{zT} + k_{p-CL}(1-f_{zT})$$

Intermediate values are obtained by linear interpolation.

Table 49 : k_{p-WL} values for OST load case

Transverse position	OST-1P, OST-2P		OST-1S, OST-2S	
	f_{xL}	k_{p-WL}	f_{xL}	k_{p-WL}
$y \geq 0$	0.0	$10f_T - 9$	0.0	-1.0
	0.15	$10f_T - 9$	0.15	1.0
	0.3	-1.0	0.55	1.0
	0.6	-1.0	0.65	$9-10f_T$
	0.8	$10f_T - 9$	0.8	$9-10f_T$
	1.0	$10f_T - 9$	1.0	$2.1f_T - 2$
$y < 0$	0.0	-1.0	0.0	$10f_T - 9$
	0.15	1.0	0.15	$10f_T - 9$
	0.55	1.0	0.3	-1.0
	0.65	$9-10f_T$	0.6	-1.0
	0.8	$9-10f_T$	0.8	$10f_T - 9$
	1.0	$2.1f_T - 2$	1.0	$10f_T - 9$

Table 50 : k_{p-CL} values for OST load case

f_{xL}	0.0	0.2	0.35	0.65	0.75	1.0
k_{p-CL}	$10f_T - 9$	$10f_T - 9$	-1.0	-1.0	$10f_T - 9$	$10f_T - 9$

2. External pressures on exposed decks

2.1 Application

2.1.1

The external pressures and forces on exposed decks are only to be applied for strength assessment.

2.1.2

The green sea pressures defined in **[2.2]** for exposed decks are to be considered independently of the pressures due to distributed cargo or other equipment loads and any concentrated forces due to cargo or other unit equipment loads, defined in **[2.3.1]** and **[2.3.2]** respectively.

2.2 Green sea loads

2.2.1 Pressure on exposed deck

The external dynamic pressure due to green sea loading, P_D, at any point of an exposed deck, in $\mathrm{kN/m^2}$, for the static plus dynamic (S + D) design load scenarios is to be derived for each dynamic load case and is to be taken as defined in **[2.2.3]** to **[2.2.4]**.

The external dynamic pressure due to green sea loading, P_D, at any point of an exposed deck for the static (S) design load scenarios is zero.

2.2.2

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

2.2.3 HSM, HSA and FSM load cases

The external pressure, P_D, for HSM, HSA and FSM load cases, at any load point of an exposed deck is to be obtained, in $\mathrm{kN/m^2}$, from the following formula.

$P_D = \chi P_W$

where:

$P_W = P_{W,D}$, but not to be taken less than P_{D-min}.

$P_{W,D}$: Pressure, in $\mathrm{kN/m^2}$, obtained at side of the exposed deck for HSM, HSA and FSM load cases as defined in **[1.3]**.

P_{D-min} : Minimum exposed deck pressure, in $\mathrm{kN/m^2}$, to be taken as:

a) For cargo hold analysis according to **Ch 7**: $P_{D-min} = 0$.

b) For other cases: P_{D-min} as defined in **Table 51.**

χ : Coefficient defined in **Table 52.**

Table 51 : Minimum pressures on exposed decks for HSM, HSA, FSM load cases

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

a : 0.0726
x_{LL} : X-coordinate of the load point measured from the aft end of the freeboard length L_{LL}.

Table 52 : Coefficient for pressure on exposed decks

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

2.2.4 BSR, BSP, OST and OSA load cases

The external pressure, P_D, for BSR, BSP, OST and OSA load cases at any load point of an exposed deck is to be obtained, in $\mathrm{kN/m^2}$, by linear interpolation between the pressures at the port and starboard deck edges :

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

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

where:

$P_{W,D-stb}$: Pressure obtained at starboard deck edge for BSR, BSP, OST or OSA load cases as defined in **[1.3]**, as appropriate.

$P_{W,D-pt}$: Pressure obtained at port deck edge for BSR, BSP, OST and OSA load cases as defined in **[1.3]**, as appropriate.

χ : Coefficient defined in **Table 52**.

2.2.5 Envelope of dynamic pressures on exposed deck

The envelope of dynamic pressure at any point of an exposed deck, P_{D-max}, is to be taken as the greatest pressure obtained from any of the load cases determined by **[2.2.3]** and **[2.2.4]**.

2.3 Load carried on exposed deck

2.3.1 Pressure due to distributed load

If a distributed load is carried on an exposed deck, for example deck cargo or other equipment, the static and dynamic pressures due to this distributed load are to be considered.

The total pressure, P_{dl} in $\mathrm{kN/m^2}$, due to this distributed load for the static (S) design load scenario is to be taken as:

$$P_{dl} = P_{dl-s}$$

The pressure P_{dl}, in $\mathrm{kN/m^2}$, due to this distributed load for the static plus dynamic (S + D) design load scenario is to be derived for each dynamic load case and is to be taken as:

$$P_{dl} = P_{dl-s} + P_{dl-d}$$

where:

P_{dl-s} : Static pressure, in $\mathrm{kN/m^2}$, due to the distributed load, to be defined by the Designer and, in general, but not less than 10.0 $\mathrm{kN/m^2}$.

P_{dl-d} : Dynamic pressure, in $\mathrm{kN/m^2}$, due to the distributed load, to be taken as:

$$P_{dl-d} = f_\beta \frac{a_Z}{g} P_{dl-s}$$

a_Z : Vertical acceleration, in $\mathrm{m/s^2}$, at the centre of gravity of the distributed load, for the considered load case, to be obtained according to **Sec 3, [3.2.4].**

2.3.2 Concentrated force due to unit load

If a unit load, for example deck cargo, is carried on an exposed deck, the static and dynamic forces due to the unit load carried are to be considered.

The force F_U, in kN, due to this concentrated load for the static (S) design load scenarios, is to be taken as:

$$F_U = F_{U-s}$$

The force F_U, in kN, due to this concentrated load for the static plus dynamic (S + D) design load scenarios is to be derived for each dynamic load case and is to be taken as:

$$F_U = F_{U-s} + F_{U-d}$$

where:

F_{U-s} : Static force, in kN, due to the unit load to be taken equal to:

$$F_{U-s} = m_U g$$

F_{U-d} : Dynamic force, in kN, due to unit load to be taken equal to:

$$F_{U-d} = m_U f_\beta a_Z$$

m_U : Mass of the unit load carried, in t.

a_Z : Vertical acceleration, in $\mathrm{m/s^2}$, at the centre of gravity of the unit load carried for the considered load case, to be obtained according to **Sec 3, [3.2.4].**

3. External impact pressures

3.1 Application

3.1.1

The impact pressures for the bow / stern area are only to be applied for strength assessment.

3.2 Equivalent design pressure

3.2.1 Entry impact pressure

The entry impact pressure, P_{EI} in $\mathrm{kN/m^2}$, as equivalent static pressure is to be taken as:

$P_{EI} = C P_E C_E$

where:

C : Vertical distribution coefficient, to be taken as:

$C = 1.0$	for bottom slamming
$C = 0.18(C_w - 0.5 h_0)$	for bow impact
$C = 0.18(C_w - 2.0 h_0)$	for stern slamming

C is not to be less than 0.0 nor greater than 1.0.

C_w : Wave coefficient as defined in **Sec 4.**

h_0 : Vertical distance, in m, from the waterline at the draught T_{SC} to the calculation point, see **Figure 2** and **Figure 3**, to be taken as:

- For bow impact

$h_0 = 0.0$	for calculation point between T_{BAL} and T_{SC}
$h_0 = z - T_{SC}$	for calculation point above the draught T_{SC}

- For stern slamming

$h_0 = 0.0$	for calculation point between T_{AE} and T_{SC}
$h_0 = z - T_{SC}$	for calculation point above the draught T_{SC}

T_{AE} : Design stern slamming draught, in m, at the AE to be provided by designer.

P_E : Impact pressure, in $\mathrm{kN/m^2}$.

$$P_E = \frac{1}{2} \rho K_E V_E^2$$

K_E : Pressure factor, to be taken as:

$K_E = 745\,\xi^{-1.22}$

V_E : Entrance speed, in $\mathrm{m/s^2}$

$V_E = 0.38(25 - 0.02 L)$	for bottom slamming and bow impact
$V_E = 0.6(8.7 + 0.005 L)$	for stern slamming

C_E : Equivalent coefficient, to be taken as:

- For $\xi \le 30^\circ$

$C_E = 0.025\xi + 0.25$ for bottom slamming

$C_E = 0.03\xi + 0.1$ for bow impact

$C_E = 0.032\xi + 0.04$ for stern slamming

- For $\xi > 30^\circ$

$C_E = 1.0$

ξ : Angle, in deg, to be taken as:

$\xi = 90 - \alpha > 3.85$ for bottom slamming and stern slamming

$\xi = 64 - \alpha > 3.85$ for bow impact

α : Flare angle, in deg, at the calculation point defined as the angle between a vertical line and the tangent to the side plating, measured in a vertical plane normal to the horizontal tangent to the shell plating, see **Figure 2** and **Figure 3**.

3.2.2 Breaking wave impact pressure

The breaking wave impact pressure, P_{BI} in $\mathrm{kN/m^2}$, is to be taken as:

$P_{BI} = CP_B$

where:

C : Vertical distribution coefficient, as given in **[3.2.1]**.

C_w : Wave coefficient, as defined in **Sec 4.**

h_0 : Vertical distance, in m, as given in **[3.2.1]**.

P_B : Impact pressure, in $\mathrm{kN/m^2}$.

$$P_B = \frac{1}{2}\rho K_B V_B^2 C_\phi$$

K_B : Coefficient, to be taken as:

$K_B = 4$

V_B : Relative velocity, in $\mathrm{m/s^2}$, to be taken as:

$V_B = 0.514\, V \bullet \sin(\beta + 30) + V_{BW}$

V_{BW} : Breaking wave velocity, in $\mathrm{m/s^2}$, to be taken as:

$V_{BW} = 12\, C_\beta$

C_β : Coefficient, to be taken as:

$C_\beta = 0.25 + \dfrac{\beta}{60}$ for $0^\circ < \beta \le 45^\circ$

$C_\beta = 1$ for $45^\circ < \beta \le 90^\circ$

C_ϕ : Hull inclination angle influence coefficient, in deg, to be taken as:

$C_\phi = 1 - \dfrac{\alpha}{60}$ for $\beta < 15^\circ$

$C_\phi = 1$ for $\beta \ge 15^\circ$

α : Flare angle, in deg, as given in **[3.2.1]**.

β : Angle, in deg, at the calculation point defined as the angle between a longitudinal line and a tangent to the side plating in a horizontal plan, see **Figure 2** and **Figure 3**.

3.3 Bottom slamming

3.3.1 Design pressures

The bottom slamming pressure, P_{SL} in $\mathrm{kN/m^2}$, to be considered for the bottom slamming design load scenario is to be taken as:

$P_{SL} = 0.7\,C_x P_{EI}$

where:

C_x : Longitudinal distribution factor along the ship length, to be taken as:

$C_x = 0.0$	for $f_{xL} \le 0.5$
$C_x = 1.0$	for $f_{xL} = 0.5 + c_1$
$C_x = 1.0$	for $f_{xL} = 0.6 + c_1$
$C_x = 0.1$	for $f_{xL} \ge 1.0$

Intermediate values of C_x are obtained by linear interpolation.

c_1 : Coefficient to be taken as:

$c_1 = 0.33C_B + \dfrac{L}{2500}$ but not greater than 0.35.

P_{EI} : Entry impact pressure, in $\mathrm{kN/m^2}$, as defined in **[3.2.1]**.

α : Flare angle, in deg, at the bottom centerline in the longitudinal direction of the ship, see **Figure 2**.

3.4 Bow impact

3.4.1 Design pressures

The bow impact pressure, P_{FB} in $\mathrm{kN/m^2}$, to be considered for the bow impact design load scenario is to be taken as:

$P_{FB} = \max(P_{EI}, P_{BI}) \cdot f_{FB}$

where:

P_{EI} : Entry impact pressure, in $\mathrm{kN/m^2}$, as defined in **[3.2.1]**.

P_{BI} : Breaking wave impact pressure, in $\mathrm{kN/m^2}$, as defined in **[3.2.2]**.

f_{FB} : Longitudinal distribution factor along the ship length, to be taken as follow but not to be taken greater than 1.0:

$f_{FB} = 2.8\left(f_{xL} + 1.5\dfrac{L}{2500} - 0.12\right)^2 - 1.4$	for $L \le 200\,\mathrm{m}$
$f_{FB} = 2.8 f_{xL}^2 - 1.4$	for $L > 200\,\mathrm{m}$

3.5 Stern slamming

3.5.1 Design pressures

The stern slamming pressure, P_{SS} in $\mathrm{kN/m^2}$, to be considered for the stern slamming design load scenario is to be taken as:

$P_{SS} = P_{EI}$

where:

P_{EI} : Entry impact pressure, in $\mathrm{kN/m^2}$, as defined in **[3.2.1]**.

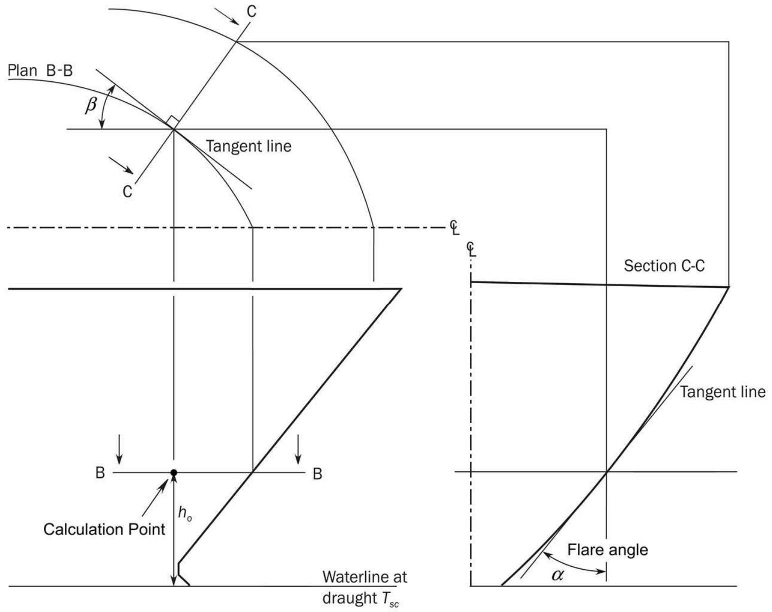


Figure 2 : Definition of bow geometry

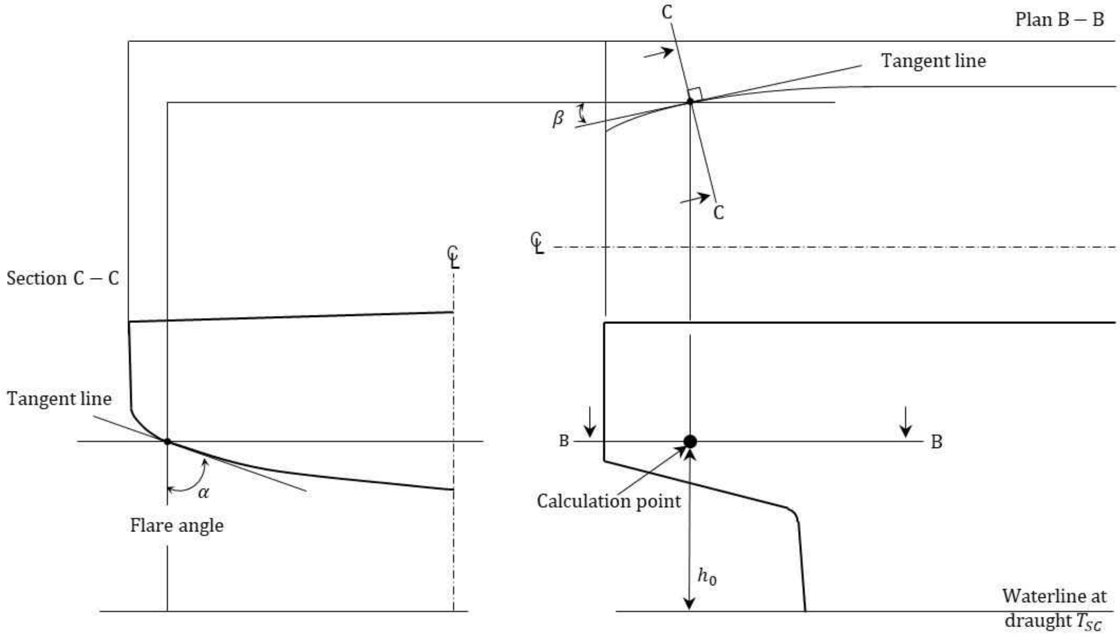


Figure 3 : Definition of stern geometry

4. External pressures on superstructure and deckhouses

4.1 Application

4.1.1

The external pressures on superstructure and deckhouses are only to be applied for strength assessment.

These pressures are to be considered as dynamic pressures and are to be applied to the appropriate structure without any static pressure load component.

4.1.2

The dynamic load case concept is not to be applied for external pressures on superstructures and deckhouses.

4.2 Exposed wheel house tops

4.2.1

The lateral pressure for exposed wheel house tops, P_D in $\mathrm{kN/m^2}$, is to be taken as:

$$P_D = 12.5$$

4.3 Sides of superstructures

4.3.1

The design pressure for the external sides of superstructures, P_{SI} in $\mathrm{kN/m^2}$, is to be taken as:

$$P_{SI} = 2.1 C_w c_F (C_B + 0.7) \frac{20}{10 + z_{SD} - T_{SC}}$$

where:

c_F : Distribution factor according to **Table 53**.

Table 53 : Distribution factor c_F

Location	c_F
$f_{xL} < 0.2$	$1.0 + \frac{5}{C_B}\left(0.2 - \frac{x}{L}\right)$ without taking x/L less than 0.1
$f_{xL} \geq 0.2$	1.0

4.4 End bulkheads of superstructures and deckhouse walls

4.4.1

The external pressure for the aft and forward external bulkheads of superstructures and deckhouse walls, in $\mathrm{kN/m^2}$, is to be taken as:

$$P_A = f_n f_c [f_b f_d - (z_{SD} - T_{SC})]$$ but is not to be less than P_{A-min}.

where:

f_n : Coefficient defined in **Table 54.**

f_c : Coefficient, to be taken as:

$$f_c = 0.3 + 0.7\frac{b_1}{B_1}$$ but not less than 0.475.

For exposed parts of machinery casings, f_c is not to be taken less than 1.0.

f_d : Coefficient, to be taken as:

$$f_d = \frac{L}{10}e^{-(L/300)} - \left(1 - \left(\frac{L}{150}\right)^2\right) \quad \text{for } L < 150\text{m}$$

$$f_d = \frac{L}{10}e^{-(L/300)} \quad \text{for } 150\text{m} \le \text{L} < 300\text{m}$$

$$f_d = 11.03 \quad \text{for } L \ge 300\text{m}$$

b_1 : Breadth of deckhouse at the position considered.

B_1 : Actual breadth of ship on the exposed weather deck at the position considered.

f_b : Coefficient defined in **Table 55.**

P_{A-min} : Minimum lateral pressure, in kN/m^2, as defined in **Table 56.**

Table 54 : Coefficient f_n

Type of bulkhead	Location	f_n
Unprotected front bulkhead(1)	Lowest tier(2)	$20+\frac{L_2}{12}$
	Second tier	$10+\frac{L_2}{12}$
	Third tier and above	$5+\frac{L_2}{15}$
Protected front bulkhead(1)	All tiers	$5+\frac{L_2}{15}$
Side bulkheads	All tiers	$5+\frac{L_2}{15}$
Aft end bulkheads	Abaft amidships	$7+\frac{L_2}{100}-8\frac{x}{L_2}$
	Forward of amidships	$5+\frac{L_2}{100}-4\frac{x}{L_2}$

(1) The front bulkhead of a superstructure or deckhouse may be considered as protected when it is located less than B_x behind another superstructure or deckhouse, and the width of the front bulkhead being considered is less than the width of the aft bulkhead of the superstructure or deckhouse forward of it. B_x is the local breadth of the ship at the front bulkhead.

(2) The lowest tier is normally that tier which is directly situated above the uppermost continuous deck to which the moulded depth D is measured. However, when $(D - T_{SC})$ exceeds the minimum non-corrected tabular freeboard (according to ICLL as amended) by at least one standard superstructure height (as defined in **Ch 1, Sec 4, [3.3]**), then this tier may be defined as the 2nd tier and the tier above as the 3rd tier.

Table 55 : Coefficient f_b

Location of bulkhead[1]	f_b
$f_{xL} < 0.45$	$1.0 + \left(\frac{x/L - 0.45}{C_{B1} + 0.2} \right)^2$
$f_{xL} \geq 0.45$	$1.0 + 1.5 \left(\frac{x/L - 0.45}{C_{B1} + 0.2} \right)^2$
C_{B1} : Block coefficient, but not less than 0.60 nor greater than 0.80. For aft deckhouse bulkheads located forward of amidships, C_{B1} may be taken as 0.80. (1) For deckhouse sides, the deckhouse is to be subdivided into parts of approximately equal length, not exceeding $0.15L$ each, and x is to be taken as the X-coordinate of the centre of each part considered.	

Table 56 : Minimum lateral pressure, P_{A-min}

L	P_{A-min}, in $\mathrm{kN/m^2}$	
	Lowest tier of unprotected fronts	Elsewhere[1]
$90 < L \leq 250$	$25 + \frac{L}{10}$	$12.5 + \frac{L}{20}$
$L > 250$	50	25
(1) For the 4th tier and above, P_{A-min} is to be taken equal to 12.5 $\mathrm{kN/m^2}$.		

Section 6 Internal Loads

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

a_X, a_Y, a_Z : Longitudinal, transverse and vertical accelerations, in $\mathrm{m/s^2}$, at x_G, y_G, z_G, as defined in **Sec 3, [3.2].**

f_β : Coefficient defined in **Sec 4.**

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

h_{max} : Maximum tank height measured from tank bottom, in m.

P_{drop} : Overpressure, in $\mathrm{kN/m^2}$, due to sustained liquid flow through air pipe or overflow pipe in case of overfilling or filling during flow through ballast water exchange. It is to be defined by the designer, but not to be less than 25 $\mathrm{kN/m^2}$.

P_{PV} : Design vapour pressure, in $\mathrm{kN/m^2}$, but not less than 25 $\mathrm{kN/m^2}$.

x, y, z : X, Y and Z coordinates, in m, of the load point with respect to the reference coordinate system defined in **Sec 1, [1.2.1].**

x_G, y_G, z_G : X, Y and Z coordinates, in m, of the volumetric centre of gravity of the tank or fully filled cargo hold, i.e. V_{Full}, considered with respect to the reference coordinate system defined in **Sec 1, [1.2].**

z_{top} : Z coordinate of the highest point of tank, excluding small hatchways, in m.

ρ_L : Density of liquid in the tank, in $\mathrm{t/m^3}$, but not less than:

- For fresh water

  ρ_L=1.0

- For liquefied natural gas as fuel

  ρ_L=0.5 for strength assessment

  ρ_L=0.46 or higher value for fatigue assessment

- For methanol as fuel

  ρ_L=0.8

- For other cases

  ρ_L=1.025

ρ_{slh} : Liquid density, in $\mathrm{t/m^3}$, to be used for sloshing assessment, taken as:

$\rho_{slh} = \rho_L$

ρ_{ST} : Density of steel, in $\mathrm{t/m^3}$, to be taken as 7.85.

θ : Roll angle, in deg, defined in **Sec 3, [2.1.1].**

1. Pressure due to liquids

1.1 Application

1.1.1 Pressures for the strength assessments of intact conditions

The internal pressure due to liquid acting on any load point of a tank, in $\mathrm{kN/m^2}$, for the static (S) design load scenarios, given in **Sec 7**, is to be taken as:

$P_{in} = P_{ls}$ but not less than 0.0

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

$P_{in} = P_{ls} + P_{ld}$ but not less than 0.0

where:

P_{ls} : Static pressure due to liquid in tanks, in $\mathrm{kN/m^2}$, as defined in **[1.2].**

P_{ld} : Dynamic inertial pressure due to liquid in tanks, in $\mathrm{kN/m^2}$, as defined in **[1.3].**

1.1.2 Pressures for the strength assessment of flooded conditions

The internal pressure in flooded condition, in $\mathrm{kN/m^2}$, acting on any load point of the watertight boundary of a hold, tank or other space for the flooded static (S) design load scenarios, given in **Sec 7,** is to be taken as:

$P_{in} = P_{fs}$ but not less than $\rho g d_0$.

where:

P_{fs} : Static pressure of seawater in flooded condition in the compartment, in $\mathrm{kN/m^2}$, as defined in **[1.4].**

d_0 : Distance, in m, to be taken as:

$d_0 = 0.02L$ for $L < 120\,\mathrm{m}$.

$d_0 = 2.4$ for $L \geq 120\,\mathrm{m}$.

1.2 Static liquid pressure

1.2.1 Normal operations at sea

The static pressure due to liquid in tanks, P_{ls} during normal operations at sea, in $\mathrm{kN/m^2}$, is to be taken as:

$P_{ls} = \rho_L g(z_{top} - z) + P_{PV}$ for tanks installed with pressure relief valves

$P_{ls} = \rho_L g(z_{top} - z)$ for other cases

1.2.2 Harbour / sheltered water operations

The static pressure, P_{ls} due to liquid in tanks for harbour / sheltered water operations, in $\mathrm{kN/m^2}$, is to be taken as:

$P_{ls} = \rho_L g(z_{top} - z) + P_{PV}$ for tanks installed with pressure relief valves

$P_{ls} = \rho_L g(z_{top} - z)$ for other cases

1.2.3 Sequential ballast water exchange

The static pressure, P_{ls} due to liquid in ballast tanks associated with sequential ballast water exchange operations, in $\mathrm{kN/m^2}$, is to be taken as:

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

1.2.4 Flow through ballast water exchange

The static pressure, P_{ls} due to liquid in ballast tanks associated with flow through ballast water exchange operations, in $\mathrm{kN/m^2}$, is to be taken as:

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

1.2.5 Ballasting using ballast water treatment system

The static pressure, P_{ls} due to liquid in tanks associated with ballasting operations using a ballast water treatment system is to be taken as defined for sequential ballast exchange in **[1.2.3].** The ship designer has to inform the Society if the ballast water treatment system implies additional pressure to be considered as P_{drop}, etc in addition to the pressure defined in **[1.2.3].**

1.2.6 Static liquid pressure for the fatigue assessment

The static pressure due to liquid in tanks, P_{ls} to be used for the fatigue assessment, in $\mathrm{kN/m^2}$, is to be taken as:

$$P_{ls} = \rho_L g(z_{top} - z)$$

1.3 Dynamic liquid pressure

1.3.1

The dynamic pressure, P_{ld} due to liquid in tanks, in $\mathrm{kN/m^2}$, is to be taken as:

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

where:

f_{ull-l} : Longitudinal acceleration correction factor to account for the ullage space above the liquid in tanks, taken as

- For strength assessment:
  - $f_{ull-l} = 0.62$ for fuel tanks filled with any liquids.
  - $f_{ull-l} = 1.0$ for other cases.
- For fatigue assessment:
  - $f_{ull-l} = 0.5 + \dfrac{|z_o - z|}{\ell_{fs}} \dfrac{180}{\phi \, \pi}$ for fuel tanks filled with any liquids.
  - $f_{ull-l} = 1.0$ for other cases.

f_{ull-l} is not to be less than 0.0 nor greater than 1.0

ℓ_{fs} : Fuel tank length at the top of the tank, in m

f_{ull-t} : Transverse acceleration correction factor to account for the ullage space above the liquid in tanks, taken as

- For strength assessment:
  - $f_{ull-l} = 0.67$ for fuel tanks filled with any liquids.
  - $f_{ull-l} = 1.0$ for other cases.
- For fatigue assessment:
  - $f_{ull-t} = 0.5 + \dfrac{|z_o - z|}{b_{top}} \dfrac{180}{\theta \, \pi}$ for fuel tanks filled with any liquids.
  - $f_{ull-t} = 1.0$ for other cases.

f_{ull-t} is not to be less than 0.0 nor greater than 1.0

b_{top} : Fuel tank breadth at the top of the tank, in m, determined at mid length of the tank.

x_0 : X coordinate, in m, of the reference point.

y_0 : Y coordinate, in m, of the reference point.

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

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

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

where:

x_j : X coordinate, in m, of the point j on the upper boundary of the tank.

y_j : Y coordinate, in m, of the point j on the upper boundary of the tank.

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

1.4 Static pressure in flooded conditions

1.4.1 Static pressure in flooded compartments

The static pressure, P_{fs} in $\mathrm{kN/m^2}$, for watertight boundaries of flooded compartments is to be taken as:

$P_{fs} = \rho g h_{fs}$ but not less than 0.0

where:

h_{fs} : Pressure height, in m, in flooded condition, to be taken as:

$h_{fs} = \max(z_{FD} - z\,,\, |y|\sin\theta_{dam} + (z_{dam} - z)\cos\theta_{dam})$ for hull local scantling according to **Ch 6**

$h_{fs} = y\sin\theta_{dam} + (z_{dam} - z)\cos\theta_{dam} + 1.0$ for direct strength analysis according to **Ch 7**

Alternatively, the worst damage water line corresponding to the damage stability calculation for every individual cargo hold may be used for direct strength assessment.

z_{FD} : Z coordinate, in m, of the freeboard deck at side in way of the transverse section considered.

z_{dam} : Z coordinate, in m, of the deepest equilibrium waterline at centre line in the damaged condition.(or in intermediate stages of flooding)

θ_{dam} : Angle, in deg, between the deepest equilibrium waterline in the damaged condition (or in intermediate stages of flooding) and the base line.

2. Pressures and forces due to container

2.1 Container design load

2.1.1 Design weight of a container

The design weight of a container, M_{con-i}, in hold and design stack weight on deck, M_{stack}, in ton, is to be used based on the trim and stability booklet. The design weight of a container is not to be less than the minimum as follow:

$M_{con-i} \geq 2.5$	for 20ft container
$M_{con-i} \geq 3.5$	for 40ft container
$M_{con-i} \geq 4.0$	for 45ft container

where:

M_{con-i} : Design weight of a container at tier 'i', in ton, and to be defined for each 20ft and 40ft container.

2.1.2 Static force of a container

The static force of a container, $F_{con-s-i}$, in kN, and the static force of stack, $F_{stack-s}$, in kN, are to be taken as:

$$F_{con-s-i} = g M_{con-i}$$

$$F_{stack-s} = g M_{stack}$$

2.1.3 Dynamic force of a container

The dynamic container force components of a container at the container center of gravity, in kN, is to be taken as:

$$F_{con-d-x-i} = M_{con-i}\, a_X$$

$$F_{con-d-y-i} = M_{con-i}\, a_Y$$

$$F_{con-d-z-i} = M_{con-i}\, a_Z$$

The reference point of a_X, a_Y and a_Z is to be taken at the center of considered cargo hold.

2.1.4 Center of gravity of a container

The vertical center of gravity of each container is assumed at 45 % of container height. And, the longitudinal and transverse center of gravity of each container is assumed at the mid of corresponding length.

2.1.5 Total container forces

The total container force acting on the bottom of each container stack is to be taken as:

$$F_{con-total-x} = \sum_{i=1}^{N} F_{con-d-x-i}$$

$$F_{con-total-y} = \sum_{i=1}^{N} F_{con-d-y-i}$$

$$F_{con-total-z} = \sum_{i=1}^{N} F_{con-s-i} + \sum_{i=1}^{N} F_{con-d-z-i} \text{ or } F_{con-total-z} = F_{stack-s} + \sum_{i=1}^{N} F_{con-d-z-i}$$

where:

N : Number of containers per stack in hold or on deck.

2.2 Container loads in hold

2.2.1 Longitudinal load component

The longitudinal load component, F_x, in kN, is to be applied to the transverse bulkhead depending on the direction of acceleration at the position of container corner in way of cell guide. See also **Figure 1.**

$$F_x = F_{con-d-x-i}/4$$

2.2.2 Transverse load component

The transverse load component, F_y, in kN, is to be applied to the transverse bulkhead depending on the direction of acceleration at the position of container corner in way of cell guide. See also **Figure 2.**

$$F_y = F_{con-d-y-i}/4$$

2.2.3 Vertical load component

The vertical load component, F_z, in kN, is to be applied to the inner bottom at the position of 4 container corners. See also **Figure 3**.

$$F_z = F_{con-total-z}/4$$

2.2.4 Load application

a) For 20ft container in 40ft container bay, 35% of the total transverse load component is to be applied to the inner bottom at the free end of the 20ft stack. At the other end, the remaining 65% of the total transverse load component is to be applied to the transverse bulkhead in way of the cell guide in the transverse force direction.

$F_y = 0.65\,F_{con-d-y-i}/2$ for the end 2 corners of 20ft container near transverse bulkhead.

$F_y = 0.35\,F_{con-total-y}/2$ for the bottom corners of free end of 20ft stack in 40ft container bay.

b) For 20ft container in 40ft container bay, the longitudinal load component combined with longitudinally nearest 20ft container, is also to be applied to the transverse bulkhead depending on the direction of combined acceleration at the position of container corner in way of cell guide.

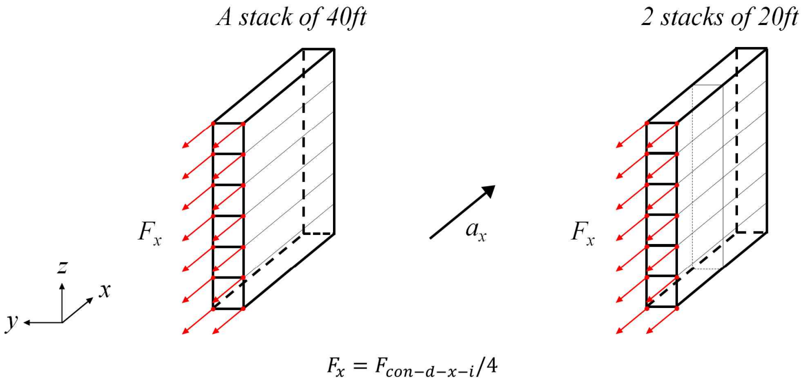


Figure 1 : Longitudinal container load component in hold

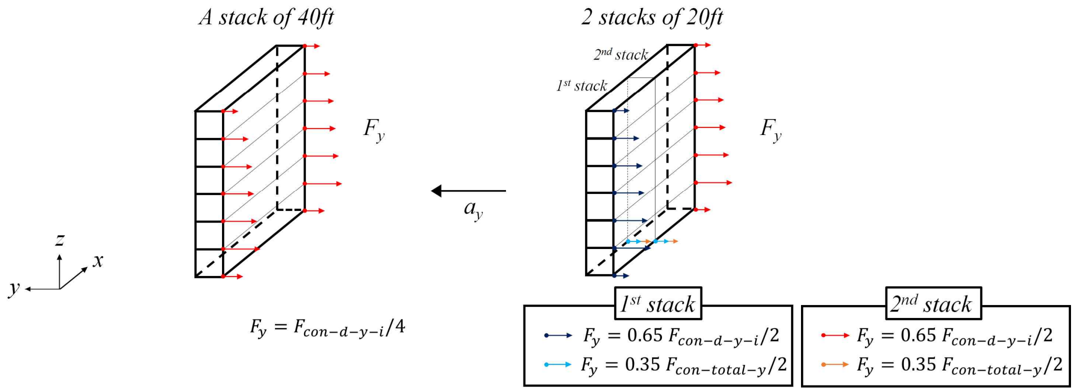


Figure 2 : Transverse container load component in hold

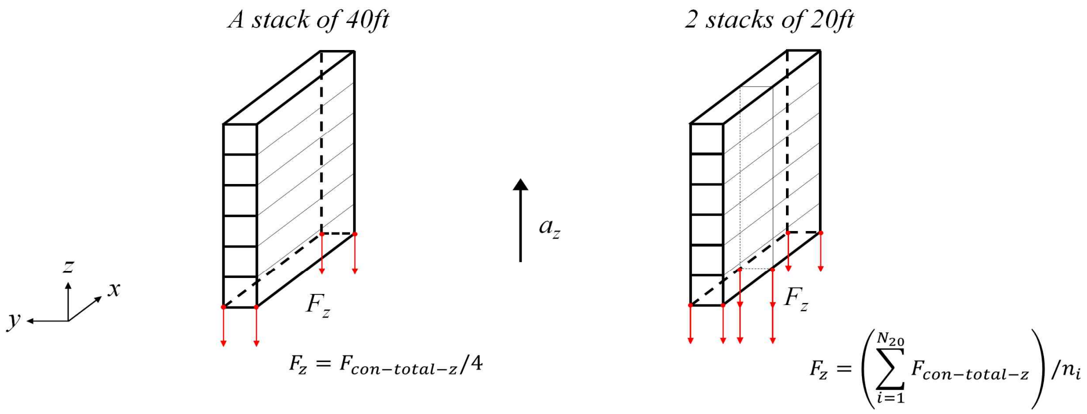


Figure 3 : Vertical container load component in hold

2.3 Container loads on deck or hatch cover

2.3.1 Load application

The effect of the hatch cover self-weight may be considered in the loads applied to the ship structures. See also **Figure 4**, **Figure 5** and **Figure 6**.

a) Each container load component at the bottom corners of each stack on deck or hatch cover is to be taken as:

$$F_x = F_{con-total-x}/4$$

$$F_y = F_{con-total-y}/4$$

$$F_z = F_{con-total-z}/4$$

b) In case of 20ft container stack on hatch cover in way of 40ft bay, each container load component acting on hatch cover is to be distributed along the top of the corresponding hatch coaming. The total force acting on the hatch cover is determined by integrating all stacks on hatch cover. Then the total force is to be distributed to the total length of the hatch coamings using the average line load.

$$F_x = \left(\sum_{i=1}^{N_{20}} F_{con-total-x}\right)/n_i \qquad F_y = \left(\sum_{i=1}^{N_{20}} F_{con-total-y}\right)/n_i \qquad F_z = \left(\sum_{i=1}^{N_{20}} F_{con-total-z}\right)/n_i$$

where:

N_{20} : Number of 20ft stacks on hatch cover.

n_i : Number of nodal points of top of hatch coaming.

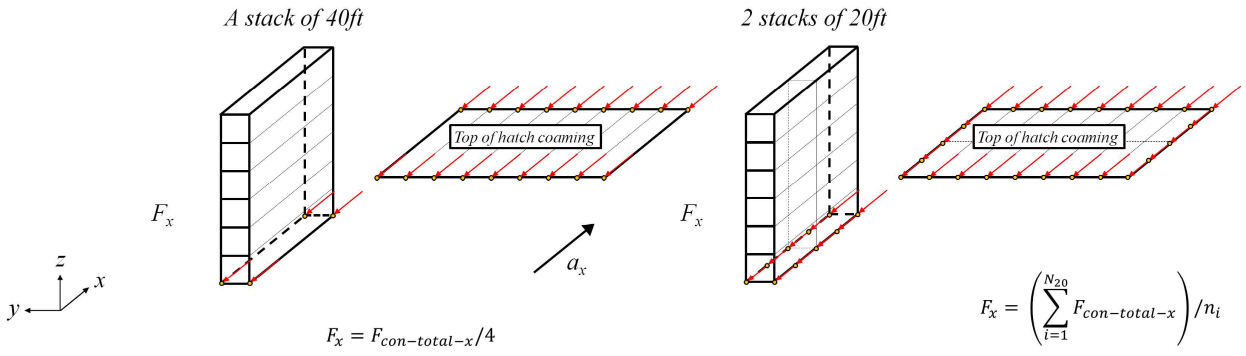


Figure 4 : Longitudinal container load component on deck

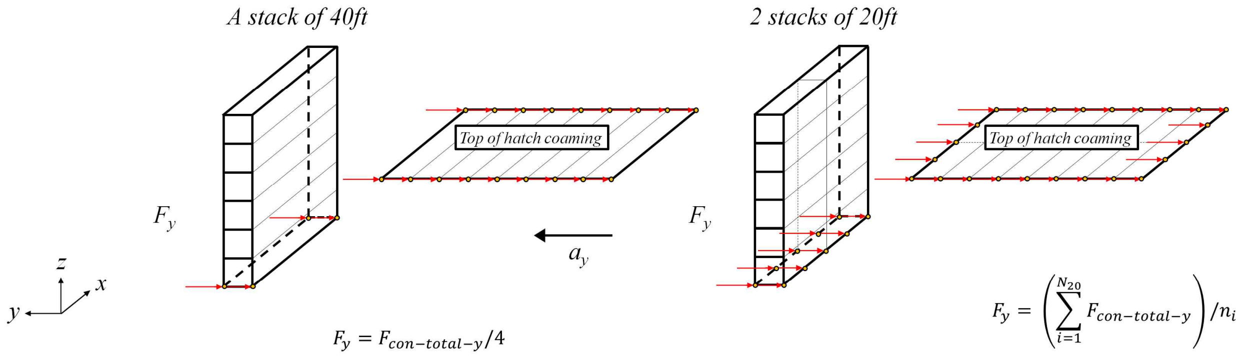


Figure 5 : Transverse container load component on deck

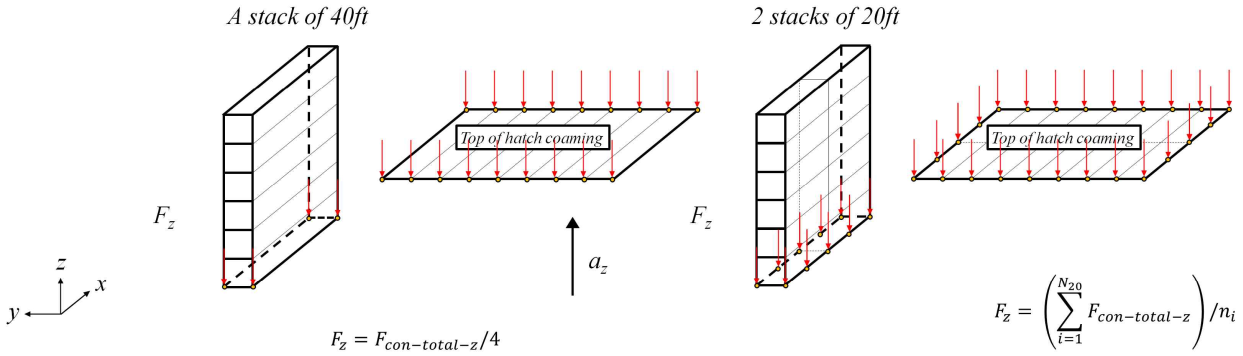


Figure 6 : Vertical container load component on deck

3. Pressure by IGF

3.1 General

3.1.1 Application

For the liquefied natural gas fuel tank, the internal pressure acting on a tank boundary, which is symbolized as P_{IGC} in **Ch 6**, is given in **"Rules/Guidance for the Classification of Ships Using Low-flashpoint Fuels", Ch 6, Sec 4, 409.** in $\mathrm{kN/m^2}$. This pressure is calculated with dimensionless acceleration, which is combined with 3 components(a_x, a_y, a_z) in an arbitrary direction according to an ellipsoid surface. For the corner points of the liquefied natural gas fuel tank, pressure may be calculated with different acceleration direction so as to have a maximum. The pressure between corner points is decided by linear interpolation.

4. Sloshing pressure in tanks

4.1 General

4.1.1 Application

This article applies to all ballast tanks and other tanks with a volume exceeding $100\mathrm{m}^3$, but the water ballast tanks located within the cargo hold region do not need to be applied.

4.1.2

The sloshing pressures defined in this article do not include the effect of impact pressures due to high velocity impacts with tank boundaries or internal structures. For tanks with a breadth of cargo tank, b_{tk-h}, greater than $0.56B$ or a length of cargo tank, ℓ_{tk-h}, greater than $0.13L$ at any filling level from $0.05h_{\max}$ to $0.95h_{\max}$, a separate impact assessment is to be carried out in accordance with the Society procedures.

4.1.3 Sloshing pressure on tank boundaries and internal divisions

The sloshing pressure due to liquid motions in a tank P_{slh} acting on any load point of a tank boundary or internal divisions, in $\mathrm{kN/m^2}$, for the sloshing design load scenario, given in **Sec 7,** is to be taken as follows, without being less than $P_{slh-\min}$, as given in **[4.2]**:

a) $P_{slh} = P_{slh-lng}$ for transverse bulkheads, as defined in **[4.3.2]**.

b) $P_{slh} = P_{slh-wf}$ for web frames and transverse stringers, as defined in **[4.3.3]**.

c) $P_{slh} = P_{slh-t}$ for longitudinal bulkheads, as defined in **[4.4.2]**.

d) $P_{slh} = P_{slh-grd}$ for longitudinal girders and stringers, see **[4.4.3]**.

4.2 Minimum sloshing pressure

4.2.1

The minimum sloshing pressure, $P_{slh-min}$, for tanks of cellular construction, i.e. double hull construction with internal structures restricting the fluid motion, is to be taken as 12.0 $\mathrm{kN/m^2}$.

The minimum sloshing pressure, $P_{slh-min}$, for all other tanks is to be taken as 20.0 $\mathrm{kN/m^2}$.

4.3 Sloshing pressure due to longitudinal liquid motion

4.3.1

The sloshing pressure due to longitudinal liquid motion, $P_{slh-lng}$, 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 levels from $0.05h_{\max}$, to $0.95h_{\max}$, in $0.05h_{max}$ increments.

4.3.2 Sloshing pressure in way of transverse bulkheads

The sloshing pressure in way of transverse bulkheads due to longitudinal liquid motion, $P_{slh-lng}$, in $\mathrm{kN/m^2}$, for a particular filling level, is to be taken as:

$$P_{slh-lng} = \rho_{slh} g \ell_{tk-h} f_{slh}\left[0.4 - \left(0.39 - \frac{1.7\ell_{tk-h}}{L}\right)\frac{L}{350}\right]$$

where:

ℓ_{tk-h} : Length of cargo tank, in m, at considered filling height.

f_{slh} : Coefficient as defined in **Table 1**.

h_{fill} : Filling height, measured from tank bottom, in m.

Table 1 : Coefficient f_{slh}

h_{fill}	f_{slh}
$0.0h_{Tank}$	0.0
$0.1h_{Tank}$	$f_{slh} = 1.5\left[1 - 2\left(0.3 - \frac{h_{fill}}{h_{Tank}^2}\right)^2\right]$
$0.3h_{Tank}$	$f_{slh} = 2.0\left[1 - 2\left(0.3 - \frac{h_{fill}}{h_{Tank}^2}\right)^2\right]$
$1.0h_{Tank}$	$f_{slh} = 1.5\left[1 - 2\left(0.3 - \frac{h_{fill}}{h_{Tank}^2}\right)^2\right]$
For intermediate values of h_{fill}, f_{slh} are to be obtained by linear interpolation.	

4.3.3 Sloshing pressure on internal web frames or transverse stringers adjacent to a transverse bulkhead

For tanks with internal web frames the sloshing pressure acting on a web frame or transverse stringer adjacent to transverse bulkheads or transverse wash bulkheads due to longitudinal liquid motion, P_{slh-wf}, in $\mathrm{kN/m^2}$, provided it is located within $0.25\ell_{slh}$ from the bulkhead, is to be taken as:

$$P_{slh-wf} = P_{slh-lng}\left(1 - \frac{s_{wf}}{\ell_{tk-h}}\right)^2$$

where:

ℓ_{tk-h} : Length of cargo tank, in m, at considered filling height.

$P_{slh-lng}$: Sloshing pressure due to longitudinal liquid motion acting on transverse bulkhead, as defined in **[3.2.6].**

s_{wf} : Distance from transverse bulkhead to web frame under consideration, in m.

The distribution of pressure across web frames and transverse stringers is given in **Figure 7.**

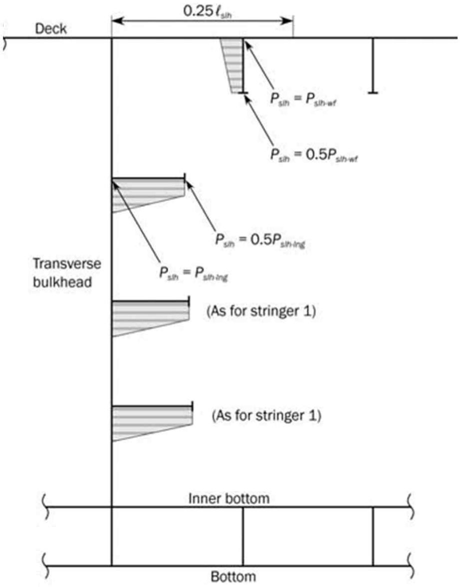


Figure 7 : Sloshing pressure distribution on transverse stringers and web frames

4.4 Sloshing pressure due to transverse liquid motion

4.4.1 Application

The sloshing pressure due to transverse liquid motion, P_{slh-t}, is to be taken constant as a constant value over the full tank depth and is to be taken as the greater of the sloshing pressures calculated for filling levels from $0.05h_{\max}$ to $0.95h_{\max}$, in $0.05h_{\max}$ increments.

4.4.2 Sloshing pressure in way of longitudinal bulkheads

The sloshing pressure in way of longitudinal bulkheads due to transverse liquid motion, P_{slh-t}, in $\mathrm{kN/m^2}$, for a particular filling level, is to be taken as:

$$P_{slh-t} = 7\,\rho_{slh}\,g\,f_{slh}\left(\frac{b_{tk-h}}{B} - 0.3\right)GM^{\,0.75}$$

where:

b_{tk-h} : Breadth of cargo tank, in m, at considered filling height.

f_{slh} : Coefficient to be taken as defined in **[4.3.2] Table 1**.

GM : Metacentric height, given in **Sec 3, [2.1.1]**.

4.4.3 Sloshing pressure on internal girders or longitudinal stringers adjacent to longitudinal bulkheads

For tanks with internal girders or stringers, the sloshing pressure acting on the girder/web frame adjacent to longitudinal bulkheads and longitudinal wash bulkhead, $P_{slh-grd}$, in $\mathrm{kN/m^2}$, provided it is located within $0.25\,b_{slh}$ from the bulkhead, is to be taken as:

$$P_{slh-grd} = P_{slh-t}\left(1 - \frac{s_{grd}}{b_{tk-h}}\right)^2$$

where:

b_{tk-h} : Breadth of cargo tank, in m, at considered filling height.

P_{slh-t} : Sloshing pressure due to transverse liquid motion acting on longitudinal bulkhead, as defined in **[3.2.9]**.

s_{grd} : Distance from longitudinal bulkhead to girder under consideration, in m.

The distribution of pressure across stringers is given in **Figure 8.** The distribution of pressure across longitudinal girders is similar to the deck web frame shown in **Figure 7**.

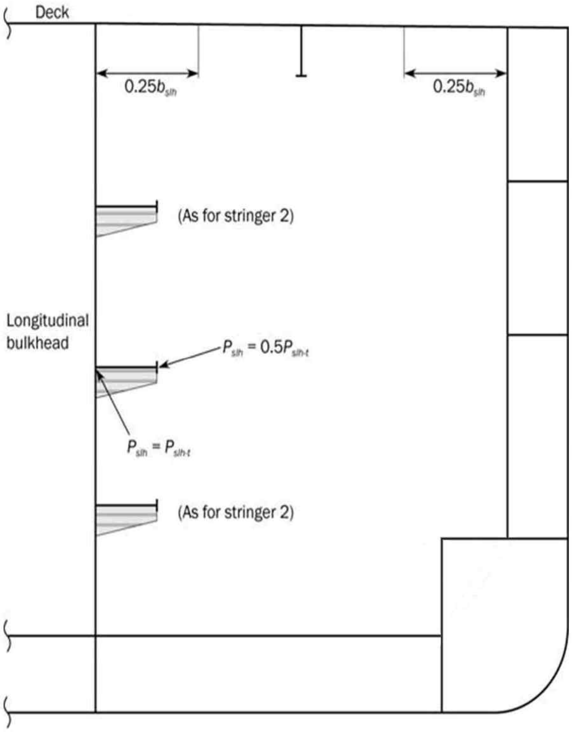


Figure 8 : Sloshing pressure distribution on longitudinal stringers and girders

5. Design pressure for tank testing

5.1 Definition

5.1.1

In order to assess the structure, static design pressures are to be applied. The design pressure for tank testing, P_{ST}, in $\mathrm{kN/m^2}$, is to be taken as:

$$P_{ST} = 10(z_{ST} - z)$$

where:

z_{ST} : Design testing load height, in m, as defined in **Table 2.**

Table 2 : Design testing load height z_{ST}

Compartment	z_{ST}
Double bottom tanks [(1)]	The greater of the following: $z_{ST} = z_{top} + h_{air}$ $z_{ST} = z_{bd}$
Double side tanks, fore and aft peaks used as tank	The greater of the following: $z_{ST} = z_{top} + h_{air}$ $z_{ST} = z_{top} + 2.4$
Tank bulkheads, deep tanks, fuel oil bunkers and methanol fuel tanks	The greater of the following: $z_{ST} = z_{top} + h_{air}$ $z_{ST} = z_{top} + 2.4$ $z_{ST} = z_{top} + 0.1P_{PV}$
Chain locker	$z_{ST} = z_c$
Independent tanks	The greater of the following: $z_{ST} = z_{top} + h_{air}$ $z_{ST} = z_{top} + 0.9$
Ballast ducts	Testing load height corresponding to ballast pump maximum pressure

z_{bd} : z coordinate, in m, of the bulkhead deck.
z_c : z coordinate, in m, of the top of the chain pipe.

(1) For double bottom tanks connected with double side tanks, corresponding to "Double side tanks, fore and aft peaks used as tank" is applicable.

6. Loads on non-exposed decks and platforms

6.1 Application

6.1.1 General

The loads defined in **[5.2]** and **[5.3]** are applicable to non-exposed decks, accommodation decks and platforms.

6.2 Pressure due to distributed load

6.2.1

If a distributed load is carried on a deck, the static and dynamic pressures due to this distributed load are to be considered.

The static distributed load is to be defined by the designer without being less than 3.0 $\mathrm{kN/m^2}$ for accommodation decks and 10.0 $\mathrm{kN/m^2}$ for other decks and platforms.

The pressure P_{dl}, in $\mathrm{kN/m^2}$, due to this distributed load for the static (S) design load scenarios, given in **Sec 7,** is to be taken as:

$$P_{dl} = P_{dl-s}$$

The pressure P_{dl}, in $\mathrm{kN/m^2}$, due to this distributed load for the static plus dynamic (S + D) design load scenarios, is to be derived for the envelope of dynamic load cases and is to be taken as:

$P_{dl} = P_{dl-s} + P_{dl-d}$ but not less than 0.0.

where:

P_{dl-s} : Static pressure, in $\mathrm{kN/m^2}$, due to the distributed load.

P_{dl-d} : Dynamic pressure, in $\mathrm{kN/m^2}$, due to the distributed load, in $\mathrm{kN/m^2}$, to be taken as:

$$P_{dl-d} = f_\beta \frac{a_{z-env}}{g} P_{dl-s}$$

a_{z-env} : Envelope of vertical acceleration, in $\mathrm{m/s^2}$, at the load position being considered, for the dynamic load cases, given in **Sec 3, [3.3.3].**

6.3 Concentrated force due to unit load

6.3.1

If a unit load is carried on an internal deck, the static and dynamic forces due to the unit load carried are to be considered when a direct analysis is applied for stiffeners or primary supporting members such as in **Ch 6, Sec 5 [1.2]** or **Ch 6, Sec 6 [3.3]** respectively.

The force F_U, in kN, due to this concentrated load for the static (S) design load scenarios, given in **Sec 7,** is to be taken as:

$$F_U = F_{U-s}$$

The force F_U, in kN, due to this concentrated load for the static plus dynamic (S + D) design load scenarios, is to be derived for the envelope of dynamic load cases and is to be taken as:

$F_U = F_{U-s} + F_{U-d}$ but not less than 0.0.

where:

F_{U-s} : Static force, in kN, due to the unit load to be taken as:

$$F_{U-s} = m_U g$$

F_{U-d} : Dynamic force, in kN, due to unit load to be taken as:

$$F_{U-d} = m_U f_\beta a_{z-env}$$

m_U : Mass of the unit load carried, in t.

a_{z-env} : Envelope of vertical acceleration, in $\mathrm{m/s^2}$, at the centre of gravity of the unit load carried for the dynamic load cases, given in **Sec 3, [3.3.3].**

Section 7 Design Load Scenarios

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

VBM : Design vertical bending moment, in kNm.

M_{sw} : Permissible hull girder hogging and sagging still water bending moment for seagoing operation, in kNm, as defined in **Sec 4, [2.2.2].**

M_{sw-p} : Permissible hull girder hogging and sagging still water bending moment for harbour / sheltered water operation, in kNm, as defined in **Sec 4, [2.2.3].**

M_{sw-f} : Permissible hull girder hogging or sagging still water bending moment M_{sw-f} for seagoing operation in the flooded condition, in kNm, as defined in **Sec 4, [2.2.4].**

M_{sw-t} : Permissible hull girder hogging and sagging still water bending moment for tank testing, in kNm, as defined in **Sec 4, [2.2.5].**

M_{wv-LC} : Vertical wave bending moment for a considered dynamic load case, in kNm, as defined in **Sec 4, [3.2].**

HBM : Design horizontal bending moment, in kNm.

M_{wh-LC} : Horizontal wave bending moment for a considered dynamic load case, in kNm, as defined in **Sec 4, [3.4].**

TM : Design torsional moment, in kNm.

M_{wt-LC} : Wave torsional moment for a considered dynamic load case, in kNm, as defined in **Sec 4, [3.6].**

VSF : Design vertical shear force, in kN.

Q_{sw} : Permissible hull girder positive and negative still water shear force limits for seagoing operation, in kN, as defined in **Sec 4, [2.3.1].**

Q_{sw-p} : Permissible hull girder positive and negative still water shear force limits for harbour / sheltered water operation, in kN, as defined in **Sec 4, [2.3.2].**

Q_{sw-f} : Permissible hull girder positive and negative still water shear force for seagoing operation in the flooded condition, in kN, as defined in **Sec 4, [2.3.3].**

Q_{sw-t} : Permissible hull girder positive and negative still water shear force limits for tank testing, in kN.

Q_{wv-LC} : Vertical wave shear force for a considered dynamic load case, in kN, as defined in **Sec 4, [3.3].**

P_{ex} : Design external pressure, in $\mathrm{kN/m^2}$.

P_S : Static sea pressure at considered draught, in $\mathrm{kN/m^2}$, as defined in **Sec 5, [1.2.1].**

P_W : Dynamic pressure for a considered dynamic load case, in $\mathrm{kN/m^2}$, as defined in **Sec 5, [1.3.2]** to **[1.3.8]**.

P_D : Green sea load for a considered dynamic load case, in $\mathrm{kN/m^2}$, as defined in **Sec 5, [2.2.3]** and **[2.2.4]**.

P_{in} : Design internal pressure, in $\mathrm{kN/m^2}$.

P_{ST} : Tank testing pressure, in $\mathrm{kN/m^2}$, see **Sec 6, [4.1.1].**

$P_{\ell s}$: Static liquid pressure in tank, in $\mathrm{kN/m^2}$, as defined in **Sec 6, [1.2].**

$P_{\ell d}$: Dynamic liquid pressure in tank for a considered dynamic load case, in $\mathrm{kN/m^2}$, as defined in **Sec 6, [1.3].**

P_{fs} : Static pressure in compartments and tanks in flooded condition, in $\mathrm{kN/m^2}$, as defined in **Sec 6, [1.4.1].**

F_{U-s} : Static load acting on supporting structures and securing systems for heavy units or cargo, equipment or structural components, in kN, as defined in **Sec 5, [2.3.2].**

F_{U-d} : Dynamic load acting on supporting structures and securing systems for heavy units of cargo, equipment or structural components, in kN, as defined in **Sec 5, [2.3.2].**

P_{SL} : Bottom slamming pressure, in $\mathrm{kN/m^2}$, as defined in **Sec 5, [3.2].**

P_{FB} : Bow impact pressure, in $\mathrm{kN/m^2}$, as defined in **Sec 5, [3.3].**

P_{SS} : Stern slamming pressure, in $\mathrm{kN/m^2}$, as defined in **Sec 5, [3.4].**

P_{slh} : Sloshing pressure, in $\mathrm{kN/m^2}$, as defined in **Sec 6, [3].**

1. General

1.1 Application

1.1.1

This section gives the design load scenarios that are to be used for:

a) Strength assessment by prescriptive and direct analysis (Finite Element Method, FEM) methods, as given in **[2].**

b) Fatigue assessment by prescriptive and direct analysis (FEM) methods, as given in **[3].**

1.1.2

For the strength assessment, the principal design load scenarios consist of either S (Static) loads or S + D (Static + Dynamic) loads. In some cases, the letter “A” prefixes the S or S + D to denote that this is an accidental design load scenario. There are some additional design load scenarios to be considered which relate to impact (I) loads and sloshing (SL) loads.

2. Design load scenarios for strength assessment

2.1 Principal design load scenarios

2.1.1

The principal design load scenarios are given in **Table 1.**

Table 1 : Principal design load scenarios for strength assessment

Design load scenario			Harbour and sheltered water	Seagoing conditions with extreme sea loads	Ballast water exchange[1]	Flooded conditions	Collision conditions
Load components			Static (S)	Static + Dynamic (S+D)	Static + Dynamic (S+D)	Accidental (A)	Accidental (A)
Hull Girder	VBM		M_{sw-p}	$M_{sw}+M_{wv-LC}$	$M_{sw}+M_{wv-LC}$	M_{sw-f}	M_{sw}
	HBM		–	M_{wh-LC}	M_{wh-LC}	–	–
	VSF		Q_{sw-p}	$Q_{sw}+Q_{wv-LC}$	$Q_{sw}+Q_{wv-LC}$	–	–
	TM		–	$M_{st}+M_{wt-LC}$	$M_{st}+M_{wt-LC}$	–	–
Local Loads	P_{ex}	External deck for green sea	–	P_D	–	–	–
		Hull envelope	P_s	P_s+P_w	P_s+P_w	–	–
	P_{in}	Ballast tanks	P_{ls}	$P_{ls}+P_{ld}$	$P_{ls}+P_{ld}$	–	–
		Liquefied natural gas fuel tanks			–	–	$0.5g,\ -0.25g$
		Other tanks			–	–	–
		Watertight boundaries	–	–	–	P_{fs}	–
	F_{con}	Container	F_{con-s}	$F_{con-s}+F_{con-d}$	–	–	–
	P_{dk}	Internal decks for dry spaces	P_{dl-s}	$P_{dl-s}+P_{dl-d}$	–	–	–
		External deck for distributed loads	P_{dl-s}	$P_{dl-s}+P_{dl-d}$	–	–	–
		External deck for heavy units	F_{U-s}	$F_{U-s}+F_{U-d}$	–	–	–

[1] Applicable to prescriptive assessment only

2.2 Additional design load scenarios

2.2.1

The design load scenarios to be considered for bow impact, bottom slamming, stern slamming, sloshing and tank testing are given in **Table 2.**

Table 2 : Design load scenarios for impact, sloshing and tank test conditions

Design load scenario			Bow impact	Bottom slamming	Stern slamming	Sloshing	Tank testing(1)
Load components			Impact (I)	Impact (I)	Impact (I)	Sloshing (SL)	Test (T)
Hull Girder	VBM		–	–	–	M_{sw}	M_{sw-t}
	HBM		–	–	–	–	–
	VSF		–	–	–	–	Q_{sw-t}
	TM		–	–	–	–	–
Local Loads	P_{ex}	External deck for green sea	–	–	–	–	–
		Hull envelope	P_{FB}	P_{SL}	P_{SS}	–	P_{s}
	P_{in}	Ballast tanks	–	–	–	P_{slh}	P_{ST}
		Liquefied natural gas fuel tanks					–
		Other tanks					P_{ST}
		Watertight boundaries	–	–	–	–	–
	F_{con}	Container	–	–	–	–	–
	P_{dk}	Internal decks for dry spaces	–	–	–	–	–
		External deck for distributed loads	–	–	–	–	–
		External deck for heavy units	–	–	–	–	–

(1) Applicable to prescriptive assessment only

3. Design load scenarios for fatigue assessment

3.1 Design load scenarios

3.1.1

The design load scenarios are given in **Table 3.**

Table 3 : Design load scenarios for fatigue assessment

Design load scenario			Fatigue: Static + Dynamic (F: S + D)
Load components			
Hull Girder	VBM		$M_{sw}+M_{wv-LC}$
	HBM		M_{wh-LC}
	VSF		$Q_{sw}+Q_{wv-LC}$
	TM		$M_{st}+M_{wt-LC}$
Local Loads	P_{ex}	External deck for green sea	–
		Hull envelope	P_s+P_w
	P_{in}	Ballast tanks	$P_{ls}+P_{ld}$
		Liquefied natural gas fuel tanks	
		Other tanks	
		Watertight boundaries	–
	F_{con}	Container	$F_{con-s}+F_{con-d}$
	P_{dk}	Internal decks for dry spaces	–
		External deck for distributed loads	–
		External deck for heavy units	–

Section 8 Loading Conditions

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

1. Application

1.1 Design loading conditions for strength assessment

1.1.1

Design loading conditions for strength assessment are given in **[2].** Unless otherwise specified, each of the design seagoing and harbour conditions are to be investigated for all dynamic load case.

1.1.2

These requirements are not intended to prevent conditions to be included in the loading manual for which calculations are to be submitted. It is not intended to replace in any way the required loading manual/instrument.

1.1.3

Loading conditions from the loading manual, which are not covered in **[2]**, if any, are to be considered.

1.2 Design load conditions for fatigue assessment

1.2.1

The design loading conditions for fatigue assessment are given in **[3].**

2. Design loading conditions

2.1 Definitions

2.1.1

In general, the design cargo and ballast loading conditions, based on the amount of bunker, fresh water and stores at departure and arrival, are to be considered for the still water bending moment and shear force calculations. Where the amount and disposition of consumables at any intermediate stage of the voyage are considered more severe, calculations for such intermediate conditions are to be submitted in addition to those for departure and arrival conditions. Also, where any ballasting and/or deballasting is intended during voyage, calculations of the intermediate condition just before and just after ballasting and/or deballasting are to be submitted and included in the loading manual.

2.1.2 Departure conditions

The departure conditions are to be based on bunker tanks not taken less than 95 % full and other consumables taken at 100 % capacity.

2.1.3 Arrival conditions

The arrival conditions are to be based on 10 % of the maximum capacity of bunker, fresh water and stores.

2.2 Seagoing conditions

2.2.1

The following seagoing loading conditions are to be included, as a minimum, in the loading manual:

a) Homogeneous cargo loading condition including a condition at the scantling draught.
b) Ballast condition where the ballast tanks may be full or empty. All cargo holds are to be empty. The propeller is to be fully immersed.
c) Conditions covering ballast water exchange procedures, if any, with the calculations of intermediate conditions just before and just after ballasting and/or deballasting any ballast tank.

2.3 Harbour and sheltered water conditions

2.3.1

The following harbour and sheltered water conditions are to be included in the loading manual:

a) Conditions representing typical complete loading and unloading operations.
b) Docking condition afloat.

2.4 Loading conditions

2.4.1 Alternative design

For structural arrangement not covered by this section, the loading conditions, including loading pattern, corresponding draught, still water bending moment and shear forces are to be agreed by the Society.

2.4.2 Standard loading conditions for cargo holds strength check

The loading conditions to be considered for cargo hold strength check are given in **Table 1.**

2.4.3 Standard loading conditions for fuel oil tanks strength check

The loading conditions to be considered for fuel oil tank strength check are given in **Table 2.**

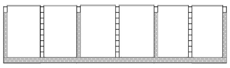
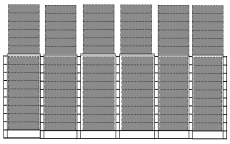
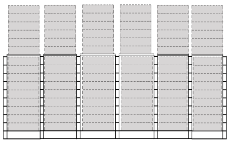
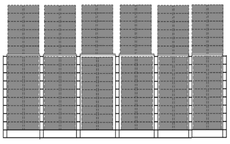
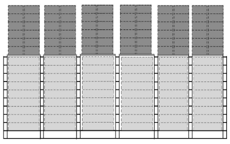
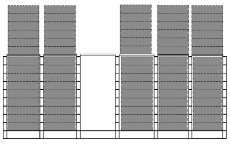
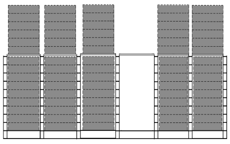
2.4.4 Standard loading conditions for liquefied natural gas fuel tank strength check

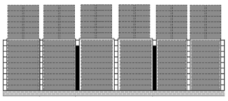
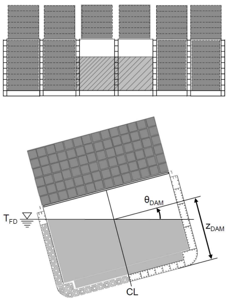
The loading conditions to be considered for liquefied natural gas fuel tank strength check are given in **Table 3**.

2.4.5 Standard loading conditions for cargo holds fatigue check

The loading conditions to be considered for cargo hold fatigue check are given in **Table 4.**

Table 1 : Standard loading conditions for cargo holds strength check to cargo hold region

No.	Loading Pattern	Still Water Loads					Dynamic Load Cases
		Draught	Container Load		% of perm. SWBM	% of perm. SWSF	Midship cargo region
			In hold	On deck			
Seagoing conditions							
B1[3]		T_{BAL}[1]	All ballast tanks full	-	SWBM in ballast condition[2]	≤100%	HSM-2 HSA-2 FSM-2 BSR-1P BSR-2P BSP-1P BSP-2P
F1[3]		T_{SC}	Max. 40 ft stack weight All tanks empty	Max. 40 ft stack weight	100% (Hog.)	≤100%	HSM-2 HSA-2 FSM-2 BSR-1P BSR-2P BSP-1P BSP-2P
F2[3]		T_{SC}	55% of Max. 40 ft stack weight not exceeding 16.5 t/FEU All tanks empty	90% of Max. 40 ft stack weight not exceeding 17 t/FEU	100% (Hog.)	≤100%	HSM-2 HSA-2 FSM-2 BSR-1P BSR-2P BSP-1P BSP-2P
F3[3]		$0.9T_{SC}$	Max. 20 ft stack weight All tanks empty	Max. 20 ft stack weight, if mixed stowage is applicable, Max. 20 ft + 40 ft stack weight	100% (Sag. or Min. Hog.)	≤100%	HSM-1 HSA-1 FSM-1 BSR-1P BSR-2P BSP-1P BSP-2P
F4[3]		$0.9T_{SC}$	55% of Max. 40 ft stack weight not exceeding 16.5 t/FEU All tanks empty	Max. 20 ft stack weight, if mixed stowage is applicable, Max. 20 ft + 40 ft stack weight	100% (Sag. or Min. Hog.)	≤100%	HSM-1 HSA-1 FSM-1 BSR-1P BSR-2P BSP-1P BSP-2P
F5		T_{SC}	Max. 40 ft stack weight All tanks empty	Max. 40 ft stack weight	100% (Hog.)	≤100%	HSM-2 HSA-2 FSM-2
F6		T_{SC}	Max. 40 ft stack weight All tanks empty	Max. 40 ft stack weight	100% (Hog.)	≤100%	HSM-2 HSA-2 FSM-2

No.	Loading Pattern	Still Water Loads					Dynamic Load Cases
		Draught	Container Load		% of perm. SWBM	% of perm. SWSF	Midship cargo region
			In hold	On deck			
F7[3]		T_{SC}	Max. 40 ft stack weight All fuel oil tanks full All ballast tanks full	Max. 20 ft stack weight, if mixed stowage is applicable, Max. 20 ft + 40 ft stack weight	100% (Sag. or Min. Hog.)	≤100%	HSM-1 HSA-1 FSM-1 BSR-1P BSR-2P BSP-1P BSP-2P
Flooded condition							
A1[4]		T_{FD}	Centre: flooded Adjacent: Max. 40 ft stack weight All ballast tanks full at inclined side	Max. 40 ft stack weight	100% (Sag. or Min. Hog.)	-	Static[5]

▩ heavy cargo □ light cargo ▦ ballast tank ■ fuel oil tank

[1] Minimum ballast draught corresponding to the ballast departure loading condition from loading manual.

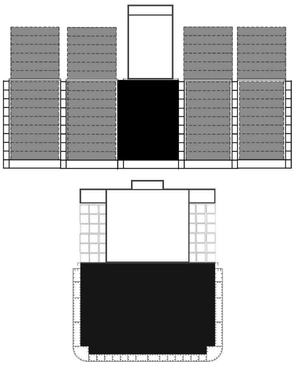
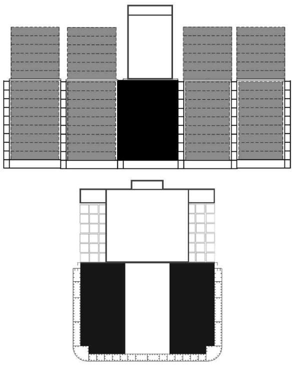
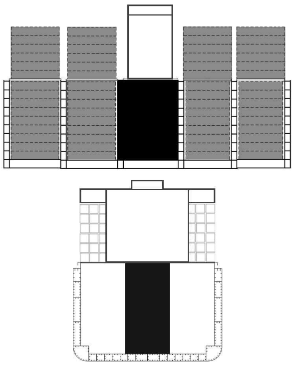
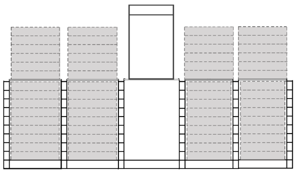
[2] Still water bending moment corresponding to the ballast departure loading condition from loading manual.

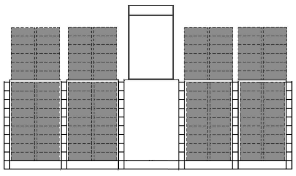
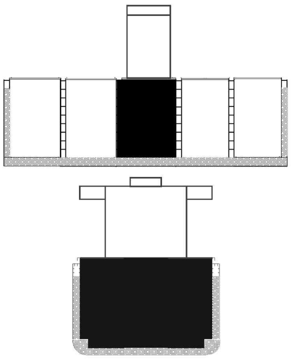
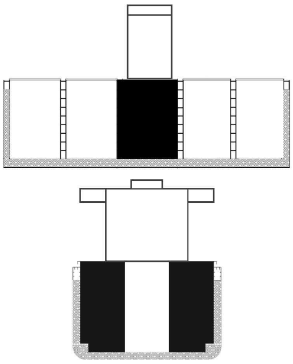
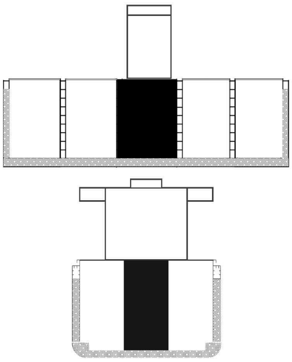
[3] For asymmetrical structures BSR-1S, BSR-2S, BSP-1S and BSP-2S shall be investigated additionally.

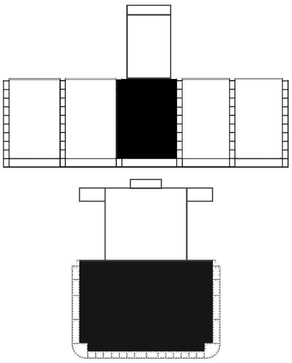
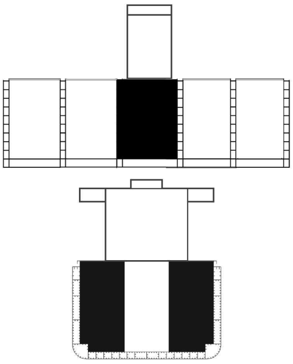
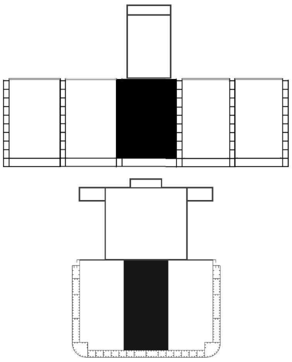
[4] With deepest equilibrium waterline T_{FD} in a heeled damage condition where the considered hold is one of the flooded compartments. Although this is a typical scenario with two or three flooded holds, in the FE-analysis only the center cargo hold is flooded.

[5] Heel condition shall be considered at least for inner pressure in the flooding cargo hold, for outer pressure on the shell and for container forces, base on design z_{dam} and θ_{dam} as designed in **Sec 6, [1.4.1]**

Table 2 : Standard loading conditions for fuel oil tanks strength check in cargo hold region

No.	Loading Pattern	Still Water Loads					Dynamic Load Cases
		Draught	Container Load		% of perm. SWBM	% of perm. SWSF	Midship cargo region
			In hold	On deck			
Seagoing conditions							
OF1		T_{SC}	Max. 40 ft stack weight All ballast tanks empty All fuel oil tanks full	Max. 40 ft stack weight	100% (Sag. or Min. Hog.)	≤100%	HSM-1 HSA-1 FSM-1 BSR-1P BSR-2P BSP-1P BSP-2P
OF2		T_{SC}	Max. 40 ft stack weight All ballast tanks empty Relevant fuel oil tanks are full and empty	Max. 40 ft stack weight	100% (Sag. or Min. Hog.)	≤100%	HSM-1 HSA-1 FSM-1 BSR-1P BSR-2P BSP-1P BSP-2P
OF3		T_{SC}	Max. 40 ft stack weight All ballast tanks empty Relevant fuel oil tanks are full and empty	Max. 40 ft stack weight	100% (Sag. or Min. Hog.)	≤100%	HSM-1 HSA-1 FSM-1 BSR-1P BSR-2P BSP-1P BSP-2P
OF4		T_{SC}	55% of Max. 40 ft stack weight not exceeding 16.5 t/FEU All ballast tanks empty All fuel oil tanks empty	90% of Max. 40 ft stack weight not exceeding 17 t/FEU	100% (Hog.)	≤100%	HSM-2 HSA-2 FSM-2

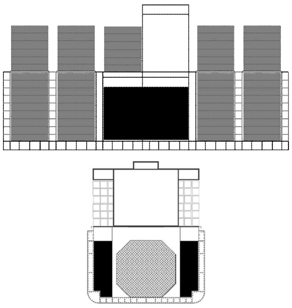
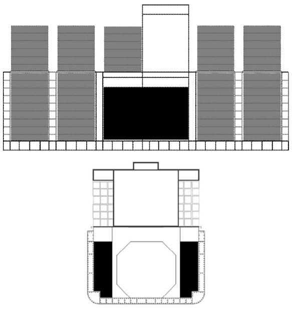
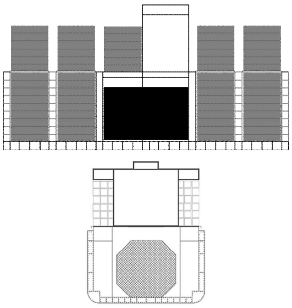
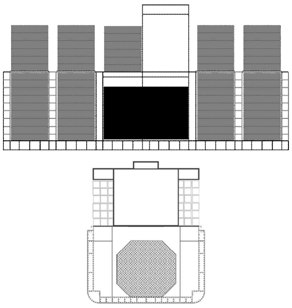
No.	Loading Pattern	Still Water Loads					Dynamic Load Cases
		Draught	Container Load		% of perm. SWBM	% of perm. SWSF	Midship cargo region
			In hold	On deck			
OF5		$0.9T_{SC}$	Max 20 ft stack weight, All ballast tanks empty All fuel oil tanks empty	Max. 20 ft stack weight, if mixed stowage is applicable, Max. 20 ft + 40 ft stack weight	100% (Sag. or Min. Hog.)	≤100%	HSM-1 HSA-1 FSM-1
Ballast conditions							
OB1		T_{BAL} 1)	All fuel oil tanks full All ballast tanks full All container bays empty	All container bays are empty	SWBM in ballast condition 2)	≤100%	HSM-1 HSA-1 FSM-1
OB2		T_{BAL} 1)	Relevant fuel oil tanks are full and empty All ballast tanks full All container bays empty	All container bays are empty	SWBM in ballast condition 2)	≤100%	HSM-1 HSA-1 FSM-1
OB3		T_{BAL} 1)	Relevant fuel oil tanks are full and empty All ballast tanks full All container bays empty	All container bays are empty	SWBM in ballast condition 2)	≤100%	HSM-1 HSA-1 FSM-1

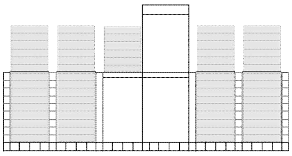
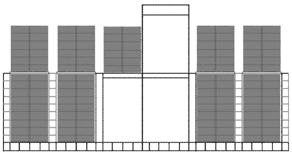
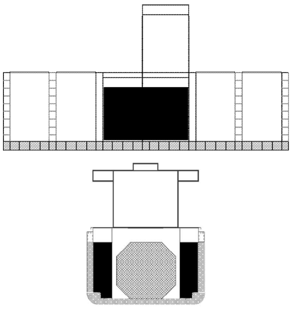
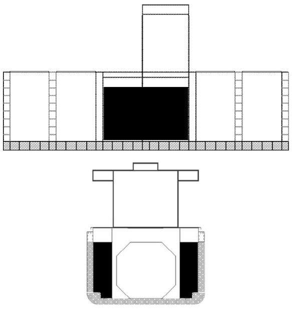
No.	Loading Pattern	Still Water Loads					Dynamic Load Cases
		Draught	Container Load		% of perm. SWBM	% of perm. SWSF	Midship cargo region
			In hold	On deck			
Testing conditions							
OT1		T_{BAL}[1]	Fuel oil tanks filling is for tank test All fuel oil tanks full All ballast tanks empty All container bays empty	All container bays are empty	SWBM in ballast condition[2]	≤100%	Static
OT2		T_{BAL}[1]	Fuel oil tanks filling is for tank test Relevant fuel oil tanks are full and empty All ballast tanks empty All container bays empty	All container bays are empty	SWBM in ballast condition[2]	≤100%	Static
OT3		T_{BAL}[1]	Fuel oil tanks filling is for tank test Relevant fuel oil tanks are full and empty All ballast tanks empty All container bays empty	All container bays are empty	SWBM in ballast condition[2]	≤100%	Static
▓ heavy cargo	░ light cargo	▨ ballast tank	■ fuel oil tank				

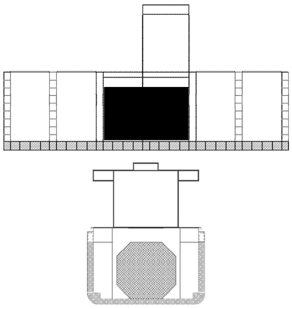
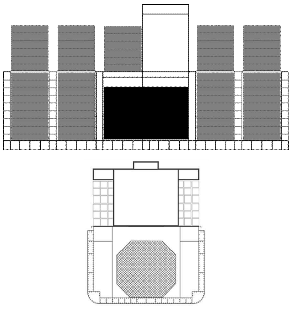
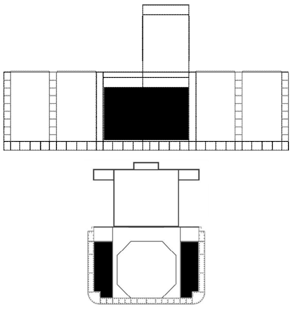
[1] Minimum ballast draught corresponding to the ballast departure loading condition from loading manual.

[2] Still water bending moment corresponding to the ballast departure loading condition from loading manual.

Table 3 : Standard loading conditions for liquefied natural gas fuel tanks strength check in cargo hold region

No.	Loading Pattern	Still Water Loads					Dynamic Load Cases
		Draught	Container Load		% of perm. SWBM	% of perm. SWSF	Midship cargo region
			In hold	On deck			
Seagoing conditions							
GF1		T_{SC}	Max. 40 ft stack weight All ballast tanks empty All fuel tanks full	Max. 40 ft stack weight	100% (Sag. or Min. Hog.)	≤100%	HSM-1 HSA-1 FSM-1 BSR-1P BSR-2P BSP-1P BSP-2P
GF2		T_{SC}	Max. 40 ft stack weight All ballast tanks empty Fuel oil tanks full Liquefied natural gas fuel tank empty	Max. 40 ft stack weight	100% (Sag. or Min. Hog.)	≤100%	HSM-1 HSA-1 FSM-1 BSR-1P BSR-2P BSP-1P BSP-2P
GF3		T_{SC}	Max. 40 ft stack weight All ballast tanks empty Fuel oil tanks empty Liquefied natural gas fuel tank full	Max. 40 ft stack weight	100% (Sag. or Min. Hog.)	≤100%	HSM-1 HSA-1 FSM-1 BSR-1P BSR-2P BSP-1P BSP-2P
GF3 -IGF		T_{SC}	Max. 40 ft stack weight All ballast tanks empty Fuel oil tanks empty Liquefied natural gas fuel tank full	Max. 40 ft stack weight	≤100%	≤100%	Static Pressure by IGF with heel angle, $\theta_\beta \le 30^\circ$

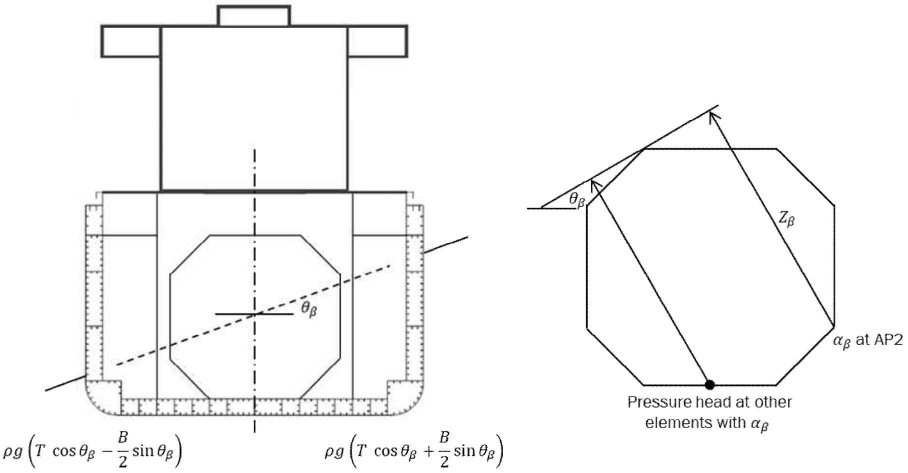
No.	Loading Pattern	Still Water Loads					Dynamic Load Cases
		Draught	Container Load		% of perm. SWBM	% of perm. SWSF	Midship cargo region
			In hold	On deck			
GF4		T_{SC}	55% of Max. 40 ft stack weight not exceeding 16.5 t/FEU All ballast tanks empty All fuel tanks empty	90% of Max. 40 ft stack weight not exceeding 17 t/FEU	100% (Hog.)	≤100%	HSM-2 HSA-2 FSM-2
GF5		$0.9T_{SC}$	Max 20 ft stack weight, All ballast tanks empty All fuel tanks empty	Max. 20 ft stack weight, if mixed stowage is applicable, Max. 20 ft + 40 ft stack weight	100% (Sag. or Min.Hog.)	≤100%	HSM-1 HSA-1 FSM-1
Ballast conditions							
GB1		T_{BAL}1)	All container bays empty All ballast tanks full All fuel tanks full	All container bays are empty	SWBM in ballast condition2)	≤100%	HSM-1 HSA-1 FSM-1
GB2		T_{BAL}1)	All container bays empty All ballast tanks full Fuel oil tanks full Liquefied natural gas fuel tank empty	All container bays are empty	SWBM in ballast condition2)	≤100%	HSM-1 HSA-1 FSM-1

No.	Loading Pattern	Still Water Loads					Dynamic Load Cases
		Draught	Container Load		% of perm. SWBM	% of perm. SWSF	Midship cargo region
			In hold	On deck			
GB3		T_{BAL}1)	All container bays empty All ballast tanks full Fuel oil tanks empty Liquefied natural gas fuel tank full	All container bays are empty	SWBM in ballast condition2)	≤100%	HSM-1 HSA-1 FSM-1
Accidental condition							
A1		T_{SC}	Max. 40 ft stack weight All ballast tanks empty Fuel oil tanks empty Liquefied natural gas fuel tank full	Max. 40 ft stack weight	≤100%	≤100%	Static Forward a_x=0.5g Aftward a_x=0.25g
Testing condition							
GT1		T_{BAL}1)	All container bays empty All ballast tanks empty Fuel oil tanks full Liquefied natural gas fuel tank empty	All container bays are empty	SWBM in ballast condition2)	≤100%	Static

▓ heavy cargo ░ light cargo ▒ ballast tank ■ fuel oil tank ▩ LNG fuel tank

1) Minimum ballast draught corresponding to the ballast departure loading condition from loading manual.

2) Still water bending moment corresponding to the ballast departure loading condition from loading manual.

<table>
<tr><th rowspan="3">No.</th><th rowspan="3">Loading Pattern</th><th colspan="5">Still Water Loads</th><th>Dynamic Load Cases</th></tr>
<tr><th rowspan="2">Draught</th><th colspan="2">Container Load</th><th rowspan="2">% of perm. SWBM</th><th rowspan="2">% of perm. SWSF</th><th rowspan="2">Midship cargo region</th></tr>
<tr><th>In hold</th><th>On deck</th></tr>
<tr><td colspan="8">
</td></tr>
</table>

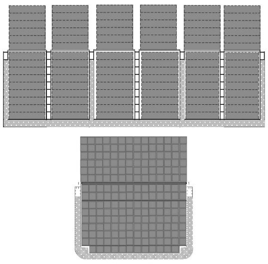
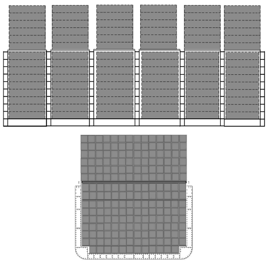
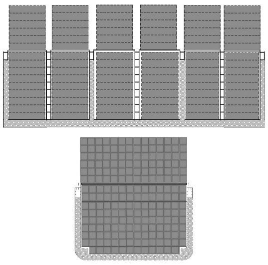
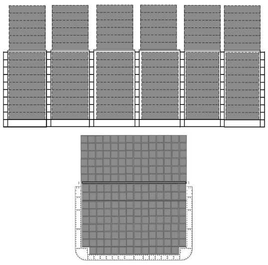
3. Standard loading conditions for fatigue assessment

3.1 General

3.1.1

The standard loading conditions to be applied for fatigue assessment as required in **Ch 9, Sec 1, [6.2]**, are defined in **Table 4**.

Table 4 : Standard loading conditions for fatigue assessment in cargo hold region

No	Description	Loading Pattern	Still Water Loads			Dynamic Load Cases
			Draught	% of perm. SWBM	% of perm. SWSF	Midship cargo region
FL-1	Full load (all ballast tanks full)		T_{Design} (but not less than $0.8T_{SC}$)	90% (Hog.)	–	HSM-1 HSM-2 FSM-1 FSM-2 BSR-1P BSR-2P BSR-1S BSR-2S BSP-1P BSP-2P BSP-1S BSP-2S
FL-2	Full load (all ballast tanks empty)					
FL-3	Full load (all ballast tanks full)		T_{Design} (but not less than $0.8T_{SC}$)	100% (Sag. or Min. Hog.)[1]	–	HSM-1 HSM-2 FSM-1 FSM-2 BSR-1P BSR-2P BSR-1S BSR-2S BSP-1P BSP-2P BSP-1S BSP-2S
FL-4	Full load (all ballast tanks empty)					

[1] $M_{sw,\min}$ is a minimum design hogging moment taken from the loading manual. If $M_{sw,\min}$ is larger (hogging positive) than 0.1 M_{sw-h}, then $M_{sw,\min}$ shall replace 0.1 M_{sw-h}

Chapter 5

Hull Girder Strength

Section 1 Hull Girder Yield and Buckling Strength

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

M_{sw} : Permissible hogging and sagging vertical still water bending moment in seagoing operation, in kNm, at the hull transverse section considered, defined in **Ch 4, Sec 4, [2.2.2].**

M_{sw-p} : Permissible hogging and sagging vertical still water bending moment for harbour/sheltered water operation, in kNm, at the hull transverse section considered, as defined in **Ch 4, Sec 4, [2.2.3].**

M_{sw-f} : Permissible hogging and sagging vertical still water bending moment in flooded condition at sea, in kNm, at the hull transverse section considered, as defined in **Ch 4, Sec 4, [2.2.4].**

M_{wv} : Vertical wave bending moment in seagoing condition, in kNm, in seagoing operation at the hull transverse section considered, defined in **Ch 4, Sec 4, [3.2.1].**

M_{wh} : Horizontal wave bending moment, in kNm, at the hull transverse section considered, defined in **Ch 4, Sec 4, [3.3.1].**

Q_{sw} : Permissible positive or negative still water shear force for seagoing operation, in kN, at the hull transverse section considered, as defined in **Ch 4, Sec 4, [2.3.1].**

Q_{sw-p} : Permissible positive or negative still water shear force for harbour/sheltered operation, in kN, at the hull transverse section considered, as defined in **Ch 4, Sec 4, [2.3.2].**

Q_{wv} : Vertical wave shear force in seagoing condition, in kN, at the hull transverse section considered, defined in **Ch 4, Sec 4, [3.3].**

Q_{wh} : Horizontal wave shear force in seagoing condition, in kN, at the hull transverse section considered, defined in **Ch 4, Sec 4, [3.3].**

x : X coordinate, in m, of the calculation point with respect to the reference coordinate system defined in **Ch 1, Sec 4, [3.5].**

V_D : Vertical distance to the equivalent deck line, in m, as defined in **[1.4.3].**

z : Z coordinate, in m, of the calculation point with respect to the reference coordinate system defined in **Ch 1, Sec 4, [3.5].**

z_n : Z coordinate, in m, of horizontal neutral axis of the hull transverse section with net scantling defined in **[1.2],** with respect to the reference coordinate system defined in **Ch 1, Sec 4, [3.5].**

I_{y-n50} : Net moment of inertia, in m^4, of the hull transverse section about its horizontal neutral axis, to be calculated according to **[1.5].**

I_{Z-n50} : Net moment of inertia, in m^4, of the hull transverse section about its vertical neutral axis, to be calculated according to **[1.5].**

Z_{A-n50} : Net section modulus, in m^3, at any point of the hull transverse section, to be calculated according **[1.4.1].**

C_w : Wave coefficient defined in **Ch 4, Sec 4.**

ρ : Seawater density, taken equal to 1.025 t/m^3.

1. Strength characteristics of hull girder transverse sections

1.1 General

1.1.1

This section specifies the criteria for calculating the hull girder strength characteristics to be used for the checks in **[2]** to **[3]**, in association with the hull girder loads specified in **Ch 4, Sec 4.**

1.2 Hull girder transverse sections

1.2.1 General

Hull girder transverse sections are to be considered as being constituted by the members contributing to the hull girder longitudinal strength, taking into account the requirements in **[1.2.2]** to **[1.2.12].**

1.2.2 Net scantling

The members contributing to the hull girder longitudinal strength are to be considered using the net offered scantlings based on gross offered thickness reduced by $0.5t_c$, as defined in **Ch 3, Sec 3,** when the hull girder strength characteristics are used for the hull girder yielding check according to **[2]** to **[3].**

1.2.3 Structural members not contributing to hull girder sectional area

The following members are not to be considered in the calculation as they are considered not contributing to the hull girder sectional area:

a) Superstructures which do not form a strength deck.
b) Deckhouses.
c) Bulwarks.
d) Gutter plates.
e) Bilge keels.
f) Sniped or non-continuous longitudinal stiffeners.
g) Non-continuous hatch coamings.

1.2.4 Continuous trunks and longitudinal continuous hatch coamings

Continuous trunks and longitudinal continuous hatch coamings may be included in the hull girder transverse sections, provided that they are effectively supported by longitudinal bulkheads or primary supporting members.

1.2.5 Longitudinal stiffeners or girders welded above the strength deck

Longitudinal stiffeners or girders welded above the strength deck, including the deck of any trunk fitted as specified in **[1.2.4]**, are to be included in the hull girder transverse sections.

1.2.6 Longitudinal girders between hatchways

Where longitudinal girders are between hatch ways, the sectional area that can be included in the hull girder transverse sections is obtained, in m^2, from the following formula:

$$A_{eff} = A_{LG}\,\xi$$

where:

A_{LG} : Sectional area, in m^2, of longitudinal girders

ξ : Ratio of inclusion of members effective for longitudinal strength

Table 1 : Ratio in inclusion of sectional area

No of holds	2			3		
ξ \ ℓ/L	0.10	0.20	0.30	0.10	0.15	0.20
0.0	0.96	0.85	0.70	0.96	0.91	0.85
0.5	0.65	0.57	0.48	0.89	0.80	0.69
1.0	0.48	0.43	0.36	0.83	0.73	0.62
2.0	0.32	0.29	0.25	0.73	0.63	0.53
3.0	0.24	0.22	0.17	0.65	0.57	0.47
4.0	0.19	0.17	0.14	0.59	0.51	0.43
5.0	0.16	0.14	0.12	0.53	0.47	0.39

Note:

1. ξ is to be in accordance with followings

$$\xi = \frac{ab^3}{\ell I_c}\left\{\frac{1+2\mu}{2(2+\mu)} \times 10^4 + 2.6\frac{I_c}{a_c b^2}\right\}$$

Where:

I_c : Moment of inertia, in cm^4, of deck hatches, including hatch coaming
a_c : Effective shear area, in cm^2, of deck between hatches
a : Sectional area, in cm^2, of continuous deck between hatches (one side)
ℓ : length, in m, of hatch
μ : coefficient as specified in **Figure 1**
b : breadth, in m, of hatch opening as specified in **Figure 1**

2. ξ or ℓ/L may obtained from the interpolation.
3. When the value of ξ is over 5.0, it may be obtained extrapolation.

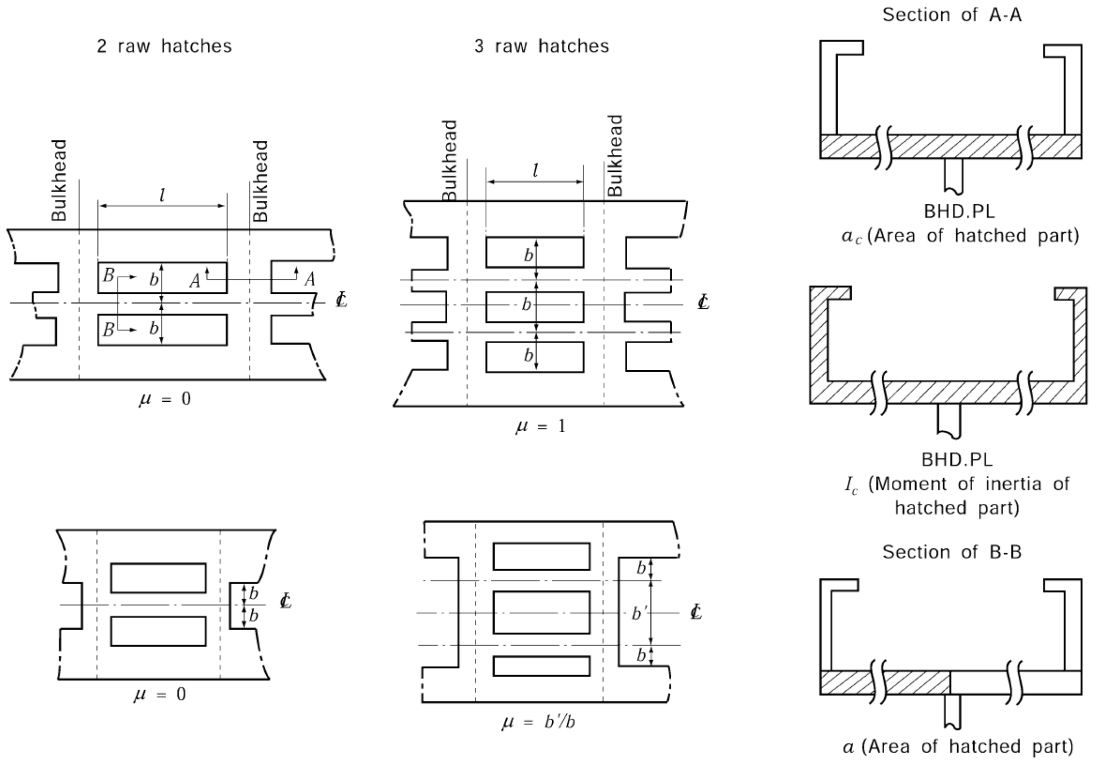


Figure 1 : Coefficient (μ), length (ℓ) and breadth (b) of hatch

1.2.7 Members in materials other than steel

Where a member contributing to the longitudinal strength is made in material other than steel with a Young's modulus, E equal to 206,000 N/mm^2, the steel equivalent sectional area that may be included in hull girder transverse section is obtained, in m^2, from the following formula:

$$A_{SE-n50} = \frac{E}{2.06 \times 10^5} A_{M-n50}$$

where:

A_{M-n50}: Sectional area, in m^2, of the member under consideration.

1.2.8 Definitions of openings

The following definitions of opening are to be applied:

a) Large openings are:
  - Elliptical openings exceeding 2.5 m in length or 1.2 m in breadth.
  - Circular openings exceeding 0.9 m in diameter.

b) Small openings (i.e. drain holes, etc) are openings that are not large ones.

c) Manholes.

d) Isolated openings are openings spaced not less than 1.0 m apart in the ship's transverse/vertical direction.

1.2.9 Large openings, manholes and nearby small openings

Large openings and manholes are to be deducted from the sectional area used in hull girder moment of inertia and section modulus. When small openings are spaced less than 1 m apart in the ship's transverse/vertical direction to large openings or manholes, the total breadth of them is to be deducted from the sectional area. Additionally, isolated small openings which do not comply with the arrangement requirements given in **Ch 3, Sec 6, [6.3.2]** are to be deducted from the sectional areas included in the hull girder transverse sections.

1.2.10 Isolated small openings

Isolated small openings in one transverse section in the strength deck or bottom area need not be deducted from the sectional areas included in the hull girder transverse sections, provided that:

$$\Sigma b_s \le 0.06(B - \Sigma b)$$

where:

Σb_s : Total breadth of isolated small openings, in m, in the strength deck or bottom area at the transverse section considered, determined as indicated in **Figure 2,** not deducted from the section area as per **[1.2.9].**

Σb : Total breadth of large openings, in m, at the transverse section considered, determined as indicated in **Figure 2,** deducted from the section area as defined in **[1.2.9].**

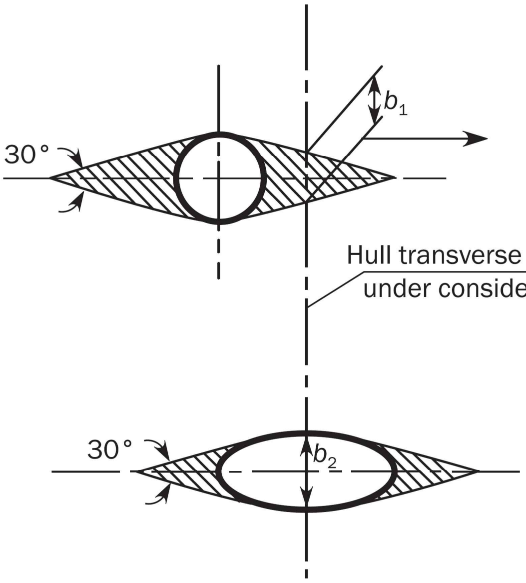
Where the total breadth of isolated small openings Σb_s does not fulfill the above criteria, only the excess of breadth is to be deducted from the sectional areas included in the hull girder transverse sections.

1.2.11 Lightening holes, draining holes and single scallops

Lightening holes, draining holes and single scallops in longitudinals need not be deducted if their height is less than $0.25h_w$, where h_w is the web height of the longitudinals, in mm. Otherwise, the excess is to be deducted from the sectional area or compensated.

1.2.12 Non-continuous decks and longitudinal bulkheads

When calculating the effective area in way of non-continuous decks and longitudinal bulkheads, the effective area is to be taken as shown in **Figure 3.** The shadow area, which indicates the ineffective area, is obtained by drawing two tangent lines with an angle of 15 deg to the longitudinal axis of the ship.



b_1 and b_2 included in Σb and Σb_s

Figure 2 : Calculation of Σb and Σb_s

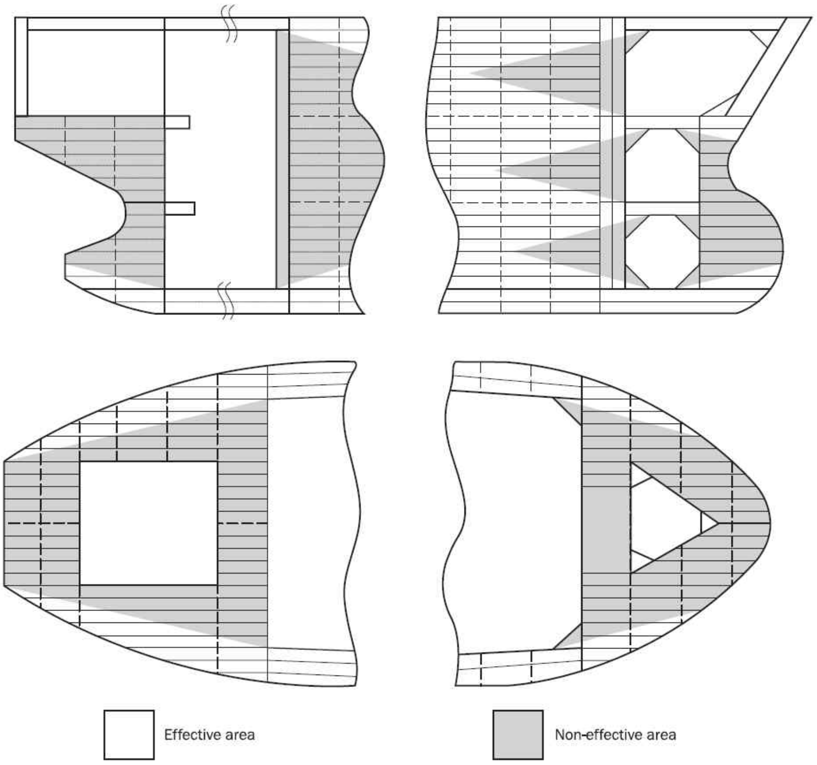


Figure 3 : Effective area in way of non-continuous decks and bulkheads

1.3 Strength deck

1.3.1

The strength deck is, in general, the uppermost continuous deck. In the case of a superstructure or deckhouses contributing to the longitudinal strength, the strength deck is the deck of the superstructure or the deck of the uppermost deckhouse.

1.4 Section modulus

1.4.1 Section modulus at any point located below z_D

The section modulus at any point of a hull transverse section is obtained, in m^3, from the following formula:

$$Z_{A-n50} = \frac{I_{y-n50}}{|z - z_n|}$$

1.4.2 Section modulus at deck

The section modulus at any point of deck and effective longitudinal members is obtained, in m^3, from the following formula:

$$Z_{D-n50} = \frac{I_{y-n50}}{V_D}$$

When no effective longitudinal members specified in **[1.2.4]** and **[1.2.5]** are positioned above a line extending from strength deck at side to a position $(z_D - z_n)/0.9$ from the neutral axis at the centreline.

$$V_D = z_D - z_n$$

When effective longitudinal members as specified in **[1.2.4]** and **[1.2.5]** are positioned above a line extending from strength deck at side to a position $(z_D - z_n)/0.9$ from the neutral axis at the centreline

$$V_D = (z_T - z_n)\left(0.9 + 0.2\frac{y_T}{B}\right) \geq z_D - z_n$$

z_D : Z coordinate, in m, of strength deck at side, defined in **[1.3]**.

y_T, z_T : Y and Z coordinates, in m, of the top of continuous trunk, hatch coaming, longitudinal stiffeners or girders, to be measured for the point which maximises the value of V_D.

1.5 Moments of inertia

1.5.1

The net moment of inertia, I_{y-n50} and I_{z-n50}, in m^4, are those, calculated about the horizontal and vertical neutral axes, respectively, of the hull transverse sections defined in **[1.2]**.

2. Hull girder stress

2.1 Normal stress

2.1.1 Normal stress induced by vertical still water bending moment

The normal stress induced, at any point, by vertical still water bending moments is to be obtained, in N/mm^2, from the following formula:

Table 2 : Normal stress induced by vertical still water bending moment

	At any point located below z_D	At any point located above z_D
Seagoing condition	$\sigma_{sw} = \frac{M_{sw}}{I_{y-n50}}(z - z_n) \times 10^{-3}$	$\sigma_{sw} = \frac{M_{sw}}{I_{y-n50}} V_D \times 10^{-3}$
Harbour/sheltered condition	$\sigma_{sw-p} = \frac{M_{sw-p}}{I_{y-n50}}(z - z_n) \times 10^{-3}$	$\sigma_{sw-p} = \frac{M_{sw-p}}{I_{y-n50}} V_D \times 10^{-3}$

2.1.2 Normal stress induced by vertical wave bending moment

The normal stress induced, at any point, by vertical wave bending moments is to be obtained, in N/mm^2, from the following formula:

$$\sigma_{wv} = \frac{M_{wv}}{I_{y-n50}}(z - z_n) \times 10^{-3}$$

2.1.3 Normal stress induced by horizontal wave bending moment

The normal stress induced, at any point, by horizontal wave bending moments is to be obtained, in N/mm^2, from the following formula:

$$\sigma_{wh} = -\frac{M_{wh}}{I_{z-n50}} y \times 10^{-3}$$

2.1.4 Normal stress induced by wave torsional moment (Conventional type)

When a direct calculation using finite element analysis is not available, the normal stress induced by wave torsional moment may be determined as specified below. The normal stress induced, at any point, by wave torsional moments is to be obtained, in N/mm^2, from the following formula:

$$\sigma_{wt} = 0.6 C_L C_z C_A C_F C_{I\omega M} C_{JM} C_{I\omega A} C_{I\omega F} C_{JF} C_{\omega A} C_{\omega F} C_{AA} C_{AF} \frac{M_{wt\max}}{I_{\omega M}} \frac{-\omega}{\omega_{Nominal}} \sigma_{Nominal}$$

Where,

C_L : Coefficient taken equal to:

$$C_L = \frac{L}{L+900}\left[\frac{-0.008(L-100)}{x_F - x_A}(x - x_A) + 0.008(L-100) + 10\right]$$

C_z : Coefficient taken equal to:

$C_z = 0.8$ for $z < 0.25D$

$C_z = 1.0$ for $z > 0.75D$

x_A : Distance between the aft end of the length and the aft edge of the hatch forward of the engine room front bulkhead on ships with cargo hatches, in m, see **Figure 4.**

x_F : Distance between the aft end of the length and the forward edge of foremost cargo hold, in m, see **Figure 4.**

$I_{\omega M}$: Sectorial moment of inertia amidships, in m^6.

$I_{\omega A}$: Sectorial moment of inertia at x_A, in m^6.

$I_{\omega F}$: Sectorial moment of inertia at x_F, in m^6.

$I_{\omega,0.7L}$: Sectorial moment of inertia at 0.7L, in m^6.

$I_{\omega N}$: Nominal sectorial moment of inertia as defined in **Table 5.**

J_M : St. Venant's moment of inertia amidships, in m^4.

J_A : St. Venant's moment of inertia at x_A, in m^4.

J_F : St. Venant's moment of inertia at x_F, in m^4.

J_N : Nominal St. Venant's moment of inertia as defined in **Table 5.**

ω : Warping function of the point being considered, in m^2, where x of considered point is between $0.85L$ and x_F, absolute vale of warping function is not to be taken greater than $\omega_{Nomianl} \cdot \omega_M / 200$.

ω_M : Warping function amidships at the inboard edge (port side) of the strength deck plating, clear of the hatch corner, in m^2, see **Figure 4.**

ω_A : Warping function at the inboard edge (port side) of the strength deck plating, clear of the hatch corner x_A, in m^2, see **Figure 4.**

ω_F : Warping function at the inboard edge (port side) of the strength deck plating, clear of the hatch corner x_F, in m^2, see **Figure 4.**

$\omega_{Nominal}$: Nominal warping function as defined in **Table 15.**

a : Ratio between sectorial moment of inertia at $0.7L$ and sectorial moment of inertia amidship, to be taken as:

$$a = \frac{I_{\omega,0.7L}}{I_{\omega M}}$$

A_M : Cross section area amidships, in m^2.

A_A : Cross section area at x_A, in m^2.

A_F : Cross section area at x_F, in m^2.

C_A : Correction factor for x_A as defined in **Table 3.**

C_F : Correction factor for x_F as defined in **Table 4.**

$C_{I\omega M}$: Correction factor for $I_{\omega M}$ as defined in **Table 6.**

C_{JM} : Correction factor for J_M as defined in **Table 7.**

$C_{I\omega A}$: Correction factor for $I_{\omega A}$ as defined in **Table 8.**

$C_{I\omega F}$: Correction factor for $I_{\omega F}$ as defined in **Table 9.**

C_{JF} : Correction factor for J_F as defined in **Table 10.**

$C_{\omega A}$: Correction factor for ω_A as defined in **Table 11.**

$C_{\omega F}$: Correction factor for ω_F as defined in **Table 12.**

C_{AA} : Correction factor for A_A as defined in **Table 13.**

C_{AF} : Correction factor for A_F as defined in **Table 14.**

$M_{wt\max}$: Wave torsional moment at $0.25L$ as defined in **Ch 4, Sec 4 3.6.**

$\sigma_{Nominal}$: Nominal stress as defined in **Table 16.**

Note 1: For intermediate value of x, correction factors, nominal stress and section property are to be obtained by linear interpolation.

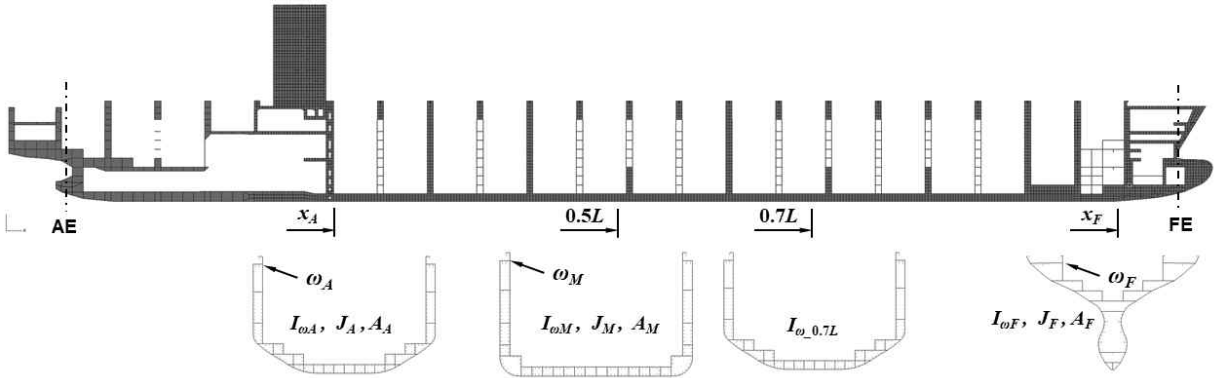


Figure 4 : Section Property – Conventional Type

Table 3 : Correction factor for x_A – C_A

	x_A	$0.5L$	$0.7L$	$0.85L$	x_F
C_A	$1+3\left(\frac{x_A}{L}-0.25\right)$	$1-4a\left(\frac{x_A}{L}-0.25\right)$	$1-4a\left(\frac{x_A}{L}-0.25\right)$	1.0	1.0

Table 4 : Correction factor for x_F – C_F

	x_A	$0.5L$	$0.7L$	$0.85L$	x_F
C_F	$1+(10a-8)\left(\frac{x_F}{L}-0.95\right)$	$1+4\left(\frac{x_F}{L}-0.95\right)$	$1+5\left(\frac{x_F}{L}-0.95\right)$	$1-3\left(\frac{x_F}{L}-0.95\right)$	1.0

Table 5 : Nominal sectorial moment of inertia ($I_{\omega N}$) and St. Venant's moment of inertia (J_N)

	L = 100 m	L = 150 m	L = 200 m	L = 250 m	L = 300 m	L = 350 m
$I_{\omega N}$	7,500	10,000	50,000	100,000	200,000	300,000
J_N	4	5	7	10	15	20

Table 6 : Correction factor for sectorial moment of inertia amidships – $C_{I\omega M}$

	$I_{\omega M}/I_{\omega N}\le 1$	$I_{\omega M}/I_{\omega N}>1$
x_A	$\left[-3\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\left(\frac{x_A}{L}-0.25\right)+1-0.24\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\right]$ $\times\left[-3.6\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$	$\left[-2\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\left(\frac{x_A}{L}-0.25\right)+1-0.16\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\right]$ $\times\left[-3\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$
$0.5L$	$\left[\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\left(\frac{x_A}{L}-0.25\right)+1+0.3\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\right]$ $\times\left[3\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$	$\left[0.64\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\left(\frac{x_A}{L}-0.25\right)+1+0.24\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\right]$ $\times\left[1.6\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$
$0.7L$	$\left[1+0.28\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\right]\times\left[3\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$	$\left[1+0.2\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\right]\times\left[1.6\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$
x_F	$\left[1+0.48\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\right]\times\left[6\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$	$\left[1+0.32\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\right]\times\left[3\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$

Table 7 : Correction factor for St. Venant's moment of inertia amidships – C_{JM}

	$J_M/J_N \leq 1$	$J_M/J_N > 1$
x_A	$\left[2.4\left(\frac{J_M}{J_N}-1\right)\left(\frac{x_A}{L}-0.25\right)+1+0.2\left(\frac{J_M}{J_N}-1\right)\right] \times\left[4\left(\frac{J_M}{J_N}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$	$\left[2\left(\frac{J_M}{J_N}-1\right)\left(\frac{x_A}{L}-0.25\right)+1+0.16\left(\frac{J_M}{J_N}-1\right)\right] \times\left[2.4\left(\frac{J_M}{J_N}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$
$0.5L$	$\left[-0.8\left(\frac{J_M}{J_N}-1\right)\left(\frac{x_A}{L}-0.25\right)+1-0.24\left(\frac{J_M}{J_N}-1\right)\right] \times\left[-2.4\left(\frac{J_M}{J_N}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$	$\left[-0.6\left(\frac{J_M}{J_N}-1\right)\left(\frac{x_A}{L}-0.25\right)+1-0.2\left(\frac{J_M}{J_N}-1\right)\right] \times\left[-1.4\left(\frac{J_M}{J_N}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$
$0.7L$	$\left[-0.6\left(\frac{J_M}{J_N}-1\right)\left(\frac{x_A}{L}-0.25\right)+1-0.2\left(\frac{J_M}{J_N}-1\right)\right] \times\left[-2.4\left(\frac{J_M}{J_N}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$	$\left[1-0.16\left(\frac{J_M}{J_N}-1\right)\right]\times\left[-1.6\left(\frac{J_M}{J_N}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$
x_F	$\left[1-0.4\left(\frac{J_M}{J_N}-1\right)\right]\times\left[-4.2\left(\frac{J_M}{J_N}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$	$\left[1-0.28\left(\frac{J_M}{J_N}-1\right)\right]\times\left[-3\left(\frac{J_M}{J_N}-1\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$

Table 8 : Correction factor for sectorial moment of inertia at x_A – $C_{I\omega A}$

	x_A	$0.35L$	$0.7L$	x_F
$I_{\omega A}/I_{\omega M} \leq 0.6$	$\left[-3\left(\frac{I_{\omega A}}{I_{\omega M}}-0.6\right)\left(\frac{x_A}{L}-0.25\right)+1-\left(\frac{I_{\omega A}}{I_{\omega M}}-0.6\right)\right] \times\left[-3\left(\frac{I_{\omega A}}{I_{\omega M}}-0.6\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$	$1-0.1\left(\frac{I_{\omega A}}{I_{\omega M}}-0.6\right)$	$1-0.1\left(\frac{I_{\omega A}}{I_{\omega M}}-0.6\right)$	1.0
$I_{\omega A}/I_{\omega M} > 0.6$	$\left[-2.2\left(\frac{I_{\omega A}}{I_{\omega M}}-0.6\right)\left(\frac{x_A}{L}-0.25\right)+1-0.7\left(\frac{I_{\omega A}}{I_{\omega M}}-0.6\right)\right] \times\left[-3\left(\frac{I_{\omega A}}{I_{\omega M}}-0.6\right)\left(\frac{x_F}{L}-0.95\right)+1\right]$	$1-0.1\left(\frac{I_{\omega A}}{I_{\omega M}}-0.6\right)$	$1-0.1\left(\frac{I_{\omega A}}{I_{\omega M}}-0.6\right)$	1.0

Table 9 : Correction factor for sectorial moment of inertia at x_F – $C_{I\omega F}$

	x_A~$0.9L$	x_F
$I_{\omega F}/I_{\omega M} \leq 0.007$	1.0	$-16\left(\frac{I_{\omega F}}{I_{\omega M}}-0.007\right)+1$
$I_{\omega F}/I_{\omega M} > 0.007$	1.0	$-5.38\left(\frac{I_{\omega F}}{I_{\omega M}}-0.007\right)+1$

Table 10 : Correction factor for St. Venant's moment of inertia at x_F - C_{JF}

	x_A	$0.5L$	$0.85L$	x_F
C_{JF}	$0.044\left(\frac{J_F}{J_M}-1.1\right)+1$	$-0.058\left(\frac{J_F}{J_M}-1.1\right)+1$	1.0	$\left[-2.9\left(\frac{x_F}{L}-0.95\right)+1\right]\left[-0.19\left(\frac{J_F}{J_M}-1.1\right)+1\right]$

Table 11 : Correction factor for warping function at x_A - $C_{\omega A}$

	x_A	$0.35L$	x_F
$C_{\omega A}$	$-0.63\left(\frac{\omega_A}{\omega_M}-0.8\right)+1$	1.0	1.0

Table 12 : Correction factor for warping function at x_F - $C_{\omega F}$

	x_A	$0.5L$	$0.7L$	x_F
$\omega_F/\omega_M \le 0.15$	$-0.7\left(\frac{\omega_F}{\omega_M}-0.15\right)+1$	$0.8\left(\frac{\omega_F}{\omega_M}-0.15\right)+1$	$0.8\left(\frac{\omega_F}{\omega_M}-0.15\right)+1$	$50\left(0.15-\frac{\omega_F}{\omega_M}\right)^2+2.5\left(0.15-\frac{\omega_F}{\omega_M}\right)+1$
$\omega_F/\omega_M > 0.15$	$-0.7\left(\frac{\omega_F}{\omega_M}-0.15\right)+1$	$0.8\left(\frac{\omega_F}{\omega_M}-0.15\right)+1$	$0.8\left(\frac{\omega_F}{\omega_M}-0.15\right)+1$	$-2\left(\frac{\omega_F}{\omega_M}-0.15\right)+1$

Table 13 : Correction factor for cross section area at x_A - C_{AA}

	x_A	$0.35L$	x_F
C_{AA}	$-0.5\left(\frac{A_A}{A_M}-0.95\right)+1$	1.0	1.0

Table 14 : Correction factor for cross section area at x_F - C_{AF}

	x_A	$0.65L$	$0.85L$	x_F
C_{AF}	1.0	1.0	$-0.1\left(\frac{A_F}{A_M}-0.5\right)+1$	$-0.4\left(\frac{A_F}{A_M}-0.5\right)+1$

Table 15 : Nominal warping function - $\omega_{Nominal}$

	x_A	$0.35L$	$0.6L$	x_F
$\omega_{Nominal}$	160	200	200	30

Table 16 : Nominal warping stress – Conventional Type

x/L	$a=0.2$	$a=0.3$	$a=0.4$	$a=0.5$	$a=0.6$
0.20	2.58	3.09	3.51	3.85	4.12
0.25	1.33	1.84	2.26	2.60	2.87
0.30	0.26	0.77	1.18	1.52	1.78
0.35	-0.86	-0.35	0.07	0.41	0.67
0.40	-1.76	-1.24	-0.81	-0.46	-0.19
0.45	-2.60	-2.05	-1.61	-1.25	-0.97
0.5	-3.15	-2.58	-2.12	-1.75	-1.46
0.55	-3.56	-2.96	-2.48	-2.09	-1.78
0.60	-3.76	-3.12	-2.61	-2.19	-1.87
0.65	-3.65	-2.99	-2.45	-2.02	-1.68
0.70	-3.25	-2.66	-2.14	-1.72	-1.39
0.75	-1.55	-1.51	-1.27	-1.01	-0.79
0.80	2.04	0.85	0.34	0.15	0.08
0.85	6.82	4.79	3.16	2.07	1.38
0.90	5.51	4.46	3.37	2.36	1.56
0.95	6.27	5.45	4.52	3.45	2.38
0.97	6.27	5.45	4.52	3.45	2.38

2.1.5 Normal stress induced by wave torsional moment (2-Island type : Aft Part)

When a direct calculation using finite element analysis is not available, the normal stress induced by wave torsional moment may be determined as specified below. The normal stress induced, at any point, by wave torsional moments is to be obtained, in N/mm^2, from the following formula:

$$\sigma_{wt}=0.6C_{I\omega M}C_{JM}C_{I\omega A1}C_{\omega A1}C_{\omega F1}\,C_{AA1}C_{AF1}\frac{M_{wt\max}}{I_{\omega M}}\frac{-\omega}{\omega_{Nominal}}\sigma_{Nominal}$$

Where,

x_{A1} : Distance between the aft end of the length and the aft edge of the hatch forward of the engine room front bulkhead on ships with cargo hatches, in m, see **Figure 5.**

x_{F1} : Distance between the aft end of the length and the forward edge of cargo hold adjacent to after wall of deck house, in m, see **Figure 5.**

$I_{\omega M}$: Sectorial moment of inertia amidships, in m^6.

$I_{\omega A1}$: Sectorial moment of inertia at x_{A1}, in m^6.

$I_{\omega F1}$: Sectorial moment of inertia at x_{F1}, in m^6.

$I_{\omega N}$: Nominal sectorial moment of inertia as defined in **Table 17.**

J_M : St. Venant's moment of inertia amidships, in m^4.

J_{A1} : St. Venant's moment of inertia at x_{A1}, in m^4.

J_{F1} : St. Venant's moment of inertia at x_{F1}, in m^4.

J_N : Nominal St. Venant's moment of inertia as defined in **Table 17.**

ω : Warping function of the point being considered, in m^2.

ω_M : Warping function amidships at the inboard edge (port side) of the strength deck plating, clear of the hatch corner, in m^2, see **Figure 5**.

ω_{A1} : Warping function at the inboard edge (port side) of the strength deck plating, clear of the hatch corner x_{A1}, in m^2, see **Figure 5**.

ω_{F1} : Warping function at the inboard edge (port side) of the strength deck plating, clear of the hatch corner x_{F1}, in m^2, see **Figure 5**.

$\omega_{Nominal}$: Nominal warping function as defined in **Table 25.**

A_M : Cross section area amidships, in m^2.

A_{A1} : Cross section area at x_{A1}, in m^2.

A_{F1} : Cross section area at x_{F1}, in m^2.

$C_{I\omega M}$: Correction factor for $I_{\omega M}$ as defined in **Table 18.**

C_{JM} : Correction factor for J_M as defined in **Table 19.**

$C_{I\omega A1}$: Correction factor for $I_{\omega A1}$ as defined in **Table 20.**

$C_{\omega A1}$: Correction factor for ω_{A1} as defined in **Table 21.**

$C_{\omega F1}$: Correction factor for ω_{F1} as defined in **Table 22.**

C_{AA1} : Correction factor for A_{A1} as defined in **Table 23.**

C_{AF1} : Correction factor for A_{F1} as defined in **Table 24.**

$M_{wt\max}$: Wave torsional moment at $0.25L$ as defined in **Ch 4, Sec 4 3.6.**

$\sigma_{Nominal}$: Nominal stress, to be taken as:

$$\sigma_{Nominal} = \sigma_{aft} + C_{xF1}\left(\frac{x_{F1}}{L} - 0.63\right)$$

C_{xf1} : Correction factor for x_{F1} as defined in **Table 26.**

σ_{Aft} : Nominal stress coefficient as defined in **Table 27.**

Note 1: For intermediate value of x, correction factors, nominal stress and section property are to be obtained by linear interpolation.

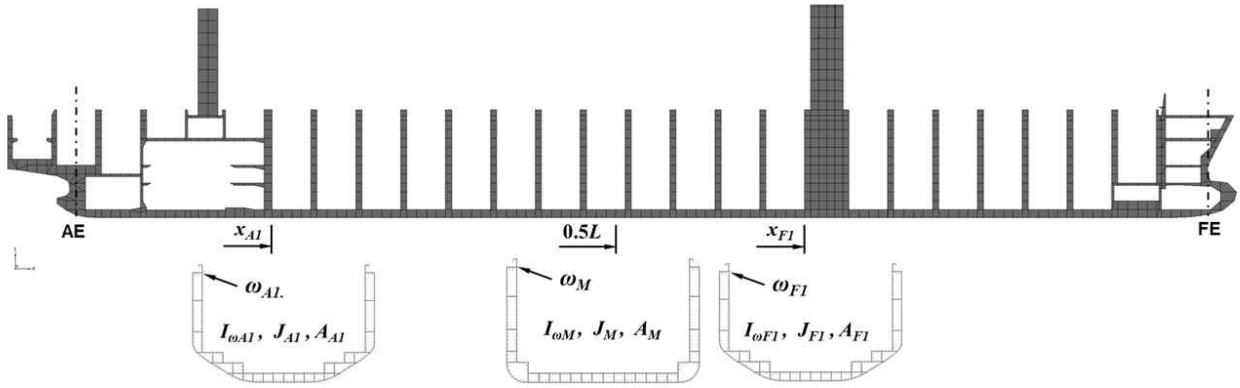


Figure 5 : Section Property – 2-Island (Aft Part)

Table 17 : Nominal sectorial moment of inertia ($I_{\omega N}$) and St. Venant's moment of inertia (J_N)

	340 m $\le L \le$ 350 m	370 m $\le L \le$ 380 m
$I_{\omega N}$	350,000	700,000
J_N	22	30

Table 18 : Correction factor for sectorial moment of inertia amidships – $C_{I\omega M}$

	x_A	$0.45L$	x_{F1}
$340 \le L \le 350$	$\left[2\left(\frac{x_{F1}}{L}-0.63\right)-0.35\right]\times\left[\frac{I_{\omega M}}{I_{\omega N}}-1\right]+1$	$0.5\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)+1$	$0.5\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)+1$
$370 \le L \le 380$	$\left[3\left(\frac{x_{F1}}{L}-0.63\right)-0.55\right]\times\left[\frac{I_{\omega M}}{I_{\omega N}}-1\right]+1$	$0.6\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)+1$	$0.5\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)+1$

Table 19 : Correction factor for St. Venant's moment of inertia amidships – C_{JM}

	x_A	$0.45L$	x_{F1}
$340 \le L \le 350$	$-0.15\left(\frac{J_M}{J_N}-1\right)+1$	$-0.05\left(\frac{J_M}{J_N}-1\right)+1$	$-0.1\left(\frac{J_M}{J_N}-1\right)+1$
$370 \le L \le 380$	$-0.15\left(\frac{J_M}{J_N}-1\right)+1$	$-0.05\left(\frac{J_M}{J_N}-1\right)+1$	$-0.05\left(\frac{J_M}{J_N}-1\right)+1$

Table 20 : Correction factor for sectorial moment of inertia at x_{A1} – $C_{I\omega A1}$

	x_{A1}	$0.45L$	x_{F1}
$340 \le L \le 350$	$\left[2\left(\frac{x_{F1}}{L}-0.63\right)-0.9\right]\times\left[\frac{I_{\omega A1}}{I_{\omega M}}-0.5\right]+1$	$-0.2\left(\frac{I_{\omega A1}}{I_{\omega M}}-0.5\right)+1$	$-0.1\left(\frac{I_{\omega A1}}{I_{\omega M}}-0.5\right)+1$
$370 \le L \le 380$	$\left[2\left(\frac{x_{F1}}{L}-0.63\right)-1\right]\times\left[\frac{I_{\omega A1}}{I_{\omega M}}-0.5\right]+1$	$-0.2\left(\frac{I_{\omega A1}}{I_{\omega M}}-0.5\right)+1$	$-0.1\left(\frac{I_{\omega A1}}{I_{\omega M}}-0.5\right)+1$

Table 21 : Correction factor for warping function at x_{A1} – $C_{\omega A1}$

		x_{A1}	$0.45L$	x_{F1}
$340 \le L \le 350$	$x_{F1} \le 0.63L$	$-1.2\left(\frac{\omega_{A1}}{\omega_M}-0.8\right)+1$	$0.7\left(\frac{\omega_{A1}}{\omega_M}-0.8\right)+1$	$0.5\left(\frac{\omega_{A1}}{\omega_M}-0.8\right)+1$
	$x_{F1} > 0.63L$	$-\left(\frac{\omega_{A1}}{\omega_M}-0.8\right)+1$		
$370 \le L \le 380$	$x_{F1} \le 0.63L$	$-1.4\left(\frac{\omega_{A1}}{\omega_M}-0.8\right)+1$	$0.8\left(\frac{\omega_{A1}}{\omega_M}-0.8\right)+1$	$0.6\left(\frac{\omega_{A1}}{\omega_M}-0.8\right)+1$
	$x_{F1} > 0.63L$	$-1.1\left(\frac{\omega_{A1}}{\omega_M}-0.8\right)+1$		

Table 22 : Correction factor for warping function at x_{F1} – $C_{\omega F1}$

	x_{A1}	$0.55L$	x_{F1}
$C_{\omega F1}$	1.0	1.0	$-\left(\frac{\omega_{A1}}{\omega_M}-0.93\right)+1$

Table 23 : Correction factor for cross section area at x_{A1} - C_{AA1}

	x_{A1}	$0.35L$	x_{F1}
C_{AA1}	$-0.4\left(\frac{A_{A1}}{A_M}-0.9\right)+1$	1.0	1.0

Table 24 : Correction factor for cross section area at x_{F1} - C_{AF1}

	x_{A1}	$0.55L$	x_{F1}
C_{AF1}	1.0	1.0	$0.8\left(\frac{A_F}{A_M}-0.975\right)+1$

Table 25 : Nominal warping function, $\omega_{Nominal}$

	x_{A1}	$0.35L$	$0.55L$	$0.7L$
$\omega_{Nominal}$	240	300	300	255

Table 26 : Correction factor for x_{F1} - C_{xF1}

	$x_{F1} \le 0.63L$	$x_{F1} > 0.63L$
$340 \le L \le 350$	37.6	27.1
$370 \le L \le 380$	45.1	33.4

Table 27 : Nominal stress coefficient (2-Island type : Aft Part) - σ_{aft}

x/L	σ_{Aft} $(340 \le L \le 350)$	σ_{Aft} $(370 \le L \le 380)$
0.20	15.1	14.5
0.25	8.8	7.5
0.30	2.6	1.3
0.35	-2.2	-4.2
0.40	-6.9	-8.9
0.45	-10.5	-12.7
0.50	-12.8	-15.6
0.55	-14.2	-17.0
0.58	-14.5	-17.4
0.60	-14.5	-17.4
0.63	-13.9	-16.8
0.65	13.5	-16.3
0.68	-12.4	-15.2

2.1.6 Normal stress induced by wave torsional moment (2-Island type : FWD Part)

When a direct calculation using finite element analysis is not available, the normal stress induced by wave torsional moment may be determined as specified below. The normal stress induced, at any point, by wave torsional moments is to be obtained, in N/mm^2, from the following formula:

$$\sigma_{wt} = 0.6 C_{I\omega M} C_{I\omega A2} C_{I\omega F2} C_{JA2} C_{JF2} C_{\omega F2} C_{AF2} \frac{M_{wt\max}}{I_{\omega M}} \frac{-\omega}{\omega_{Nominal}} \sigma_{Nominal}$$

Where,

x_{A2} : Distance between the aft end of the length and the aft edge of cargo hold adjacent to front wall of deck house, in m, see **Figure 6**.

x_{F2} : Distance between the aft end of the length and the forward edge of foremost cargo hold, in m, see **Figure 6**.

$I_{\omega M}$: Sectorial moment of inertia amidships, in m^6.

$I_{\omega A2}$: Sectorial moment of inertia at x_{A2}, in m^6.

$I_{\omega F2}$: Sectorial moment of inertia at x_{F2}, in m^6.

$I_{\omega N}$: Nominal sectorial moment of inertia as defined in **Table 28.**

J_M : St. Venant's moment of inertia amidships, in m^4.

J_{A2} : St. Venant's moment of inertia at x_{A2}, in m^4.

J_{F2} : St. Venant's moment of inertia at x_{F2}, in m^4.

J_N : Nominal St. Venant's moment of inertia as defined in **Table 28.**

ω : Warping function of the point being considered, in m^2, Where x of considered point is between $0.85L$ and x_F, absolute vale of warping function is not greater than $\omega_{Nomianl} \cdot \omega_M / 300$.

ω_M : Warping function amidships at the inboard edge (port side) of the strength deck plating, clear of the hatch corner, in m^2, see **Figure 6**.

ω_{A2} : Warping function at the inboard edge (port side) of the strength deck plating, clear of the hatch corner x_{A2}, in m^2, see **Figure 6**.

ω_{F2} : Warping function at the inboard edge (port side) of the strength deck plating, clear of the hatch corner x_{F2}, in m^2, see **Figure 6**.

$\omega_{Nominal}$: Nominal warping function as defined in **Table 36.**

A_M : Cross section area amidships, in m^2.

A_{A2} : Cross section area at x_{A1}, in m^2.

A_{F2} : Cross section area at x_{F1}, in m^2.

$C_{I\omega M}$: Correction factor for $I_{\omega M}$ as defined in **Table 29.**

C_{JA2} : Correction factor for J_{A2} as defined in **Table 30.**

$C_{I\omega A2}$: Correction factor for $I_{\omega A2}$ as defined in **Table 31.**

C_{JF2} : Correction factor for J_{F2} as defined in **Table 32.**

$C_{I\omega F2}$: Correction factor for $I_{\omega F2}$ as defined in **Table 33.**

$C_{\omega F2}$: Correction factor for ω_{F2} as defined in **Table 34.**

C_{AF2} : Correction factor for A_{F2} as defined in **Table 35.**

$M_{wt\max}$: Wave torsional moment at $0.25L$ as defined in **Ch 4, Sec 4 3.6.**

$\sigma_{Nominal}$: Nominal stress, to be taken as:

$$\sigma_{Nominal} = \sigma_{FWD} + C_{xA2}\left(\frac{x_{A2}}{L} - 0.67\right)$$

C_{xA2} : Correction factor for x_{A2} as defined in **Table 37.**

σ_{FWD} : Nominal stress coefficient as defined in **Table 38.**

Note 1: For intermediate value of x, correction factors, nominal stress and section property are to be obtained by linear interpolation.

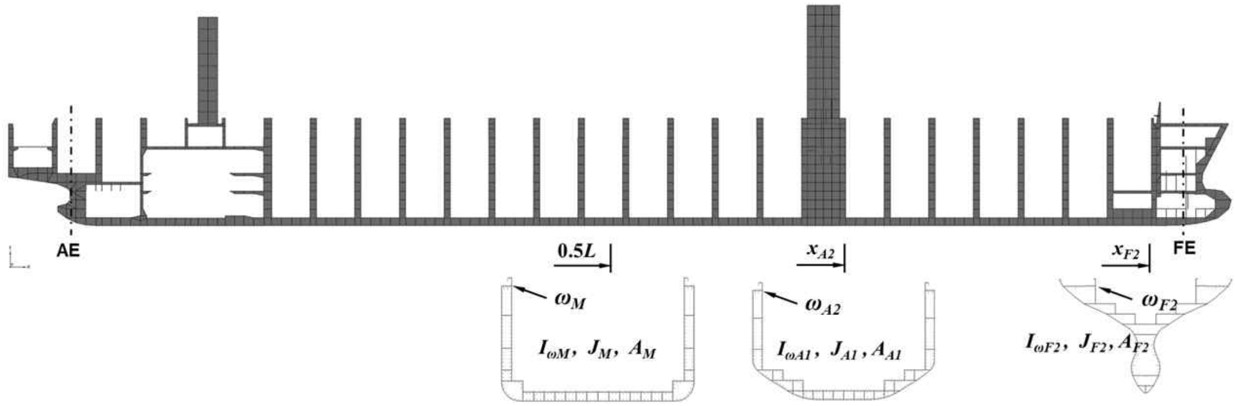


Figure 6 : Section Property – 2-Island (FWD Part)

Table 28 : Nominal sectorial moment of inertia ($I_{\omega N}$) and St. Venant's moment of inertia (J_N)

	340 m $\leq L \leq$ 350 m	370 m $\leq L \leq$ 380 m
$I_{\omega N}$	350,000	700,000
J_N	22	30

Table 29 : Correction factor for sectorial moment of inertia amidships – $C_{I\omega M}$

	x_{A2}	$0.75L$	x_{F2}
$C_{I\omega M}$	$0.2\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)+1$	$0.25\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)+1$	$0.35\left(\frac{I_{\omega M}}{I_{\omega N}}-1\right)+1$

Table 30 : Correction factor for St. Venant's moment of inertia at x_{A2} – C_{JA2}

	x_{A2}	$0.75L$	x_{F2}
$340 \leq L \leq 350$	$-0.2\left(\frac{J_{A2}}{J_N}-1\right)+1$	$-0.25\left(\frac{J_{A2}}{J_N}-1\right)+1$	$-0.4\left(\frac{J_{A2}}{J_N}-1\right)+1$
$370 \leq L \leq 380$	$-0.15\left(\frac{J_{A2}}{J_N}-1\right)+1$	$-0.2\left(\frac{J_{A2}}{J_N}-1\right)+1$	$-0.3\left(\frac{J_{A2}}{J_N}-1\right)+1$

Table 31 : Correction factor for sectorial moment of inertia at x_{A2} – $C_{I\omega A2}$

	$C_{I\omega A2}$
x_{A2}	$\left[-6\left(\frac{x_{A2}}{L}-0.67\right)-0.9\right]\times\left[\frac{I_{\omega A2}}{I_{\omega M}}+5\left(\frac{x_{A2}}{L}-0.67\right)-0.7\right]+1$
$0.75L$	$\left[-7\left(\frac{x_{A2}}{L}-0.67\right)-0.5\right]\times\left[\frac{I_{\omega A2}}{I_{\omega M}}+5\left(\frac{x_{A2}}{L}-0.67\right)-0.7\right]+1$
x_{F2}	$-0.2\left[\frac{I_{\omega A2}}{I_{\omega M}}+5\left(\frac{x_{A2}}{L}-0.67\right)-0.7\right]+1$

Table 32 : Correction factor for St. Venant's moment of inertia at x_{F2} – C_{JF2}

	x_{A2}	$0.75L$	x_{F2}
C_{JF2}	$-0.1\left(\frac{J_{F2}}{J_M}-0.9\right)+1$	$-0.2\left(\frac{J_{F2}}{J_M}-0.9\right)+1$	$-0.3\left(\frac{J_{F2}}{J_M}-0.9\right)+1$

Table 33 : Correction factor for sectorial moment of inertia at x_{F2} – $C_{I\omega F2}$

	x_{A2}	$0.9L$	x_{F2}
$C_{I\omega F2}$	1.0	1.0	$-15\left[\frac{I_{\omega F2}}{I_{\omega M}}-0.007\right]+1$

Table 34 : Correction factor for warping function at x_{F2} – $C_{\omega F2}$

		$x_{A2}\sim 0.75L$	$0.9L$	x_{F2}
$C_{\omega F2}$	$x_{A1}=0.62L$	$\left(\frac{\omega_{F2}}{\omega_M}-0.05\right)+1$	$-1.8\left(\frac{\omega_{F2}}{\omega_M}-0.05\right)+1$	$48\left(\frac{\omega_{F2}}{\omega_M}-0.05\right)^2-9.8\left(\frac{\omega_{F2}}{\omega_M}-0.05\right)+1$
	$x_{A1}=0.67L$	$\left(\frac{\omega_{F2}}{\omega_M}-0.05\right)+1$	$-4\left(\frac{\omega_{F2}}{\omega_M}-0.05\right)+1$	$60\left(\frac{\omega_{F2}}{\omega_M}-0.05\right)^2-12.2\left(\frac{\omega_{F2}}{\omega_M}-0.05\right)+1$
	$x_{A1}=0.72L$	$\left(\frac{\omega_{F2}}{\omega_M}-0.05\right)+1$	1.0	$68\left(\frac{\omega_{F2}}{\omega_M}-0.05\right)^2-13.8\left(\frac{\omega_{F2}}{\omega_M}-0.05\right)+1$

Table 35 : Correction factor for cross section area at x_{F2} – C_{AF2}

	x_{A2}	$0.75L$	x_{F2}
C_{AF2}	$-0.1\left(\frac{A_{F2}}{A_M}-0.5\right)+1$	$-0.2\left(\frac{A_{F2}}{A_M}-0.5\right)+1$	$-0.3\left(\frac{A_{F2}}{A_M}-0.5\right)+1$

Table 36 : Nominal warping function – $\omega_{Nominal}$

x	$\omega_{Nominal}$
$0.35L\sim 0.55L$	300
x_F	15

Table 37 : Correction factor for cross section area at x_{A2} – C_{xA2}

		$x_{A2} \leq 0.67L$	$x_{A2} > 0.67L$
$340 \leq L \leq 350$	$x_{A2}/L \leq 0.75$	3.2	-4.8
	$x_{A2}/L > 0.75$	$3.2-12.8(x/L-0.75)$	$-4.8+19.2(x/L-0.75)$
$370 \leq L \leq 380$	$x_{A2}/L \leq 0.75$	2.7	-4
	$x_{A2}/L > 0.75$	$2.7-10.8(x/L-0.75)$	$-4+16(x/L-0.75)$

Table 38 : Nominal stress coefficient (2-Island type : FWD Part) – σ_{FWD}

x/L	σ_{FWD} ($340 \leq L \leq 350$)	σ_{FWD} ($370 \leq L \leq 380$)
0.62	-17.8	-15.4
0.65	-17.1	-14.8
0.67	-16.6	-14.4
0.70	-15.6	-13.7
0.72	-14.8	-12.9
0.75	-13.0	-11.4
0.80	-8.6	-7.6
0.85	0.8	-0.4
0.90	9.2	8.0
0.93	12.5	11.4
0.96	13.5	12.3

2.1.7 Normal stress induced by still water torsional moment (Conventional type)

When a direct calculation using finite element analysis is not available, the normal stress induced by still water torsional moment may be determined as specified below. The normal stress induced, at any point, by still water torsional moments is to be obtained, in N/mm^2, from the following formula:

$$\sigma_{st} = 0.5 C_L C_z C_A C_F C_{I\omega M} C_{JM} C_{I\omega A} C_{I\omega F} C_{JF} C_{\omega A} C_{\omega F} C_{AA} C_{AF} \frac{M_{st\,\max}}{I_{\omega M}} \frac{-\omega}{\omega_{Nominal}} \sigma_{Nominal}$$

$M_{st\,\max}$: maximum value of still water torsional moment, in kNm, as defined in **Ch 4, Sec 4 [2.4]**.

C_L, C_z, $I_{\omega M}$, ω, $\omega_{Nominal}$, C_A, C_F, $C_{I\omega M}$, C_{JM}, $C_{I\omega A}$, $C_{I\omega F}$, C_{JF}, $C_{\omega A}$, $C_{\omega F}$, C_{AA}, C_{AF} and $\sigma_{Nominal}$ are defined in **[2.1.4]**.

2.1.8 Normal stress induced by still water torsional moment (2-Island : Aft Part)

When a direct calculation using finite element analysis is not available, the normal stress induced by still water torsional moment may be determined as specified below. The normal stress induced, at any point, by still water torsional moments is to be obtained, in N/mm^2, from the following formula:

$$\sigma_{st} = 0.5 C_{I\omega M} C_{JM} C_{I\omega A1} C_{\omega A1} C_{\omega F1} C_{AA1} C_{AF1} \frac{M_{st\,\max}}{I_{\omega M}} \frac{-\omega}{\omega_{Nominal}} \sigma_{Nominal}$$

$M_{st\,\max}$: maximum value of still water torsional moment, in kNm, as defined in **Ch 4, Sec 4 [2.4]**.

$I_{\omega M}$, ω, $\omega_{Nominal}$, $C_{I\omega M}$, C_{JM}, $C_{I\omega A1}$, $C_{I\omega F1}$, $C_{\omega A1}$, $C_{\omega F1}$, C_{AA1}, C_{AF1} and $\sigma_{Nominal}$ are defined in **[2.1.5]**.

2.1.9 Normal stress induced by still water torsional moment (2-Island : FWD Part)

When a direct calculation using finite element analysis is not available, the normal stress induced by still water torsional moment may be determined as specified below. The normal stress induced, at any point, by still water torsional moments is to be obtained, in N/mm^2, from the following formula:

$$\sigma_{st} = 0.5 C_{I\omega M} C_{I\omega A2} C_{I\omega F2} C_{JA2} C_{JF2} C_{\omega F2} C_{AF2} \frac{M_{st\max}}{I_{\omega M}} \frac{-\omega}{\omega_{Nominal}} \sigma_{Nominal}$$

$M_{st\max}$: maximum value of still water torsional moment, in kNm, as defined in **Ch 4, Sec 4 [2.4]**.

$I_{\omega M}$, ω, $\omega_{Nominal}$, $C_{I\omega M}$, $C_{I\omega A2}$, $C_{I\omega F2}$, C_{JA2}, C_{JF2}, $C_{\omega F2}$, C_{AF2} and $\sigma_{Nominal}$ are defined in **[2.1.6]**.

2.2 Shear stress

2.2.1 Shear stress induced by vertical still water shear force

The hull girder shear stress, in N/mm^2, induced by vertical still water shear forces is to be determined, at the load calculation point under consideration, as follows:

a) for seagoing condition:

$$\tau_{sw} = \frac{Q_{sw}}{t} q_{vi} \times 10^3$$

b) for harbour / sheltered condition

$$\tau_{sw} = \frac{Q_{sw-p}}{t} q_{vi} \times 10^3$$

where:

q_{vi} : Contribution ratio for hull girder shear force per mm, in mm^{-1}, for the plate i based on net scantlings with deduction of 0.5 t_C, which is equal to the unit shear flow per mm, in N/mm, for a unit vertical shear force, from a numerical calculation based on thin-walled beam theory according to **Ch 5 App 1**.

2.2.2 Shear stress induced by vertical wave shear force

The hull girder shear stress, in N/mm^2, induced by vertical wave shear forces is to be determined, at the load calculation point under consideration, as follows:

$$\tau_{sw} = \frac{Q_{wv}}{t} q_{vi} \times 10^3$$

2.2.3 Shear stress induced by horizontal wave shear force

The hull girder shear stress, in N/mm^2, induced by horizontal wave shear forces is to be determined, at the load calculation point under consideration, as follows:

$$\tau_{sw} = \frac{Q_{wh}}{t} q_{hi} \times 10^3$$

where:

q_{hi} : Contribution ratio for hull girder shear force per mm, in mm-1, for the plate i based on net scantlings with deduction of 0.5 t_C, which is equal to the unit shear flow per mm, in N/mm, for a unit horizontal shear force, from a numerical calculation based on thin-walled beam theory according to **App 1.**

3. Hull girder strength assessment

3.1 General

3.1.1

Continuity of structure is to be maintained throughout the length of the ship. Where significant changes in structural arrangement occur adequate transitional structure is to be provided.

3.2 Longitudinal extent of strength assessment

3.2.1

The stiffness, yield strength and buckling strength assessment are to be carried out in way of 0.2 L to 0.75 L with due consideration given to locations where there are significant changes in hull cross-section, e.g. changes of framing system and the fore and aft ends of the forward superstructure in case of 2-island design.

3.2.2

In addition, yield strength and buckling strength assessments are to be carried out outside this area. As a minimum, these assessments are to be carried out at forward end of the foremost cargo hold and at aft end of the aftermost cargo hold.

3.3 Hull girder stiffness

3.3.1 Stiffness criterion

For both hogging and sagging conditions, the net moment of inertia I_{y-n50}, in m^4, of the hull transverse section is to be not less than:

$$I_{y-n50} \geq 1.55L|M_{sw}+M_{wv}| \times 10^{-7}$$

3.4 Hull girder bending strength assessment

3.4.1 General acceptance criteria

The normal stress, σ_L is to be assessed for all conditions, along the full length of the hull girder, from AE to FE. The normal stress at any point of the hull transverse section is to comply with the following formula:

$$\sigma_L \leq \sigma_{perm}$$

$$\sigma_L = \sigma_{sw} + C_{WV}\sigma_{wv} + C_{WH}\sigma_{wh} + C_{st}\sigma_{st} + C_{tor}\sigma_{wt}$$

C_{WV}, C_{WH} : Load combination factors, as given in **Ch 4, Sec 2, [2.2.1]**

C_{st} : Static warping stress combination factors, to be taken as:

- $C_{st} = 0.0$ for HSM, HSA, FSM, BSR, BSP load cases
- $C_{st} = 1.0$ for OST-1P, OST-2S, OSA-2P, OSA-1S load cases
- $C_{st} = -1.0$ for OST-2P, OST-1S, OSA-1P, OSA-2S load cases

C_{tor} : Dynamic warping stress combination factors, to be taken as:

- $C_{tor} = 0.0$ for HSM, HSA, FSM, BSR, BSP load cases
- $C_{tor} = 1.0$ for OST-1P, OST-2S load cases
- $C_{tor} = -1.0$ for OST-2P, OST-1S load cases
- $C_{tor} = -0.6$ for OSA-1P, OSA-2S load cases
- $C_{tor} = 0.6$ for OSA-2P, OSA-1S load cases

σ_{perm} : Permissible hull girder bending stress, in N/mm^2, as given in **Table 39**.

σ_{sw} : Normal stress, in N/mm^2, induced by vertical still water bending moment, as defined in **[2.1.1]**.

σ_{wv} : Normal stress, in N/mm^2, induced by vertical wave bending moment, as defined in **[2.1.2]**.

σ_{wh} : Normal stress, in N/mm^2, induced by horizontal wave bending moment, as defined in **[2.1.3]**.

σ_{st} : Normal stress, in N/mm^2, induced by static torsional moment, as defined in **[2.1.7]** to **[2.1.9]**. The longitudinal assessment range of warping stress is shown in **Figure 7** and **Figure 8**.

σ_{wt} : Normal stress, in N/mm^2, induced by wave torsional moment, as defined in **[2.1.4]** to **[2.1.6]**. The longitudinal assessment range of warping stress is shown in **Figure 7** and **Figure 8**.

Table 39 : Permissible hull girder bending stress

Operation	Design load	Permissible hull girder bending stress, σ_{perm}
Seagoing	(S+D)	$\frac{235}{1.24k}$
Harbour/sheltered water	(S)	$\frac{143}{k}$

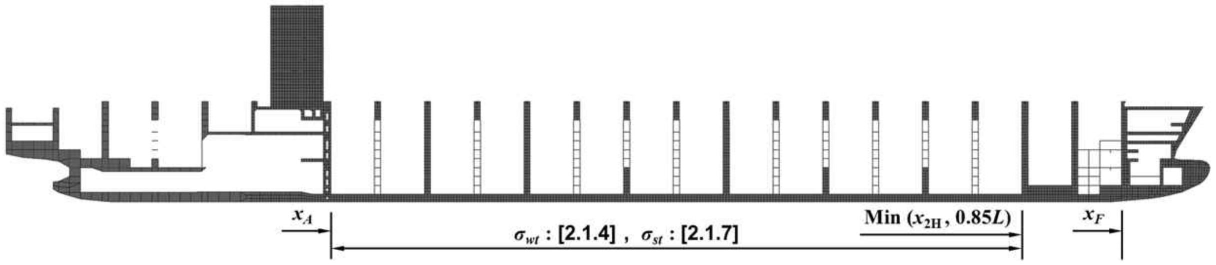


Figure 7 : Application of normal stress induced by wave torsional bending moment – Conventional type

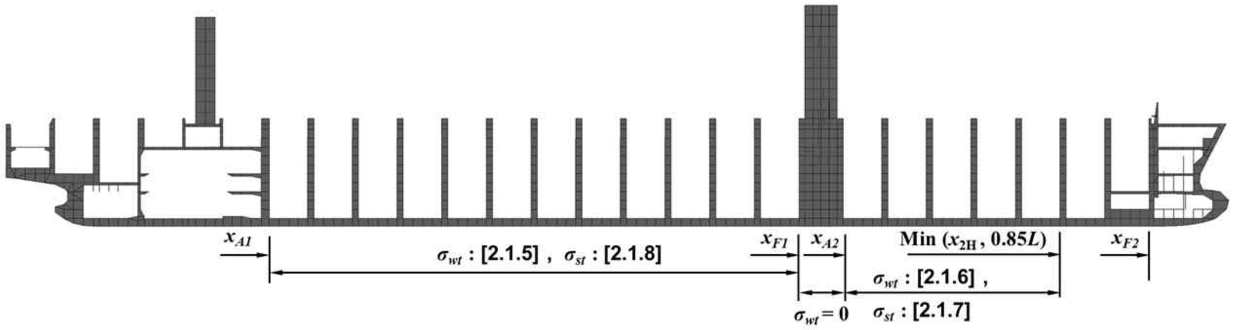


Figure 8 : Application of normal stress induced by wave torsional bending moment – 2-Island type

3.4.2 Bending strength assessment

The bending strength is to be assessed at the following locations of the cross-section:

a) at bottom
b) at deck
c) at top of hatch coaming
d) at any point where there is a change of steel yield strength.

3.4.3 Material other than steel

In a member made in material other than steel with a Young's modulus E equal to 2.06×105 N/mm^2 and included in the hull girder transverse sections as specified in **[1.2.7]**, the normal stress is obtained from the following formula:

$$\sigma_L = \frac{E}{2.06 \times 10^5} \sigma_{LS}$$

where:

σ_{LS} : Normal stress, in N/mm^2, in the member under consideration, calculated according to **[3.4.1]** considering this member as having the steel equivalent sectional area A_{SE-n50} defined in **[1.2.7]**.

3.5 Extent of high tensile steel

3.5.1 Vertical extent

The vertical extent of higher strength steel, $z_{hts,i}$, in m, used in the deck zone or bottom zone and measured respectively from the moulded deck line at side or baseline is not to be taken less the value obtained from the following formula, see **Figure 9:**

$$z_{hts,i} = z_1\left(1 - \frac{\sigma_{perm,i}}{\sigma_L}\right)$$ for structural members located below strength deck

$$z_{hts,i} = \frac{(\sigma_{perm,i} - \sigma_{dk})}{(\sigma_{VD} - \sigma_{dk})}(z_T - z_{dk})$$ for effective longitudinal members located above strength deck

where:

z_1 : Distance from horizontal neutral axis to moulded deck line or baseline respectively, in m.

$\sigma_{perm,i}$: Permissible hull girder bending stress of the considered steel, in N/mm^2, as given in **Table 39** and **Figure 9.**

σ_L : Hull girder bending stress, σ_{dk} at moulded deck line or σ_{bl} at baseline respectively, in N/mm^2 given in **Table 40.**

σ_{VD} : Hull girder bending stress at equivalent deck line, in N/mm^2 given in **Table 40.**

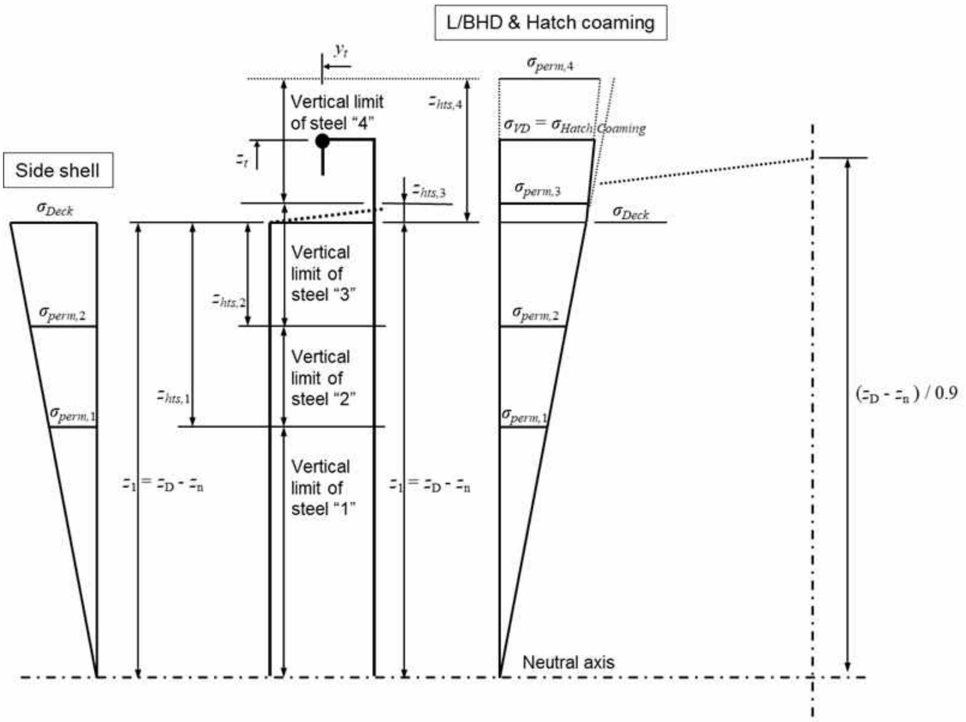


Figure 9 : Vertical extent of higher strength steel

Table 40 : Hull girder stresses at baseline and moulded deck line

Operation	Seagoing	Harbour/sheltered water
At baseline	$\sigma_{b\ell} = \dfrac{\lvert M_{sw} + M_{wv} \rvert}{I_{y-n50}} z_n \times 10^{-3}$	$\sigma_{b\ell} = \dfrac{\lvert M_{sw-p} \rvert}{I_{y-n50}} z_n \times 10^{-3}$
At moulded deck line	$\sigma_{dk} = \dfrac{\lvert M_{sw} + M_{wv} \rvert}{I_{y-n50}} (z_{dk-s} - z_n) \times 10^{-3}$	$\sigma_{dk} = \dfrac{\lvert M_{sw-p} \rvert}{I_{y-n50}} (z_{dk-s} - z_n) \times 10^{-3}$
At equivalent deck line	$\sigma_{VD} = \dfrac{\lvert M_{sw} + M_{wv} \rvert}{I_{y-n50}} V_D \times 10^{-3}$	$\sigma_{VD} = \dfrac{\lvert M_{sw-p} \rvert}{I_{y-n50}} V_D \times 10^{-3}$
z_{dk-s} : Distance from baseline to moulded deck line at side, in m. V_D : Vertical distance of the equivalent deck line, in m, defined in **[1.4.3]**		

3.5.2 Longitudinal extent

Where used, the application of higher strength steel is to be continuous over the length of the ship to the location where the longitudinal stress levels are within the allowable range for mild steel structure, as shown in **Figure 10.**

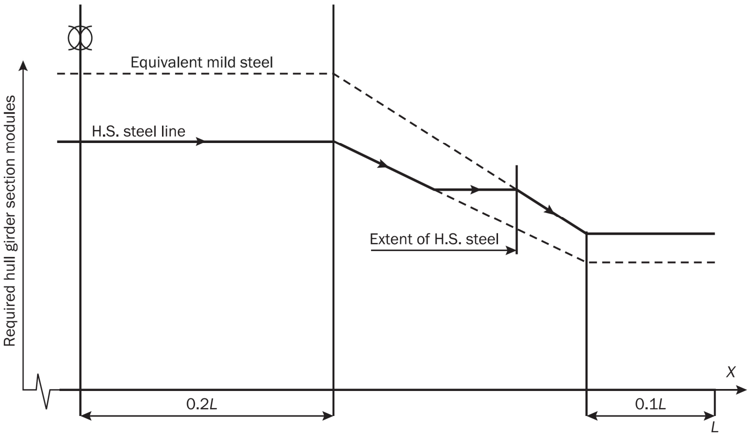


Figure 10 : Longitudinal extent of higher strength steel

3.6 Hull girder shear strength assessment

3.6.1

The shear stress, τ_{hg} is to be assessed for all conditions, along the full length of the hull girder, from AE to FE. The shear stress, τ_{hg}, at any point of the hull transverse section is to comply with the following formula:

$$\tau_{hg} \le \tau_{perm}$$

$$\tau_{hg} = \tau_{sw} + C_{WV}\tau_{wv} + C_{WH}\tau_{wh}$$

C_{WV}, C_{WH} : Load combination factors, as given in **Ch 4, Sec 2, [2.2.1]**

τ_{perm} : Permissible hull girder shear stress, in N/mm^2, as given in **Table 41.**

Table 41 : Permissible hull girder shear stress

Operation	Design load	Permissible hull girder shear, τ_{i-perm}
Seagoing	(S + D)	$\frac{235}{1.13\sqrt{3}k}$
Harbour/sheltered water	(S)	$\frac{105}{k}$

3.7 Hull girder buckling strength assessment

3.7.1

Hull girder buckling strength of members contributing to the longitudinal strength is to be assessed according to **Ch 8**.

4. Stress control of inner hull forming liquefied natural gas fuel tank

4.1 General

4.1.1

Liquefied natural gas fuel tanks with a membrane containment system may have some limitation such as elongation or stress level of adjacent installed hull structure. Any required criteria for inner hull is to be confirmed by the designer of the fuel containment system.

Section 2 Hull girder ultimate strength

1. Application

1.1 General

1.1.1

The requirements of this Section apply to ships with length L equal to or greater than 150 m.

1.1.2

The hull girder ultimate strength is to be assessed in way of 0.2 L to 0.75 L.

1.1.3

The hull girder ultimate bending capacity is to be checked to ensure that it satisfies the checking criteria given in **[2]**. Such criteria are applicable to intact ship structures for both hogging and sagging conditions, in seagoing and harbour/sheltered water conditions.

2. Checking criteria

2.1 General

2.1.1

The vertical hull girder ultimate bending capacity at any hull transverse section is to satisfy the following criterion:

$$M \leq \frac{M_U}{\gamma_M \gamma_{DB}}$$

where:

M : Vertical bending moment, in kNm, to be obtained as specified in **[2.2.1]**.

M_U : Hull girder ultimate bending moment capacity, in kNm, to be obtained as specified in **[2.3]**.

γ_M : Partial safety factor covering material, geometric and strength prediction uncertainties, in general to be taken equal to:

γ_M = 1.05

γ_{DB} : Partial safety factor covering the effect of double bottom bending under lateral loads, to be taken equal to:

- γ_{DB} = 1.15 for hogging condition
- γ_{DB} = 1.0 for sagging condition

For cross-sections where the breadth of the inner bottom is less than the one amidships, or where the double bottom structure differs from the one amidships (e.g. engine room sections), the factor γ_{DB} for hogging condition may be reduced, based upon agreement with the Society.

2.2 Hull girder ultimate bending loads

2.2.1

The vertical hull girder bending moment M, in kNm, in hogging and sagging conditions, to be considered in the ultimate strength check, is to be taken as:

$$M = \gamma_s M_{sw} + \gamma_w M_{wv}$$

where:

M_{sw} : Permissible hogging and sagging vertical still water bending moment, in kNm, at the hull transverse section considered as defined in **Ch 4, Sec 4, [2.2.2]**

M_{wv} : Vertical wave bending moment in seagoing operation, in kNm, at the hull transverse section considered as defined in **Ch 4, Sec 4, [3.2.1]**

γ_s : Partial safety factor for the still water bending moment, to be taken as: γ_s=1.0

γ_w : Partial safety factor for the vertical wave bending moment, to be taken as: γ_w=1.2.

2.3 Hull girder ultimate bending moment capacity

2.3.1 General

The hull girder ultimate bending moment capacity M_U is defined as the maximum bending moment capacity of the hull girder beyond which the hull structure collapses.

2.3.2 Determination of hull girder ultimate bending moment capacity

The ultimate bending moment capacities of a hull girder transverse section, in hogging and sagging conditions, are defined as the maximum values of the curve of bending moment M_U versus the curvature χ of the transverse section considered (M_{UH} for hogging condition and M_{US} for sagging condition, see **Figure 1**). The curvature χ is positive for hogging condition and negative for sagging condition.

The hull girder ultimate bending moment capacity M_U is to be calculated according to **App 2**.

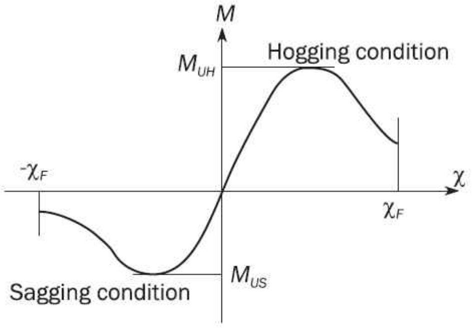


Figure 1 : Bending moment capacity versus curvature χ

2.3.3

The effective area to be considered for the hull girder ultimate strength capacity assessment is specified in **App 2.**

2.4 Whipping

2.4.1

Ultimate strength check of the hull considering the whipping effect is to be performed according to the requirements of the **Guidance on Strength Assessment of Container ships Considering the Whipping Effect.**

Appendix 1 – Direct Calculation of Shear Flow

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

1. Calculation formula

1.1 General

1.1.1

This Appendix describes the procedures of direct calculation of shear flow around a ship cross-section due to hull girder vertical shear force. The shear flow q_V, at each location in the cross-section, is calculated considering the cross-section subjected to a unit vertical shear force of 1 N.

The unit shear flow per mm q_v, in N/mm, is to be taken as:

$$q_V = q_D + q_I$$

where:

q_D : Determinate shear flow, as defined in **[1.2].**

q_I : Indeterminate shear flow which circulates around the closed cells, as defined in **[1.3].**

In the calculation of the unit shear flow q_V, the longitudinal stiffeners are to be taken into account.

1.2 Determinate shear flow, q_D

1.2.1

The determinate shear flow q_D, in N/mm, at each location in the cross-section is to be obtained from the following line integration:

$$q_D(s) = -\frac{1}{10^6 I_{y-n50}} \int_0^s (z - z_n) t_{n50} ds$$

where:

s : Coordinate value of the running coordinate along the cross-section, in m

I_{y-n50} : Net moment of inertia of the cross-section, in m4

t_{n50} : Net thickness of plating, in mm.

z_n : Z coordinate of horizontla neutral axis from baseline, in m

1.2.2

It is assumed that the cross-section is composed of line segments as shown in **Figure 1,** where each line segment has a constant plate net thickness. The determinate shear flow, in N/mm, is obtained by the following equation:

$$q_{Dk} = q_D(\ell) = -\frac{t\,\ell}{2 \times 10^6 I_{y-n50}} (z_k + z_i - 2z_n) + q_{Di}$$

where:

q_{Dk}, q_{Di} : Determinate shear flow, at node k and node i respectively, in N/mm

ℓ : Length of line segments, in m

y_i, y_k : Y coordinates, in m, of the end points i and k of a line segment, as defined in **Figure 1.**

z_i, z_k : Z coordinates, in m, of the end points i and k of a line segment, as defined in **Figure 1.**

1.2.3

Where the cross-section includes closed cells, the closed cells are to be cut with virtual slits, as shown in **Figure 2** in order to obtain the determinate shear flow.

These virtual slits are not to be located in walls which form part of another closed cell.

1.2.4

Determinate shear flow at bifurcation points is to be calculated by water flow calculations or similar, as shown in **Figure 2.**

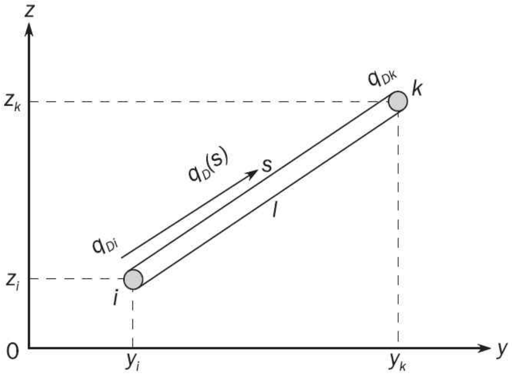


Figure 1 : Definition of line segment

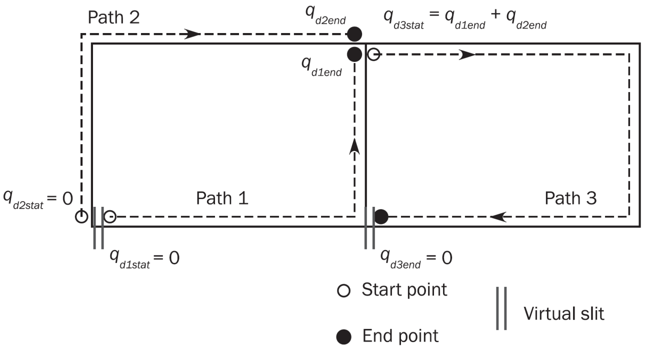


Figure 2 : Calculation of determinate shear flow at bifurcation

1.3 Indeterminate shear flow, q_I

1.3.1

The indeterminate shear flow qI around the closed cells of a cross-section is considered as a constant value within the same closed cell. The following system of equation for determination of indeterminate shear flows can be developed. In the equations, contour integrations of several parameters around all the closed cells are performed.

$$q_{Ic}\oint_{c}\frac{1}{t_{n50}}ds-\sum_{m=1}^{Nw}\left(q_{Im}\oint_{cm}\frac{1}{t_{n50}}ds\right)=-\oint_{c}\frac{q_D}{t_{n50}}ds$$

where:

N_W : Number of common walls shared by cell c and all the other cells

cm : Common wall shared by cells *c* and *m*

q_{Ic}, q_{Im} : Indeterminate shear flows around the closed cells c and m respectively, in N/mm.

1.3.2

Under the assumption of the assembly of line segments shown in **Figure 1** and constant plate thickness of each line segment, the equation in **[1.3.1]** is expressed as follows:

$$q_{Ic}\sum_{j=1}^{Nc}\left(\frac{\ell}{t_{n50}}\right)_j-\sum_{m=1}^{Nw}\left\{q_{Im}\left[\sum_{j=1}^{Nm}\left(\frac{\ell}{t_{n50}}\right)\right]\right\}=-\sum_{j=1}^{Nc}\phi_j$$

$$\phi_j=\left[-\frac{\ell^2}{6\times10^3 I_{y-n50}}(z_k+2z_i-3z_n)+\frac{\ell}{t_{n50}}q_{Di}\right]$$

where:

Nc : Number of line segments in cell *c*

Nm : Number of line segments on the common wall shared by cells *c* and *m*

q_{Di} : Determinate shear flow, in N/mm, calculated according to **[1.2.2].**

The difference in the directions of running coordinates specified in **[1.2]** and the present **[1.3]** is to be considered.

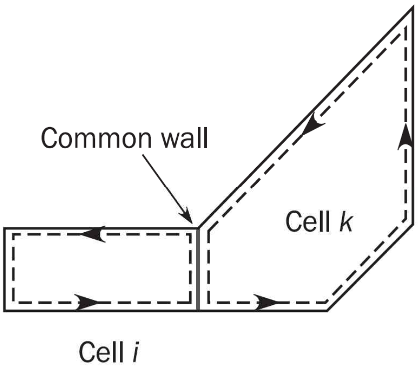


Figure 3 : Closed cells and common wall

1.4 Computation of sectional properties

1.4.1

Properties of the cross-section are to be obtained by the following formulae, where the cross-section is assumed to be made of the assembly of line segments:

$$\ell=\sqrt{(y_k-y_i)^2+(z_k-z_i)^2}$$

$$a_{n50}=10^{-3}\ell t_{n50} \qquad A_{n50}=\sum a_{n50}$$

$$s_{y-n50}=\frac{a_{n50}}{2}(z_k+z_i) \qquad S_{y-n50}=\sum s_{y-n50}$$

$$i_{y0-n50}=\frac{a_{n50}}{3}(z_k^2+z_kz_i+z_i^2) \qquad I_{y0-n50}=\sum i_{y0-n50}$$

where:

y_i, z_i : Y and Z coordinates of start point i of a line segment, in m, as defined in **Figure 1**

y_k, z_k : Y and Z coordinates of end point k of a line segment, in m, as defined in **Figure 1**

a_{n50}, A_{n50} : Areas of the line segment and the cross-section respectively, in m^2

s_{y-n50}, S_{y-n50} : First moments of the line segment and the cross-section about the baseline, in m^3.

i_{y0-n50}, I_{y0-n50} : Moments of inertia of the line segment and the cross-section about the baseline, in m^4.

1.4.2

The height of the horizontal neutral axis z_n, in m, is to be obtained as follows:

$$z_n = \frac{S_{y-n50}}{A_{n50}}$$

1.4.3

The moment of inertia about the horizontal neutral axis, in m^4, is to be obtained as follows:

$$I_{y-n50} = I_{y0-n50} - z_n^2 A_{n50}$$

Appendix 2 - Hull Girder Ultimate Bending Capacity

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4**

I_{y-n50} : Moment of inertia, in m^4, of the hull transverse section around its horizontal neutral axis, to be calculated according to **Ch 5, Sec 1**

Z_{B-n50} : Section modulus at bottom, in m^3, defined in **Ch 5, Sec 1**

Z_{D-n50} : Section modulus at deck, in m^3, defined in **Ch 5, Sec 1**

R_{eHs} : Minimum yield stress, in N/mm^2, of the material of the considered stiffener

R_{eHp} : Minimum yield stress, in N/mm^2, of the material of the considered plate

A_{s-n50} : Net sectional area, in cm^2, of stiffener, without attached plating

A_{p-n50} : Net sectional area, in cm^2, of attached plating.

1. General

1.1 Application

1.1.1

This Appendix provides the criteria to obtain the ultimate longitudinal bending moment capacity M_U to be used in the hull girder ultimate capacity check according to **Ch 5, Sec 2.**

1.1.2

M_U is defined as the maximum bending moment capacity of the hull girder beyond which the hull structure collapses. Hull girder failure is controlled by buckling, ultimate strength and yielding of longitudinal structural elements.

1.2 Methods

1.2.1 Incremental-iterative method

The hull girder ultimate bending moment capacity is to be assessed by the incremental-iterative method defined in **[2].**

1.2.2 Alternative methods

Principles for alternative methods for the calculation of the hull girder ultimate bending moment capacity, e.g. the nonlinear finite element analysis, are given in Article **[3].** Application of alternative methods is to be agreed by the Society prior to commencement. Documentation of the analysis methodology and detailed comparison of its results are to be submitted for review and acceptance. The use of such methods may require the partial safety factors to be recalibrated.

1.3 General assumptions

1.3.1

The method for calculating the ultimate hull girder bending capacity is to identify the critical failure modes of all the main longitudinal structural elements.

1.3.2

Structures compressed beyond their buckling limit have reduced load carrying capacity. 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 in order to identify the weakest inter-frame failure mode.

2. Incremental-iterative method

2.1 Assumptions

2.1.1

In applying the procedure described in **[2.2]**, the following assumptions are generally to be made:

- The ultimate strength is calculated at hull transverse sections between two adjacent transverse webs.
- The hull girder transverse section remains plane during each curvature increment.
- The hull material has an elasto-plastic behaviour.
- The hull girder transverse section is divided into a set of elements, see **[2.2.2]**, which are considered to act independently.

These elements are:

- Transversely framed plating panels and/or stiffeners with attached plating, whose structural behaviour is described in **[2.3.1]**.
- Hard corners, constituted by plating crossing, whose structural behaviour is described in **[2.3.2]**.

According to the iterative procedure, the bending moment M_i acting on the transverse section at each curvature value χ_i is obtained by summing the contribution given by the stress σ acting on each element. The stress σ corresponding to the element strain ε is to be obtained, for each curvature increment, from the non-linear load-end shortening curves $\sigma-\varepsilon$ of the element.

These curves are to be calculated, for the failure mechanisms of the element, from the formulae specified in **[2.3]**. The stress σ is selected as the lowest value among those obtained from each of the considered load-end shortening curves $\sigma-\varepsilon$.

The procedure is to be repeated until the value of the imposed curvature reaches the value χ_F, in m-1, in hogging and sagging conditions, obtained from the following formula:

where:

$$\chi_F = \pm 0.003 \frac{M_Y}{EI_{y-n50}}$$

M_Y : The lesser of the following values M_{Y1} and M_{Y2}, in kNm

$$M_{Y1} = 10^3 R_{eH} Z_{B-n50}$$

$$M_{Y2} = 10^3 R_{eH} Z_{D-n50}$$

If the value χ_F is not sufficient to evaluate the peaks of the curve $M-\chi$, the procedure is to be repeated until the value of the imposed curvature permits the calculation of the maximum bending moments of the curve.

2.2 Procedure

2.2.1 General

The curve $M-\chi$ is to be obtained by means of an incremental-iterative approach, summarised in the flow chart of **Figure 1.**

In this procedure, the hull girder ultimate bending moment capacity M_U is defined as the peak value of the curve with vertical bending moment M versus the curvature χ of the ship cross-section as shown in **Figure 1.** The curve is to be obtained through an incremental-iterative approach.

Each step of the incremental procedure is represented by the calculation of the bending moment M_i which acts on the hull transverse section as the effect of an imposed curvature χ_i.

For each step, the value χ_i is to be obtained by summing an increment of curvature $\Delta\chi$ to the value relevant to the previous step χ_{i-1}. This increment of curvature corresponds to an increment of the rotation angle of the hull girder transverse section around its horizontal neutral axis.

This rotation increment induces axial strains ε in each hull structural element, whose value depends on the position of the element. In hogging condition, the structural elements above the neutral axis are lengthened, while the elements below the neutral axis are shortened, and vice-versa in sagging condition.

The stress σ induced in each structural element by the strain ε is to be obtained from the load-end shortening curve $\sigma-\varepsilon$ of the element, which takes into account the behaviour of the element in the non-linear elasto-plastic domain.

The distribution of the stresses induced in all the elements composing the hull transverse section determines, for each step, a variation of the neutral axis position, due to the nonlinear $\sigma-\varepsilon$ relationship. The new position of the neutral axis relevant to the step considered is to be obtained by means of an iterative process, imposing the equilibrium among the stresses acting in all the hull elements on the transverse section.

Once the position of the neutral axis is known and the relevant element stress distribution in the section is obtained, the bending moment of the section M_i around the new position of the neutral axis, which corresponds to the curvature χ_i imposed in the step considered, is to be obtained by summing the contribution given by each element stress.

The main steps of the incremental-iterative approach described above are summarised as follows (see also **Figure 1**):

a) Step 1 : Divide the transverse section of hull into stiffened plate elements

b) Step 2 : Define stress-strain relationships for all the elements, as shown in **Table 1**

c) Step 3 : Initialise curvature χ_1 and neutral axis for the first incremental step with the value of incremental curvature (i.e. curvature that induces a stress equal to 1% of yield strength in strength deck) as:

$$\chi_1 = \Delta\chi = 0.01\frac{R_{eH}}{E}\frac{1}{z_D - z_n}$$

where:

z_D : Z coordinate, in m, of the strength deck at side, with respect to the reference coordinate system defined in **Ch 1, Sec 4, [3.5]**

z_n : Z coordinate, in m, of the horizontal neutral axis of the hull transverse section, with respect to the reference coordinate system defined in **Ch 1, Sec 4, [3.5]**

d) Step 4 : Calculate, for each element, the corresponding strain $\varepsilon_i = \chi(z_i - z_n)$ and the corresponding stress σ_i

e) Step 5 : Determine the neutral axis z_{NA-cur} at each incremental step by establishing force equilibrium over the whole transverse section as:

$$\Sigma A_{i-n50}\sigma_i = \Sigma A_{j-n50}\sigma_j$$

the *i*-th element being under compression and the *j*-th element under tension

f) Step 6 : Calculate the corresponding moment by summing the contributions of all the elements:

$$M_u = \Sigma\sigma_{Ui}A_{i-n50}|(z_i - z_{NA-cur})|$$

g) Step 7 : Compare the moment in the current incremental step with the moment in the previous incremental step. If the slope in $M-\chi$ relationship is less than a negative fixed value, terminate the process and define the peak value M_U. Otherwise, increase the curvature by the amount of $\Delta\chi$ and go to Step 4.

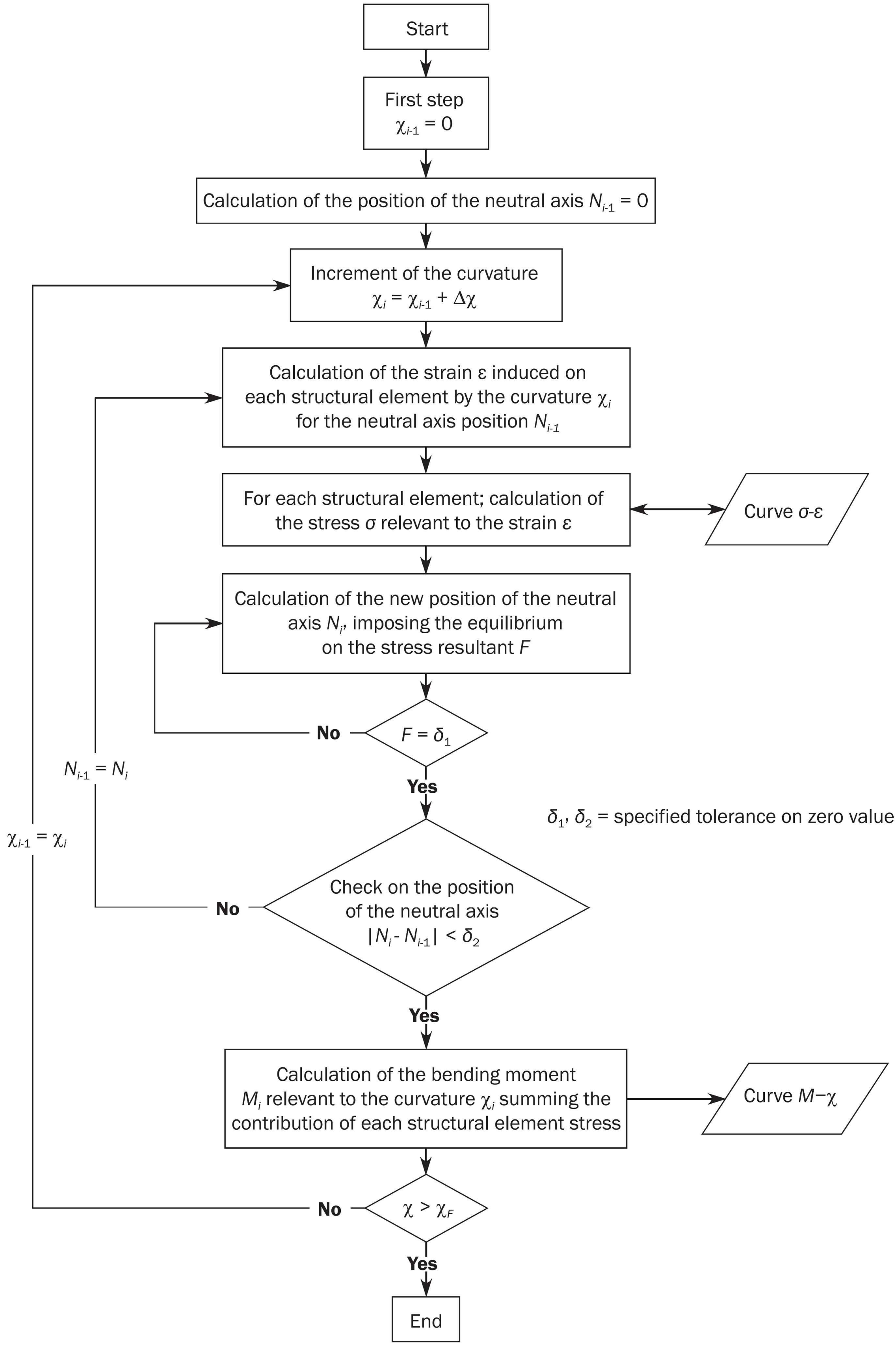


Figure 1 : Flow chart of the procedure for the evaluation of the curve $M-\chi$

2.2.2 Modelling of the hull girder cross-section

Hull girder transverse sections are to be considered as being constituted by the members contributing to the hull girder ultimate strength.

Sniped stiffeners are also to be modelled, taking account of the fact that they do not contribute to the hull girder strength.

The structural members are categorised into a stiffener element, a stiffened plate element or a hard corner element.

The plate panel including web plate of girder or side stringer is idealised into either a stiffened plate element, an attached plate of a stiffener element, or a hard corner element.

The plate panel is categorised into the following two kinds:

- Longitudinally stiffened panel, the longer side of which is in the ship longitudinal direction, and
- Transversely stiffened panel, the longer side of which is in the direction perpendicular to the ship longitudinal direction.

a) Hard corner element

Hard corner elements are sturdier elements composing the hull girder transverse section, which collapse mainly according to an elasto-plastic mode of failure (material yielding); they are generally constituted by two plates not lying in the same plane.

The extent of a hard corner element from the point of intersection of the plates is taken equal to 20 t_{n-50} on a transversely stiffened panel and to 0.5 s on a longitudinally stiffened panel, see **Figure 2.**

where:

t_{n-50} : Net offered thickness of the plate, in mm

s : Spacing of the adjacent longitudinal stiffener, in m.

Bilge, sheer strake-deck stringer elements, girder-deck connections and face plate-web connections on large girders are typical hard corners.

b) Stiffener element

The stiffener constitutes a stiffener element together with the attached plate.

The attached plate width is, in principle, equal to:

- The mean spacing of the stiffener, when the panels on both sides of the stiffener are longitudinally stiffened, or
- The width of the longitudinally stiffened panel, when the panel on one side of the stiffener is longitudinally stiffened and the other panel is transversely stiffened, see **Figure 2.**

c) Stiffened plate element

The plate between stiffener elements, between a stiffener element and a hard corner element or between hard corner elements is to be treated as a stiffened plate element, see **Figure 2.**

The typical examples of modelling of hull girder section are illustrated in **Figure 3.** Notwithstanding the foregoing principle, these figures are to be applied to the modelling in the vicinity of upper deck, sheer strake and hatch coaming.

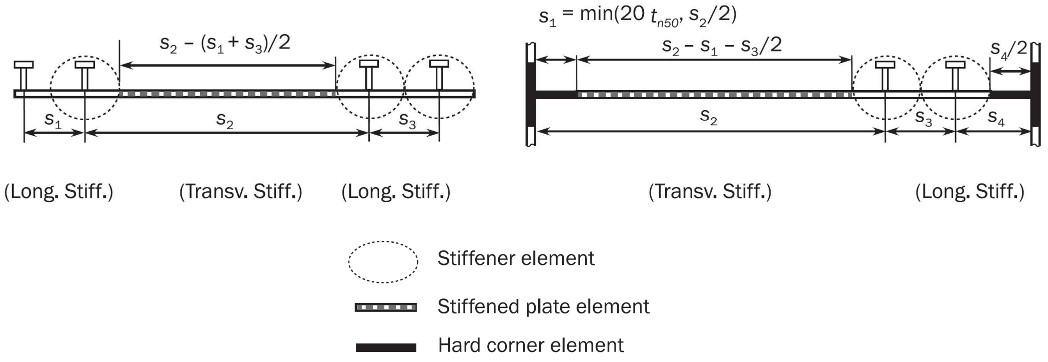


Figure 2 : Extension of the breadth of the attached plating and hard corner element

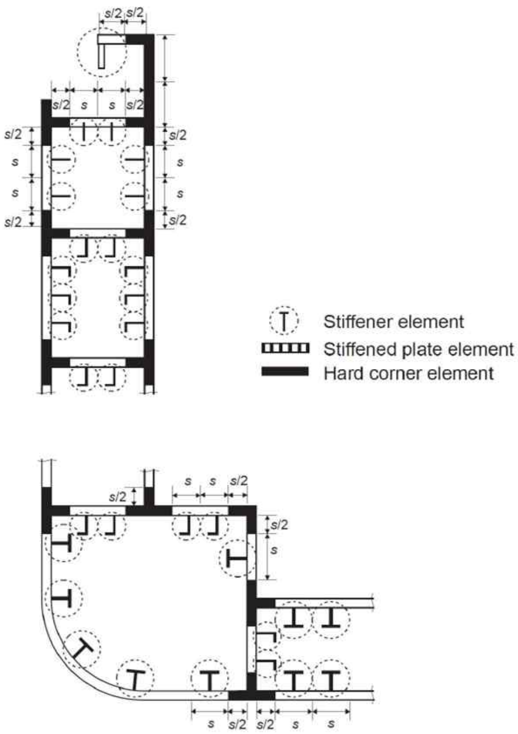


Figure 3 : Examples of the configuration of stiffened plate elements, stiffener elements and hard corner elements on a hull section

- In case of knuckle points as shown in **Figure 4**, the plating area adjacent to the knuckles in a plating having an angle greater than 30° is defined as a hard corner. The extent, from the knuckle point, of one side of the corner is taken equal to 20 t_{n-50} on transversely framed panels and to 0.5 s on longitudinally framed panels.
- Where plate elements are stiffened by non-continuous longitudinal stiffeners, the non-continuous stiffeners are considered only as dividing a plate into various elementary plate panels.
- Where openings are provided in stiffened plate elements, the openings are to be considered in accordance with **Ch 5, Sec 1, [1.2.8]**.

- Where an attached plating is made of steels having different thicknesses and/or yield stresses, an average thickness and/or average yield stress, obtained from the following formulae, are to be used for the calculation:

$$t = \frac{t_{1-n50}s_1 + t_{2-n50}s_2}{s} \qquad R_{eHp} = \frac{R_{eHp1}t_{1-n50}s_1 + R_{eHp2}t_{2-n50}s_2}{t_{n50}S}$$

where,

R_{eHp1}, R_{eHp2}, t_{1-n50}, t_{2-n50}, s_1, s_2 and s are shown in **Figure 5.**

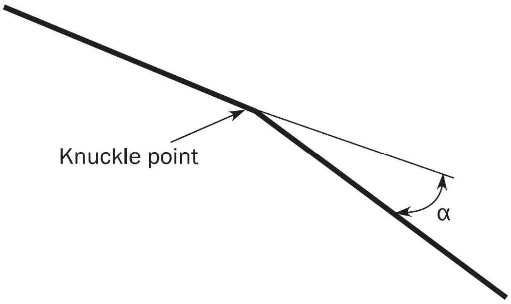


Figure 4 : Plating with knuckle point

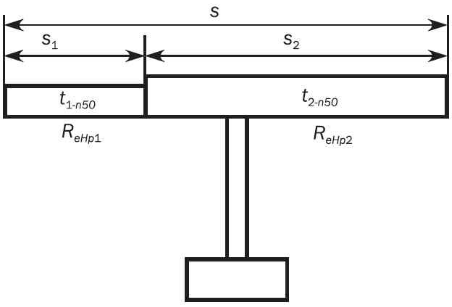


Figure 5 : Element with different thickness and yield strength

2.3 Load-end shortening curves

2.3.1 Stiffened plate element and stiffener element

Stiffened plate element and stiffener element composing the hull girder transverse sections may collapse, following one of the modes of failure specified in **Table 1.**

a) Where the plate elements are stiffened by non-continuous longitudinal stiffeners, the stress of the element is to be obtained in accordance with **[2.3.3]** to **[2.3.8]**, taking account of the non-continuous longitudinal stiffener. In the calculation of the total forces for checking the hull girder ultimate strength, the area of the non-continuous longitudinal stiffener is to be assumed as zero.

b) Where an opening is provided in the stiffened plate element, the considered area of the stiffened plate element is to be obtained by deducting the opening area from the plating in the calculation of the total forces for checking the hull girder ultimate strength. The consideration of the opening is in accordance with the requirement in **Ch 5, Sec 1, [1.2.8]** to **[1.2.12]**.

c) For the stiffened plate element, the effective width of plate for the load shortening portion of the stress-strain curve is to be taken as the full plate width, i.e. to the intersection of the other plate or longitudinal stiffener - neither from the end of the hard corner element nor from the attached plating of the stiffener element, if any. In the calculation of the total forces for checking the hull girder ultimate strength, the area of the stiffened plate element is to be taken between the hard corner element and the stiffener element or between the hard corner elements, as applicable.

Table 1 : Modes of failure of stiffened plate element and stiffener element

Element	Mode of failure	Curve $\sigma-\varepsilon$ defined in
Lengthened stiffened plate element or stiffener element	Elasto-plastic collapse	**[2.3.3]**
Shortened stiffener element	Beam column buckling Torsional buckling Web local buckling of flanged profiles Web local buckling of flat bars	**[2.3.4]** **[2.3.5]** **[2.3.6]** **[2.3.7]**
Shortened stiffened plate element	Plate buckling	**[2.3.8]**

2.3.2 Hard corner element

The relevant load-end shortening curve $\sigma-\varepsilon$ is to be obtained for lengthened and shortened hard corners according to **[2.3.3].**

2.3.3 Elasto-plastic collapse of structural elements

The equation describing the load-end shortening curve $\sigma-\varepsilon$ for the elasto-plastic collapse of structural elements composing the hull girder transverse section is to be obtained from the following formula, valid for both positive (shortening) and negative (lengthening) strains (see **Figure 6**):

$$\sigma = \Phi R_{eHA}$$

where:

R_{eHA} : Equivalent minimum yield stress, in N/mm^2, of the considered element, obtained by the following formula:

$$R_{eHA} = \frac{R_{eHP}A_{p-n50} + R_{eHs}A_{s-n50}}{A_{p-n50} + A_{s-n50}}$$

Φ : Edge function, equal to:

$\Phi = -1$ for ε 〈 -1

$\Phi = \epsilon$ for $-1 \le \varepsilon \le 1$

$\Phi = 1$ for ε 〈 1

ε : Relative strain, equal to:

$$\varepsilon = \frac{\varepsilon_E}{\varepsilon_Y}$$

ε_E : Element strain

ε_Y : Strain at yield stress in the element, equal to:

$$\varepsilon_Y = \frac{R_{eHA}}{E}$$

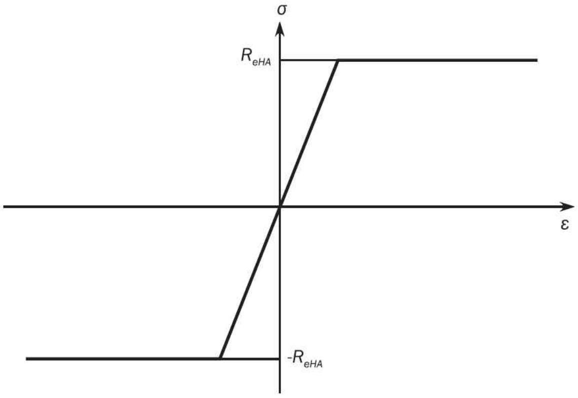


Figure 6 : Load-end curve $\sigma-\varepsilon$ for elasto plastic collapse

2.3.4 Beam column buckling

The equation describing the load-end shortening curve $\sigma - \varepsilon$ for the beam column buckling of stiffeners composing the hull girder transverse section is to be obtained from the following formula, see **Figure 7:**

$$\sigma_{CR1} = \Phi \sigma_{C1} \frac{A_{s-n50} + A_{pE-n50}}{A_{s-n50} + A_{p-n50}}$$

where:

Φ : Edge function, as defined in **[2.3.3]**

σ_{C1} : Critical stress, in N/mm^2, equal to:

$$\sigma_{C1} = \frac{\sigma_{E1}}{\varepsilon}, \qquad \text{for } \sigma_{E1} \le \frac{R_{eHB}}{2}\varepsilon$$

$$\sigma_{C1} = R_{eHB}\left(1 - \frac{R_{eHB}\varepsilon}{4\sigma_{E1}}\right) \qquad \text{for } \sigma_{E1} > \frac{R_{eHB}}{2}\varepsilon$$

R_{eHB} : Equivalent minimum yield stress, in N/mm^2, of the considered element, obtained by the following formula:

$$R_{eHB} = \frac{R_{eHp} A_{pE1-n50} \ell_{pE} + R_{eHs} A_{s-n50} \ell_{sE}}{A_{pE1-n50} \ell_{pE} + A_{s-n50} \ell_{sE}}$$

$A_{pE1-n50}$: Effective area, in cm^2, equal to:

$$A_{pE1-n50} = 10 b_{E1} t_{n50}$$

ℓ_{pE} : Distance, in mm, measured from the neutral axis of the stiffener with attached plate of width b_{E1} to the bottom of the attached plate

ℓ_{sE} : Distance, in mm, measured from the neutral axis of the stiffener with attached plating of width b_{E1} to the top of the stiffener

ε : Relative strain, as defined in **[2.3.3]**

σ_{E1} : Euler column buckling stress, in N/mm^2, equal to:

$$\sigma_{E1} = \pi^2 E \frac{I_{E-n50}}{A_{E-n50} \ell^2} 10^{-4}$$

I_{E-n50} : Net moment of inertia of stiffeners, in cm^4, with attached plating of width b_{E1}

A_{E-n50} : Net area, in cm^2, of stiffeners with attached plating of width b_E

b_{E1} : Effective width corrected for relative strain, in m, of the attached plating, equal to:

$$b_{E1} = \frac{s}{\beta_E} \qquad \text{for } \beta_E > 1.0$$

$$b_{E1} = s \qquad \text{for } \beta_E \le 1.0$$

$$\beta_E = 10^3 \frac{s}{t_{n50}} \sqrt{\frac{\varepsilon R_{eHP}}{E}}$$

A_{pE-n50} : Net sectional area, in cm^2, of attached plating of width b_E, equal to:

$$A_{pE-n50} = 10 b_E t_{n50}$$

b_E : Effective width, in m, of the attached plating, equal to:

$$b_E = \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2}\right) s \qquad \text{for } \beta_E > 1.25$$

$$b_E = s \qquad \text{for } \beta_E \le 1.25$$

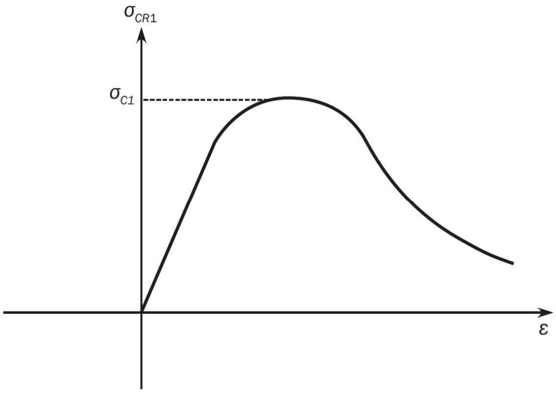


Figure 7 : Load-end shortening curve $\sigma_{CR1}-\varepsilon$ for beam column buckling

2.3.5 Torsional buckling

The load-end shortening curve $\sigma_{CR2}-\varepsilon$ for the flexural-torsional buckling of stiffeners composing the hull girder transverse section is to be obtained according to the following formula, see **Figure 8:**

$$\sigma_{CR2}=\Phi\frac{A_{s-n50}\sigma_{C2}+A_{p-n50}\sigma_{CP}}{A_{s-n50}+A_{p-n50}}$$

where:

Φ : Edge function, as defined in **[2.3.3]**

σ_{C2} : Critical stress, in N/mm^2, equal to:

$$\sigma_{C2}=\frac{\sigma_{E2}}{\varepsilon} \quad \text{for } \sigma_{E2}\le\frac{R_{eHs}}{2}\varepsilon$$

$$\sigma_{C2}=R_{eHs}\left(1-\frac{R_{eHs}\varepsilon}{4\sigma_{E2}}\right) \quad \text{for } \sigma_{E2}>\frac{R_{eHs}}{2}\varepsilon$$

σ_{E2} : Euler column buckling stress, in N/mm^2, taken equal to σ_{ET} , as defined in **Ch 8, Sec 5, [3.1.3]**

ε : Relative strain, as defined in **[2.3.3]**

σ_{CP} : Buckling stress of the attached plating, in N/mm^2, equal to:

$$\sigma_{CP}=\left(\frac{2.25}{\beta_E}-\frac{1.25}{\beta_E^2}\right)R_{eHp} \quad \text{for } \beta_E>1.25$$

$$\sigma_{CP}=R_{eHp} \quad \text{for } \beta_E\le 1.25$$

β_E : Coefficient, as defined in **[2.3.4].**

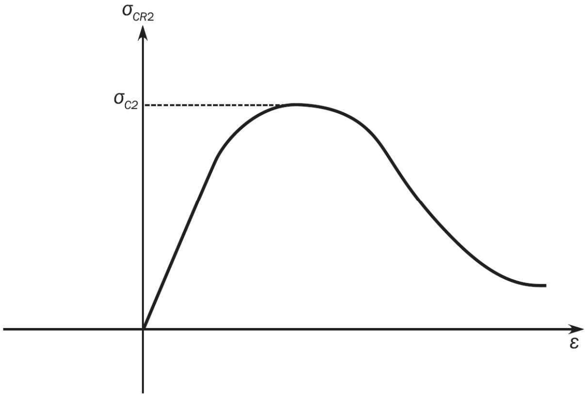


Figure 8 : Load-end shortening curve $\sigma_{CR2}-\varepsilon$ for flexural-torsional buckling

2.3.6 Web local buckling of stiffeners made of flanged profiles

The equation describing the load-end shortening curve $\sigma_{CR3} - \varepsilon$ for the web local buckling of flanged stiffeners composing the hull girder transverse section is to be obtained from the following formula:

$$\sigma_{CR3} = \Phi \frac{10^3 b_E t_{n50} R_{eHp} + (h_{we} t_{w-n50} + b_f t_{f-n50}) R_{eHs}}{10^3 s t_{n50} + h_w t_{w-n50} + b_f t_{f-n50}}$$

where:

Φ : Edge function, as defined in **[2.3.3]**

b_E : Effective width, in m, of the attached shell plating, as defined in **[2.3.4]**

h_{we} : Effective height of the web, in mm, equal to:

$$h_{we} = \left(\frac{2.25}{\beta_w} - \frac{1.25}{\beta_w^2} \right) h_w \quad \text{for } \beta_w > 1.25$$

$$h_{we} = h_w \quad \text{for } \beta_w \leq 1.25$$

$$\beta_w = \frac{h_w}{t_{w-n50}} \sqrt{\frac{\varepsilon R_{eHs}}{E}}$$

ε : Relative strain, as defined in **[2.3.3].**

2.3.7 Web local buckling of stiffeners made of flat bars

The load-end shortening curve $\sigma_{CR4} - \varepsilon$ for the web local buckling of flat bar stiffeners composing the hull girder transverse section is to be obtained from the following formula, see **Figure 9:**

$$\sigma_{CR4} = \Phi \frac{A_{P-n50} \sigma_{CP} + A_{s-n50} \sigma_{C4}}{A_{p-n50} + A_{s-n50}}$$

where:

Φ : Edge function, as defined in **[2.3.3]**

σ_{CP} : Buckling stress of the attached plating, in N/mm^2, as defined in **[2.3.5]**

σ_{C4} : Critical stress, in N/mm^2, equal to:

$$\sigma_{C4} = \frac{\sigma_{E4}}{\varepsilon} \quad \text{for } \sigma_{E4} \leq \frac{R_{eHs}}{2} \varepsilon$$

$$\sigma_{C4} = R_{eHs} \left(1 - \frac{R_{eHs} \varepsilon}{4 \sigma_{E4}} \right) \quad \text{for } \sigma_{E4} > \frac{R_{eHs}}{2} \varepsilon$$

σ_{E4} : Local Euler buckling stress, in N/mm^2, equal to:

$$\sigma_{E4} = 160000 \left(\frac{t_{w-n50}}{h_w} \right)^2$$

ε : Relative strain, as defined in **[2.3.3].**

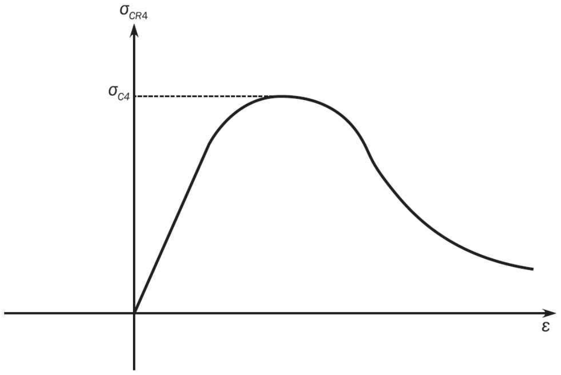


Figure 9 : Load-end shortening curve $\sigma_{CR4} - \varepsilon$ for web local buckling

2.3.8 Plate buckling

The load-end shortening curve $\sigma_{CR5} - \varepsilon$ for the buckling of transversely stiffened panels composing the hull girder transverse section is to be obtained from the following formula:

$$\sigma_{CR5} = \min \begin{cases} \Phi R_{eHp} \\ \Phi R_{eHp} \left[\frac{s}{\ell} \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2} \right) + 0.1 \left(1 - \frac{s}{\ell} \right) \left(1 + \frac{1}{\beta_E^2} \right)^2 \right] \end{cases}$$

where:

Φ : Edge function, as defined in **[2.3.3]**

β_E : value of following formula

$$\beta_E = 10^3 \frac{s}{t_{n50}} \sqrt{\frac{\varepsilon R_{eHp}}{E}}$$

s : Plate breadth, in m, taken as the spacing between the stiffeners

ℓ : Longer side of the plate, in m.

3. Alternative methods

3.1 General

3.1.1

Application of alternative methods is to be agreed by the Society prior to commencement. Documentation of the analysis methodology and detailed comparison of its results are to be submitted for review and acceptance. The use of such methods may require the partial safety factors to be recalibrated.

3.1.2

The bending moment-curvature relationship M-χ may be established by alternative methods. Such models are to consider all the relevant effects important to the non-linear response, with due consideration to:

a) Non-linear geometrical behaviour

b) Inelastic 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

i) Overstressed elements on the compression side of hull girder cross-section possibly leading to local permanent sets/buckle damages in plating, stiffeners etc (double bottom effects or similar).

3.2 Non-linear finite element analysis

3.2.1

Advanced non-linear finite element analysis models may be used for the assessment of the hull girder ultimate capacity. Such models are to consider the relevant effects important to the non-linear responses, with due consideration to the items listed in **[3.1.1]**.

3.2.2

Particular attention is to be given to modelling the shape and size of geometrical imperfections. It is to be ensured that the shape and size of geometrical imperfections trigger the most critical failure modes.

Appendix 3 - Definition of Hull Girder Torsional Properties

1. General

The hull girder torsional properties may be calculated based on the thin walled beam theory. The torsional properties for each design will be calculated with SeaTrust-HullScan.

2. Warping Function

The warping fuction for node "N", $\omega(s)$, may be obtained from the following equation.

$$\omega(s) = \int_0^N \left(\frac{q_s}{t_s} - h(s) \right) ds$$

where

s : length along girth

q_s : Specific stress flow of cell to which each segment belongs

t_s : Plate thickness of each segment with the area of longitudinal stiffeners smeared

$h(s)$: Distance from the center of twist to the tangent to the point in question. This distance shall be considered positive when, in conjunction with the positive direction of the arc length coordinate s, it would correspond to a positive twist.

The specific stress flow, q, of each cell may be obtained from the following set of equations; the number of the equation is equal to the number of cells in hull girder section.

$$q_i \oint_i \frac{ds}{t} - q_{i-1} \oint_{i-1} \frac{ds}{t} - q_{i+1} \oint_{i+1} \frac{ds}{t} = 2A_i \quad (i = 1, 2, \cdots, k)$$

where

q_i : Specific flow for cell "i"

q_{i-1} : Specific flow for adjacent cell "i-1"

q_{i+1} : Specific flow for adjacent cell "i+1"

k : Number of the cells in hull girder section

A_i : Enclosed area of cell "i"

t : Plate thickness of segment with the area of longitudinal stiffeners smeared

3. Sectorial Moment of Inertia

The sectorial moment of inertia, I_ω, for the hull girder section may be obtained from the following equation:

$$I_\omega = \sum_{n-1}^{p} t_n \int_0^{l_n} \omega^2(s) ds$$

where

p : number of segments in hull girder section

ℓ_n : length of segment "n"

t_n : Plate thickness of segment "n" with the area of longitudinal stiffeners smeared

$\omega(s)$: Warping function

4. Saint-Venant Moment of Inertia

The Saint-Venant moment of inertia, J, may be obtained from the following equation:

$$J = 4\sum_{i=1}^{k} \frac{A_i^2}{\oint \frac{ds}{t}} + \frac{\Sigma\left(h_w t_w^3 + b_f t_f^3\right)}{3}$$

where

A_i : Enclosed area of cell “i”

t : Plate thickness of segment in cell “i ” without smearing longitudinal stiffeners

k : Number of the cells in hull girder section

b_w : Web height of longitudinal stiffener

t_w : Web thickness of longitudinal stiffener

b_f : Face plate width of longitudinal stiffener

t_f : Face plate thickness of longitudinal stiffener ⚓

Chapter 6

Hull Local Scantling

Section 1 General

1. Application

1.1 Application

1.1.1

This chapter applies to hull structure over the full length of the ship including fore end, cargo hold region, machinery space and aft end, the side shell above the freeboard deck, engine casing, exposed decks of superstructure and internal decks except those inside superstructure and deckhouse.

1.1.2

This chapter provides requirements for evaluation of plating, stiffeners and Primary Supporting Members (PSM) subject to lateral pressure, local loads and to hull girder loads, as applicable. Requirements are specified for:

a) Load application in **Ch 6, Sec 2**.
b) Minimum thickness of plates, stiffeners and PSM in **Ch 6, Sec 3**.
c) Plating in **Ch 6, Sec 4**.
d) Stiffeners in **Ch 6, Sec 5**.
e) PSM and pillars in **Ch 6, Sec 6**.

In addition, other requirements not related to defined design load sets, are provided.

1.1.3

The offered net scantling is to be greater than or equal to the required scantlings based on requirements provided in this chapter.

1.1.4

Additional local strength requirements are provided in **Ch 10** considering bow impact loads, bottom slamming loads, stern slamming loads and sloshing loads, and for fore end, machinery space and aft end.

1.2 Acceptance criteria

1.2.1

Acceptance criteria set to be selected based on design load as follows:

a) AC-S for design load S : static loads
b) AC-SD for design load S + D : combination of static and dynamic loads
c) AC-A for design load A : accidental loads
d) AC-T for design load T : tank testing loads

Section 2 Load Application

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4**.

1. Load combination

1.1 Hull girder bending

1.1.1 Normal stresses

The normal stress σ_{hg}, in $\mathrm{N/mm^2}$, induced by acting vertical and horizontal bending moments at the position being considered is given as follow. This stress is to be calculated for each design load set, as defined in **[2]** covering all dynamic load cases defined in **Ch 4** in combination with M_{sw} both in hogging and in sagging.

$$\sigma_{hg} = \left(\frac{M_{sw} + M_{wv-LC}}{I_{y-n50}} (z - z_n) - \frac{M_{wh-LC}}{I_{z-n50}} y \right) 10^{-3} + C_{tor} \sigma_{WT}$$

where:

M_{sw} : Still water bending moment, in kNm, as defined in **Ch 4, Sec 4, [2.2]** in accordance with the considered design load scenario in **Ch 4, Sec 7, Table 1.**

M_{wv-LC} : Vertical wave bending moment, in kNm, of the considered dynamic load case, as defined in **Ch 4, Sec 4, [3.2]** in accordance with the considered design load scenario in **Ch 4, Sec 7, Table 1,** at the considered longitudinal position.

M_{wh-LC} : Horizontal wave bending moment, in kNm, of the considered dynamic load case, as defined in **Ch 4, Sec 4, [3.4]** in accordance with the considered design load scenario in **Ch 4, Sec 7, Table 1,** at the considered longitudinal position.

I_{y-n50} : Net vertical hull girder moment of inertia, at the longitudinal position being considered, in $\mathrm{m^4}$

I_{z-n50} : Net horizontal hull girder moment of inertia, at the longitudinal position being considered, in $\mathrm{m^4}$

y : Transverse coordinate of load calculation point, in m.

z : Vertical coordinate of the load calculation point under consideration, in m.

z_n : Distance from the baseline to the horizontal neutral axis, in m.

C_{tor} : Warping stress coefficient, as defined in **Ch 5, Sec 1, [3.4.1]**.

σ_{WT} : Warping stress, in $\mathrm{N/mm^2}$, as defined in **Ch 5, Sec 1, [2.1.4]** to **[2.1.6].**

1.2 Lateral pressures

1.2.1 Static and dynamic pressures in intact conditions

The static and dynamic lateral pressures in intact condition induced by the sea and the various types of cargoes, ballast and other liquids are to be considered. Applied loads will depend on the location of the elements under consideration, and the adjacent type of compartments.

1.2.2 Pressure in collision condition

The internal liquefied natural gas fuel pressure due to collision is to be considered with colliding acceleration a_x, whose direction is decided depending on the position of transverse bulkhead of the liquefied natural gas fuel tank considered, combined with static liquefied natural gas fuel pressure.

1.2.3 Lateral pressure in flooded conditions

Watertight boundaries of compartments not intended to carry liquids, excluding shell envelope, are to be subjected to lateral pressure in flooded conditions.

1.3 Pressure combination

1.3.1 Elements of the outer shell

If the compartment adjacent to the outer shell is intended to carry liquids, the static and dynamic lateral pressures to be considered are the differences between the internal pressures and the external sea pressures at the corresponding draught.

If the compartment adjacent to the outer shell is not intended to carry liquids, the internal pressures and external sea pressures are to be considered independently.

1.3.2 Elements other than those of the outer shell

Except as specified in **[1.3.1]**, the static and dynamic lateral pressures on an element separating two adjacent compartments are those obtained considering the two compartments individually loaded.

2. Design load sets

2.1 Application of load components

2.1.1 Application

These requirements apply to:

a) Plating and stiffeners along the full length of the ship.

b) PSM outside the cargo hold region.

2.1.2 Load components

The static and dynamic load components are to be determined in accordance with **Ch 4, Sec 7, Table 1.** Radius of gyration, k_r, and metacentric height, GM, are to be in accordance with **Ch 4, Sec 3, Table 1** for the considered loading conditions specified in the design load sets given in **Table 1.**

2.1.3 Design load sets for plating, stiffeners and PSM

Design load sets for plating, stiffeners and primary supporting members are given in **Table 1.**

Table 1 : Design load sets

Structural member	Design load set	Load component	Draught	Design load	Loading condition
External shell and Exposed deck	SEA-1	P_{ex}, P_D	T_{SC}	S + D	Full load condition
	SEA-2	P_{ex}	T_{SC}	S	Harbour condition
Water ballast tanks	WB-1	$P_{in} - P_{ex}$ (1)	T_{BAL}	S + D	Normal ballast condition
	WB-2	$P_{in} - P_{ex}$ (1)	T_{BAL}	S + D	Normal ballast condition Water ballast exchange
	WB-3	$P_{in} - P_{ex}$ (1)	$0.25T_{SC}$	S	Harbour condition
	WB-4	$P_{in} - P_{ex}$ (1)	$0.25T_{SC}$	T	Test condition
Other tanks • Fuel oil tanks • Methanol fuel tanks	TK-1	$P_{in} - P_{ex}$ (1)	T_{BAL}	S + D	Normal ballast condition
	TK-2	$P_{in} - P_{ex}$ (1)	$0.25T_{SC}$	S	Harbour condition
	TK-3	$P_{in} - P_{ex}$ (1)	$0.25T_{SC}$	T	Test condition
Liquefied natural gas fuel tank	FTK-1	P_{in}	T_{SC}	S + D	Full load condition
	COL(2)	P_{in}	-	A	Collision condition
Watertight boundaries	FD-1(3)	P_{in}	-	A	Flooded condition
Dry space and hatch coaming	VD-1	P_{ex}, P_{in}	T_{SC}	S + D	Full load condition

(1) P_{ex} is to be considered for external shell only.

(2) COL set means collision conditions that 0.5g and -0.25g of colliding accelerations in way of longitudinal direction are to be applied for liquefied natural gas fuel tank full condition under Accidental design load (A) in order to verify structural integrity of liquefied natural gas fuel tank boundary and support structures, refer to "**Rules/Guidance for the Classification of Ships Using Low-flashpoint Fuels", Ch 6, Sec 4, 409.5.**

(3) FD-1 is not applicable to external shell.

Section 3 Minimum Thickness

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

1. Plating

1.1 Minimum thickness requirements

1.1.1

The net thickness of plating in mm, is to comply with the appropriate minimum thickness requirements given in **Table 1.**

Table 1 : Minimum net thickness for plating

Element	Location	Area	Net thickness
Shell	Keel	–	$7.5+0.03L_2\sqrt{k}$
	Bottom Side shell Bilge	Fore Part	$5.5+0.03L_2\sqrt{k}$
		Machinery space, Aft part	$7.0+0.02L_2\sqrt{k}$
		Elsewhere	$4.0+0.035L_2\sqrt{k}$
Breast hook	–	Fore part	6.5
Deck	Weather deck, strength deck, internal tank boundary	–	$3.7+0.019L_2\sqrt{k}$
	Platform deck	Machinery space	$4.5+0.02L_2\sqrt{k}$
		Elsewhere	6.5
Inner bottom(1)	–	Machinery space	$6.1+0.024L_2\sqrt{k}$
		Elsewhere	$4.0+0.028L_2\sqrt{k}$
Bulkheads	Ballast tank boundary	–	$4.5+0.016L_2\sqrt{k}$
	Transverse / longitudinal watertight bulkhead and other tanks bulkheads	–	$4.5+0.01L_2\sqrt{k}$
	Non-tight bulkhead, Bulkheads between dry spaces.	–	$4.5+0.01L_2\sqrt{k}$
	Pillar bulkheads in fore and aft peaks	–	7.5
Other members	Engine casing (in the cargo hold region)	Cargo hold region	5.5
	Engine casing (in way of accommodation)	Accommodation	4.0
	Other plates in general	–	$4.5+0.01L_2\sqrt{k}$

(1) Applicable for both tight and non tight members

2. Stiffeners and tripping brackets

2.1 Minimum thickness requirements

2.1.1

The net thickness of the web and face plate, if any, of stiffeners and tripping brackets in mm, is to comply with the minimum net thickness given in **Table 2.**

In addition, the net thickness of the web of stiffeners and tripping brackets, in mm, is to be:

a) Not less than 40 % of the net required thickness of the attached plating, to be determined according to **Ch 6, Sec 4.**

b) Less than twice the net offered thickness of the attached plating.

Table 2 : Minimum net thickness for stiffeners

Element	Location	Net thickness
Stiffeners and attached end brackets	Watertight boundary	$4.5+0.007L_2$
	Other structure	$4.0+0.007L_2$
Tripping brackets		$4.5+0.01L_2$

3. Primary supporting members

3.1 Minimum thickness requirements

3.1.1

The net thickness of web plating and flange of primary supporting members in mm, is to comply with the minimum net thickness given in **Table 3.**

Table 3 : Minimum net thickness for primary supporting members

Element	Location	Net thickness
Double bottom centreline girder	Machinery space	$0.50\sqrt{L_2k}+5.5$
	Elsewhere	$0.45\sqrt{L_2k}+5.0$
Other bottom girder	Machinery space	$0.45\sqrt{L_2k}+5.0$
	Fore part	$0.45\sqrt{L_2k}+4.0$
	Elsewhere	$0.35\sqrt{L_2k}+3.5$
Girders bounding a duct keel	Machinery space	$0.50\sqrt{L_2k}+5.0$
Bottom floor	Machinery space	$0.40\sqrt{L_2k}+5.0$
	Fore part	$0.30\sqrt{L_2k}+5.0$
	Elsewhere	$0.30\sqrt{L_2k}+4.0$
Aft peak floor	-	$0.30\sqrt{L_2k}+4.0$
Other primary supporting member	-	$0.20\sqrt{L_2k}+4.0$

Section 4 Plating

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

α_p : Correction factor for the panel aspect ratio to be taken as follow but not to be taken greater than 1.0.

$$\alpha_p = 1.2 - \frac{b}{2.1a}$$

a : Length of plate panel, in mm, as defined in **Ch 3, Sec 7, [2.2.2].**

b : Breath of plate panel, in mm, as defined in **Ch 3, Sec 7, [2.2.2].**

P : Design pressure for the considered design load set, see **Ch 6, Sec 2, [2],** calculated at the load calculation point defined in **Ch 3, Sec 7, [2.2],** in $\mathrm{kN/m^2}$.

σ_{hg} : Hull girder bending stress, in $\mathrm{N/mm^2}$, as defined in **Ch 6, Sec 2, [1.1],** calculated at the load calculation point as defined in **Ch 3, Sec 7, [2.2].**

χ : Coefficient taken equal to:

a) In intact condition

- $\chi = 1.00$

b) In flooded condition

- $\chi = 0.95$ for collision bulkheads for acceptance criteria set AC-A
- $\chi = 1.15$ for other watertight boundaries of compartments

1. Plating subjected to lateral pressure

1.1 Yielding check

1.1.1 Plating

The net thickness, t in mm, is not to be taken less than the greatest value for all applicable design load sets, as defined in **Ch 6, Sec 2, [2.1.3],** given by:

$$t = 0.0158\alpha_p b\sqrt{\frac{|P|}{\chi C_a R_{eH}}}$$

where:

C_a : Permissible bending stress coefficient for plate taken equal to:

$$C_a = \beta - \alpha\frac{|\sigma_{hg}|}{R_{eH}}$$, not to be taken greater than $C_{a-\max}$

β : Coefficient as defined in **Table 1.**

α : Coefficient as defined in **Table 1.**

$C_{a-\max}$: Maximum permissible bending stress coefficient as defined in **Table 1.**

Table 1 : Definition β, α and C_{a-max}

Acceptance criteria set	Structural member		β	α	C_{a-max}
AC-S	Longitudinal strength members	Longitudinally stiffened plating	0.90	0.5	0.80
		Transversely stiffened plating	0.90	1.0	0.80
	Other members		0.80	0.0	0.80
AC-SD	Longitudinal strength members	Longitudinally stiffened plating	1.05	0.5	0.95
		Transversely stiffened plating	1.05	1.0	0.95
	Other members		1.00	0.0	1.00
AC-A	Longitudinal strength members	Longitudinally stiffened plating	1.10	0.5	1.00
		Transversely stiffened plating	1.10	1.0	1.00
	Other members		1.00	0.0	1.00
AC-T	Longitudinal strength members	Longitudinally stiffened plating	1.25	0.5	1.15
		Transversely stiffened plating	1.15	1.0	1.15
	Other members		1.15	0.0	1.15

1.2 Plating of corrugated bulkheads

1.2.1 Cold, hot formed and built up corrugations

The net thicknesses, t in mm, of the web and flange plates of corrugated bulkheads are not to be taken less than the greatest value calculated for all applicable design load sets, as defined in **Sec 2, [2.1.3]**, given by:

$$t = 0.0158\, b_p \sqrt{\frac{|P|}{C_{CB} R_{eH}}}$$

where:

b_p : Breadth of plane corrugation plating:

$b_p = b_{f-cg}$ for flange plating, in mm, as defined in **Ch 3, Sec 6, Figure 21**.

$b_p = b_{w-cg}$ for web plating, in mm, as defined in **Ch 3, Sec 6, Figure 21**.

C_{CB} : Permissible bending stress coefficient for corrugated bulkheads plating taken equal to:

$C_{CB} = \beta_{CB} - \alpha_{CB} \frac{|\sigma_{hg}|}{R_{eH}}$, not to be taken greater than C_{CB-max}

β_{CB} : Coefficient as defined in **Table 2**.

α_{CB} : Coefficient as defined in **Table 2**.

C_{CB-max} : Maximum permissible bending stress coefficient as defined in **Table 2**.

Table 2 : Definition β_{CB}. α_{CB} and C_{CB-max}

Acceptance criteria set	Structural member	β_{CB}	α_{CB}	C_{CB-max}
AC-S	Horizontally corrugated longitudinal bulkheads	0.90	0.50	0.75
	Other corrugated bulkheads	0.75	0.00	0.75
AC-SD	Horizontally corrugated longitudinal bulkheads	1.05	0.50	0.90
	Other corrugated bulkheads	0.90	0.00	0.90
AC-T	Horizontally corrugated longitudinal bulkheads	1.10	0.50	0.95
	Other corrugated bulkheads	1.00	0.00	1.00

1.2.2 Built-up corrugations

For built-up corrugations, with flange and web plate of different thickness, the net thickness, t_1 in mm, is to be taken as the greatest value calculated for all applicable design load sets, as defined in **Sec 2, [2.1.3]**, given by:

$$t_1 = \sqrt{\frac{0.0005 b_p^2 |P|}{C_{CB} R_{eH}} - t_2^2}$$

where:

t_1 : Net thickness of the thicker plating, either flange or web, in mm.

t_2 : Net thickness of the thinner plating, either flange or web, in mm.

b_p : Breadth of thicker plate, either flange or web, in mm.

C_{CB} : Permissible bending stress coefficient as defined in **[1.2.1]**.

1.2.3 Net section modulus over the height with no lower and upper stool

The net section modulus at the lower and upper ends and at the mid length of the corrugation of a unit corrugation, Z_{cg} are to be taken as the greatest value calculated for all applicable design load sets, as given in **Sec 2, [2]** and given by the following.

$$Z_{cg} = \frac{1000 M_{cg}}{C_{s-cg} R_{eH}}$$

where:

M_{cg} : Vertical bending moment in kNm.

$$M_{cg} = \frac{|P| s_{cg} \ell_{bdg}^2}{12000}$$

P : Averaged pressure in $\mathrm{kN/m^2}$.

$$P = \frac{P_u + P_\ell}{2}$$

P_ℓ, P_u : Design pressure given in **Sec 2, Table 1** for the design load set being considered, calculated at the lower and upper ends of the corrugation, respectively, in $\mathrm{kN/m^2}$:

- 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.
- 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} : Half pitch length of corrugation, in mm, as defined in **Ch 3, Sec 6, Figure 21**.

ℓ_{bdg} : Effective bending span of the corrugation, in m, as defined in **Ch 3, Sec 6, Figure 22,** measured from the mid depth of the lower stool to the mid depth of the upper stool. Where no lower or upper stool is fitted, $\ell_{bdg}(=\ell_c)$ is to be measured to lower or upper end.

C_{s-cg} : Permissible bending stress coefficient for corrugated bulkheads taken as to:

$$C_{s-cg} = \beta_{CB} - \alpha_{CB}\frac{|\sigma_{hg}|}{R_{eH}}$$, not to be taken greater than $C_{s-cg-max}$

β_{CB} : Coefficient as defined in **Table 3.**

α_{CB} : Coefficient as defined in **Table 3.**

$C_{s-cg-max}$: Maximum permissible bending stress coefficient as defined in **Table 3.**

Table 3 : Definition β_{CB}, α_{CB} and $C_{s-cg-max}$

Acceptance criteria set	Structural member	β_{CB}	α_{CB}	$C_{s-cg-max}$
AC-S	Horizontally corrugated longitudinal bulkheads	0.85	1.00	0.75
	Other corrugated bulkheads	0.75	0.00	0.75
AC-SD	Horizontally corrugated longitudinal bulkheads	1.00	1.00	0.90
	Other corrugated bulkheads	0.90	0.00	0.90
AC-T	Horizontally corrugated longitudinal bulkheads	1.00	1.00	0.95
	Other corrugated bulkheads	1.00	0.00	1.00

2. Special requirements

2.1 Minimum thickness of keel plating

2.1.1

The net thickness of the keel plating is not to be taken less than the required net thickness of the adjacent 2.0 m width bottom plating, measured from the edge of the keel strake.

The width of the keel is defined in **Ch 3, Sec 6, [7.2.1].**

2.2 Bilge plating

2.2.1 Definition of bilge plating

The definition of bilge plating is given in **Ch 1, Sec 4, [3.8.1].**

2.2.2 Bilge plate thickness

a) The net thickness of bilge plating is not to be taken less than the offered net thickness for the adjacent bottom shell or adjacent side shell plating, whichever is greater.

b) The net thickness of rounded bilge plating, t, in mm, is not to be taken less than:

$$t = 6.45 \times 10^{-4}\,(P_{ex}\, s_b)^{0.4}\, R^{0.6}$$

where:

P_{ex} : Design sea pressure for the design load set SEA-1 as defined in **Sec 2, [2.1.3]** calculated at the lower turn of the bilge, in $\mathrm{kN/m^2}$.

R : Effective bilge radius in mm.

$$R = R_0 + 0.5(\Delta s_1 + \Delta s_2)$$

R_0 : Radius of curvature, in mm. See **Figure 1.**

Δs_1 : Distance between the lower turn of bilge and the outermost bottom longitudinal, in mm, see **Figure 1.** Where the outermost bottom longitudinal is within the curvature, this distance is to be taken as zero.

Δs_2 : Distance between the upper turn of bilge and the lowest side longitudinal, in mm, see **Figure 1.** Where the lowest side longitudinal is within the curvature, this distance is to be taken as zero.

s_b : Distance between transverse stiffeners, webs or bilge brackets, in mm.

c) Longitudinally stiffened bilge plating is to be assessed as regular stiffened plating. The bilge thickness is not to be less than the lesser of the value obtained by **[1.1.1]** and **[2.2.2]** b). A bilge keel is not considered as an effective 'longitudinal stiffening' member.

2.2.3 Transverse extension of bilge minimum plate thickness

Where a plate seam is located in the straight plate just below the lowest stiffener on the side shell, any increased thickness required for the bilge plating does not have to be extended to the adjacent plate above the bilge provided the plate seam is not more than $s_2/4$ below the lowest side longitudinal. Similarly, for the flat part of adjacent bottom plating, any increased thickness for the bilge plating does not have to be extended to the adjacent plate provided that the plate seam is not more than $s_1/4$ beyond the outboard bottom longitudinal. For definition of s_1 and s_2, see **Figure 1.**

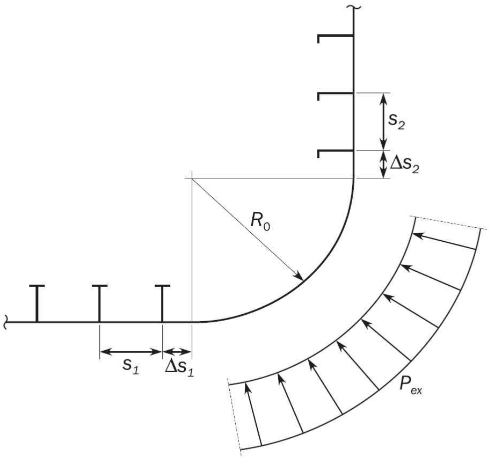


Figure 1 : Transverse stiffened bilge plating

2.2.4 Hull envelope framing in bilge area

For transversely stiffened bilge plating, 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. The scantling of those longitudinals are to be not less than the one of the closer adjacent stiffener. The distance between the lower turn of bilge and the outermost bottom longitudinal, Δs_1, is generally not to be greater than one-third of the spacing between the two outermost bottom longitudinals, s_1. Similarly, the distance between the upper turn of the bilge and the lowest side longitudinal, Δs_2, is generally not to be greater than one-third of the spacing between the two lowest side longitudinals, s_2, See **Figure 1.**

2.3 Side shell plating

2.3.1 Fender contact zone

The net thickness, t in mm, of the side shell plating within the fender contact zone as specified in **[2.3.2]** is not to be taken less than:

$$t = 26\left(\frac{b}{1000}+0.7\right)\left(\frac{B\,T_{SC}}{R_{eH}^2}\right)^{0.25}$$

2.3.2 Application of fender contact zone requirement

The application extends within the cargo hold region as defined in **Ch 1, Sec 1, [2.4.3],** from the ballast draught T_{BAL} to 0.25 T_{SC} (minimum 2.2 m) above T_{SC}.

2.3.3 Strengthening for harbour and tug manoeuvres

In those zones of the side shell which may be exposed to concentrated loads due to harbour manoeuvres the plate net thickness is not to be less than given in **[2.3.4]**. These zones are mainly the plates in way of the ship's fore and aft shoulder and in addition amidships. The exact locations where the tugs shall push are to be defined in the building specification. They are to be identified in the shell expansion plan. The length of the strengthened areas shall not be less than approximately 5 m. The height of the strengthened areas shall extend from about 0.5 m above ballast draught to about 4.0 m above scantling draught. (Where the side shell thickness so determined exceeds the thickness required by this section, it is recommended to specially mark these areas.)

2.3.4 Plate thickness in tug pushing area

The net thickness, in mm, in the strengthened areas is to be determined by the following formula:

$$t = 0.65\sqrt{P_{fl}\,k}$$

where:

P_{fl} : local design force, in kN, shall not be taken less than:

$$P_{fl} = \varDelta/100 \qquad (200 \le P_{fl} \le 700)$$

2.4 Sheer strake

2.4.1 General

The minimum width of the sheer strake is defined in **Ch 3, Sec 6, [8.2.4]**. The thickness of sheer strakes at the strength deck for midship part is not to be less than 75% of the stringer plate of the strength deck. Where the global analysis is performed in compliance with **Pt.3, Annex 3-2**, the sheer strake may be reduced in thickness.

In no case, however, is the thickness to be less than that of the adjacent side shell plating.

2.4.2 Welded sheer strake

Within 0.6 L of amidships, the net thickness of a welded sheer strake is not to be less than the offered net thickness of the adjacent 2.0 m width side plating.

2.4.3 Rounded sheer strake

The net thickness of a rounded sheer strake is not to be less than:

a) The offered net thickness of the adjacent 2.0 m width deck plating, or

b) The offered net thickness of the adjacent 2.0 m width side plating, whichever is greater.

2.5 Deck stringer plating

2.5.1

The minimum width of deck stringer plating is defined in **Ch 3, Sec 6, [9.1.2].**

2.5.2

Within 0.6 L of amidships, the net thickness of the deck stringer plate is not to be less than the offered net thickness of the adjacent deck plating.

2.6 Aft peak bulkhead

2.6.1

The net thickness of the aft peak bulkhead plating in way of the stern tube penetration is to be at least 1.6 times the required thickness for the bulkhead plating.

2.7 Plating in liquefied natural gas fuel tank boundary

2.7.1 By IGF pressure

The net thickness of inner hull plating protected by fuel containment system, t in mm, is not to be taken less than:

$$t = 0.0158\alpha_p b\sqrt{\frac{|P_{IGF}|}{\chi C_{a-IGF}R_{eH}}}$$

where:

P_{IGF} : Pressure given in **"Rules/Guidance for the Classification of Ships Using Low-flashpoint Fuels", Ch 6, Sec 4, 409.**, in $\mathrm{kN/m^2}$

C_{a-IGF} : Permissible bending stress coefficient for plate taken equal to:

$$C_{a-IGF} = \beta_{IGF} - \alpha_{IGF}\frac{|\sigma_{hg-IGF}|}{R_{eH}}$$, not to be taken greater than $C_{a-IGF-\max}$

$$\sigma_{hg-IGF} = \max\left[\left|\left(\frac{M_{sw}+M_{wv-LC}}{I_{y-n50}}(z-z_n)\right)10^{-3}\right|, \left|\left\{\left(\frac{M_{sw}+0.5M_{wv-LC}}{I_{y-n50}}(z-z_n)\right)+\left(\frac{M_{wh-LC}}{I_{z-n50}}(y-y_n)\right)\right\}10^{-3}\right|\right]$$

β_{IGF} : Coefficient as defined in **Table 4.**

α_{IGF} : Coefficient as defined in **Table 4.**

$C_{a-IGF-\max}$: Maximum permissible bending stress coefficient as defined in **Table 4.**

Table 4 : Definition β_{IGF}, α_{IGF} and $C_{a-IGF-max}$

Acceptance criteria set	Structural member		β_{IGF}	α_{IGF}	$C_{a-IGF-max}$
IGF condition	Longitudinal strength members	Longitudinally stiffened plating	1.05	0.5	0.95
		Transversely stiffened plating	1.05	1.0	0.95
	Other members		1.0	0.0	1.0

2.7.2 By sloshing pressure

The net thickness of plating, t in mm, subjected to sloshing pressures is not to be less than:

$$t = 0.0158\alpha_p b\sqrt{\frac{P_{slh}}{\chi C_{a-slh} R_{eH}}}$$

where:

P_{slh} : Pressure given in **Ch 4, Sec 6, [3.2.3]**, in $\mathrm{kN/m^2}$.

C_{a-slh} : Permissible bending stress coefficient for plate taken equal to:

$$C_{a-slh} = \beta - \alpha\frac{|\sigma_{hg-slh}|}{R_{eH}}$$, not to be taken greater than $C_{a-\max}$

$$\sigma_{hg-slh} = \left[\frac{M_{sw}}{I_{y-n50}}(z - z_n)\right]10^{-3} \text{ in } \mathrm{N/mm^2}$$

β : Coefficient of AC-S as defined in **Table 1.**

α : Coefficient of AC-S as defined in **Table 1.**

$C_{a-\max}$: Maximum permissible bending stress coefficient of AC-S as defined in **Table 1.**

Section 5 Stiffeners

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

d_{shr} : Effective shear depth, in mm, as defined in **Ch 3, Sec 7, [1.4.3].**

ℓ_{bdg} : Effective bending span, in m, as defined in **Ch 3, Sec 7, [1.1.2].**

ℓ_{shr} : Effective shear span, in m, as defined in **Ch 3, Sec 7, [1.1.3].**

P : Design pressure for the design load set being defined in **Ch 6, Sec 2** and calculated at the load calculation point defined in **Ch 3, Sec 7, [3.2],** in $\mathrm{kN/m^2}$

χ : Coefficient taken equal to:

a) In intact condition

- $\chi = 1.00$

b) In flooded condition

- $\chi = 0.95$ for collision bulkheads for acceptance criteria set AC-A
- $\chi = 1.15$ for other watertight boundaries of compartments

1. Stiffeners subject to lateral pressure

1.1 Yielding check

1.1.1 Web plating

The minimum net web thickness, t_w in mm, is not to be taken less than the greatest value calculated for all applicable design load sets as defined in **Ch 6, Sec 2, [2],** given by:

$$t_w = \frac{f_{shr}\,|P|\,s\,\ell_{shr}}{d_{shr}\,\chi\,C_t\,\tau_{eH}}$$ with $\chi\,C_t$ not to be taken greater than 1.0.

where:

f_{shr} : Shear force distribution factor taken as:

a) For continuous stiffeners with fixed ends, f_{shr} is not to be taken less than:

- $f_{shr} = 0.5$ for horizontal stiffeners and upper end of vertical stiffeners.
- $f_{shr} = 0.7$ for lower end of vertical stiffeners

b) For stiffeners with reduced end fixity, variable load or being part of grillage, the requirement in **[1.2]** applies.

C_t : Permissible shear stress coefficient for the design load set being considered, taken as:

a) $C_t = 0.75$ for acceptance criteria set AC-S.

b) $C_t = 0.90$ for acceptance criteria set AC-SD.

c) $C_t = 1.00$ for acceptance criteria set AC-A.

d) $C_t = 0.95$ for acceptance criteria set AC-T.

1.1.2 Section modulus

The minimum net section modulus, Z in cm^3, is not to be taken less than the greatest value calculated for all applicable design load sets as defined in **Ch 6, Sec 2, [2.1.3],** given by:

$$Z = \frac{|P|\, s\, \ell_{bdg}^2}{f_{bdg}\, \chi\, C_s\, R_{eH}} \quad \text{with } \chi C_s \text{ not to be taken greater than 1.0}$$

where:

f_{bdg} : Bending moment factor taken as:

a) For continuous stiffeners with fixed ends, f_{bdg} is not to be taken higher than:

- $f_{bdg} = 12$ for horizontal stiffeners and upper end of vertical stiffeners.
- $f_{bdg} = 10$ for lower end of vertical stiffeners.

b) For stiffeners with reduced end fixity, variable load or being part of grillage, the requirement in **[1.2]** applies.

C_s : Permissible bending stress coefficient as defined in **Table 1** for the design load set being considered.

σ_{hg} : Hull girder bending stress, in $\mathrm{N/mm}^2$, as defined in **Ch 6, Sec 2, [1.1],** calculated at the load calculation point as defined in **Ch 3, Sec 7, [3.2].**

β_s : Coefficient as defined in **Table 2.**

α_s : Coefficient as defined in **Table 2.**

$C_{s-\max}$: Coefficient as defined in **Table 2.**

Table 1 : Definition of C_s

Sign of hull girder bending stress, σ_{hg}	Lateral pressure acting on	Coefficient C_s
Tension (positive)	Stiffener side	$C_s = \beta_s - \alpha_s \frac{\lvert\sigma_{hg}\rvert}{R_{eH}}$ but not to be taken greater than $C_{s-\max}$
Compression (negative)	Plate side	
Tension (positive)	Plate side	$C_s = C_{s-\max}$
Compression (negative)	Stiffener side	

Table 2 : Definition of β_s, α_s and $C_{s-\max}$

Acceptance criteria set	Structural member	β_s	α_s	$C_{s-\max}$
AC-S	Longitudinal strength member	0.95	1.0	0.85
	Transverse or vertical member	0.85	0.0	0.85
AC-SD	Longitudinal strength member	1.10	1.0	0.95
	Transverse or vertical member	0.95	0.0	0.95
AC-A	Longitudinal strength member	1.10	1.0	1.00
	Transverse or vertical member	1.00	0.0	1.00
AC-T	Longitudinal strength member	1.25	1.0	1.15
	Transverse or vertical member	1.15	0.0	1.15

1.1.3 Group of stiffeners

Scantlings of stiffeners based on requirements in **[1.1.1]** and **[1.1.2]** may be decided based on the concept of grouping designated sequentially placed stiffeners of equal scantlings on a single stiffened panel between primary supporting members. 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 required for any one stiffener within the group.

1.1.4 Plate and stiffener of different materials

When the minimum specified yield stress of a stiffener exceeds the minimum specified yield stress of the attached plate by more than 35 %, the following criterion is to be satisfied:

$$R_{eH-s} \le \left(R_{eH-P} - \frac{\alpha_s |\sigma_{hg}|}{\beta_s} \right) \frac{Z_P}{Z} + \frac{\alpha_s |\sigma_{hg}|}{\beta_s}$$

where:

R_{eH-S} : Minimum specified yield stress of the material of the stiffener, in $\mathrm{N/mm^2}$.

R_{eH-P} : Minimum specified yield stress of the material of the attached plate, in $\mathrm{N/mm^2}$

σ_{hg} : Hull girder bending stress, in $\mathrm{N/mm^2}$, as defined in **Ch 6, Sec 2, [1.1]** with $|\sigma_{hg}|$ not to be taken less than 0.4 R_{eH-P}.

Z : Net section modulus, in way of face plate/free edge of the stiffener, in $\mathrm{cm^3}$.

Z_P : Net section modulus, in way of the attached plate of stiffener, in $\mathrm{cm^3}$.

α_s, β_s : Coefficients defined in **Table 2.**

1.2 Beam analysis

1.2.1 Direct analysis

The maximum normal bending stress, σ and shear stress, τ in a stiffener using net properties with reduced end fixity, variable load or being part of grillage are to be determined by direct calculations taking into account:

a) The distribution of static and dynamic pressures and forces, if any.

b) The number and position of intermediate supports (e.g. decks, girders, etc).

c) The condition of fixity at the ends of the stiffener and at intermediate supports.

d) The geometrical characteristics of the stiffener on the intermediate spans.

1.2.2 Stress criteria

The stress is to comply with the following criteria where the coefficients C_t and C_s, are defined in **[1.1.1]** and **[1.1.2]**.

a) $\tau \le \chi \, C_t \, \tau_{eH}$

b) $\sigma \le \chi \, C_s \, R_{eH}$

2. Special requirement

2.1 Section modulus in tug pushing area

2.1.1

In the strengthened areas the net section modulus, Z in cm^3, of side longitudinals is to be determined by the following formula:

$$Z = 0.3\, P_{fl}\, \ell_{bdg}\, k$$

where:

P_{fl} : local design force, in kN, as defined in **Ch 6, Sec 4 [2.3.4].**

2.2 Section modulus of stiffener attached on liquefied natural gas fuel tank boundary

2.2.1 By IGF pressure

The minimum net section modulus of stiffeners connected to inner hull protected by fuel containment system, Z_{IGF} in cm^3, is not to be taken less than:

$$Z_{IGF} = \frac{|P_{IGF}|\, s\, \ell_{bdg}^2}{f_{bdg}\, \chi\, C_{s-IGF}\, R_{eH}} \qquad \text{with } \chi C_{s-IGF} \text{ not to be taken greater than 1.0}$$

where:

P_{IGF} : Dynamic pressure defined in **Ch 6, Sec 4, [2.7.1].**

f_{bdg} : Bending moment factor taken as:

a) For continuous stiffeners with fixed ends, f_{bdg} is not to be taken higher than:

- $f_{bdg} = 12$ for horizontal stiffeners and upper end of vertical stiffeners.
- $f_{bdg} = 10$ for lower end of vertical stiffeners.

b) For stiffeners with reduced end fixity, variable load or being part of grillage, the requirement in **[1.2]** applies.

C_{s-IGF} : Permissible bending stress coefficient as defined in **Table 3** for the design load set being considered.

σ_{hg-IGF} : Hull girder bending stress as defined in **Ch 6, Sec 4, [2.7.1].**

β_{s-IGF} : Coefficient as defined in **Table 4.**

α_{s-IGF} : Coefficient as defined in **Table 4.**

$C_{s-IGF-\max}$: Coefficient as defined in **Table 4.**

Table 3 : Definition of C_{s-IGF}

Sign of hull girder bending stress, σ_{hg-IGF}	Lateral pressure acting on	Coefficient C_{s-IGF}
Compression (negative)	Plate side	$C_{s-IGF} = \beta_{s-IGF} - \alpha_{s-IGF} \frac{\lvert\sigma_{hg-IGF}\rvert}{R_{eH}}$ but not to be taken greater than $C_{s-IGF-\max}$
Tension (positive)	Plate side	$C_{s-IGF} = C_{s-IGF-\max}$

Table 4 : Definition of β_{s-IGF}, α_{s-IGF} and $C_{s-IGF-\max}$

Acceptance criteria set	Structural member	β_{s-IGF}	α_{s-IGF}	$C_{s-IGF-\max}$
IGF condition	Longitudinal strength member	1.0	1.0	0.9
	Transverse or vertical member	0.9	0.0	0.9

2.2.2 By sloshing pressure

The net section modulus Z in cm^3, of stiffeners subject to sloshing pressure is not to be taken less than:

$$Z = \frac{P_{slh} s \ell_{bdg}^2}{f_{bdg} \chi C_{s-slh} R_{eH}}$$

where:

P_{slh} : Pressure given in **Ch 4, Sec 6, [3.2.3]**, in $\mathrm{kN/m^2}$.

f_{bdg} : Bending moment factor taken as:

a) For continuous stiffeners generally, $f_{bdg} = 12$

b) For discontinuous stiffeners, $f_{bdg} = 8$

C_{s-slh} : Permissible bending stress coefficient taken equal to:

$$C_{s-slh} = \beta_s - \alpha_s \frac{|\sigma_{hg-slh}|}{R_{eH}}$$, not to be taken greater than C_{s-max}

$$\sigma_{hg-slh} = \left[\frac{M_{sw}}{I_{y-n50}}(z - z_n)\right] 10^{-3} \text{ in } \mathrm{N/mm^2}$$

β_s : Coefficient of AC-S as defined in **Table 2.**

α_s : Coefficient of AC-S as defined in **Table 2.**

C_{s-max} : Maximum permissible bending stress coefficient of AC-S as defined in **Table 2.**

Section 6 Primary Support members and Pillars

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4**

ℓ_{bdg} : Effective bending span, as defined in **Ch 3, Sec 7, [1.1.6]**, in m.

ℓ_{shr} : Effective shear span, as defined in **Ch 3, Sec 7, [1.1.7]**, in m.

ℓ_h : Length of the double bottom within hold under consideration, in m. Where support bulkhead are provided adjacent to the transverse bulkhead, ℓ_h may be taken as the distance between support bulkhead and transverse bulkhead, as shown in **Figure 1.**

B_{DB} : Breadth of the double bottom within hold under consideration, in m, as shown in **Figure 2.**

h_{DS} : Height of the double side structure between the lower end and the upper end of double side structure, as shown in **Figure 2.**

x, y, z : X, Y and Z coordinates, in m, of the evaluation point with respect to the reference coordinate system, as defined in **Ch 1, Sec 4, [3.5].**

x_c : X coordinate, in m, of the centre of double bottom structure under consideration with respect to the reference coordinate system, as shown in **Figure 1.**

ϕ : Major diameter of the openings, in m.

α : The greater of a or S_1, in m.

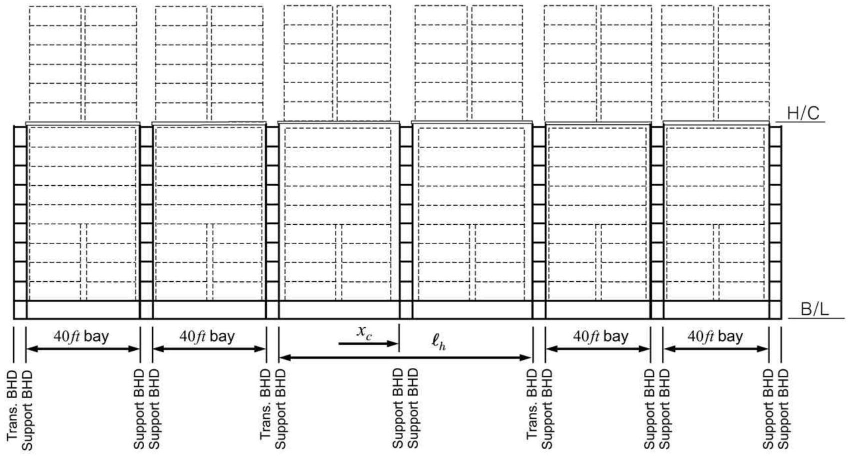


Figure 1 : x_c , X coordinate of the centre of double bottom structure

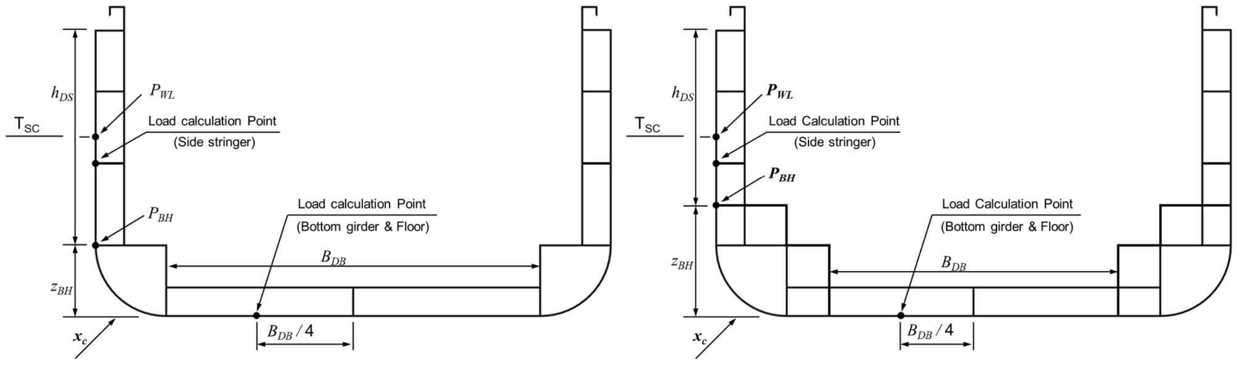


Figure 2 : Load calculation point for design pressure

1. General

1.1 Application

1.1.1

The requirements of this section apply to primary supporting members subjected to lateral pressure and concentrated loads and pillars subjected to compressive axial loads. The yielding check is to be carried out for such members subjected to specific loads.

2. Primary support members within cargo hold region

2.1 Midship cargo hold region of container ship having a length *L* of 150 m and above

2.1.1

The scantlings of primary supporting members within the midship cargo hold region are to be verified by FE structural analysis as defined in **Ch 7.**

2.2 Cargo hold region of container ship having a length *L* less than 150 m and outside midship cargo hold region of container ship having a length *L* of 150 m and above

2.2.1

The requirements of this sub-article section apply to the strength check of primary supporting members in cargo hold structures, subjected to lateral pressure.

2.2.2

As an alternative to **[2.2.1]**, the strength check may be verified by direct strength assessment deemed as appropriate by the Society.

2.2.3

Thickness of a primary support member may be reduced scantlings comply with the direct strength analysis and with **Ch 6, Sec 3, [3.1.1].**

2.2.4 Design load sets

The severest loading conditions from the loading manual or otherwise specified by the designer are to be considered for the calculation of P_{in} in design load sets SEA-1. If primary supporting members support deck structure or tank / watertight boundaries, applicable design load sets in **Ch 6, Sec 2, Table 1** are also to be considered.

Table 1 : Design load sets for primary supporting members in cargo hold region

Item	Design load set	Load component	Draught	Design load	Loading condition	Dynamic load cases
Bottom girders & Floors	SEA-1	P_{ex}	T_{SC}	S + D	Full load condition	HSM, HSA, FSM, OST, OSA
Stringers & Transverse webs	SEA-1	P_{ex}	T_{SC}	S + D	Full load condition	BSR, BSP, OST, OSA

2.2.5 Centre girders and side girders

The net thickness of girders in double bottom structure, in mm, is not to be less than the greater of the value t_1 and t_2 specified in the followings according to each location:

$$t_1 = 0.7 C_{1\_1}\, C_{1\_2}\, C_{1\_3} \frac{|P|\, S_{gir}\, \ell_h}{(d_0 - d_1)\, C_{t-pr1}\, \tau_{eH}}$$

$$t_2 = 1.75 \sqrt[3]{\frac{H^2\, a^2\, C_{t-pr1}\, \tau_{eH}}{C_1'}} \cdot t_1$$

P : Design pressure in $\mathrm{kN/m^2}$, for the design load set being considered according to **Table 1**, calculated at reference point as shown in **Figure 2.**

S_{gir} : Distance between the centres of the two spaces adjacent to the centre or side girder under consideration, in m.

d_0 : Depth of the centre or side girder under consideration, in m.

d_1 : Depth of the opening, if any, at the point under consideration, in m.

C_{1_1} : Coefficient given in **Table 2** depending on B_{DB}/ℓ_h. For intermediate values of B_{DB}/ℓ_h, C_{1_1} is to be obtained by linear interpolation.

C_{1_2} : Coefficient given depending on y/B. Value obtained from the following formulae:

- $C_{1\_2} = 1.4$ for $|2y|/B_{DB} < 0.3$
- $C_{1\_2} = 1.4 - \frac{4}{3}\left(\frac{2y}{B_{DB}} - 0.3\right)$ for $|2y|/B_{DB} \geq 0.3$

C_{1_3} : Coefficient given depending on $(x - x_c)/\ell_h$. Value obtained from the following formulae:

- $C_{1\_3} = 0.25$ for $|x - x_c|/\ell_h \leq 0.25$
- $C_{1\_3} = \frac{|x - x_c|}{\ell_h}$ for $0.25 < |x - x_c|/\ell_h \leq 0.5$

C_{t-pr1} : Permissible shear stress coefficient for centre girders and side girders taken equal to:

$C_{t-pr1} = 0.92$

a : Depth of girders at the point under consideration, in m. However, where horizontal stiffeners are fitted on the girder, a is the distance from the horizontal stiffener under consideration to the bottom shell plating or inner bottom plating, or the distance between the horizontal stiffeners under consideration.

S_1 : Spacing, in m, of vertical stiffeners or floors.

C_1' : Coefficient given in **Table 3** depending on s_1/a. For intermediate values of s_1/a, C_1' is to be determined by linear interpolation.

H : Value obtained from the following formulae:

- Where the girder is provided with an unreinforced opening:

  $H = 1 + 0.5\frac{\phi}{\alpha}$

- In other cases:

  $H = 1.0$

Table 2 : Coefficient C_{1_1}

B_{DB}/ℓ_h	0.85	1.03	1.12	1.32	1.87
C_{1_1}	0.41	0.50	0.55	0.61	0.69

Table 3 : Coefficient C_1'

S_1/a	0.3 and under	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4 and over
C_1'	64	38	25	19	15	12	10	9	8	7

2.2.6 Floors

The net thickness of floors in the double bottom structure, in mm, is not to be less than the greatest of values t_1 and t_2 specified in the following according to each location:

$$t_1 = 0.7\ C_{2\_1}\ C_{2\_2}\ C_{2\_3} \frac{|P|\ S_{floor}\ B_{DB}}{(d_0 - d_1)\ C_{t-pr2}\ \tau_{eH}}$$

$$t_2 = 1.75 \sqrt[3]{\frac{H^2\ a^2\ C_{t-pr2}\ \tau_{eH}}{C_2'}} \cdot t_1$$

P : Design pressure in $\mathrm{kN/m^2}$, for the design load set being considered according to **Table 1**, calculated at reference point as shown in **Figure 2.**

S_{floor} : Spacing of solid floors, in m.

d_0 : Depth of the solid floor at the point of under consideration, in m.

d_1 : Depth of the opening, if any, at the point under consideration, in m.

C_{2_1} : Coefficient given in **Table 4** depending on B_{DB}/ℓ_h. For intermediate values of B_{DB}/ℓ_h, C_{2_1} is to be obtained by linear interpolation.

C_{2_2} : Coefficient given in **Table 5** depending on position and number of floors, in m.

C_{2_3} : Coefficient given depending on y/B. Value obtained from the following formulae:

- $C_{2\_3} = 0.25$ for $|2y|/B_{DB} \le 0.5$
- $C_{2\_3} = \frac{|y|}{B_{DB}}$ for $0.5 < |2y|/B_{DB} \le 1$

C_{t-pr2} : Permissible shear stress coefficient for floors taken equal to:

$C_{t-pr2} = 0.97$

a : Depth of the solid floor at the point under consideration, in m. However, where horizontal stiffeners are fitted on the floor, a is the distance from the horizontal stiffener under consideration to the bottom shell plating or the inner bottom plating or the distance between the horizontal stiffeners under consideration.

S_1 : Spacing, in m, of vertical stiffeners or girders.

C_2' : Coefficient given in **Table 6** depending on s_1/d_0. For intermediate values of s_1/d_0, C_2' is to be determined by linear interpolation.

H : Value obtained from the following formulae:

- Where openings with reinforcement or no opening are provided on solid floors:
  - Where slots without reinforcement are provided:

    $H = \sqrt{4.0 \frac{d_2}{S_1} - 1.0}$ without being taken less than 1.0.
  - Where slots with reinforcement are provided:

    $H = 1.0$

- Where openings without reinforcement are provided on solid floors:
  - Where slots without reinforcement are provided:

    $H=\left(1+0.5\frac{\phi}{d_0}\right)\sqrt{4.0\frac{d_2}{S_1}-1.0}$ without being taken less than $1+0.5\frac{\phi}{d_0}$
  - Where slots with reinforcement are provided:

    $H=1+0.5\frac{\phi}{d_0}$

d_2 : Depth of slots without reinforcement provided at the upper and lower parts of solid floors, in m, whichever is greater.

Table 4 : Coefficient C_{2_1}

B_{DB}/ℓ_h	0.85	1.03	1.12	1.32	1.87
C_{2_1}	0.59	0.50	0.45	0.39	0.31

Table 5 : Coefficient C_{2_2}

Floors	Floor 1	Floor 2	Floor 3	Floor 4	Floor 5	Floor 6	Floor 7	Floor 8
C_{2_2}	0.85	1.1	1.18	1.05	1.05	1.18	1.1	0.85
Floors	Floor 1′	Floor 2′	-	Floor 4	Floor 5	Floor 6′	Floor 7′	-
C_{2_2}	0.95	1.15	-	1.05	1.05	1.15	0.95	-

Table 6 : Coefficient C_2'

S_1/d_0	0.3 and under	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4 and over
C_2'	64	38	25	19	15	12	10	9	8	7

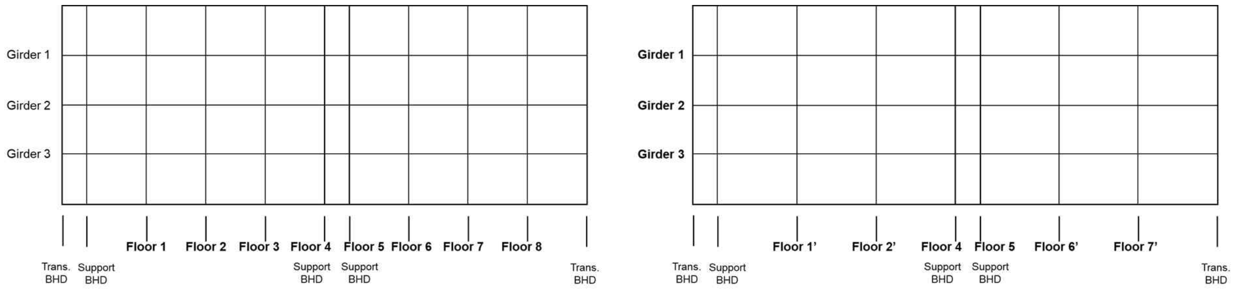


Figure 3 : Position of floors

2.2.7 Stringer of double side structure

The net thickness of stringers in double side structure, in mm, is not to be less than the greater of the value t_1 and t_2 specified in the followings according to each location:

$$t_1 = 0.9\, C_{3\_1}\, C_{3\_2}\, C_{3\_3} \frac{3\,|P|\,\ell_h}{(d_0 - d_1)\, C_{t-pr3}\, \tau_{eH}}$$

$$t_2 = 1.75 \sqrt[3]{\frac{H^2 a^2 C_{t-pr3}\, \tau_{eH}}{C_3'}} \cdot t_1$$

P : Design pressure in $\mathrm{kN/m^2}$, for the design load set being considered according to **Table 1,** calculated at reference point as shown in **Figure 2.**

d_0 : Depth of stringers, in m.

d_1 : Depth of the opening, if any, at the point under consideration, in m.

C_{3_1} : Coefficient given in **Table 7** depending on h_{DS}/ℓ_h. For intermediate values of h_{DS}/ℓ_h, C_{3_1} is to be obtained by linear interpolation.

C_{3_2} : Coefficient given in **Table 8** depending on $(z - z_{BH})/h_{DS}$. For intermediate values of $(z - z_{BH})/h_{DS}$, C_{3_2} is to be obtained by linear interpolation.

C_{3_3} : Coefficient given depending on $(x - x_c)/\ell_h$. Value obtained from the following formulae:

- $C_{3\_3} = 0.25$ for $|x - x_c|/\ell_h \le 0.25$
- $C_{3\_3} = \dfrac{|x - x_c|}{\ell_h}$ for $0.25 < |x - x_c|/\ell_h \le 0.5$

C_{t-pr3} : Permissible shear stress coefficient for primary supporting members taken equal to:

$C_{t-pr3} = 0.92$

a : Depth of stringers at the point under consideration, in m. However, where longitudinal stiffeners are fitted on the stringer, a is the distance from the horizontal stiffener under consideration to the side shell plating or the longitudinal bulkhead of double side structure or the distance between the horizontal stiffeners under consideration.

S_1 : Spacing, in m, of transverse stiffeners or web frames.

C_3' : Coefficient given in **Table 9** depending on S_1/a. For intermediate values of S_1/a, C_3' is to be obtained by linear interpolation.

H : Value obtained from the following formulae:

- Where the stringer is provided with an unreinforced opening:

  $H = 1 + 0.5\dfrac{\phi}{a}$

- In other cases:

  $H = 1.0$

Table 7 : Coefficient C_{3_1}

h_{DS}/ℓ_h	0.72 and under	0.84	1.02
C_{3_1}	0.7	1.0	1.25

Table 8 : Coefficient C_{3_2}

$(z - z_{BH})/h_{DS}$	0.2	0.3	0.4	0.6	0.8
C_{3_2}	0.4	0.6	0.7	0.9	1.2

Table 9 : Coefficient C_3'

S_1/a	0.3 and under	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4 and over
C_3'	64	38	25	19	15	12	10	9	8	7

2.2.8 Transverse web in double side structure

The net thickness of transverse webs in double side structure, in mm, is not to be less than the greater of the value t_1 and t_2 specified in the followings according to each location:

$$t_1 = 0.9\, C_{4\_1}\, C_{4\_2}\, C_{4\_3} \frac{|P|\, S_{trans}\,(T_{SC} - z_{BH})}{(d_0 - d_1)\, C_{t-pr4}\, \tau_{eH}}$$

$$t_2 = 1.75 \sqrt[3]{\frac{H^2 a^2 C_{t-pr4} \tau_{eH}}{C_4'} \cdot t_1}$$

P : Design pressure in $\mathrm{kN/m^2}$, for the design load set being considered according to **Table 1**, value obtained from the following formulae:

$$P = \frac{P_{BH} + P_{WL}}{2}$$

P_{BH} : Design pressure in $\mathrm{kN/m^2}$, for the design load set being considered according to **Table 1**, as measured at the lower end of double side structure.(see **Figure 2**)

P_{WL} : Design pressure in $\mathrm{kN/m^2}$, for the design load set being considered according to **Table 1**, as measured at waterline.(see **Figure 2**)

S_{trans} : Breadth of part supported by transverses, in m.

d_0 : Depth of transverses, in m.

d_1 : Depth of opening at the point under consideration, in m.

C_{4_1} : Coefficient given in **Table 10** depending on h_{DS}/ℓ_h. For intermediate values of h_{DS}/ℓ_h, C_{4_1} is to be obtained by linear interpolation. Where Transverse webs are not extended up to the uppermost continuous deck, C_{4_1} is not less than 0.8.

C_{4_2} : Coefficient given in **Table 11** depending on position of transverse web.

C_{4_3} : Coefficient given depending on $(z - z_{BH})/h_{DS}$. Value obtained from the following formulae:

- $C_{4\_3} = 1.0$ for $(z - z_{BH})/h_{DS} \le 0.05$
- $C_{4\_3} = \frac{10}{9}\left(0.5 - \frac{z - z_{BH}}{h_{DS}}\right) + 0.5$ for $0.05 < (z - z_{BH})/h_{DS} < 0.5$
- $C_{4\_3} = 0.5$ for $(z - z_{BH})/h_{DS} > 0.5$

z_{BH} : Z coordinate, in m, of the lower end of double side structure as shown in **Figure 2.**

C_{t-pr4} : Permissible shear stress coefficient for transverse web in double side structure taken equal to:

$$C_{t-pr4} = 0.97$$

a : Depth of transverses at the point under consideration, in m. However, where vertical stiffeners are fitted on the transverse, a is the distance from the vertical stiffener under consideration to the side shell or the longitudinal bulkhead of double side hull or the distance between the vertical stiffeners under consideration.

S_1 : Spacing, in m, of horizontal stiffeners or stringers.

C_4' : Coefficient given in **Table 12** depending on S_1/a. For intermediate values of S_1/a, C_4' is to be obtained by linear interpolation.

H : Value obtained from the following formulae:

- Where the transverse web is provided with an unreinforced opening:

$$H = 1 + 0.5\frac{\phi}{\alpha}$$

- In other cases:

$$H = 1.0$$

Table 10 : Coefficient C_{4_1}

h_{DS}/ℓ_h	0.55	0.72	0.84	1.02
C_{4_1}	0.8	0.66	0.60	0.57

Table 11 : Coefficient C_{4_2}

<table>
<tr><td>Transverse</td><td>Trans. 1</td><td>Trans. 2</td><td>Trans. 3</td><td>Trans. 4</td><td>Trans. 5</td><td>Trans. 6</td><td>Trans. 7</td><td>Trans. 8</td></tr>
<tr><td>C_{4_2}</td><td>1.0</td><td>1.15</td><td>1.15</td><td>0.9</td><td>0.9</td><td>1.15</td><td>1.15</td><td>1.0</td></tr>
<tr><td>Transverse</td><td colspan="1.5">Trans. 1′</td><td colspan="1.5">Trans. 2′</td><td>Trans. 4</td><td>Trans. 5</td><td colspan="1.5">Trans. 6′</td><td colspan="1.5">Trans. 7′</td></tr>
<tr><td>C_{4_2}</td><td>1.0</td><td>1.15</td><td>0.9</td><td>0.9</td><td>1.15</td><td>1.15</td></tr>
</table>

Table 12 : Coefficient C_4'

S_1/a	0.3 and under	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4 and over
C_4'	64	38	25	19	15	12	10	9	8	7

3. Primary supporting members outside cargo hold region

3.1 Application

The requirements of this article apply to primary supporting members, subjected to lateral pressure within the fore part, aft part and machinery space.

3.2 Scantling requirements

3.2.1 Net section modulus

The net section modulus, Z_{n50} in cm^3, of primary supporting members subjected to lateral pressure is not to be taken less than the greatest value for all applicable design load sets defined in **Ch 6, Sec 2, [2],** given by:

$$Z_{n50} = 1000\,\frac{|P|\;S\;\ell_{bdg}^2}{f_{bdg}\;C_s\;R_{eH}}$$

where:

f_{bdg} : Bending moment distribution factor, as given in **Table 14.**

C_s : Permissible bending stress coefficient for the acceptance criteria set, as given in **Table 13.**

3.2.2 Net shear area

The net shear area, $A_{shr-n50}$ in cm^2, of primary supporting members subjected to lateral pressure is not to be taken less than the greatest value for all applicable design load sets defined in **Ch 6, Sec 2, [2],** given by:

$$A_{shr-n50} = 10\,\frac{f_{shr}\;|P|\;S\;\ell_{shr}}{C_t\;\tau_{eH}}$$

where:

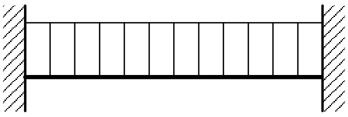
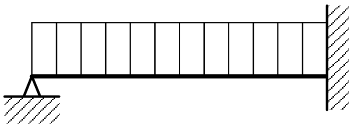
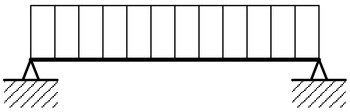
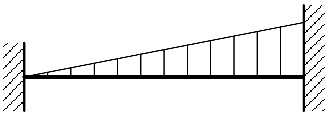
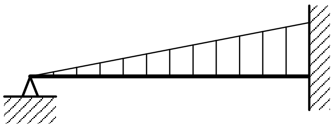
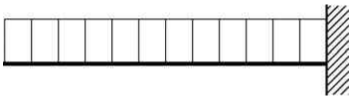
f_{shr} : Shear force distribution factor, as given in **Table 14.**

C_t : Permissible shear stress coefficient for the acceptance criteria set being considered, as given in **Table 13.**

Table 13 : Permissible bending and shear stress coefficients for primary supporting members

Acceptance criteria set	Structure attached to primary supporting member	C_s and C_t
AC-S	All boundaries, including decks and flats	0.70
AC-SD	All boundaries, including decks and flats	0.85
AC-A AC-T	All boundaries, including decks and flats	0.95

Table 14 : Bending moment and shear force factors, f_{bdg} and f_{shr}

Load and boundary condition				Bending moment and shear force distribution factors (based on load at mid span, where load varies)		
Position				1 f_{bdg1} f_{shr1}	2 f_{bdg2} –	3 f_{bdg3} f_{shr3}
Load model	1 Support	2 Field	3 Support			
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
F				– –	– –	2.0 1.0

Note 1: The bending moment distribution factor, f_{bdg} for the support positions is applicable for a distance of 0.2 ℓ_{bdg} from the end of the effective bending span of the primary supporting member.

Note 2: The shear force distribution factor, f_{shr} for the support positions is applicable for a distance of 0.2 ℓ_{shr} from the end of the effective shear span of the primary supporting member.

Note 3: Application of f_{bdg} and f_{shr}:

The section modulus requirement within 0.2 ℓ_{bdg} from the end of the effective span is to be determined using the applicable f_{bdg1} and f_{bdg3}, however f_{bdg} is not to be taken greater than 12. The section modulus of mid-span area is to be determined using f_{bdg} = 24, or f_{bdg2} from the table if lesser.

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.

For models A through F, the value of f_{shr} may be gradually reduced outside of 0.2 ℓ_{shr} towards 0.5 f_{shr} at mid-span, where f_{shr} is the greater value of f_{shr1} and f_{shr3}.

3.3 Advanced calculation methods

3.3.1 Direct analysis

Where complex grillage structures are employed or cross ties are fitted in side shell primary supporting members, the scantlings are to be determined by direct calculation taking into account:

- The distribution of still water and wave pressure and forces, if any.
- The number and position of intermediate supports (e.g. decks, girders, etc).
- The condition of fixity at the ends of the primary supporting members and at intermediate supports.
- The geometrical characteristics of the primary supporting members on the intermediate spans.

3.3.2 Analysis criteria

The calculated stresses are to comply with the following criteria where the coefficients C_t and C_s, are defined in **[3.2]**:

- $\sigma \le C_s R_{eH}$
- $\tau \le C_t \tau_{eH}$

where:

τ : Shear stress in member, in $\mathrm{N/mm^2}$, based on t_{n50}.

σ : Normal stress in member, in $\mathrm{N/mm^2}$, based on t_{n50}.

4. Pillars

4.1 Pillars subjected to compressive axial load

4.1.1 Criteria

The maximum applied compressive axial load on a pillar, F_{pill}, in kN, is to be taken as the greatest value calculated for all applicable design load sets defined in **Ch 6, Sec 2, [2]**, and is given by the following formula:

$$F_{pill} = P b_{a-sup} \ell_{a-sup} + F_{pill-upr}$$

where:

b_{a-sup} : Mean breadth of area supported, in m.

ℓ_{a-sup} : Mean length of area supported, in m.

$F_{\pi ll-upr}$: Axial load from pillar including axial load from pillars above, in kN, if any.

$A_{\pi ll-n50}$: Net cross section area of the pillar, in $\mathrm{cm^2}$.

The buckling check of the pillar is to be performed according to **Ch 8, Sec 4, [3.1]**, with σ_{av} in $\mathrm{N/mm^2}$, as defined in **Ch 8, Sec 5, [3.1]** given by:

$$\sigma_{av} = 10 \frac{F_{pill}}{A_{pill-n50}}$$

4.2 Pillars subject to tensile axial load

4.2.1 Criteria

Pillars and PSM members subjected to tensile axial load are to satisfy the criteria given in **[3.3.2]**. ⚓

Chapter 7

Direct Strength Analysis

Section 1 Strength Assessment

1. General

1.1 Application

1.1.1

This chapter provides requirements applicable to ships having rule length L of 150 m or above to assess the scantlings of the hull structure using finite element analysis. A flow diagram showing the minimum requirement of finite element analysis is shown in **Figure 1.**

1.1.2

The finite element analysis consists of three parts:

a) Cargo hold analysis to assess the strength of longitudinal hull girder structural members, primary supporting structural members and bulkheads.
b) Fine mesh analysis to assess detailed stress levels in local structural details.
c) Very fine mesh analysis to assess the fatigue capacity of the structural details according to **Ch 9.**

1.1.3

Strength assessment based on finite element analysis is applicable for the cargo hold region.

1.1.4

The analysis is to verify the following:

a) Stress levels are within the acceptance criteria for yielding.
b) Buckling capability of plates and stiffened panels are within the acceptance criteria for bucking defined in **Ch 8**.
c) Fatigue capacity of structural details is within the acceptance criteria defined in **Ch 9.**

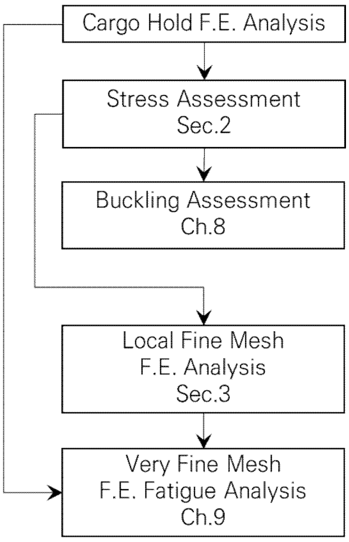


Figure 1 : Flow diagram of finite element analysis

1.1.5

Cargo Hold Analysis is to be carried out for ships of length 150 m or above in accordance with the requirements in this chapter. In case of ships of lengths less than 150 m, where there is a significant variation in the arrangement of structure(e.g. extremely narrow ballast tank, evaluation of PSMs, etc.), the Cargo Hold Analysis should be performed additionally.

Global Analysis is to be carried out for ships of length 290 m or above in accordance with the requirements in **Pt 3, Annex 3-2**.

1.1.6 Deleted [2023]

2. Corrosion addition

2.1 General

2.1.1

FE models for cargo hold FE analyses, local fine mesh FE analysis and very fine mesh FE analyses, are to be based on the net scantling approach, applying a corrosion addition as defined in **Ch 3, Sec 2, Table 1.**

All buckling capacity assessment are to be based on corrosion addition, as defined in **Ch 3, Sec 2, Table 1.**

3. Finite element types

3.1 Used finite element types

3.1.1

The structural assessment is to be based on linear finite element analysis of three dimensional structural models. The general types of finite elements to be used in the finite element analysis are given in **Table 1.**

Table 1 : Types of finite element

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

3.1.2

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

4. Submission of results

4.1 Detailed report

4.1.1

A detailed report of the structural analysis is to be submitted by the designer / builder to demonstrate compliance with the specified structural design criteria. This report is to include the following information:

a) List of plans used including dates and versions.
b) Detailed description of structural modelling including all modelling assumptions and any deviations in geometry 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, bending moment and torsional moment distributions.
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 any member.
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 and fatigue properties showing compliance with design criteria.
n) Reference of the finite element computer program, including its version and date.

5. Computer programs

5.1 Use of computer programs

5.1.1

Any finite element computation program complying with **Ch 1, Sec 3** may be employed to determine the stress and deflection of the hull structure, provided that the combined effects of bending, shear, axial and torsional deformations are considered.

Section 2 Cargo Hold Structural Strength Analysis

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

M_{sw} : Permissible vertical still water bending moment, in kNm, as defined in **Ch 4, Sec 4.**

M_{wv} : Vertical wave bending moment, in kNm, in hogging or sagging condition, as defined in **Ch 4, Sec 4.**

M_{wh} : Horizontal wave bending moment, in kNm, as defined in **Ch 4, Sec 4.**

M_{wt} : Wave torsional moment in seagoing condition, in kNm, as defined in **Ch 4, Sec 4.**

Q_{sw} : Permissible still water shear force, in kN, at the considered bulkhead position, as provided in **Ch 4, Sec 4.**

Q_{wv} : Vertical wave shear force, in kN, as defined in **Ch 4, Sec 4.**

x_{b-aft}, x_{b-fwd} : X-coordinate, in m, of respectively the aft and forward bulkhead of the mid-hold.

x_{aft} : X-coordinate, in m, of the aft end support of the FE model.

x_{fore} : X-coordinate, in m, of the fore end support of the FE model.

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

Q_{aft} : Vertical shear force, in kN, at aft bulkhead of mid-hold as defined in **[4.4.6].**

Q_{fwd} : Vertical shear force, in kN, at fore bulkhead of mid-hold as defined in **[4.4.6].**

$Q_{targ-aft}$: Target shear force, in kN, at the aft bulkhead of mid-hold as defined in **[4.3.3].**

$Q_{targ-fwd}$: Target shear force, in kN, at the forward bulkhead of mid-hold as defined in **[4.3.3].**

1. Objective and scope

1.1 General

1.1.1

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

1.1.2

Holds in the midship cargo hold region are defined as holds with their longitudinal centre of gravity position at or forward of 0.3 *L* from AE and at or aft of 0.7 *L* from AE, as defined in **Figure 1:**

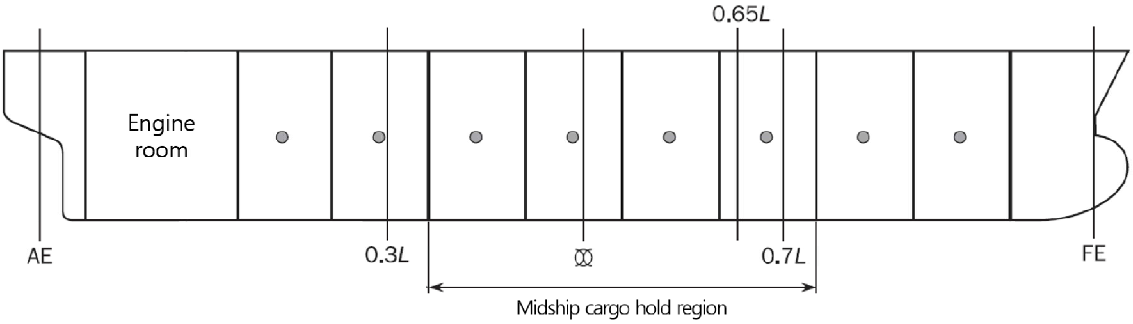


Figure 1 : Definition of cargo hold regions for FE structural assessment

1.2 Cargo hold structural strength analysis procedure

1.2.1 Procedure description

The structural FE analysis is to be performed in accordance with the following:

a) Model: Three cargo hold model with:
  - Extent as given in **[2.2]**
  - Finite element types as given in **[2.3]**
  - Structural modelling as defined in **[2.4]**

b) Boundary conditions as defined in **[2.5]**

c) FE load combinations as defined in **[3]**

d) Load application as defined in **[4]**

e) Evaluation area as defined in **[5.1]**

f) Strength assessment as defined in **[5.2]** and **[5.3]**

1.2.2 Mid-hold definition

For the purpose of the FE analysis, the mid-hold is defined as the middle hold(s) of the three cargo hold length FE model.

1.2.3 Scantling assessment

The scantling assessment is carried out according to **Ch 7, Sec 1** for mid cargo hold using the FE load combinations defined in **Ch 4, Sec 8** applicable to the considered cargo hold. The FE analysis results are applicable to the evaluation area as defined in **[5.1.1]**, of the considered cargo hold.

2. Structural model

2.1 Members to be modelled

2.1.1

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

- Inner and outer shell,
- Upper deck,
- Double bottom floors and girders,
- Transverse and vertical web frames,
- Hatch coamings,
- Stringers and lower decks,
- Transverse and longitudinal bulkhead structures,
- Other primary supporting members,
- Other structural members which contribute to hull girder strength.

All plates and stiffeners on the structure, including web stiffeners, are to be modelled. Brackets which contribute to primary supporting member strength and the size of which is not less than the typical mesh size (s-by-s) described in **[2.4.2],** are to be modelled.

2.2 Extent of model

2.2.1 Longitudinal extent

Except the foremost and aftermost cargo hold models, the longitudinal extent of the cargo hold FE model is to cover three cargo hold lengths. The transverse bulkheads at the ends of the model are to be modelled. Typical finite element models representing the midship cargo hold region is shown in **Figure 2.**

2.2.2 Hull form modelling

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

2.2.3 Transverse extent

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

2.2.4 Vertical extent

The full depth of the ship is to be modelled including primary supporting members above the upper deck, trunks and cargo hatch coaming, if any. In case of twin-island design the deckhouse or superstructure above the fuel oil tanks are required to be included in the model.

2.3 Finite element types

2.3.1

Shell elements are to be used to represent plates.

2.3.2

All stiffeners are to be modelled with beam elements having axial, torsional, bi-directional shear and bending stiffness. The eccentricity of the neutral axis is to be modelled.

2.3.3

Face plates of primary supporting members and brackets are to be modelled using rod or beam elements.

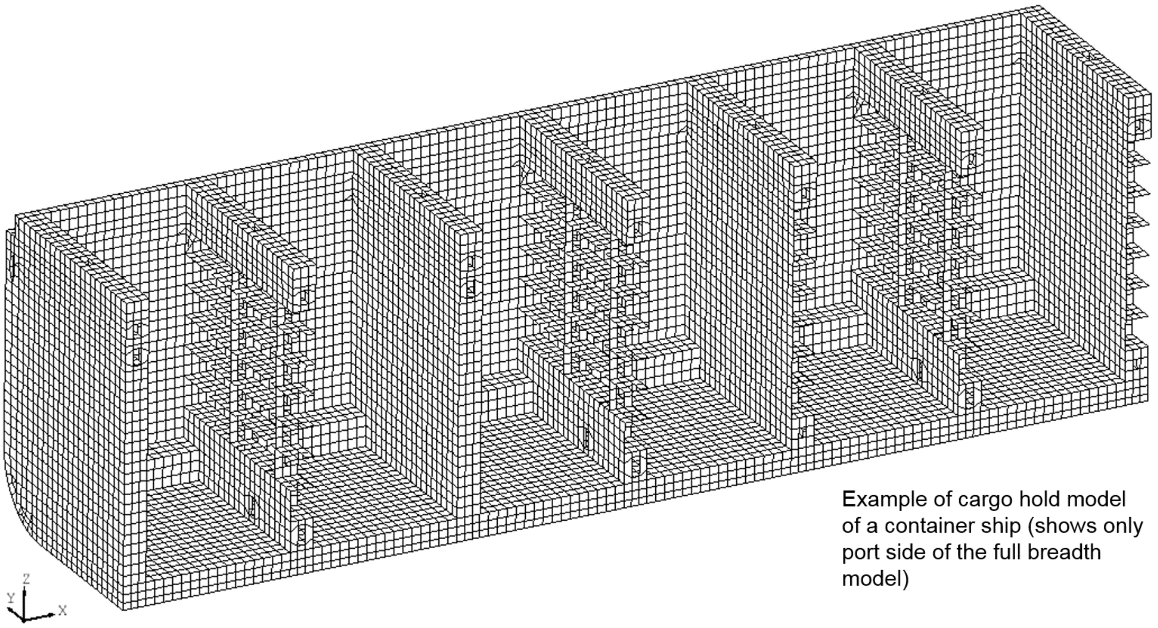


Figure 2 : Example of 3 cargo hold model within midship region

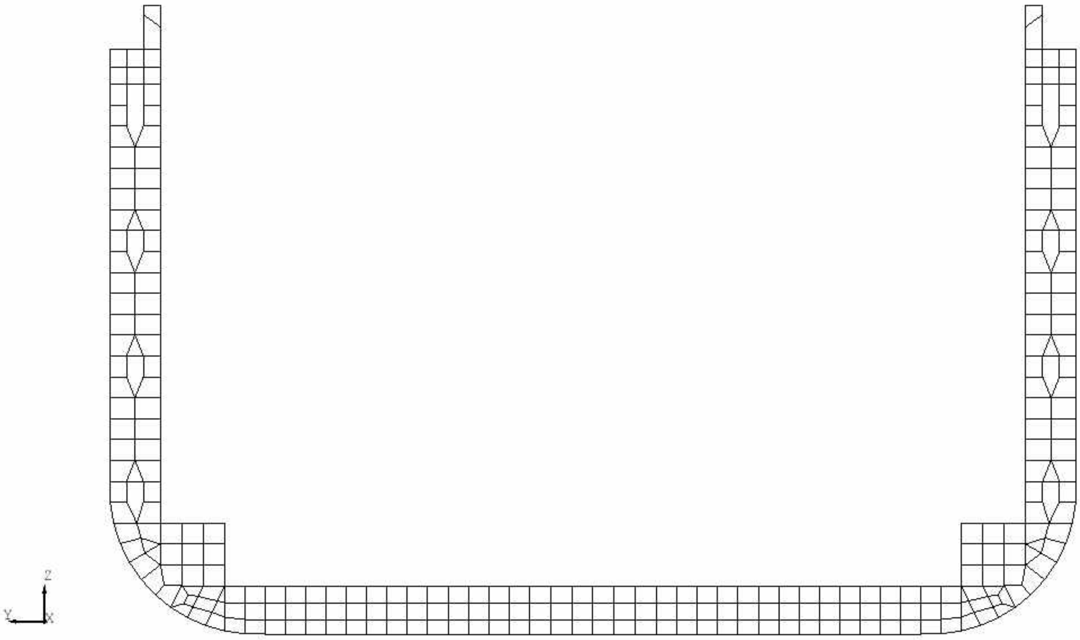


Figure 3 : Typical finite element mesh on web frame

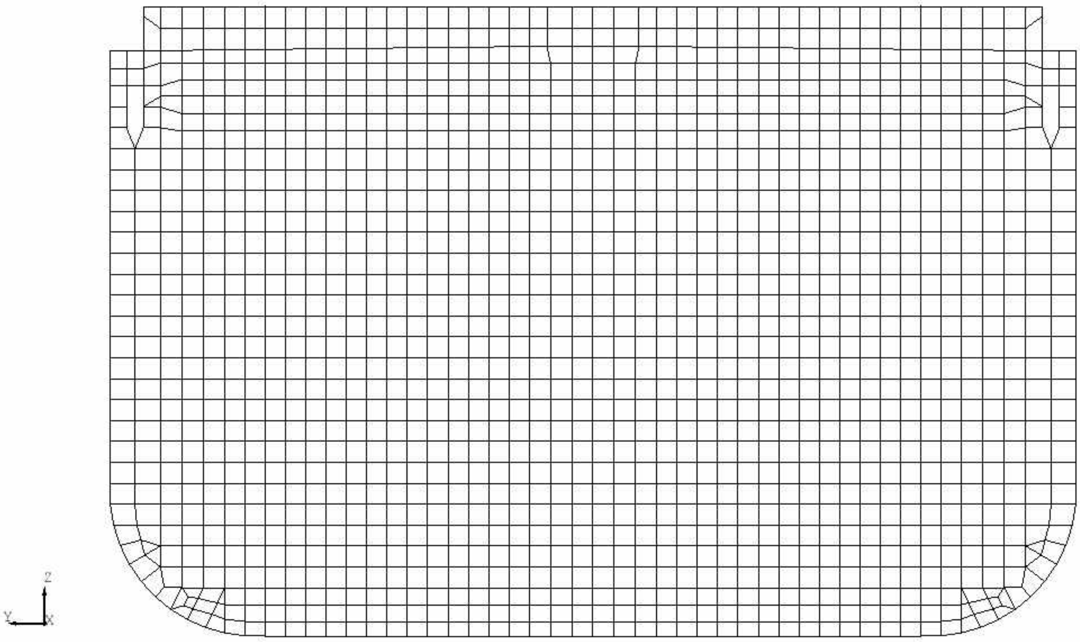


Figure 4 : Typical finite element mesh on transverse bulkhead

2.4 Structural modelling

2.4.1 Aspect ratio

The aspect ratio of the shell elements is in general not to exceed 3. The use of triangular shell elements is to be kept to a minimum. Where possible, the aspect ratio of shell elements in areas where there are likely to be high stresses or a high stress gradient is to be kept close to 1 and the use of triangular elements is to be avoided.

2.4.2 Mesh

The shell element mesh is to follow the stiffening system as far as practicable, hence representing the actual plate panels between stiffeners. In general, the shell element mesh is to satisfy the following requirements:

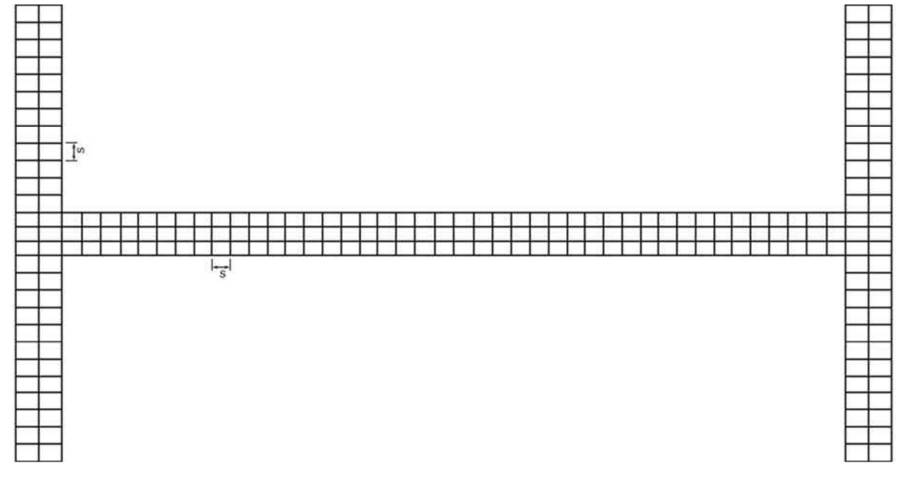
a) One element between every longitudinal stiffener, see **Figure 3.** Longitudinally, the element length is not to be greater than 2 longitudinal spaces with a minimum of three elements between primary supporting members.

b) One element between every stiffener on transverse bulkheads, see **Figure 4.**

c) One element between every web stiffener on transverse and vertical web frames and stringers, see **Figure 3** and **Figure 5.**

d) At least 3 elements over the depth of double bottom girders, floors, transverse web frames, vertical web frames and horizontal stringers on transverse bulkheads. For deck transverse and horizontal stringers on transverse wash bulkheads and longitudinal bulkheads with a smaller web depth, modelling using 2 elements over the depth is acceptable provided that there is at least 1 element between every web stiffener. The mesh size of adjacent structure is to be adjusted accordingly.

e) The curvature of the free edge on large brackets of primary supporting members is to be modelled to avoid unrealistic high stress due to geometry discontinuities. In general, a mesh size equal to the stiffener spacing is acceptable. The bracket toe may be terminated at the nearest nodal point provided that the modelled length of the bracket arm does not exceed the actual bracket arm length. The bracket flange is not to be connected to the plating, as shown in **Figure 6**. The modelling of the tapering part of the flange is to be in accordance with **[2.4.7].** An example of acceptable mesh is shown in **Figure 6.** A finer mesh is to be used for the determination of detailed stress at the bracket toe, as given in **Ch 7, Sec 3.**



s = Stiffener spacing

Figure 5 : Typical finite element mesh on horizontal transverse stringer on transverse bulkhead

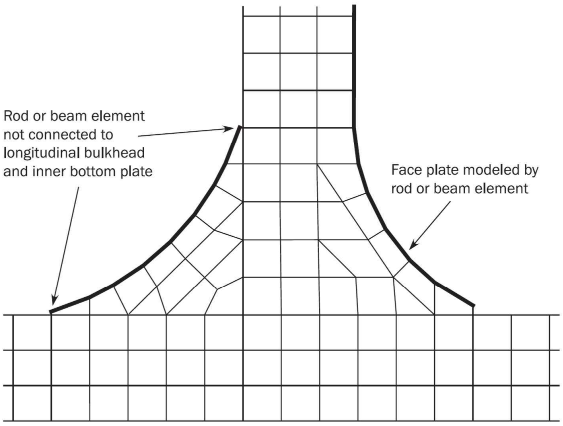


Figure 6 : Typical finite element mesh on transverse web frame main bracket

2.4.3 Finer mesh

Where the geometry cannot be adequately represented in the cargo hold model and the stress exceeds the cargo hold mesh acceptance criteria, a finer mesh may be used for such geometry to demonstrate satisfactory scantlings. The mesh size required for such analysis can be governed by the geometry. In such cases, the average stress within an area equivalent to that specified in **[2.4]** is to comply with the requirements given in **[5.2]**.

2.4.4

Example of mesh arrangements of the cargo hold structure are shown in **Figure 7.**

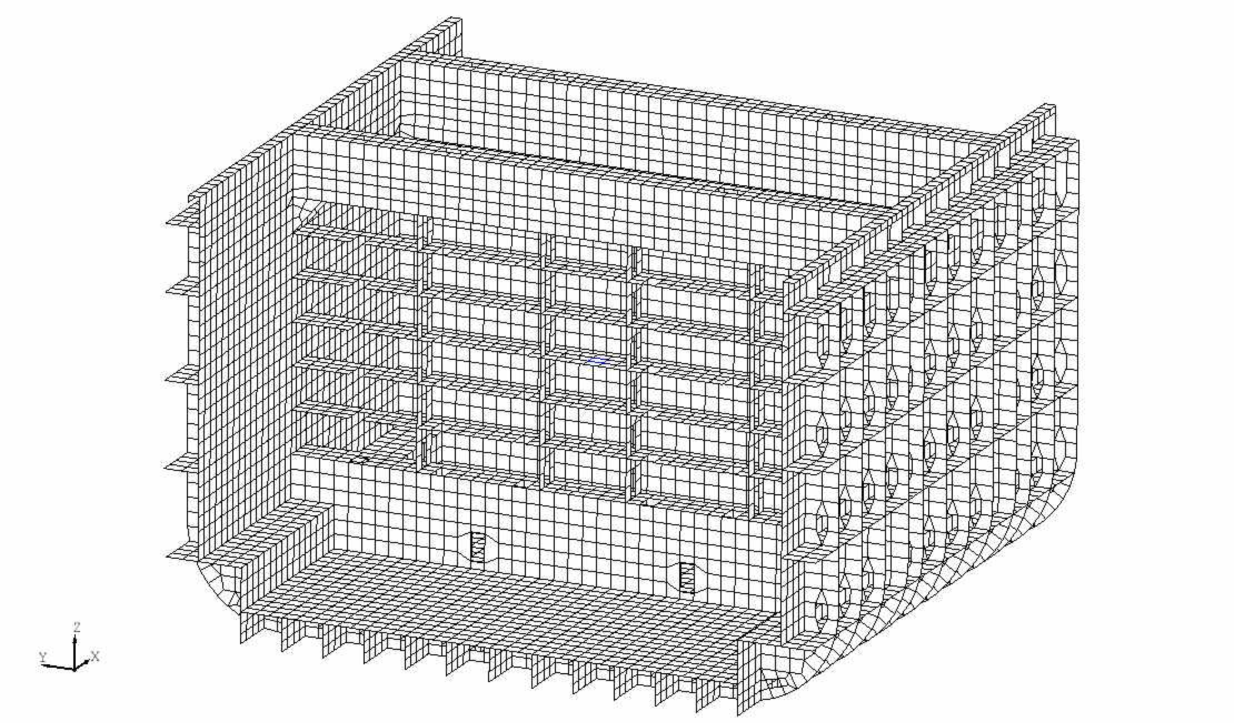


Figure 7 : Example of FE mesh arrangements of cargo hold structure for a container ship

2.4.5 Sniped stiffener

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

2.4.6 Web stiffeners of primary supporting members

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

2.4.7 Face plate of primary supporting member

The effective cross sectional area at the curved part of the face plate of primary supporting members and brackets is to be calculated in accordance with **Ch 3, Sec 7.** The cross sectional area of a rod or beam 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 the element length.

2.4.8 Openings

Methods of representing openings and manholes in webs of primary supporting members are to be in accordance with **Table 1.** Regardless of size, manholes are to be modelled by removing the appropriate elements.

Table 1 : Representation of openings in primary supporting member webs

Criteria	Modelling decision	Analysis
$h_o/h < 0.5$ and $g_o < 2.0$	Openings do not need to be modelled	To be evaluated by fine mesh as given in **Ch 7, Sec 3, [1.2]**
Manholes	The geometry of the opening is to be modelled by removing the adequate elements	
$h_o/h \geq 0.5$ or $g_o \geq 2.0$	The geometry of the opening is to be modelled	

where:

$$g_0 = \left(1 + \frac{\ell_0^2}{2.6(h-h_0)^2}\right)$$

ℓ_o : Length of opening parallel to primary supporting member web direction, in m, see **Figure 8.** 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 9.**

h_o : Height of opening parallel to depth of web, in m, see **Figure** 8 and **Figure** 9.

h : Height of web of primary supporting member in way of opening, in m, see **Figure** 8 and **Figure** 9.

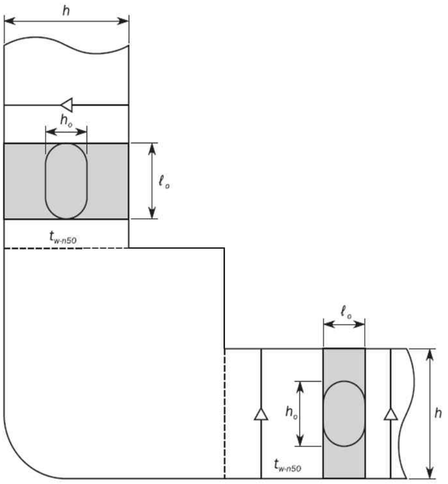


Figure 8 : Openings in web

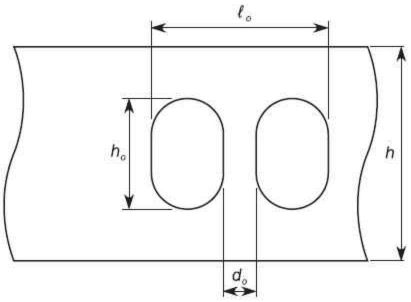


Figure 9 : Length ℓ_0 for sequential openings with $d_o < h/4$

2.5 Boundary conditions

2.5.1 General

All boundary conditions described in this section are in accordance with the global coordinate system defined in **Ch 4, Sec 1.**

2.5.2 Application

The boundary conditions given **[2.5.3]** are applicable to cargo hold finite element model analyses in cargo hold region.

2.5.3 Boundary Conditions

The boundary conditions consist of the rigid links at model ends, point constraints and end-beams. The rigid links connect the nodes on the longitudinal members at the model ends to an independent point at neutral axis in centreline. The boundary conditions to be applied at the ends of the cargo hold FE model are given in **Table 2.**

Table 2 : Boundary constraints at model ends

Location	Translation			Rotation		
	δ_x	δ_y	δ_z	θ_x	θ_y	θ_z
Aft End						
Independent point	–	Fix	Fix	M_{T-end}	–	–
Cross Section	–	Rigid link	Rigid link	Rigid link	–	–
	End beam, see **[2.5.4]**					
Fore End						
Independent point	–	Fix	Fix	Fix	–	–
Intersection of centreline and inner bottom	Fix	–	–	–	–	–
Cross Section	–	Rigid link	Rigid link	Rigid link	–	–
	End beam, see **[2.5.4]**					
Note 1: [–] means no constraint applied (free). Note 2: See **Figure 10.**						

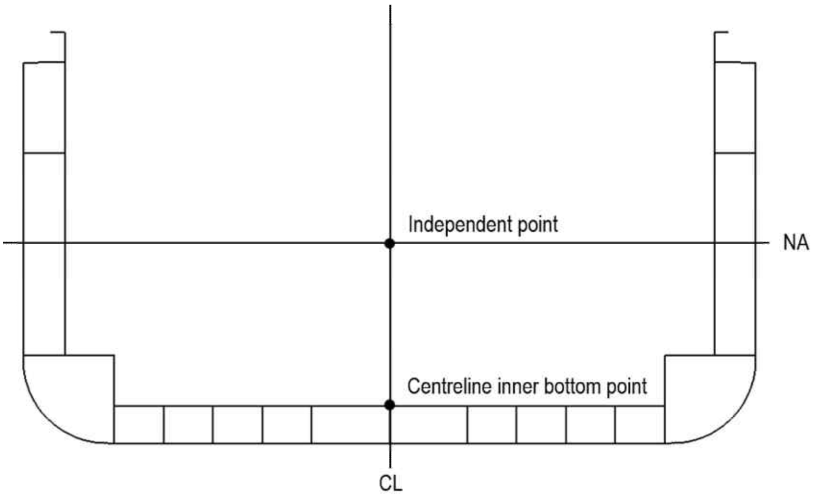


Figure 10 : Boundary conditions applied at the model end sections

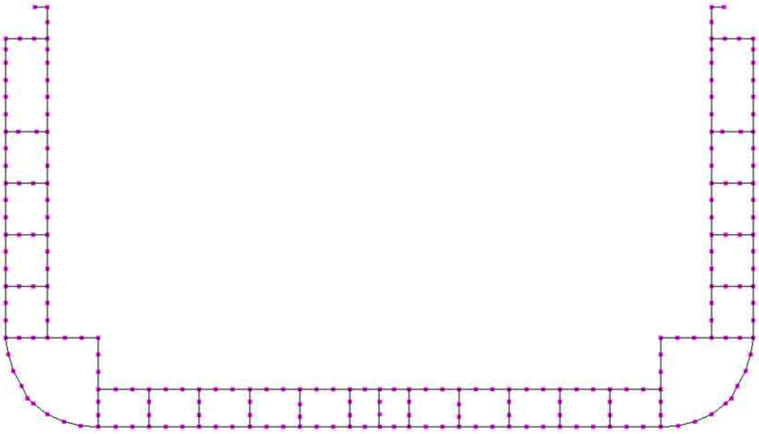


Figure 11 : End constraint beams for a container ship

2.5.4 End constraint beams

End constraint beams are to be modelled at the both end sections of the model along all longitudinally continuous structural members. An example of end beams at one end for a container ship is shown in **Figure 11.**

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

- Net moment of inertia: I_{yy-n50} = I_{zz-n50} = $I_{xx-n50}(J)$ = 1/10 of the vertical hull girder moment of inertia of fore/aft end cross sections based on the net FE model.
- Net cross sectional area: A_{y-n50} and A_{z-n50} = 1/80 of the fore/aft end cross sectional areas based on the net FE model.

where:

I_{yy-n50} : Moment of inertia about local beam Y axial, in m^4.

I_{zz-n50} : Moment of inertia about local beam Z axial, in m^4.

$I_{xx-n50}(J)$: Torsional inertia, in m^4.

A_{y-n50} : Shear area in local beam Y direction, in m^2.

A_{z-n50} : Shear area in local beam Z direction, in m^2.

3. FE load combinations

3.1 Design load combinations

3.1.1 FE load combination definition

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

3.1.2 Mandatory load combinations

For cargo hold structural strength analysis, the design load combinations specified in **Ch 4, Sec 8** are to be used.

Each design load combination given in **Ch 4, Sec 8** consists of a loading pattern and dynamic load cases as given in **Ch 4, Sec 2.** Each load combination requires the application of the structural weight, internal and external loads and hull girder loads. For seagoing condition, both static and dynamic load components (S + D) are applied. For tank testing and flooding condition, only static load components (S) are applied.

3.1.3 Additional loading conditions

Where the loading conditions specified by the designer are not covered by the load combinations given in **Ch 4, Sec 8,** these additional loading conditions are to be examined according to the procedure in **[4].**

4. Load application

4.1 General

4.1.1 Structural weight

Effect of the weight of hull structure is to be included in static loads, but is not to be included in dynamic loads. Density of steel is to be taken as given in **Ch 4, Sec 6.**

4.1.2 Sign convention

Unless otherwise mentioned in this Section, the sign of moments and shear force is to be in accordance with the sign convention defined in **Ch 4, Sec 1.**

4.2 External and internal loads

4.2.1 External loads

External pressure is to be calculated for each load case in accordance with **Ch 4, Sec 5.** External pressures include static sea pressure, wave pressure and green sea pressure.

4.2.2 Internal loads

Internal loads are to be calculated for each load case in accordance with **Ch 4, Sec 6** for design load scenarios given in **Ch 4, Sec 7, Table 1.** They include static dry cargo (including containers on deck), ballast and other liquid pressure, setting pressure on relief valve and dynamic load of dry cargo (including containers on deck), ballast and other liquid pressure due to acceleration.

4.2.3 Liquefied natural gas fuel density

Maximum liquefied natural gas fuel density is generally taken as not less than 0.5 $\mathrm{t/m^3}$. To take into account of the volume difference between 1st barrier and inner hull, the liquefied natural gas fuel density may be used as adjusted below,

$$\rho_{c_{adjusted}} = \rho_c \frac{V_C}{V_{Hull}} + \rho_{CCS} \frac{V_{Hull} - V_C}{V_{Hull}}$$

where:

V_C : Volume of liquefied natural gas fuel tank enclosed by primary barrier of fuel containment system in $\mathrm{m^3}$.

V_{Hull} : Volume of liquefied natural gas fuel tank enclosed by inner hull structure in $\mathrm{m^3}$.

ρ_{CCS} : Density of fuel containment system in $\mathrm{t/m^3}$, generally 0.12 can be used.

And, effective liquefied natural gas fuel density may be adjusted to consider the maximum filling height as below,

$$\rho_{c_{eff}} = \rho_{c_{adjusted}} \frac{M_{Max\,filling\%\,by\,\rho_{Max-LM}}}{M_{100\%\,by\,\rho_c}}$$

where:

$M_{Max\,filling\%\,by\,\rho_{Max-LM}}$: Mass of liquefied natural gas fuel when filled to maximum level(%) with design fuel density

$M_{100\%\,by\,\rho_c}$: Mass of liquefied natural gas fuel when filled to 100% with ρ_c= 0.5 $\mathrm{t/m^3}$

$\rho_{c_{eff}}$: Effective liquefied natural gas fuel density for internal loads in FE analysis ($\mathrm{t/m^3}$)

4.2.4 Pressure application on FE element

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

4.3 Hull girder loads

4.3.1 General

Each loading condition is to be associated with its corresponding hull girder loads which is to be applied to the model according to the procedure described in **[4.4]** for shear force and bending moment and in [4.5] for torsional moment. The hull girder loads are the combinations of still water hull girder loads and wave induced hull girder loads as specified in **Ch 4, Sec 8**. For each required FE load combination, the wave induced hull girder loads are to be calculated with the Load Combination Factors (LCFs), specified in **Ch 4, Sec 2**.

4.3.2 Target hull girder vertical bending moment

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

$$M_{v-targ} = M_{sw} + M_{wv-LC}$$

where:

M_{sw} : Permissible still water bending moments in kNm, at the considered longitudinal position for seagoing as defined in **Ch 4, Sec 4, [2.2.2]** and **Ch 4, Sec 4, [2.2.3]** respectively.

M_{wv-LC} : Vertical wave bending moment in kNm, for the dynamic load case under consideration, calculated in accordance with **Ch 4, Sec 4, [3.7.2]**.

The values of M_{v-targ} are taken as the maximum hull girder bending moment within the mid-hold(s) for each individual cargo hold for each given FE load combination as defined in **Ch 4, Sec 8**.

4.3.3 Target hull girder shear force

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

- $Q_{fwd} \geq Q_{aft}$:

  $$Q_{targ-aft} = Q_{sw-neg} + f_\beta |C_{QW}| Q_{wv-neg}$$

  $$Q_{targ-fwd} = Q_{sw-pos} + f_\beta |C_{QW}| Q_{wv-pos}$$

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

  $$Q_{targ-aft} = Q_{sw-pos} + f_\beta |C_{QW}| Q_{wv-pos}$$

  $$Q_{targ-fwd} = Q_{sw-neg} + f_\beta |C_{QW}| Q_{wv-neg}$$

where:

Q_{fwd}, Q_{aft} : Vertical shear forces, in kN, due to the local loads respectively at the forward and aft bulkhead position of the mid-hold, as defined in **[4.4.6]**.

Q_{sw-pos}, Q_{sw-neg} : Positive and negative permissible still water shear forces, in kN, at any longitudinal position for seagoing as defined in **Ch 4, Sec 4, [2.3.1]** and **Ch 4, Sec 4, [2.3.2]** respectively.

f_β : Wave heading factor, as given in **Ch 4, Sec 4.**

C_{QW} : Load combination factor for vertical wave shear force, as given in **Ch 4, Sec 2.**

Q_{wv-pos}, Q_{wv-neg} : Positive and negative vertical wave shear force, in kN, as defined in **Ch 4, Sec 4, [3.2.1].**

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

4.3.4 Target hull girder horizontal bending moment

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

$$M_{h-targ} = M_{wh-LC}$$

where:

M_{wh-LC} : Horizontal wave bending moment, in kNm, for the dynamic load case under consideration, calculated in accordance with **Ch 4, Sec 4, [3.7.4].**

The values of M_{wh-LC} are taken as the value calculated for the middle of the individual cargo hold under consideration.

4.3.5 Target hull girder torsional moment

For dynamic load cases, hull girder torsional moment $M_{wt-targ}$, at the middle of the mid-hold is to be adjusted to zero.

4.4 Procedure to adjust hull girder shear forces and bending moments

4.4.1 General

The procedure given in this sub-article **[4.4]** describes how to adjust the hull girder horizontal bending moment, vertical force and vertical bending moment distribution on the three cargo hold FE model to achieve the required target values at required locations. The hull girder load target values are specified in **[4.3]**.

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

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

4.4.2 Local load distribution

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

a) Ship structural steel weight distribution over the length of the cargo hold model (static loads). The structural steel weight is to be calculated based on the FE model with a net thickness of 0.5 t_c deduction, as used in the cargo hold FE model.

b) Weight of cargo / containers and ballast and fuel oil (static loads).

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

d) Dynamic cargo / containers, ballast and fuel oil loads for seagoing load cases.

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

4.4.3 Hull girder forces and bending moment due to local loads

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

$$R_{V\_fore} = -\frac{\sum_i (x_i - x_{aft}) f_{vi}}{x_{fore} - x_{aft}} \qquad R_{V\_aft} = \sum_i f_{vi} + R_{V\_fore}$$

$$R_{H\_fore} = -\frac{\sum_i (x_i - x_{aft}) f_{hi}}{x_{fore} - x_{aft}} \qquad R_{H\_aft} = -\sum_i f_{hi} + R_{H\_fore}$$

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

$$Q_{V\_FEM}(x_j) = R_{V\_aft} - \sum_i f_{vi} \qquad \text{when } x_i < x_j$$

$$Q_{H\_FEM}(x_j) = R_{H\_aft} + \sum_i f_{hi} \qquad \text{when } x_i < x_j$$

$$M_{V\_FEM}(x_j) = (x_j - x_{aft}) R_{V\_aft} - \sum_i (x_j - x_i) f_{vi} \qquad \text{when } x_i < x_j$$

$$M_{H\_FEM}(x_j) = (x_j - x_{aft}) R_{H\_aft} + \sum_i (x_j - x_i) f_{hi} \qquad \text{when } x_i < x_j$$

where:

$R_{V\_aft}, R_{V\_fore}, R_{H\_aft}, R_{H\_fore}$: Vertical and horizontal reaction forces at the aft and fore ends, in kN.

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

$x_{\mathrm{for}e}$: X-coordinate of the fore end support, in m.

f_{vi} : Lumped vertical local load at longitudinal station i as defined in **[4.4.2]**, in kN.

f_{hi} : Lumped horizontal local load at longitudinal station i as defined in **[4.4.2]**, in kN.

F_l : Total net longitudinal force of the model, in kN.

f_{li} : Lumped longitudinal local load at longitudinal station i as defined in **[4.4.2]**, in kN.

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

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

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

4.4.4 Longitudinal unbalanced force

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

$$(F_x)_j = \frac{F_l}{A_{x-n50}} \frac{A_{j-n50}}{n_j}$$

where:

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

F_l : Total net longitudinal force of the model, as defined in **[4.4.3]**, in kN.

A_{j-n50} : Net cross sectional area of the j-th element, in m^2.

A_{x-n50} : Net cross sectional area of fore end section, in m^2,

$$A_{x-n50} = \sum_j A_{j-n50}$$

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

4.4.5 Hull girder shear force adjustment procedure

The hull girder shear force adjustment procedure defined in this requirement applies to all FE load combinations given in **Ch 4, Sec 8.** The FE load combinations not directly covered by the load combination tables of **Ch 4, Sec 8** are to be considered on a case by case basis.

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

- Method 1 (M1) : for shear force adjustment at one bulkhead of the mid-hold as given in **[4.4.6]**,
- Method 2 (M2) : for shear force adjustment at both bulkheads of the mid-hold as given in **[4.4.7]**.

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

- The shear force adjustment is not requested when the shear forces at both bulkheads are lower or equal to the target values.
- The method 1 applies when the shear force exceeds the target at one bulkhead and the shear force at the other bulkhead after the adjustment with method 1 does not exceed the target value. Otherwise the method 2 applies,
- The method 2 applies when the shear forces at both bulkheads exceed the target values,

4.4.6 Method 1 for shear force adjustment at one bulkhead

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

- Aft bulkhead:

$$M_{Y\_aft} = M_{Y\_fore} = \frac{(x_{fore} - x_{aft})}{2}(Q_{targ-aft} - Q_{aft})$$

- Forward bulkhead:

$$M_{Y\_aft} = M_{Y\_fore} = \frac{(x_{fore} - x_{aft})}{2}(Q_{targ-fwd} - Q_{aft})$$

where:

M_{Y_aft}, M_{Y_fore}: Vertical bending moment, in kNm, to be applied at the aft and fore ends in accordance with **[4.4.9]**, to enforce the hull girder vertical shear force adjustment as shown in **Table 3**. The sign convention is that of the FE model axis.

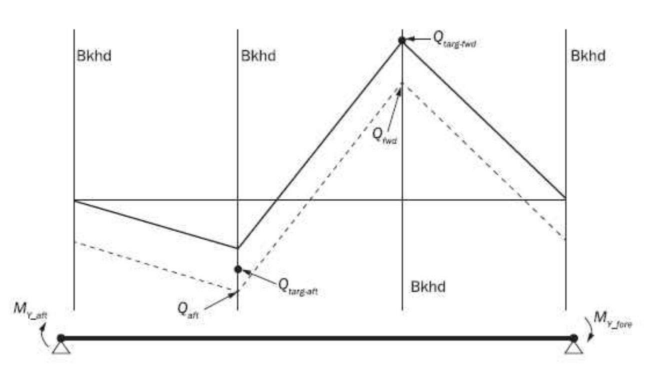
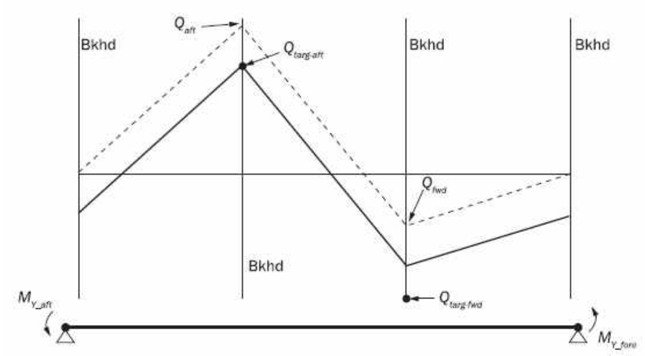
Q_{aft} : Vertical shear force, in kN, due to local loads at aft bulkhead location of mid-hold, x_{b_aft}, resulting from the local loads calculated according to **[4.4.3]**.

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

Q_{fwd} : Vertical shear force, in kN, due to local loads at the forward bulkhead location of mid-hold, x_{b_fwd}, resulting from the local loads calculated according to **[4.4.3]**.

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

Table 3 : Vertical shear force adjustment by application of vertical bending moments M_{Y_aft} and M_{Y_fore} for method 1

Vertical shear force diagram	Target position in mid-hold
	Forward bulkhead
	Aft bulkhead
———————— Vertical shear force after adjustment - - - - - - - - Vertical shear due to local loads	

4.4.7 Method 2 for vertical shear force adjustment at both bulkheads

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

- Vertical bending moments, M_{Y_aft}, M_{Y_fore} at model ends and,
- Vertical loads at the transverse frame positions as shown in **Table 5** in order to generate vertical shear forces, ΔQ_{aft} and ΔQ_{fwd}, at the transverse bulkhead positions.

Table 4 shows examples of the shear adjustment application due to the vertical bending moments and to vertical loads.

$$M_{Y\_aft} = \frac{x_{fore} - x_{aft}}{2} \cdot \frac{Q_{targ-fwd} - Q_{fwd} + Q_{targ-aft} - Q_{aft}}{2}$$

$$M_{Y\_fore} = M_{Y\_aft}$$

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

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

where:

$M_{Y\_aft}, M_{Y\_\mathrm{fore}}$: Vertical bending moment, in kNm, to be applied at the aft and fore ends in accordance with **[4.4.9],** to enforce the hull girder vertical shear force adjustment. The sign convention is that of the FE model axis.

ΔQ_{aft} : Adjustment of shear force, in kN, at aft bulkhead of mid-hold.

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

The above adjustments in shear forces, ΔQ_{aft} and ΔQ_{fwd}, at the transverse bulkhead positions are to be generated by applying vertical loads at the transverse frame positions as shown in **Table 5.** Vertical correction loads are not to be applied to any transverse tight bulkheads, any frames forward of the forward cargo hold and any frames aft of the aft cargo hold of the FE model.

The vertical loads to be applied to each transverse frame to generate the increase/decrease in shear force at the bulkheads may be calculated as shown in **Table 5.** In case of uniform frame spacing, the amount of vertical force to be distributed at each transverse frame may be calculated in accordance with **Table 6.**

Table 4 : Target and required shear force adjustment by applying vertical forces

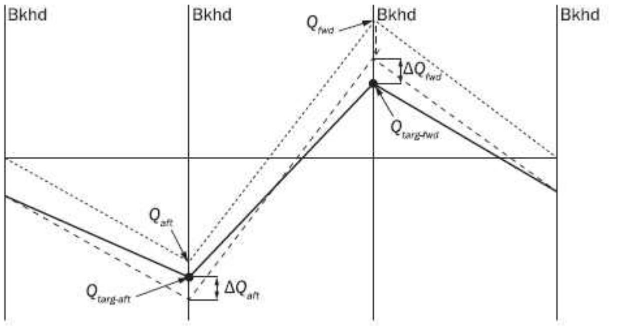
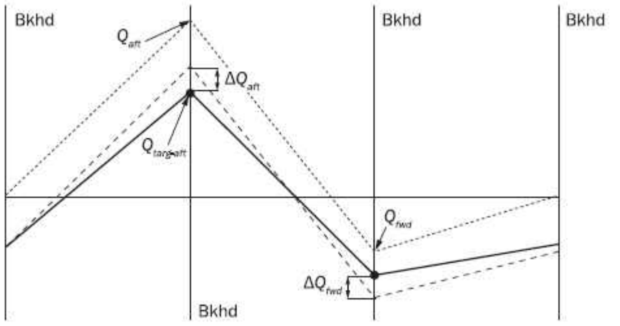
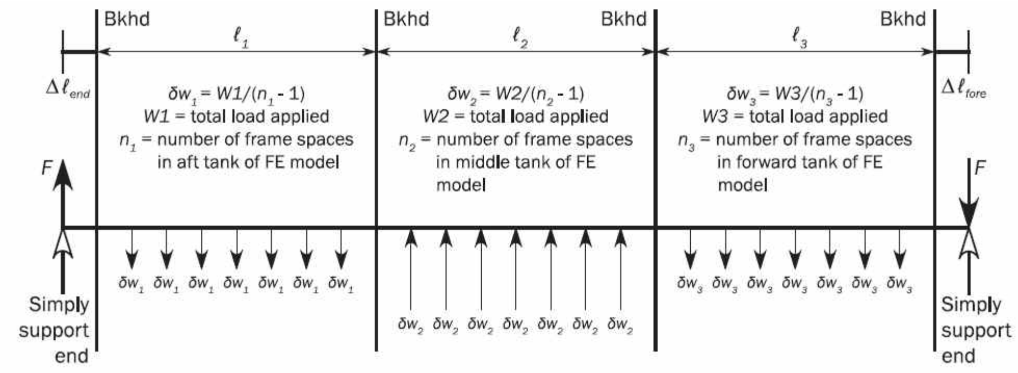
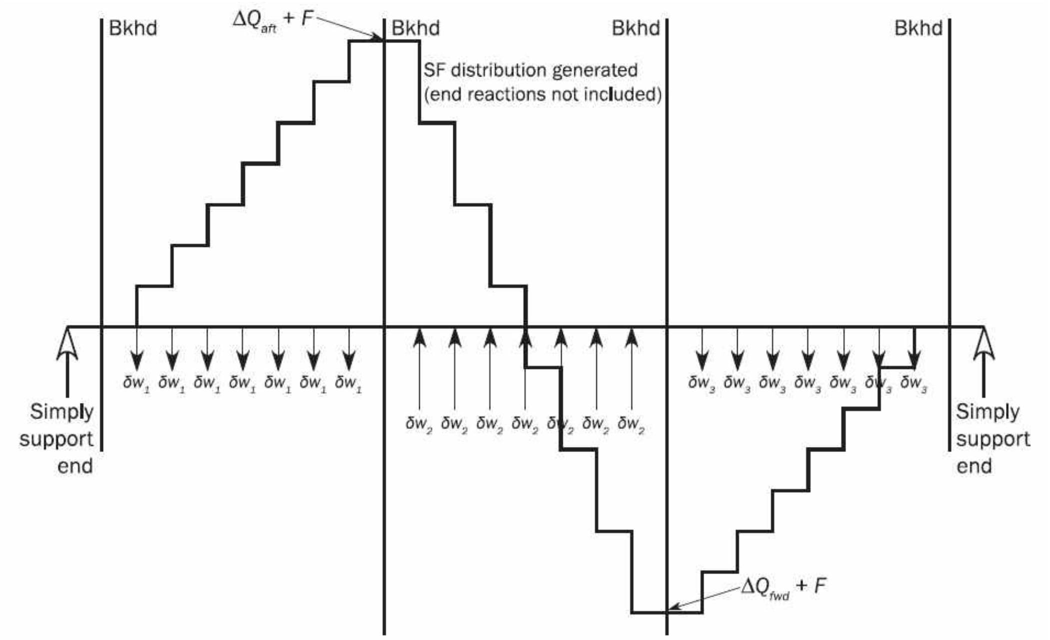
<table>
<tr><td rowspan="2">Vertical shear force diagram</td><td>Aft BHD</td><td>Fore BHD</td></tr>
<tr><td>SF Target</td><td>SF target</td></tr>
<tr><td>
</td><td>$Q_{targ-aft}(-ve)$</td><td>$Q_{targ-fwd}(+ve)$</td></tr>
<tr><td>
</td><td>$Q_{targ-aft}(+ve)$</td><td>$Q_{targ-fwd}(-ve)$</td></tr>
<tr><td colspan="3">——————— Vertical shear force after both adjustments
– – – – – – – – Vertical shear force after adjustment by use of M_{Y_aft} and M_{Y_fore}
--------------- Vertical shear due to local loads</td></tr>
<tr><td colspan="3">Note 1: -ve means negative.
Note 2: +ve means positive.</td></tr>
</table>

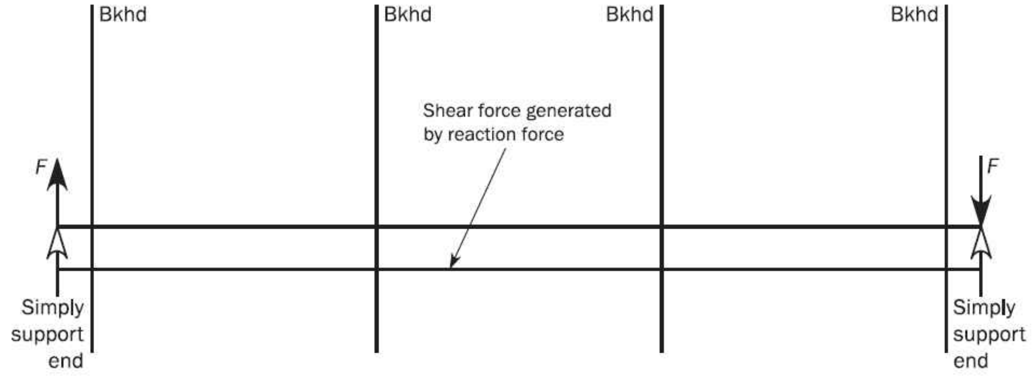
Table 5 : Target and required shear force adjustment by applying vertical forces



Note: Transverse bulkhead frames not loaded
Frames beyond aft transverse bulkhead of aft most tank and forward bulkhead of forward most tank not loaded
F = Reaction load generated by supported ends



Shear Force distribution due to adjusting vertical force at frames



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

Note 1: For definition of symbols, see **Table 6.**

Table 6 : Formulae for calculation of vertical loads for adjusting vertical shear forces

$$\delta w_1 = \frac{\Delta Q_{aft}(2\ell - \ell_2 - \ell_3) + \Delta Q_{fwd}(\ell_2 + \ell_3)}{(n_1 - 1)(2\ell - \ell_1 - 2\ell_2 - \ell_3)}$$

$$F = 0.5\left(\frac{W1(\ell_1 + \ell_1) - W3(\ell_2 + \ell_3)}{\ell}\right)$$

$$\delta w_2 = \frac{(W1 + W3)}{(n_2 - 1)} = \frac{(\Delta Q_{aft} - \Delta Q_{fwd})}{(n_2 - 1)}$$

$$\delta w_3 = \frac{-\Delta Q_{fwd}(2\ell - \ell_1 - \ell_2) - \Delta Q_{aft}(\ell_1 + \ell_2)}{(n_3 - 1)(2\ell - \ell_1 - 2\ell_2 - \ell_3)}$$

where:

ℓ_1 : Length of aft cargo hold of model, in m.

ℓ_2 : Length of mid-hold of model, in m.

ℓ_3 : Length of forward cargo hold of model, in m.

ΔQ_{aft} : Required adjustment in shear force, in kN, at aft bulkhead of middle hold, see **[4.4.7]**.

ΔQ_{fwd} : Required adjustment in shear force, in kN, at fore bulkhead of middle hold, see **[4.4.7]**.

F : End reactions, in kN, due to application of vertical loads to frames.

$W1$: Total evenly distributed vertical load, in kN, applied to aft hold of FE model, $(n_1 - 1)\ \delta w_1$.

$W2$: Total evenly distributed vertical load, in kN, applied to mid-hold of FE model, $(n_2 - 1)\ \delta w_2$.

$W3$: Total evenly distributed vertical load, in kN, applied to forward hold of FE model, $(n_3 - 1)\ \delta w_3$.

n_1 : Number of frame spaces in aft cargo hold of FE model.

n_2 : Number of frame spaces in mid-hold of FE model.

n_3 : Number of frame spaces in forward cargo hold of FE model.

δw_1 : Distributed load, in kN, at frame in aft cargo hold of FE model.

δw_2 : Distributed load, in kN, at frame in mid-hold of FE model.

δw_3 : Distributed load, in kN, at frame in forward cargo hold of FE model.

ℓ_{end} : Distance, in m, between end bulkhead of aft cargo hold to aft end of FE model.

ℓ_{fore} : Distance, in m, between fore bulkhead of forward cargo hold to forward end of FE model.

ℓ : Total length, in m, of FE model including portions beyond end bulkheads:
$= \ell_1 + \ell_2 + \ell_3 + \Delta\ell_{end} + \Delta\ell_{fore}$

Note 1: Positive direction of loads, shear forces and adjusting vertical forces in the formulae is in accordance with **Table 4** and **Table 5**.

Note 2: $W1 + W3 = W2$

Note 3: The above formulae are only applicable if uniform frame spacing is used within each hold. The length and frame spacing of individual cargo holds may be different.

If non-uniform frame spacing is used within each cargo hold, the average frame spacing ℓ_{av-i} is used to calculate the average distributed frame loads δw_{av-i}, according to **Table 6,** where i = 1, 2, 3 for each hold.

Then δw_{av-i} is redistributed to the non-uniform frame as follows:

$\delta w_i^k = \delta w_{av-i}\frac{\ell_{av-i}^k}{\ell_{av-i}}$ k = 1, 2, ..., $n_i - 1$, for each frame in cargo hold i, i = 1, 2, 3

where:

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

ℓ_i : Length, in m, of the cargo hold i with i = 1, 2, 3 as defined in **Table 6.**

n_i : Number of frame spacing in cargo hold i with i = 1, 2, 3 as defined in **Table 6.**

δw_{av-i} : Average uniform frame spacing, in m, distributed force calculated according to **Table 6** with the average frame spacing ℓ_{av-i} in cargo hold i with i = 1, 2, 3.

δw_i^k : Distributed load, in kN, for non-uniform frame k in cargo hold i.

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

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

$$\ell^k_{av-i} = \frac{\ell_i^k}{2} + \frac{\ell_i^{k+1}}{2}$$ for k = 2, 3, ⋯, n_i − 2, in cargo i

$$\ell^k_{av-i} = \ell_i^{n_i} - \frac{\ell_{av-i}\ell_i^{n_i}}{\ell_i^1 + \ell_i^{n_i}} + \frac{\ell_i^{n_i-1}}{2}$$ for k = n_i − 1 (last frame), in cargo i

ℓ_i^k : Frame spacing, in m, between the frame k − 1 and k in the cargo hold i.

The required vertical load δw_i for a uniform frame spacing or δw_i^k for non-uniform frame spacing, are to be applied by following the shear flow distribution at the considered cross section, as described in **Ch 5, App 1.** For a frame section under vertical load δw_i, the shear flow, q_f, at the middle point of the element is calculated as:

$$q_{f-k} = \frac{\delta w_i}{l_{y-n50}} Q_{k-n50}$$

where:

q_{f-k} : Shear flow calculated at the middle of the k-th element of the transverse frame, in N/mm.

δw_t : Distributed load at each transverse frame location for i-th cargo hold, i = 1, 2, 3, as defined in **Table 6,** in N.

I_{y-n50} : Moment of inertia of the hull girder cross section, in mm^4.

Q_{k-n50} : First moment about neutral axis of the accumulative section area starting from the open end (shear stress free end) of the cross section to the point s_k for shear flow q_{f-k}, in mm^3, taken as;

$$Q_{k-n50} = \int_0^{S_k} z_{neu} t_{n50} ds$$

z_{neu} : Vertical distance from the integral point, s, to the vertical neutral axis.

t_{n50} : Net thickness, in mm, of the plate at the integral point of the cross section.

The distributed shear force at j-th FE grid of the transverse frame, F_{j-grid}, is obtained from the shear flow of the connected elements as following:

$$F_{j-grid} = \sum_{k=1}^{n} q_{f-k} \frac{l_k}{2}$$

where:

ℓ_k : Length of the k-th element of the transverse frame connected to the grid j, in mm.

n : Total number of elements connect to the grid j.

The shear flow has direction along the cross section and therefore the distributed force, F_{j-grid}, is a vector force. For vertical hull girder shear correction, the vertical and horizontal force components calculated with above mentioned shear flow method need to be applied to the cross section.

4.4.8 Procedure to adjust vertical and horizontal bending moments for midship cargo hold region

In case the target vertical bending moment needs to be reached, an additional vertical bending moment is to be applied at both ends of the cargo hold FE model to generate this target value in the mid-hold of the model. This end vertical bending moment is given as follows:

$$M_{v-end} = M_{v-targ} - M_{v-peak}$$

where:

M_{v-end} : Additional vertical bending moment, in kNm, to be applied to both ends of FE model in accordance with **[4.4.9]**.

M_{v-targ} : Hogging(positive) or sagging(negative) vertical bending moment, in kNm, as specified in **[4.3.2]**.

M_{v-peak} : Maximum or minimum bending moment, in kNm, within the length of the mid-hold due to the local loads described in **[4.4.3]** and due to the shear force adjustment as defined in **[4.4.5]**.

M_{v-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} is to be calculated as follows based on a simply supported beam model:

$$M_{v-peak} = Extremum\left\{M_{V-FEM}(x) + M_{lineload} + M_{Y\_aft}\left(2\frac{x - x_{aft}}{x_{fore} - x_{aft}} - 1\right)\right\}$$

$M_{V-FEM}(x)$: Vertical bending moment, in kNm, at position x, due to the local loads as described in **[4.4.3]**.

M_{Y_aft} : End bending moment, in kNm, to be taken as:

- When method 1 is applied: the value as defined in **[4.4.6]**.
- When method 2 is applied: the value as defined in **[4.4.7]**.
- Otherwise: M_{Y_aft} = 0.0

$M_{lineload}$: Vertical bending moment, in kNm, at position x, due to application of vertical line loads at frames according to method 2, to be taken as:

$$M_{lineload} = -(x - x_{aft})F - \sum_i (x - x_i)\,\delta w_i \qquad \text{when } x_i < x$$

F : Reaction force, in kN, at model ends due to application of vertical loads to frames as defined in **Table 5**.

x : X-coordinate, in m, of frame in way of the mid-hold.

δw_i : vertical load, in kN, at web frame station i applied to generate required shear force.

In case the target horizontal bending moment needs to be reached, an additional horizontal bending moment is to be applied at the ends of the cargo hold FE model to generate this target value within the mid-hold. The additional horizontal bending moment is to be taken as:

$$M_{h-end} = M_{h-targ} - M_{h-peak}$$

where:

M_{v-end} : Additional horizontal bending moment, in kNm, to be applied to both ends of the FE model according to **[4.4.9]**.

M_{h-targ} : Horizontal bending moment, as defined in **[4.3.4]**.

M_{h-peak} : Maximum or minimum horizontal bending moment, in kNm, within the length of the mid-hold due to the local loads described in **[4.4.3]**.

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).

M_{h-peak} is to be calculated as follows based on a simply supported beam model:

$$M_{h-peak} = Extremum\{M_{H\_FEM}(x)\}$$

$M_{H-FEM}(x)$: Horizontal bending moment, in kNm, at position x, due to the local loads as described in **[4.4.3]**.

The vertical and horizontal bending moments are to be calculated over the length of the mid-hold to identify the position and value of each maximum/minimum bending moment.

4.4.9 Application of bending moment adjustments on the FE model

The required vertical and horizontal bending moment adjustments are to be applied to the considered cross section of the cargo hold model by distributing longitudinal axial nodal forces to all hull girder bending effective longitudinal elements of the considered cross section according to **Ch 5, Sec 1, [1.2]** as follows:

- For vertical bending moment:

$$(F_x)_i = \frac{M_v}{I_{y-n50}} \frac{A_{i-n50}}{n_i} z_i$$

- For horizontal bending moment:

$$(F_x)_i = \frac{M_h}{I_{z-n50}} \frac{A_{i-n50}}{n_i} y_i$$

where:

M_v : Vertical bending moment adjustment, in kNm, to be applied to the considered cross section of the model.

M_h : Horizontal bending moment adjustment, in kNm, to be applied to the considered cross section the ends of the model.

$(F_x)_i$: Axial force, in kN, applied to a node of the i-th element.

I_{y-n50} : Hull girder vertical moment of inertia, in m^4, of the considered cross section about its horizontal neutral axis.

I_{z-n50} : Hull girder horizontal moment of inertia, in m^4, of the considered cross section about its vertical neutral axis.

Z_i : Vertical distance, in m, from the neutral axis to the centre of the cross sectional area of the i-th element.

Y_i : Horizontal distance, in m, from the neutral axis to the centre of the cross sectional area of the i-th element.

A_{i-n50} : Cross sectional area, in m^2, of the i-th element.

n_i : Number of nodal points of i-th element on the cross section, n_i = 1 for beam element, n_i = 2 for 4-node shell element.

For cross sections other than cross sections at the model end, the average area of the corresponding i-th elements forward and aft of the considered cross section is to be used.

4.5 Procedure to adjust hull girder torsional moments

4.5.1 General

The procedure in this sub-article describes how to adjust the hull girder torsional moment distribution on the cargo hold FE model to achieve the target torsional moment at the target location. The hull girder torsional moment target values are given in **[4.3.5]**.

4.5.2 Torsional moment due to local loads

Torsional moment, in kNm, at longitudinal station i due to local loads, M_{T-FEMi} in kNm, is determined by the following formula (see **Figure 12**):

$$M_{T-FEMi} = \sum_k [f_{hik}(z_{ik} - z_r)] - \sum_k (f_{vik} y_{ik})$$

where:

M_{T-FEMi} : Lumped torsional moment, in kNm, due to local load at longitudinal station i.

z_r : Vertical coordinate of torsional reference point, in m:

$z_r = z_{sc}$, shear centre at the middle of the mid-hold.

f_{hik} : Horizontal nodal force, in kN, of node k at longitudinal station i.

f_{vik} : Vertical nodal force, in kN, of node k at longitudinal station i.

y_{ik} : Y-coordinate, in m, of node k at longitudinal station i.

z_{ik} : Z-coordinate, in m, of node k at longitudinal station i.

M_{T-FEMO} : Lumped torsional moment, in kNm, due to local load at aft end of the FE model, taken as:

$$M_{T-FEMO} = \sum_k [f_{h0k}(z_{0k} - z_r)] - \sum_k (f_{v0k} y_{0k}) + R_{H\_aft}(z_{ind} - z_r)$$

R_{H_fwd} : Horizontal reaction forces, in kN, at the forward end, as defined in **[4.4.3]**.

R_{H_aft} : Horizontal reaction forces, in kN, at the aft end, as defined in **[4.4.3]**.

z_{ind} : Vertical coordinate, in m, of independent point as defined in **[2.5.3]**.

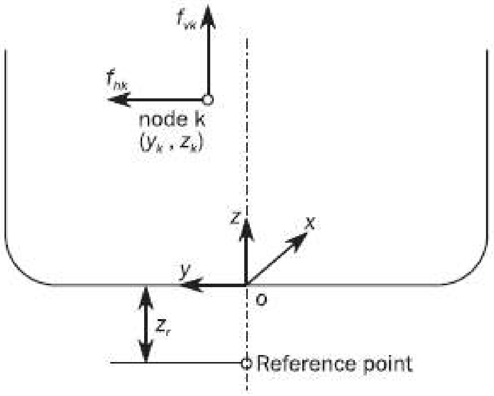


Figure 12 : Station forces and acting location of torsional moment at section

4.5.3 Hull girder torsional moment

The hull girder torsional moment, $M_{T-FEM}(x_j)$ in kNm, is obtained by accumulating the station torsional moment from the aft end section as follows:

$$M_{T-FEM}(x_j) = \sum_i M_{T-FEMi} \quad \text{when } x_i < x_j$$

where:

$M_{T-FEM}(x_j)$: Hull girder torsional moment, in kNm, at longitudinal station x_j.

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

The torsional moment distribution given in **[4.5.2]**, has a step at each longitudinal station.

4.5.4 Procedure to adjust hull girder torsional moment to target value

The torsional moment is to be adjusted by applying a hull girder torsional moment M_{T-end} in kNm, at the independent point of the aft end section of the model, given as follows:

$$M_{T-end} = M_{wt-targ} - M_{T-FEM}(x_{targ})$$

where:

x_{targ} : X-coordinate, in m, of the target location for hull girder torsional moment, as defined in **[4.3.5]**.

$M_{wt-targ}$: Target hull girder torsional moment, in kNm, specified in **[4.3.5],** to be achieved at the target location.

$M_{T-FEM}(x_{targ})$: Hull girder torsional moment, in kNm, at target location due to local loads.

Due to the step of hull girder torsional moment at each longitudinal station, the hull girder torsional moment is to be selected from the values aft and forward of the target location as follows: Maximum value for positive torsional moment and minimum value for negative torsional moment.

4.6 Summary of hull girder load adjustments

4.6.1

The required methods of hull girder load adjustments for cargo hold regions are given in **Table 7.**

Table 7 : Overview of hull girder load adjustments in FE analyses

	Midship cargo hold region
Adjustment of Vertical Shear Forces	See **[4.4.5]**
Adjustment of Bending Moments	See **[4.4.8]**
Adjustment of Torsional Moment	See **[4.5.4]**

5. Analysis criteria

5.1 General

5.1.1 Evaluation areas

Verification of results against the acceptance criteria is to be carried out within the longitudinal extent of the mid-hold, as shown in **Figure 13.**

For accidental condition, the evaluation is carried out for the members within one web frame forward and one frame aftward in way of cofferdam structure, where the collision load direction is coincided. Refer to **Figure 14.**

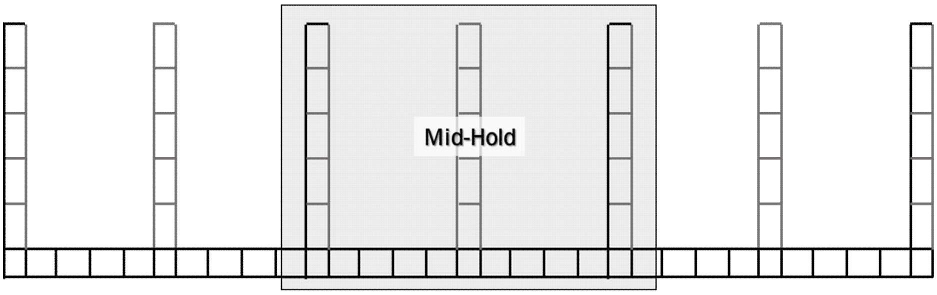


Figure 13 : Longitudinal extent of evaluation area

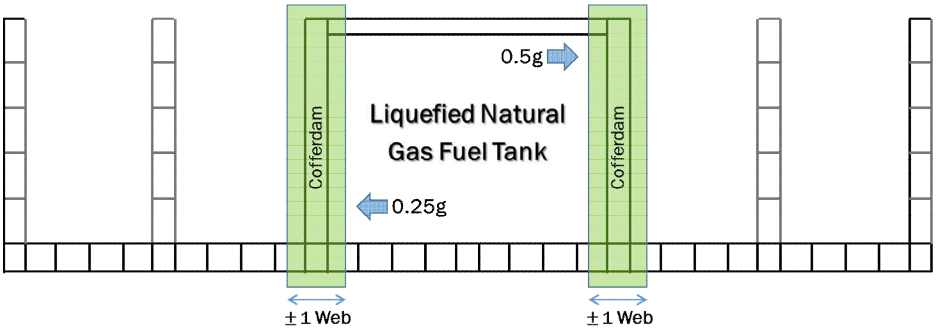


Figure 14 : Longitudinal extent of evaluation area for accidental condition

5.1.2 Structural members

The following structural elements within the evaluation area are to be verified with the criteria given in **[5.2]** and **[5.3]**:

- All hull girder longitudinal structural members.
- All primary supporting structural members and bulkheads within the mid-hold.
- All structural members being part of the transverse bulkheads.

5.2 Yield strength assessment

5.2.1 Von Mises stress

For all plates of the structural members defined in **[5.1.2]**, the von Mises stress, σ_{vm}, in N/mm^2, is to be calculated based on the membrane normal and shear stresses of the shell element. The stresses are to be evaluated at the element centroid of the mid-plane (layer), as follows:

$$\sigma_{vm} = \sqrt{\sigma_x^2 - \sigma_x \sigma_y + \sigma_y^2 + 3\tau_{xy}^2}$$

where:

σ_x, σ_y : Element normal membrane stresses, in N/mm^2.

τ_{xy} : Element shear stress, in N/mm^2.

5.2.2 Axial stress in beams and rod elements

For beams and rod elements, the axial stress, σ_{axial}, in N/mm^2, is to be calculated based on axial force alone. The axial stress is to be evaluated at the middle of element length.

5.2.3 Coarse mesh permissible yield utilisation factors

The coarse mesh permissible yield utilisation factors, λ_{yperm}, given in **Table 8**, are based on the mesh sizes and element types described in **[2.3]** to **[2.4]**.

The yield utilisation factor resulting from element stresses of each structural component are not to exceed the permissible values as given in **Table 8.**

5.2.4 Yield criteria

The structural elements given in **[5.1.2]** are to comply with the following criteria:

$\lambda_y \le \lambda_{yperm}$

where:

λ_y : Yield utilisation factor.

$\lambda_y = \dfrac{\sigma_{vm}}{R_Y}$ for shell elements in general.

$\lambda_y = \dfrac{|\sigma_{axial}|}{R_Y}$ for rod or beam elements in general.

σ_{vm} : Von Mises stress, in N/mm^2.

σ_{axial} : Axial stress in rod or beam element, in N/mm^2.

λ_{yperm} : Coarse mesh permissible yield utilisation factors defined in **Table 8.**

The yield check criteria is to be based on axial stress for the flange of primary supporting members.

Where the von Mises stress of the elements in the cargo hold FE model in way of the area under investigation by fine mesh exceeds the yield criteria, average von Mises stress, obtained from the fine mesh analysis, calculated over an area equivalent to the mesh size of the cargo hold finite element model is to satisfy the yield criteria above.

In way of cut-outs, yield utilisation factor is to be obtained with shear stress correction, as given in **[5.2.5]**.

Table 8 : Coarse mesh permissible yield utilisation factor

Structural component	Load combination	λ_{yperm}
Plating of all longitudinal hull girder structural members, primary supporting structural members and bulkheads. Face plate of primary supporting members modelled using shell or rod elements. Dummy rod of corrugated bulkhead	S + D	1.00
	S	0.80
	A, T	1.00
Corrugation of vertically corrugated bulkheads with lower stool and horizontally corrugated bulkhead, under lateral pressure from liquid loads, for shell elements only. Supporting structure in way of lower end of corrugated bulkheads without lower stool.	S + D	0.90
	S	0.72
	A, T	0.90
Corrugation of vertically corrugated bulkheads without lower stool under lateral pressure from liquid loads and without lower stool, for shell elements only.	S + D	0.81
	S	0.65
	A, T	0.81

5.2.5 Shear stress correction for cut-out

Except as indicated in **[5.2.6]**, the element shear stress in way of cut-outs in webs is to be corrected for loss in shear area in accordance with the following formula. The corrected element shear stress is to be used to calculate the von Mises stress of the element for verification against the yield criteria.

$$\tau_{cor} = \frac{h\,t_{\mathrm{mod}}}{A_{shr}}\tau_{elem}$$

where:

τ_{cor} : Corrected element shear stress, in N/mm^2.

h : Height of web of girder, in mm, in way of opening, see **Table 1**. Where the geometry of the opening is modelled, h is to be taken as the height of web of the girder deducting the height of the modelled opening.

t_{mod} : Modelled web thickness, in mm, in way of opening.

A_{shr} : Effective shear area of web, in mm^2, taken as the web area deducting the area lost of all openings, including slots for stiffeners, calculated in accordance with **Ch 3, Sec 7, [1.4.8]**.

τ_{elem} : Element shear stress, in N/mm^2, before correction.

5.2.6 Exceptions for shear stress correction for openings

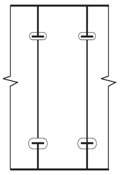
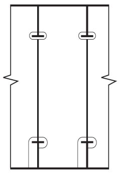
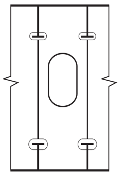
Correction of element shear stress due to presence of cut-outs is not required for cases given in **Table 9** provided λ_y / C_r complies with the criteria given in **[5.2.4]**.

5.3 Buckling strength assessment

5.3.1

All structural elements in FE analysis carried out in accordance with this Section are to be assessed individually against the buckling requirements as defined in **Ch 8, Sec 4.**

Table 9 : Exceptions for shear stress correction

Identification	Figure	Difference between modelled shear area and the effective shear area in % of the modelled shear area $\frac{A_{FEM}-A_{shr}}{A_{FEM}} \cdot 100\%$	Reduction factor for yield criteria, C_r
Upper and lower slots for local support stiffeners fitted with lugs or collar plates		$<$ 15 %	0.85
Upper or lower slots for local support stiffeners fitted with lugs or collar plates		$<$ 20 %	0.80
In way of opening; upper and lower slots for local support stiffeners fitted with collar plates		$<$ 40 %	0.60
A_{shr} : Effective shear area of web, in mm^2, taken as the web area deducting the area lost of all openings, including slots for stiffeners, calculated in accordance with **Ch 3, Sec 7, [1.4.8]**.			

Section 3 Local Structural Strength Analysis

1. Objective and scope

1.1 General

1.1.1

The local strength analysis of structural details is to be in accordance with the requirements given in this section.

1.1.2 Fine mesh analysis procedure

The details to be assessed by fine mesh analysis are to be modelled according to the requirements given in **[2]**, under the FE load combinations defined in **[3]** and to comply with the criteria given in **[4]**.

1.2 Modelling of standard structural details

The fine mesh analysis may be carried out the area of high stress concentration identified during coarse mesh analysis.

2. Structural modelling

2.1 General

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 fine mesh zones incorporated into the cargo hold model. Alternatively, separate local FE model with fine mesh zones in conjunction with the boundary conditions obtained from the cargo hold model may be used.

2.2 Extent of model

2.2.1

If a separate local fine mesh model is used, its extent is to be such that the calculated stresses at the areas of interest are not significantly affected by the imposed boundary conditions. The boundary of the fine mesh model is to coincide with primary supporting members in the cargo hold model, such as web frame, girders, stringers and floors.

2.3 Mesh size

2.3.1

The mesh size in the fine mesh zones is not to be greater than 50 × 50 mm.

2.3.2

The extent of the fine mesh zone is not to be less than 10 elements in all directions from the area under investigation. A smooth transition of mesh density from fine mesh zone to the boundary of the fine mesh model is to be maintained.

2.4 Elements

2.4.1

All plating within the fine mesh zone is to be represented by shell elements. The aspect ratio of elements within the fine mesh zone is to be kept as close to 1 as possible. Variation of mesh density within the fine mesh zone and the use of triangular elements are to be avoided. In all cases, the elements within the fine mesh model are to have an aspect ratio not exceeding 3. Distorted elements, with element corner angles of less than 45 ° or greater than 135 °, are to be avoided. Stiffeners inside the fine mesh zone are to be modelled using shell elements. Stiffeners outside the fine mesh zones may be modelled using beam elements.

2.4.2

Where fine mesh analysis is required for main bracket end connections and hatch opening, the fine mesh zone is to be extended at least 10 elements in all directions from the area subject to assessment, see **Figure 2.**

2.4.3

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 50 x 50 mm. 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 shell elements. Web stiffeners close to an opening may be modelled using rod or beam elements located at a distance of at least 50 mm from the edge of the opening. Example of fine mesh zone around an opening is shown in **Figure 3.**

2.4.4

Face plates of openings, primary supporting members and associated brackets are to be modelled with at least two elements across their width on either side.

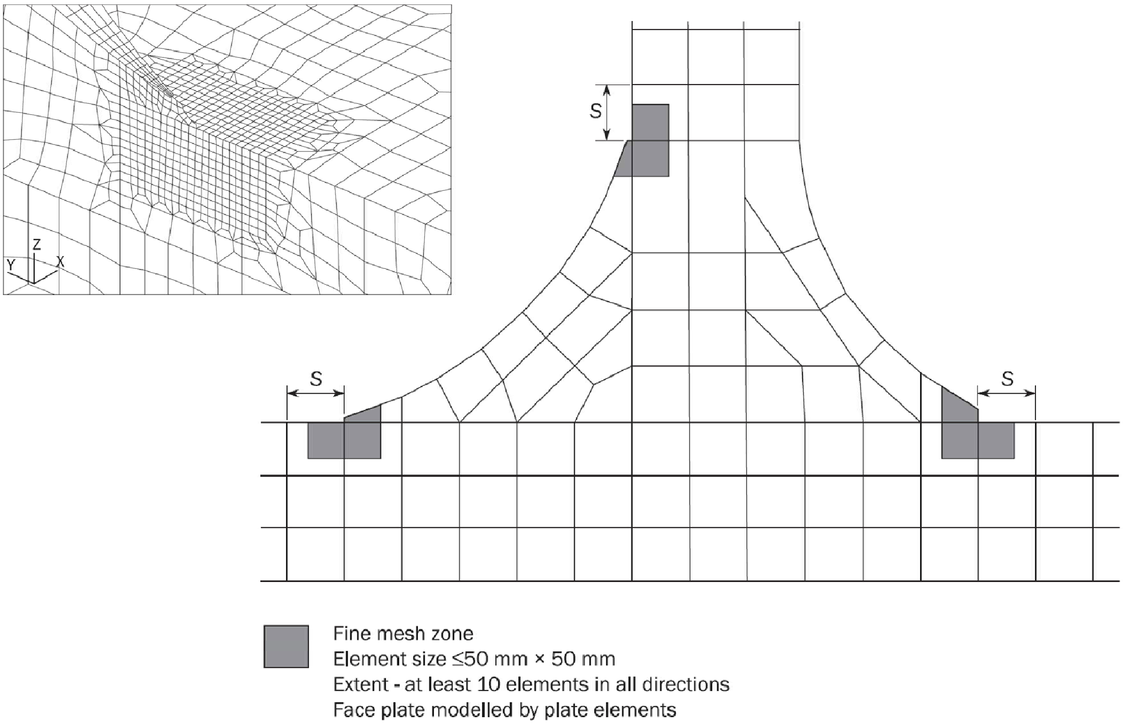


Figure 1 : Fine mesh zone around bracket toes

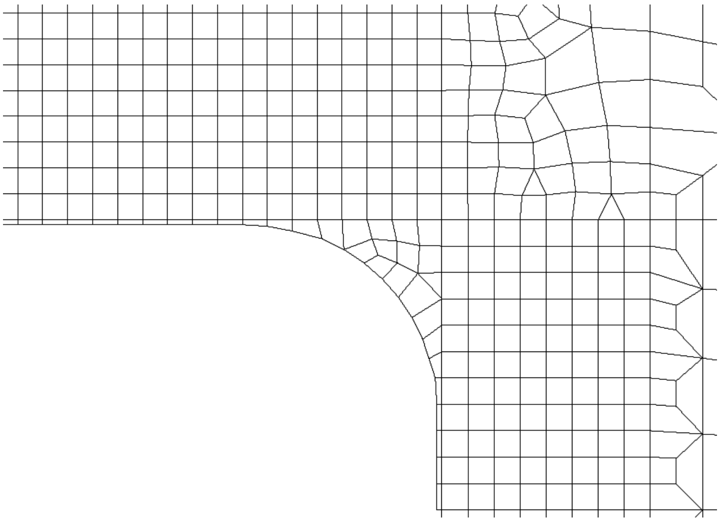


Figure 2 : Fine mesh zone around hatch opening structures

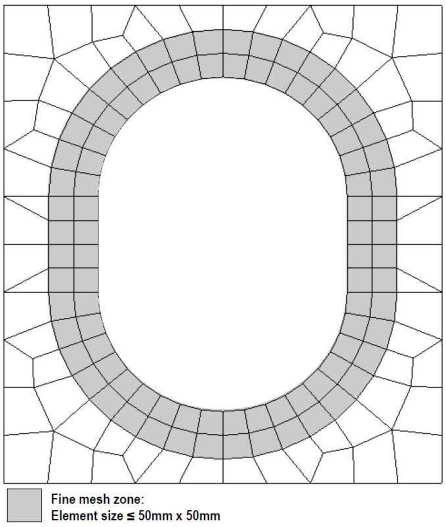


Figure 3 : Fine mesh zone around an opening

3. FE load combinations

3.1 General

3.1.1

The fine mesh detailed stress analysis is to be carried out for all FE load combinations applied to the corresponding cargo hold analysis.

3.2 Application of loads and boundary conditions

3.2.1 General

Where a separate local model is used for the fine mesh detailed stress analysis, the nodal displacements from the cargo hold model are to be applied to the corresponding boundary nodes on the local model as prescribed displacements. Alternatively, equivalent nodal forces from the cargo hold model may be applied to the boundary nodes.

Where there are nodes on the local model boundaries which are not coincident with the nodal points on the cargo hold 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.

All local loads, including any loads applied for hull girder bending moment and/or shear force adjustments, in way of the structure represented by the separate local finite element model are to be applied to the model.

4. Analysis criteria

4.1 Stress assessment

4.1.1 General

Stress assessment of the fine mesh analysis is to be carried out for the FE load combinations specified in **Ch 4, Sec 8**.

4.1.2 Reference stress

Reference stress is von Mises stress, σ_{vm}, which is to be calculated based on the membrane normal and shear stresses of the shell element evaluated at the element centroid. The stresses are to be evaluated at the mid plane of the element.

4.1.3 Permissible stress

The maximum permissible stresses are based on the mesh size of 50 x 50 mm as specified in **[2.1]** to **[2.4]**. Where a smaller mesh size is used, an area weighted von Mises stress calculated over an area equal to the specified mesh size may be used to compare with the permissible stresses. The averaging is to be based only on elements with their entire boundary located within the desired area. The average stress is to be calculated based on stresses at element centroid; stress values obtained by interpolation and/or extrapolation are not to be used. Stress averaging is not to be carried across structural discontinuities and abutting structure.

4.2 Acceptance criteria

4.2.1

Verification of stress results against the acceptance criteria is to be carried out in accordance with **[4.1]**. The structural assessment is to demonstrate that the stress complies with the following criteria:

$\lambda_f \le \lambda_{fperm}$

where:

λ_f : Fine mesh yield utilisation factor.

$\lambda_f = \dfrac{\sigma_{vm}}{R_Y}$ for shell elements in general.

$\lambda_f = \dfrac{|\sigma_{axial}|}{R_Y}$ for rod or beam elements in general.

σ_{vm} : Von Mises stress, in N/mm^2.

σ_{axial} : Axial stress in rod element, in N/mm^2.

λ_{fperm} : Permissible fine mesh utilisation factor, taken as:

a) Element not adjacent to weld:
- $\lambda_{fperm} = 1.70 f_f$ for AC-SD, AC-A and AC-T
- $\lambda_{fperm} = 1.36 f_f$ for AC-S

b) Element adjacent to weld:
- $\lambda_{fperm} = 1.50 f_f$ for AC-SD, AC-A and AC-T
- $\lambda_{fperm} = 1.20 f_f$ for AC-S

f_f : Fatigue factor, taken as:
- $f_f = 1.0$ in general, including the free edge of base material.
- $f_f = 1.2$ for details assessed by very fine mesh analysis complying with the fatigue assessment criteria given in **Ch 9, Sec 2.**

Note 1: The maximum permissible stresses are based on the mesh size of 50 x 50 mm. Where a smaller mesh size is used, an average von Mises stress calculated in accordance with **[4.1]** over an area equal to the specified mesh size may be used to compare with the permissible stresses.

Note 2: Average von Mises stress, σ_{vm-av}, is to be calculated based on weighted average against element areas:

$$\sigma_{vm-av} = \frac{\Sigma_1^n A_i \sigma_{vm-i}}{\Sigma_1^n A_i}$$

Note 3: Stress averaging is not to be carried across structural discontinuities and abutting structure.

4.2.2 Lower stool not fitted to a transverse or longitudinal corrugated bulkhead

Where a lower stool is not fitted to a transverse or longitudinal corrugated bulkhead, the permissible stresses given in **[4.2.1]** are to be reduced by 10% for the areas under investigation by fine mesh analysis. ⚓

Chapter 8

Buckling

Section 1 General

1. Introduction

1.1 Assumption

1.1.1

This chapter contains the strength criteria for buckling and ultimate strength of local supporting members, primary supporting members and other structures such as pillars, corrugated bulkheads and brackets. These criteria are to be applied as specified in Ch 6 for hull local scantlings and in Ch 7 for direct strength analysis.

1.1.2

For each structural member, the characteristic buckling strength is to be taken as the most unfavourable / critical buckling failure mode.

1.1.3

Unless otherwise specified, the scantling requirements of structural members in this chapter are based on net scantling obtained by removing t_c from the gross offered thickness, where t_c is defined in Ch 3, Sec 3.

1.1.4

In this chapter, compressive and shear stresses are to be taken as positive, tension stresses are to be taken as negative.

2. Application

2.1 Scope

2.1.1

The buckling checks are to be performed according to:

a) Sec 2 for the slenderness requirements of plates and longitudinal / transverse stiffeners.
b) Sec 3 for the prescriptive buckling requirements of plates, longitudinal and transverse stiffeners and primary supporting members.
c) Sec 4 for the buckling requirements of the FE analysis for the plates, longitudinal and transverse stiffeners and primary supporting members.
d) Sec 5 for the buckling capacity of prescriptive and FE buckling requirements.

2.1.2 Stiffener

The buckling check of the stiffeners referred to in this Chapter is applicable to the stiffener fitted along the long edge of the buckling panel.

2.1.3 Enlarged stiffener

Enlarged stiffeners, with or without web stiffening, used for Permanent Means of Access (PMA) are to comply with the following requirements:

a) Buckling strength of prescriptive requirements as follows:
   - For enlarged stiffener web, see Sec 3, [3.2].
   - For stiffeners fitted on enlarged stiffener web, see Sec 3, [3.1] and Sec 3, [3.3].
b) All structural elements used for PMA are to be complied with for the buckling requirements of the FE analysis in Sec 4 when applicable.

3. Definitions

3.1 General

3.1.1 Buckling definition

'Buckling' is used as a generic term to describe the strength of structures, generally under in-plane compressions and / or shear and lateral load. The buckling strength or capacity can take into account the internal redistribution of loads depending on the load situation, slenderness and type of structure.

3.1.2 Buckling capacity

Buckling capacity based on this principle gives a lower bound estimate of ultimate capacity, or the maximum load the panel can carry without suffering major permanent set.

Buckling capacity assessment utilises the positive elastic post-buckling effect for plates and accounts for load redistribution between the structural components, such as between plating and stiffeners. For slender structures, the capacity calculated using this method is typically higher than the ideal elastic buckling stress (minimum Eigen value). Accepting elastic buckling of structural components in slender stiffened panels implies that large elastic deflections and reduced in-plane stiffness will occur at higher buckling utilisation levels.

3.1.3 Assessment methods

The buckling assessment is carried out according to one of the two methods taking into account different boundary condition types:

a) Method A : All the edges of the elementary plate panel are forced to remain straight (but free to move in the in-plane directions) due to the surrounding structure / neighbouring plates.

b) Method B : The edges of the elementary plate panel are not forced to remain straight due to low in-plane stiffness at the edges and/or no surrounding structure / neighbouring plates.

3.2 Buckling utilisation factor

3.2.1

The utilisation factor, η, is defined as the ratio between the applied loads and the corresponding ultimate capacity or buckling strength.

3.2.2

For combined loads, the utilisation factor, η_{act}, is to be defined as the ratio of the equivalent applied stress and the corresponding buckling capacity, as shown in Figure 1, and is to be taken as:

$$\eta_{act} = \frac{W_{act}}{W_u} = \frac{1}{\gamma_c}$$

where:

W_{act} : Equivalent applied stress, in $\mathrm{N/mm^2}$, the actual applied stress are given in Sec 3 and Sec 4 respectively for buckling assessment by prescriptive and direct strength analysis.

W_u : Equivalent buckling capacity, in $\mathrm{N/mm^2}$, for plates and stiffeners, their respective buckling or ultimate capacities are given in Sec 5.

γ_c : Stress multiplier factor at failure.

For each typical failure mode, the corresponding capacity of the panel is calculated by applying the actual stress combination and then increasing or decreasing the stresses proportionally until collapse.

Figure 1 illustrates the buckling capacity and the buckling utilisation factor of a structural member subject to σ_x and σ_y stresses.

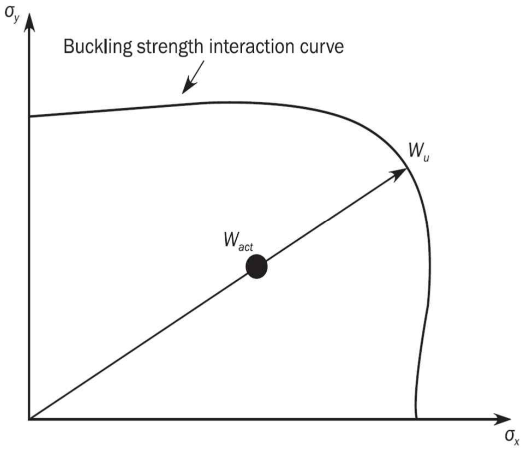


Figure 1 : Example of buckling capacity and buckling utilisation factor

3.3 Allowable buckling utilisation factor

3.3.1 General structural elements

The allowable buckling utilisation factor is defined in Table 1.

Table 1 : Allowable buckling utilisation factor, η_{all}

Structural component	Load combination	η_{all}
• Plates and stiffeners • Stiffened and unstiffened panels • Web plate in ways of openings	S + D	1.00
	S	0.80
	A, T	1.00
• Pillars	S + D	0.75
	S	0.65
	A, T	0.75
• Corrugation of vertically corrugated bulkheads with lower stool and horizontally corrugated bulkhead, under lateral pressure from liquid loads, for shell elements only. • Supporting structure in way of lower end of corrugated bulkheads without lower stool.	S + D	0.90
	S	0.72
	A, T	0.90
• Corrugation of vertically corrugated bulkheads without lower stool under lateral pressure from liquid loads, for shell elements only.	S + D	0.81
	S	0.65
	A, T	0.81

Note 1: Supporting structure for a transverse corrugated bulkhead refers to the structure in longitudinal direction within half a web frame space forward and aft of the bulkhead, and within a vertical extent equal to the corrugation depth.

Note 2: Supporting structure for a longitudinal corrugated bulkhead refers to the structure in transverse direction within three longitudinal stiffener spacings from each side of the bulkhead, and within a vertical extent equal to the corrugation depth.

3.4 Buckling acceptance criteria

3.4.1

A structural member is considered to have an acceptable buckling strength if it satisfies the following criterion:

$\eta_{act} \leq \eta_{all}$

where:

η_{act} : Buckling utilisation factor based on the applied stress, defined in [3.2.2].

η_{all} : Allowable buckling utilisation factor as defined in [3.3].

Section 2 Slenderness requirements

Symbols

For symbols not defined in this section, refer to Ch 1, Sec 4.

b_{f-out} : Maximum distance, in mm, from mid thickness of the web to the flange edge, as shown in Figure 1.

h_w : Depth of stiffener web, in mm, as shown in Figure 1.

ℓ : Length of stiffener between effective supports, in m

s_{eff} : Effective width of attached plate of stiffener, in mm, taken equal to:

$s_{eff} = 0.8\, s$

t_f : Net flange thickness, in mm.

t_p : Net thickness of plate, in mm.

t_w : Net web thickness, in mm.

1. Structural elements

1.1 General

1.1.1

All structural elements are to comply with the applicable slenderness and proportion requirements given in [2] to [6], except for the ones listed below:

- Bilge plates within the cylindrical part of the ship and radius gunwale;
- Corrugation
- Structure members in superstructures and deck houses, if the structural members do not contribute to the longitudinal strength.

2. Plates

2.1 Net thickness of plate panels

2.1.1

The net thickness of plate panels is to satisfy the following criteria:

$$t_p \geq \frac{b}{C}$$

where:

C : Slenderness coefficient taken as:

$C = 100$ for hull envelope

$C = 125$ for other structures.

3. Stiffeners

3.1 Proportions of stiffeners

3.1.1 Net thickness of all stiffener types

The net thickness of stiffeners is to satisfy the following criteria:

a) Stiffener web plate:

$$t_w \geq \frac{h_w}{C_w}\sqrt{\frac{R_{eH}}{235}}$$

b) Flange:

$$t_f \geq \frac{b_{t-out}}{C_f}\sqrt{\frac{R_{eH}}{235}}$$

where:

C_w, C_f : Slenderness coefficients given in Table 1.

If requirement b) is not fulfilled, the effective free flange outstand, in mm, used in strength assessment including the calculation of actual net section modulus, is not to be taken greater than:

$$b_{t-out-max} = C_f\, t_f\sqrt{\frac{235}{R_{eH}}}$$

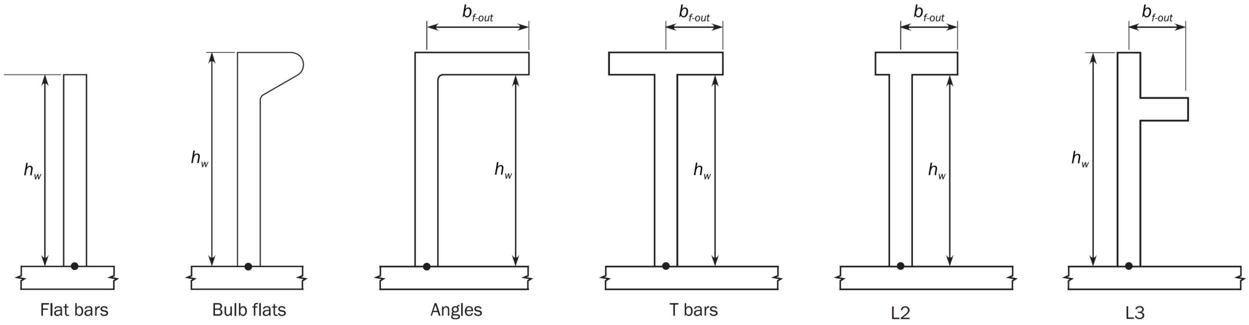


Figure 1 : Stiffener scantling parameters

Table 1 : Slenderness coefficients

Type of Stiffener	C_w	C_f
Angle, L2 and L3 bars	75	12
T-bars	75	12
Bulb bars	45	-
Flat bars	22	-

For built-up profile where the relevant yielding strength defined in Ch 6 and Ch 7 for the web of built-up profile without the edge stiffener is acceptable, as an alternative the web can be assessed according to the web requirements of Angle, L2 and L3 in Ch 8, Sec 2, Table 1 and the edge stiffener can be assessed as a flat bar stiffener according to [3.1.1]. The requirement to flange in [3.1.2] shall still apply.

3.1.2 Net dimensions of angle and T-bars

The total flange breadth, b_f in mm, for angle and T-bars is to satisfy the following criterion:

$$b_f \geq 0.2\, h_w$$

3.1.3 Bending stiffness of stiffeners

The net moment of inertia, in cm^4, of the stiffener with the effective width of attached plate, s_{eff}, about the neutral axis parallel to the attached plating, is not to be less than the minimum value given by:

$$I_{st} \geq C \ell^2 A_{eff} \frac{R_{eH}}{235}$$

where:

A_{eff} : Net sectional area of stiffener including effective attached plate, s_{eff}, in cm^2.

R_{eH} : Specified minimum yield stress of the material of the attached plate, in $\mathrm{N/mm}^2$.

C : Slenderness coefficient taken as:

C = 0.81for longitudinal stiffeners including sniped stiffeners.

C = 0.72for other stiffeners.

4. PRIMARY SUPPORTING MEMBERS

4.1 Proportions and stiffness

4.1.1 Proportions of web plate and flange

The net thicknesses of the web plates and flanges of primary supporting members are to satisfy the following criteria:

a) Web plate:

$$t_w \geq \frac{s_w}{C_w}\sqrt{\frac{R_{eH}}{235}}$$

b) Flange:

$$t_f \geq \frac{b_{f-out}}{C_f}\sqrt{\frac{R_{eH}}{235}}$$

where:

s_w : Plate breadth, in mm, taken as the spacing of the web stiffeners.

C_w : Slenderness coefficient for the web plate taken as:

$C_w = 125$	for double skin construction
$C_w = 100$	elsewhere

C_f : Slenderness coefficient for the flange taken as:

$C_f = 12$

If requirement b) is not fulfilled, the effective free flange outstand, in mm, used in strength assessment including the calculation of actual net section modulus, is not to be taken greater than:

$$b_{t-out-max} = C_f\, t_f \sqrt{\frac{235}{R_{eH}}}$$

4.1.2 Deck transverse primary supporting members

The net moment of inertia for deck transverse primary supporting members, $I_{psm-n50}$ in cm^4, supporting deck longitudinals subject to axial compressive hull girder stress, is to comply, within its central half of the bending span, with the following criterion:

$$I_{psm-n50} \geq 300 \frac{\ell_{bdg}^{4}}{S^3 s} I_{st}$$

where:

$I_{psm-n50}$: Net moment of inertia, in cm^4, of deck transverse primary supporting member, with effective width of attached plate equal to $0.8S$.

ℓ_{bdg} : Effective bending span of deck transverse primary supporting member, in m, as defined in Ch 3, Sec 7.

S : Spacing of deck transverse primary supporting members, in m, as defined in Ch 3, Sec 7.

I_{st} : Moment of inertia of deck stiffeners within the central half of the bending span, in cm^4, as given in [3.1.3].

4.2 Web stiffeners of primary supporting members

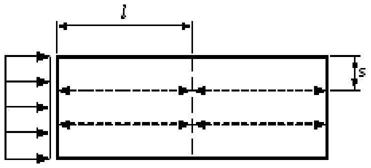
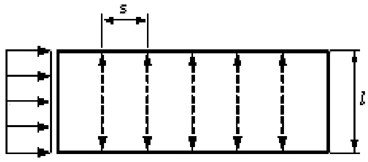
4.2.1 Proportions of web stiffeners

The net thickness of web and flange of web stiffeners fitted on primary supporting members is to satisfy the requirements specified in [3.1.1] and [3.1.2].

4.2.2 Bending stiffness of web stiffeners

The net moment of inertia, in cm^4, of web stiffener, I_{st}, fitted on primary supporting members, with effective attached plate, s_{eff}, is not to be less than the minimum moment of inertia defined in Table 2.

Table 2 : Stiffness criteria for web stiffeners

Stiffener arrangement		Minimum moment of inertia of web stiffeners, in cm^4
A	Web stiffeners fitted along the PSM span 	$I_{st} \geq C \ell^2 A_{eff} \dfrac{R_{eH}}{235}$
B	Web stiffeners fitted normal to the PSM span 	$I_{st} \geq 1.14\, \ell\, s^2 t_w \left(2.5 \dfrac{1000\,\ell}{s} - 2 \dfrac{s}{1000\,\ell}\right) \dfrac{R_{eH}}{235} 10^{-5}$

C : Slenderness coefficient to be taken as:
C = 0.81 for longitudinal stiffeners including sniped stiffeners.
C = 0.72 for other stiffeners.
ℓ : Length of web stiffener, in m.
For web stiffeners welded to local supporting members, 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 supporting member as shown for stiffener arrangement B.
A_{eff} : Net section area of web stiffener including effective attached plate, s_{eff}, in cm^2.
t_w : Net web thickness of the primary supporting member, in mm.
R_{eH} : Specified minimum yield stress of the material of the web plate of the primary supporting member, in $\mathrm{N/mm}^2$.

5. BRACKETS

5.1 Tripping brackets

5.1.1 Unsupported flange length

The unsupported length of the flange of the primary supporting member, in m, i.e. the distance between tripping brackets, is not to be greater than:

$$S_b = b_f C \sqrt{\frac{A_{f-n50}}{\left(A_{f-n50} + \dfrac{A_{w-n50}}{3}\right)} \left(\frac{235}{R_{eH}}\right)}$$, but need not be less than $S_{b-\min}$

where:

b_f : Flange breadth of primary supporting members, in mm.

C : Slenderness coefficient taken as:

$C = 0.022$ for symmetrical flanges.

$C = 0.033$ for asymmetrical flanges.

A_{f-n50} : Net cross sectional area of flange, in cm^2.

A_{w-n50} : Net cross sectional area of the web plate, in cm^2.

R_{eH} : Specified minimum yield stress of the PSM material, in $\mathrm{N/mm^2}$.

$S_{b-\min}$: Minimum unsupported flange length taken as:

$S_{b-\min} = 3.0\,\mathrm{m}$ for hold boundaries or hull envelope including external decks.

$S_{b-\min} = 4.0\,\mathrm{m}$ for other areas.

5.1.2 Edge stiffening

Tripping brackets on primary supporting members are to be stiffened by a flange or edge stiffener if the effective length of the edge, ℓ_b as defined in Table 3, in mm, is greater than:

$$\ell_b = 75\, t_b$$

where:

t_b : Bracket net web thickness, in mm.

5.2 End brackets

5.2.1 Proportions

The net web thickness of end brackets, in mm, subject to compressive stresses is not to be less than:

$$t_b = \frac{d_b}{C}\sqrt{\frac{R_{eH}}{235}}$$

where:

d_b : Depth of brackets, in mm, as defined in Table 3.

C : Slenderness coefficient as defined in Table 3.

R_{eH} : Specified minimum yield stress of the end bracket material, in $\mathrm{N/mm^2}$.

5.3 Edge reinforcement

5.3.1 Edge reinforcements of bracket edges

The depth of stiffener web, h_w in mm, of edge stiffeners in way of bracket edges is not to be less than:

$$h_w = \frac{C\,\ell_b}{1000}\sqrt{\frac{R_{eH}}{235}}$$ or 50 mm, whichever is greater.

where:

C : Slenderness coefficient taken as:

$C = 75$ for end brackets.

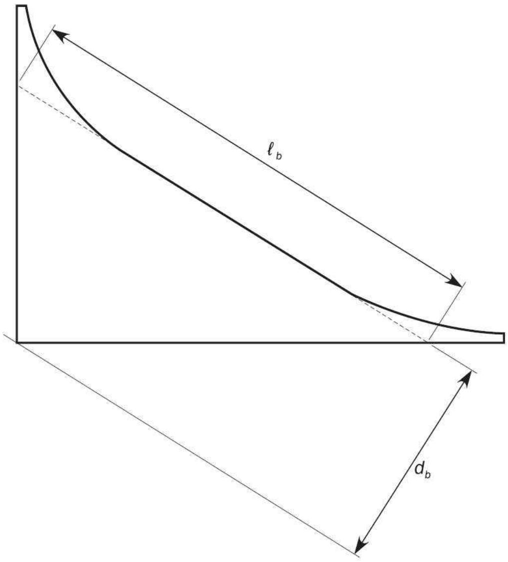
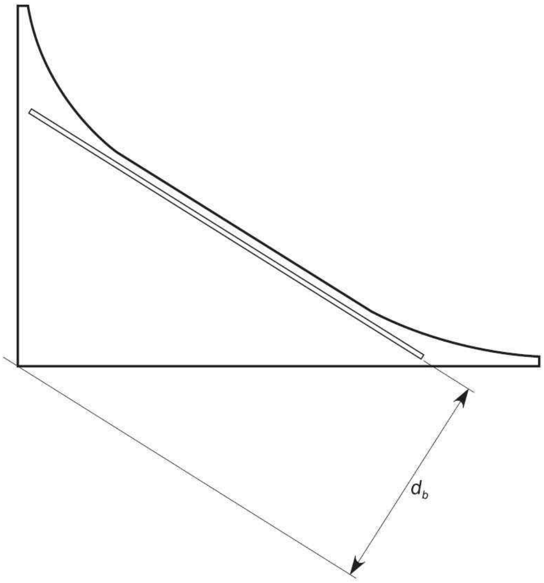
$C = 50$ for tripping brackets.

R_{eH} : Specified minimum yield stress of the stiffener material, in $\mathrm{N/mm^2}$.

5.3.2 Proportions of edge stiffeners

The net thickness of the web plate and flange of the edge stiffener is to satisfy the requirements specified in [3.1.1] and [3.1.2].

Table 3 : Buckling coefficient, C, for proportions of brackets

Mode	C
Brackets without edge stiffener 	$C = 20\left(\frac{d_b}{\ell_b}\right) + 16$ where: $0.25 \le \frac{d_b}{\ell_b} \le 1.0$
Brackets with edge stiffener 	$C = 70$

6. OTHER STRUCTURES

6.1 Pillars

6.1.1 Proportions of I-section pillars

For I-sections, the thickness of the web plate and the flange thickness are to comply with requirements specified in [3.1.1] and [3.1.2].

6.1.2 Proportions of box section pillars

The thickness of thin walled box sections is to comply with the requirements specified in item (a) of [3.1.1].

6.1.3 Proportions of circular section pillars

The net thickness, t, of circular section pillars, in mm, is to comply with the following criterion:

$$t \geq \frac{r}{50}$$

where:

r : Mid thickness radius of the circular section, in mm.

6.2 Edge reinforcement in way of openings

6.2.1 Depth of edge stiffener

When fitted as shown in Figure 2, the depth of web, h_w in mm, of edge stiffeners in way of openings is not to be less than:

$$h_w = C\,\ell\sqrt{\frac{R_{eH}}{235}}$$ or $50\ \mathrm{mm}$, whichever is greater.

where:

C : Slenderness coefficient taken as:

C = 50

R_{eH} : Specified minimum yield stress of the edge stiffener material, in $\mathrm{N/mm^2}$.

ℓ : Length of edge stiffener in way of opening, in m, as defined in Figure 2.

6.2.2 Proportions of edge stiffeners

The net thickness of the web plate and flange of the edge stiffener is to satisfy the requirements specified in [3.1.1] and [3.1.2].

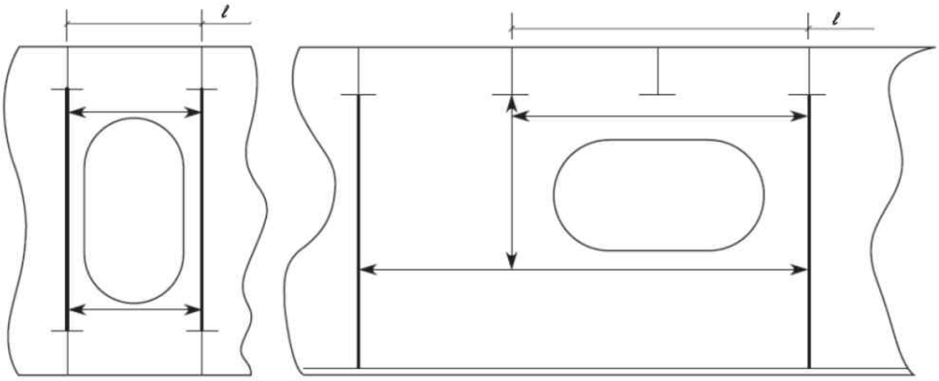


Figure 2 : Typical edge reinforcements

Section 3 Prescriptive buckling requirements

Symbols

η_{all} : Allowable buckling utilisation factor, as defined in Sec 1, [3.3].

EPP : Elementary Plate Panel as defined in Ch 3, Sec 7, [2.1].

LCP : Load calculation point as defined in Ch 3, Sec 7, [2.2.2] and Ch 3, Sec 7, [3.2].

1. General

1.1 Scope

1.1.1

This section applies to plate panels including curved plate panels and stiffeners subject to hull girder compression and shear stresses. In addition the following structural members subject to compressive stresses are to be checked.

- Corrugation of longitudinal corrugated bulkhead.
- Pillar.

1.1.2

The hull girder buckling strength requirements apply along the full length of the ship.

1.1.3 Design load sets

The buckling checks are to be performed for all design load sets defined in Ch 6, Sec 2, [2], both in intact and in flooded conditions with pressure combination defined in Ch 6, Sec 2, [1.3].

For each design load set, for all dynamic load cases, the lateral pressure is to be determined according to Ch 4 at the load calculation point defined in Ch 3, Sec 7, and is to be applied together with the hull girder stress combinations given in [2.2].

1.2 Equivalent plate panel

1.2.1

In longitudinal stiffening arrangement, when the plate thickness varies over the width b, of a plate panel, the buckling check is to be performed for an equivalent plate panel width, combined with the smaller plate thickness, t_1. The width of this equivalent plate panel, b_{eq}, in mm, is defined by the following formula:

$$b_{eq} = \ell_1 + \ell_2 \left(\frac{t_1}{t_2}\right)^{1.5}$$

where:

ℓ_1 : Width of the part of the plate panel with the smaller net plate thickness, t_1, in mm, as defined in Figure 1.

ℓ_2 : Width of the part of the plate panel with the smaller net plate thickness, t_2, in mm, as defined in Figure 1.

1.2.2

In transverse stiffening arrangement, when an *EPP* is made with different thicknesses, the buckling check of the plate and stiffeners is to be made for each thickness considered constant on the *EPP*, the stresses and pressures being estimated for the *EPP* at the *LCP*.

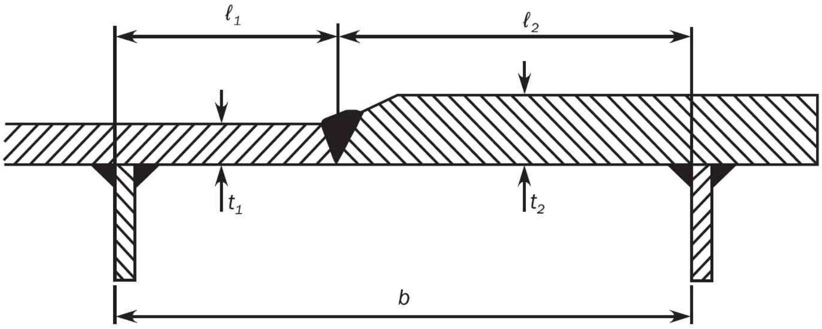


Figure 1 : Plate thickness change over the width

1.2.3

When the plate panel is made of different materials, the minimum yield strength is to be used for the buckling assessment.

2. Hull girder stress

2.1 General

2.1.1

The hull girder bending stresses, σ_{hg} in $\mathrm{N/mm^2}$, are determined according to Ch 6, Sec 2.

2.1.2

The hull girder shear stresses, τ_{hg}, in $\mathrm{N/mm^2}$, in the plate i are determined as follows:

$$\tau_{hg} = \frac{Q_{Tot}(x)\, q_{vi}}{t_{i-n50}} 10^3$$

where:

$Q_{Tot}(x)$: Total vertical shear force, in kN, at the ship longitudinal location x, taken as follows:

a) For the design load combination S + D

- For seagoing operations:

$$Q_{Tot}(x) = |Q_{sw} + Q_{wv-LC}|$$

b) For the design load combination S

- For harbour / sheltered water operations:

$$Q_{Tot}(x) = |Q_{sw-p}|$$

q_{vi} : Contribution ratio in way of the plate i, as defined in Ch 5, Sec 1, [3.2.1].

t_{i-n50} : Net thickness of the plate i, in mm as defined in Ch 5, Sec 1, [3.2.1], used for shear stress calculation.

Q_{sw} : Permissible positive or negative still water shear force for seagoing operation, in kN, at the hull transverse section considered, as defined in Ch 4, Sec 4, [2.3.1].

Q_{sw-p} : Permissible positive or negative still water shear force for harbour/sheltered operation, in kN, at the hull transverse section considered, as defined in Ch 4, Sec 4, [2.3.2].

Q_{wv-LC} : Vertical wave shear force in seagoing condition, in kN, in intact or flooded conditions at the hull transverse section considered for the considered dynamic load case, defined in Ch 4, Sec 4, [3.3].

2.2 Stress combinations

2.2.1

Each elementary plate panel and stiffeners are to satisfy the criteria defined in [3] with the following stress combinations:

a) Longitudinal stiffening arrangement

- Stress combination 1 with:

  $\sigma_x = \sigma_{hg}$

  $\sigma_y = 0.0$

  $\tau = 0.7\tau_{hg}$

- Stress combination 2 with:

  $\sigma_x = 0.7\sigma_{hg}$

  $\sigma_y = 0.0$

  $\tau = \tau_{hg}$

b) Transverse stiffening arrangement

- Stress combination 1 with:

  $\sigma_x = 0.0$

  $\sigma_y = \sigma_{hg}$

  $\tau = 0.7\tau_{hg}$

- Stress combination 2 with:

  $\sigma_x = 0.0$

  $\sigma_y = 0.7\sigma_{hg}$

  $\tau = \tau_{hg}$

where:

σ_{hg} : Hull girder bending stress in the elementary plate panel or stiffener, as defined in [2.1.1], in $\mathrm{N/mm^2}$.

τ_{hg} : Hull girder shear stress, in $\mathrm{N/mm^2}$, in the elementary plate panel or stiffener attached plate as defined in [2.1.2].

3. Buckling criteria

3.1 Overall stiffened panel

3.1.1

The buckling strength of overall stiffened panels is to satisfy the following criterion:

$\eta_{Overall} \le \eta_{all}$

where:

$\eta_{Overall}$: Maximum utilisation factor as defined in Sec 5, [2.1].

3.2 Plates

3.2.1

The buckling strength of elementary plate panels is to satisfy the following criterion:

$\eta_{Plate} \le \eta_{all}$

where:

η_{Plate} : Maximum plate utilisation factor calculated according to SP-A, as defined in Sec 5, [2.2].

3.3 Stiffeners

3.3.1

The buckling strength of stiffeners is to satisfy the following criterion:

$\eta_{Stiffener} \le \eta_{all}$

where:

$\eta_{Stiffener}$: Maximum stiffener utilisation factor, as defined in Sec 5, [2.3].

This capacity check can only be fulfilled when the overall stiffened panel capacity, as defined in [3.1.1], is satisfied.

3.4 Vertically corrugated longitudinal bulkheads

3.4.1

The shear buckling strength of vertically corrugated longitudinal bulkheads is to satisfy the following criterion:

$\eta_{Shear} \le \eta_{all}$

η_{Shear} : Maximum shear corrugated bulkhead utilisation factor.

$$\eta_{Shear} = \frac{\tau_{bhd}}{\tau_c}$$

τ_{bhd} : Hull girder shear stress, in $\mathrm{N/mm^2}$, in the longitudinal bulkhead as defined in [2.1.2].

τ_c : Shear critical stress, in $\mathrm{N/mm^2}$, as defined in Sec 5, [2.2.3].

3.5 Vertically corrugated longitudinal bulkheads

3.5.1

Each corrugation, within the extension of half flange, web and half flange, is to satisfy the following criterion:

$\eta \leq \eta_{all}$

η : Overall column utilisation factor, as defined in Sec 5, [3.1].

3.6 Pillars

3.6.1

The compressive buckling strength of pillars is to satisfy the following criterion:

$\eta_{Pillar} \leq \eta_{all}$

where:

η_{Pillar} : Maximum buckling utilisation factor of pillars defined in Sec 5, [3.1].

Section 4 Buckling requirements for DSA

Symbols

η_{all} : Allowable buckling utilisation factor, as defined in Sec 1, [3.3]

α : Aspect ratio of the plate panel, defined in Sec 5

1. General

1.1 Scope

1.1.1

The requirements of this Section apply for the buckling assessment of direct strength analysis subjected to compressive stress, shear stress and lateral pressure.

1.1.2

All structural elements in the FE analysis carried out according to Ch 7 are to be assessed individually. The buckling checks have to be performed for the following structural elements:

- Stiffened and unstiffened panels, inclusive curved panels.
- Web plate in way of openings.
- Corrugated bulkhead.
- Pillars

1.1.3 Design loading conditions

The buckling assessment of direct strength analysis is to be performed for standard loading conditions defined in Ch 4, Sec 8, [2.4], both in intact and in testing conditions.

2. Stiffened and unstiffened panels

2.1 General

2.1.1

The plate panel of hull structure is to be modelled as stiffened or unstiffened panel. Method A and Method B as defined in Sec 1, [3] are to be used according to Table 1.

- For PSM web panels with one of the long edges along the face plate or along the attached plating without "in-line support", i.e. the edge is free to pull in, Method B (SP-B or UP-B) shall be applied. In other cases Method A (SP-A or UP-A) is applicable.
- Typically the short plate edge is attached to the plate flanges and Method A (SP-A or UP-A) is applicable. However in case of one of the long edges is without "in-line support" and is free to pull in, Method B (SP-B or UP-B) shall be applied.

2.1.2 Average thickness of plate panel

Where the plate thickness along a plate panel is not constant, the panel used for the buckling assessment is to be modelled according to Ch 7 with a weighted average thickness taken as:

$$t_{avr} = \frac{\sum_{1}^{n} A_i t_i}{\sum_{1}^{n} A_i}$$

where:

A_i : Area of the i-th plate element.

t_i : Net thickness of the i-th plate element.

n : Number of finite elements defining the buckling plate panel.

2.1.3 Yield stress of the plate panel

The panel yield stress R_{eH-P} is taken as the minimum value of the specified yield stresses of the elements within the plate panel.

Table 1 : Structual members

Structural elements		Assessment method	Normal panel definition
Ordinary section, see Figure 1			
Longitudinally stiffened panels Shell envelope Longitudinal bulkhead Stringer deck(bench strucutre) Longitudinal bulkhead(bench strucutre)		SP-A	Length: between web frames Width: between PSM
Stringer in line with stringer deck(bench strucutre) Double bottom girder in line with longitudinal bulkhead(bench strucutre)		SP-A	Length: between web frames Width: full web depth
Upper deck		SP-B	Length: between web frames Width: between PSM
Stringers in double side Double bottom girders		SP-B	Length: between web frames Width: full web depth
Hatch coaming top Hatch side coaming		UP-B	Length: between web frames Width: between PSM
Typical web section, see Figure 2			
Vertical web in double side	Regularly stiffened web between PSM	SP-B	Length: full web depth Width: between PSM
	Irregularly stiffened web between PSM	UP-B	Plate between local stiffeners/face plate/PSM
Double bottom floor		SP-B	Length: full web depth Width: between PSM
Webs in passage way and duct keel Irregularly stiffened web panels in way of bilge		UP-B	Plate between local stiffeners/face plate/PSM
Watertight bulkhead, see Figure 3			
Bulkhead plating	Regularly stiffened panels	SP-A	Length: between PSM Width: between PSM
	Irregularly stiffened panels	UP-A	Plate between local stiffeners/face plate/PSM
Vertical web in double side	Regularly stiffened web between PSM	SP-A	Length: between PSM Width: between PSM
	Irregularly stiffened web between PSM	UP-A	Plate between local stiffeners/face plate/PSM
Double bottom floor		SP-A	Length: between PSM Width: between PSM
Irregularly stiffened web panels in way of bilge		UP-B	Plate between local stiffeners/face plate/PSM
Support bulkhead, see Figure 4			
Vertical web in double side in way of large end bracket of box girder		SP-A	Length: full web depth Width: between PSM
Box girder		SP-B	Length: between PSM Width: between PSM
Vertical webs Horizontal stringers		SP-B	Length: between PSM Width: full web depth
Large end bracket of box girder		UP-B	Plate between local stiffeners/face plate/PSM
Transverse corrugated bulkheads			
Upper/lower stool including stiffeners		SP-A	Length: between internal web diaphragms Width: length of stool side
Stool internal web diaphragm		UP-B	Plate between local stiffeners /face plate / PSM

Note
1. SP and UP stand for stiffened and unstiffened panel respectively.
2. A and B stand for Method A and Method B respectively.

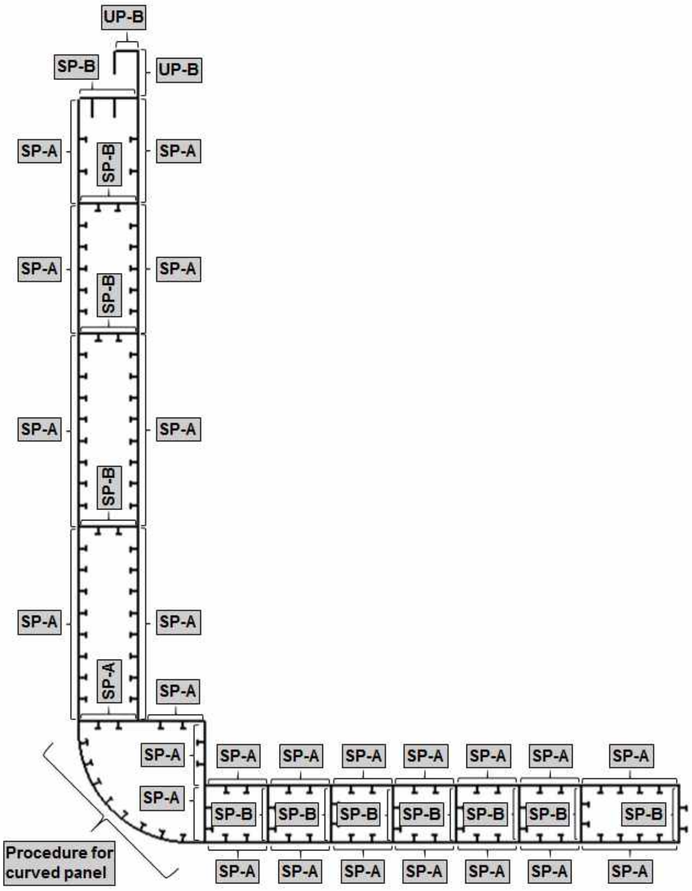


Figure 1 : Longitudinal plates for container ship

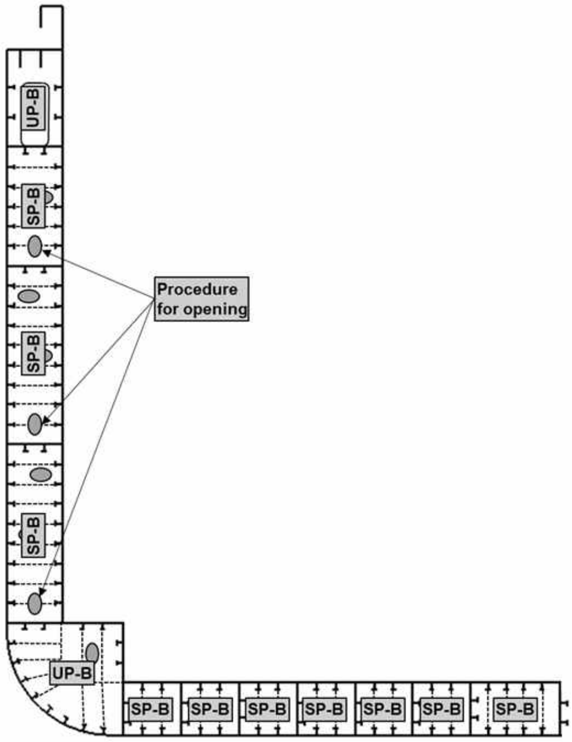


Figure 2 : Transverse web frames for container ship

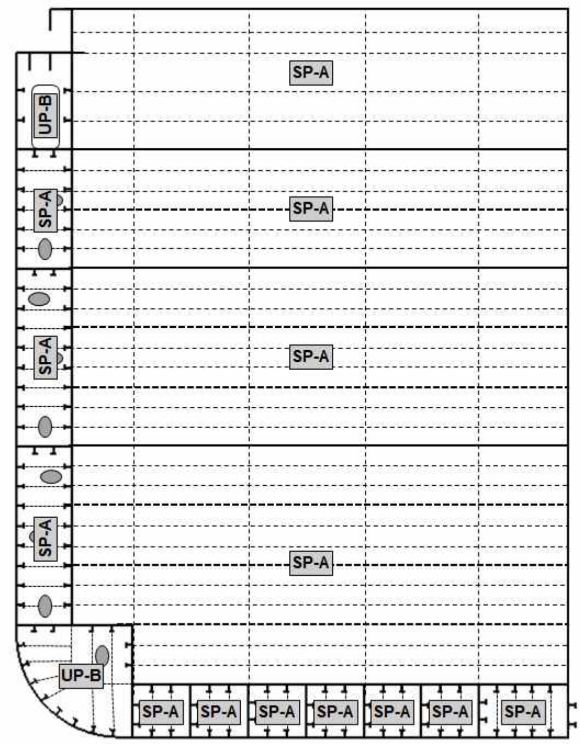


Figure 3 : Transverse bulkhead for container ship

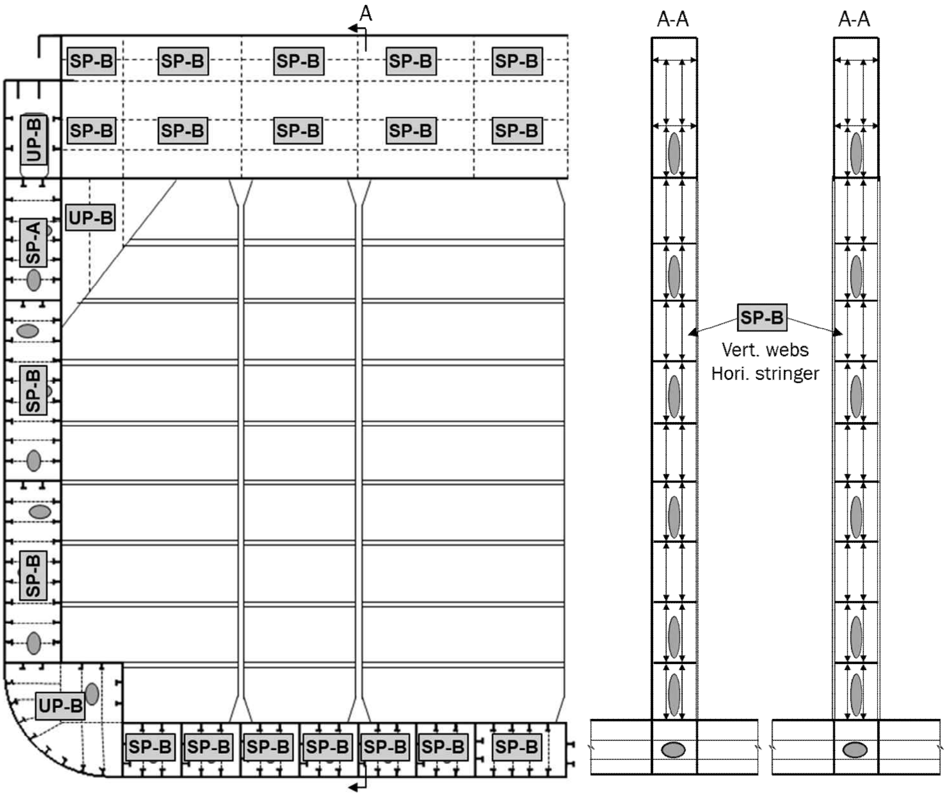


Figure 4 : Support bulkhead for container ship

2.2 Stiffened panels

2.2.1

If the stiffener properties or stiffener spacing varies within the stiffened panel, the calculations are to be performed separately for all configurations of the panels, i.e. for each stiffener and plate between the stiffeners. Plate thickness, stiffener properties and stiffener spacing at the considered location are to be assumed for the whole panel.

2.3 Unstiffened panels

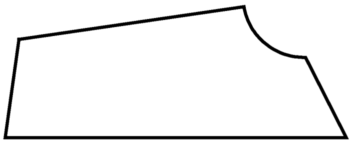
2.3.1 Irregular plate panel

In way of web frames, stringers and brackets, the geometry of the panel (i.e. plate bounded by web stiffeners / face plate) may not have a rectangular shape. In this case, an equivalent rectangular panel is to be defined according to [2.3.2] for irregular geometry and [2.3.3] for triangular geometry and to comply with buckling assessment.

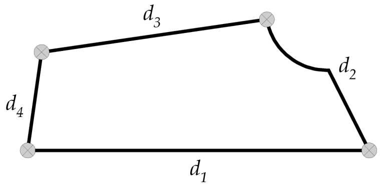
2.3.2 Modelling of an unstiffened panel with irregular geometry

Unstiffened panels with irregular geometry are to be idealised to equivalent panels for plate buckling assessment according to the following procedure:

a) The four corners closest to a right angle, 90 deg, in the bounding polygon for the plate are identified.

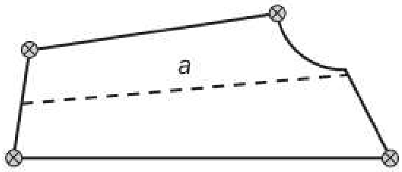


b) The distances along the plate bounding polygon between the corners are calculated, i.e. the sum of all the straight line segments between the end points.



c) The pair of opposite edges with the smallest total length is identified, i.e. minimum of d_1+d_3 and d_2+d_4.

d) A line joins the middle points of the chosen opposite edges (i.e. a mid point is defined as the point at half the distance from one end). This line defines the longitudinal direction for the capacity model. The length of the line defines the length of the capacity model, a measured from one end point.



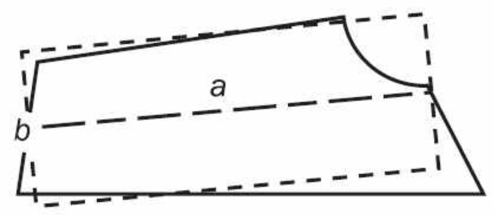
e) The length of shorter side, b in mm, is to be taken as:

$b = A/a$

where:

A : Area of the plate, in mm^2

a : length defined in (d), in mm

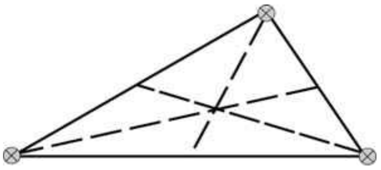


f) The stresses from the direct strength analysis are to be transformed into the local coordinate system of the equivalent rectangular panel. These stresses are to be used for the buckling assessment.

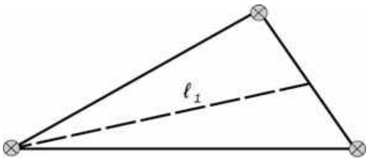
2.3.3 Modelling of an unstiffened plate panel with triangular geometry

Unstiffened panels with triangular geometry are to be idealised to equivalent panels for plate buckling assessment according to the following procedure:

a) Medians are constructed as shown below.



b) The longest median is identified. This median the length of which is ℓ_1 in mm, defines the longitudinal direction for the capacity model.

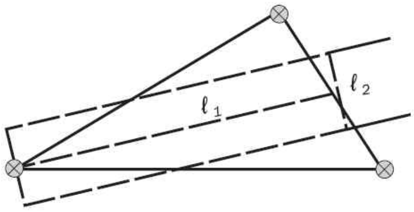


c) The width of the model, ℓ_2, in mm, is to be taken as:

$\ell_2 = A/\ell_1$

where:

A : Area of the plate, in mm^2.



d) The lengths of shorter side, b, and of the longer side, a, in mm, of the equivalent rectangular plate panel are to be taken as:

$$b = \frac{\ell_2}{C_{tri}}$$

$$a = \ell_1 C_{tri}$$

where:

$$C_{tri} = 0.4\frac{\ell_2}{\ell_1} + 0.6$$

e) The stresses from the direct strength analysis are to be transformed into the local coordinate system of the equivalent rectangular panel and are to be used for the buckling assessment of the equivalent rectangular panel.

2.4 Reference stress

2.4.1

The stress distribution is to be taken from the direct strength analysis and applied to the buckling model.

2.4.2

The reference stresses are to be calculated using the Stress based reference stresses as defined in Ch 8, Sec 6.

2.5 Lateral pressure

2.5.1

The lateral pressure applied to the direct strength analysis is also to be applied to the buckling assessment.

2.5.2

Where the lateral pressure is not constant over a buckling panel defined by a number of finite plate elements, an average lateral pressure, $\mathrm{N/mm^2}$, is calculated using the following formula:

$$P_{avr} = \frac{\sum_{1}^{n} A_i P_i}{\sum_{1}^{n} A_i}$$

where:

A_i : Area of the i-th plate element, in $\mathrm{mm^2}$.

P_i : Lateral pressure of the i-th plate element, in $\mathrm{N/mm^2}$.

n : Number of finite elements in the buckling panel.

2.6 Buckling criteria

2.6.1 UP-A

The compressive buckling strength of UP-A is to satisfy the following criterion:

$$\eta_{UP-A} \le \eta_{all}$$

where:

η_{UP-A} : Maximum plate utilisation factor, calculated according to Method A as defined in Ch 8, Sec 5, [2.2].

2.6.2 UP-B

The compressive buckling strength of UP-B is to satisfy the following criterion:

$$\eta_{UP-B} \le \eta_{all}$$

where:

η_{UP-B} : Maximum plate utilisation factor, calculated according to Method B as defined in Ch 8, Sec 5, [2.2].

2.6.3 SP-A

The compressive buckling strength of SP-A is to satisfy the following criterion:

$\eta_{SP-A} \leq \eta_{all}$

where:

η_{SP-A} : Maximum stiffened panel utilisation factor taken as the maximum of:

a) The overall stiffened panel capacity as defined in Ch 8, Sec 5, [2.1].

b) The plate capacity calculated according to Method A as defined in Ch 8, Sec 5, [2.2].

c) The stiffener buckling strength as defined in Ch 8, Sec 5, [2.3] considering separately the properties (thickness, dimensions), the pressures defined in [2.5.2] and the reference stresses of each EPP at both sides of the stiffener.

Note 1: The stiffener buckling capacity check can only be fulfilled when the overall stiffened panel capacity, as defined in Ch 8, Sec 5, [2.1], is satisfied.

2.6.4 SP-B

The compressive buckling strength of SP-B is to satisfy the following criterion:

$\eta_{SP-B} \leq \eta_{all}$

where:

η_{SP-B} : Maximum stiffened panel utilisation factor taken as the maximum of:

a) The overall stiffened panel capacity as defined in Ch 8, Sec 5, [2.1].

b) The plate capacity calculated according to Method B as defined in Ch 8, Sec 5, [2.2].

c) The stiffener buckling strength as defined in Ch 8, Sec 5, [2.3] considering separately the properties (thickness, dimensions), the pressures defined in [2.5.2] and the reference stresses of each EPP at both sides of the stiffener.

Note 1: The stiffener buckling capacity check can only be fulfilled when the overall stiffened panel capacity, as defined in Ch 8, Sec 5, [2.1], is satisfied.

2.6.5 Web plate in way of openings

The web plate of primary supporting members with openings is to satisfy the following criterion:

$\eta_{opening} \leq \eta_{all}$

where:

$\eta_{opening}$: Maximum web plate utilisation factor in way of openings, as defined in Ch 8, Sec 5, [2.4].

3. CORRUGATED BULKHEAD

3.1 General

3.1.1

Three buckling failure modes are to be assessed on corrugated bulkheads.

- Corrugation overall column buckling.
- Corrugation flange panel buckling.
- Corrugation web panel buckling.

3.2 Reference stress

3.2.1

The membrane stresses at element centroid are to be used.

3.2.2

The maximum normal stress parallel to the corrugation, σ_x, is the maximum of the 2 following stresses:

- The normal stress parallel to the corrugation taken at $b/2$ from the corrugation ends,
- The normal stress parallel to the corrugation within the mid span of the corrugation.

When the corrugation end is fitted with a shedder plate, the normal stress parallel to the corrugation at end is to be taken at $b/2$ from the intersection of the shedder plate with the point at mid breadth of the flange or of the web, as the case may be.

The maximum shear stress is the shear stress which is maximum at the corrugation flange or web at the point $b/2$ from ends as defined above for the normal stress parallel to the corrugation.

The in plane stresses, a_x and a_y, and shear stress, τ, are to be taken as the element stresses averaged over the width of the considered member (flange or web) at the considered location.

When the stress value at $b/2$ from ends cannot be obtained directly from FE element, the stress at this location is to be obtained by interpolation. This interpolation is to be made on elements extending over a distance equal to $3b$ to a point located at $b/2$ from the end of the corrugation or from the intersection of the shedder plate if fitted, measured at the mid breadth of the flange or of the web. The interpolation of the in plane stresses, a_x and a_y, are to be made in accordance with App 1, [2.1].

The shear stress at $b/2$ is obtained by linear interpolation between the elements most close to '$b/2$' location.

For the application of this requirement, b is defined as follows:

b : Width of the considered member of the corrugation, i.e. flange or web.

3.2.3

Where more than one plate thicknesses are used for flange or web panel, maximum stress is to be obtained for each thickness range and to be checked with the buckling criteria for each thickness.

3.3 Overall column buckling

3.3.1

The overall buckling failure mode of corrugated bulkheads subjected to axial compression is to be checked for column buckling (e.g. horizontally corrugated bulkheads and vertically corrugated bulkheads subjected to local vertical forces).

Table 2 : Application of overall column buckling for corrugated bulkhead

Bulkhead orientation	Corrugation Orientation	
	Horizontal	Vertical
Longitudinal bulkhead	Required	Required, when subjected to local vertical forces (e.g. crane loads)
Transverse bulkhead	Required	

3.3.2

Each corrugation unit within the extension of half flange, web and half flange (i.e. single corrugation as shown in grey in Figure 10) is to satisfy the following criterion:

$$\eta_{Overall} \leq \eta_{all}$$

$\eta_{Overall}$: Maximum overall column utilisation factor, as defined in Sec 5, [3.1.1] and Sec 5, [3.1.2], considered as a pillar with a unsupported length taken as the length of the corrugation.

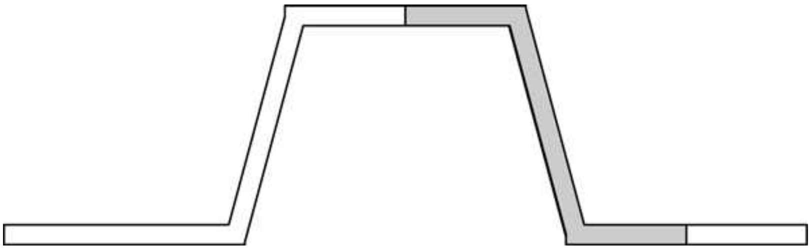


Figure 10 : Single Corrugation

3.3.3

End constraint factor, fend corresponding to pinned ends is to be applied except for fixed end support to be used in way of stool with width exceeding 2 times the depth of the corrugation.

3.4 Local buckling

3.4.1

The compressive buckling strength of a unit flange and a unit web of corrugation bulkheads is to satisfy the following criterion:

$\eta_{Overall} \leq \eta_{all}$

η_{Corr} : Maximum unit flange or unit web utilisation factor, as defined in Sec 5, [3.2.1].

Two stress combinations are to be considered for the application of the above criterion:

- The maximum normal stress parallel to the corrugation, σ_x , combined with the stress perpendicular tothe corrugation, σ_y, and with the shear stress, τ, at the location where the maximum normal stress parallel to the corrugation occurs.
- The maximum shear stress, τ, combined with the normal stress parallel to the corrugation, σ_x, and with the stress perpendicular to the corrugation, σ_y, at the location where the maximum shear stress occurs.

The buckling assessment is to be performed for an aspect ratio α equal to 2, and for the thicknesses of the member where the maximum compressive/shear stress occurs (see [3.2.4]).

4. Pillars

4.1 Buckling criteria

4.1.1

The compressive buckling strength of pillars is to satisfy the following criterion:

$\eta_{pillar} \leq \eta_{all}$

where:

$\eta_{\pi llar}$: Maximum buckling utilisation factor of pillars defined in Ch 8, Sec 5, [3.1].

Section 5 Buckling capacity

Symbols

For symbols not defined in this section, refer to Ch 1, Sec 4.

A_p : Net sectional area of the stiffener attached plating, in mm^2, taken as:

$A_p = st_p$

A_s : Net sectional area of the stiffener without attached plating, in mm^2.

a : Length of the longer side of the plate panel, in mm.

b : Length of the shorter side of the plate panel, in mm.

b_{eff} : Effective width of the attached plating of a stiffener, in mm, as defined in [2.3.5].

b_{eff1} : Effective width of the attached plating of a stiffener, in mm, without the shear lag effect taken as:

- For $\sigma_x > 0$
  - For prescriptive assessment:

$$b_{eff1} = \frac{C_{x1}b_1 + C_{x2}b_2}{2}$$

  - For FE analysis:

$$b_{eff1} = C_x b$$

- For $\sigma_x \le 0$

$$b_{eff1} = b$$

b_f : Breadth of the stiffener flange, in mm.

b_1, b_2 : Width of plate panel on each side of the considered stiffener, in mm.

C_{x1}, C_{x2} : Reduction factor defined in Table 3 calculated for the EPP1 and EPP2 on each side of the considered stiffener according to case 1.

d : Length of the side parallel to the axis of the cylinder corresponding to the curved plate panel as shown in Table 4, in mm.

d_f : Distance in mm, for the extension of flange for L2 profiles, as defined in Ch 3, Sec 2, Figure 3.

d_e : Distance from upper edge of web to the top of the flange, in mm, as defined in Ch 3, Sec 2, Figure 3.

e_f : Distance from attached plating to centre of flange, in mm, to be taken as:

$e_f = h_w$ for flat bar profile.

$e_f = h_w - 0.5t_f$ for bulb profile.

$e_f = h_w + 0.5t_f$ for angle, L2 and Tee profiles.

$e_f = h_w - d_e - 0.5t_f$ for L3 profile.

F_{long} : Coefficient defined in [2.2.4].

F_{tran} : Coefficient defined in [2.2.5].

h_w : Depth of Stiffener web, in mm, as shown in Figure 1.

ℓ : Span, in mm, of stiffener equal to the spacing between primary supporting members.

R : Radius of curved plate panel, in mm.

R_{eH_P} : Specified minimum yield stress of the plate, in $\mathrm{N/mm^2}$.

R_{eH_S} : Specified minimum yield stress of the stiffener, in $\mathrm{N/mm^2}$.

S : Partial safety factor to be taken as:

- $S = 1.1$ for structures which are exposed to local concentrated loads (e.g. container loads on hatch covers, foundations).
- $S = 1.0$ for all other cases.

t_p : Net thickness of plate panel, in mm.

t_w : Net stiffener web thickness, in mm.

t_f : Net flange thickness, in mm.

x_{axis} : Local axis of a rectangular buckling panel parallel to its long edge.

y_{axis} : Local axis of a rectangular buckling panel perpendicular to its long edge.

α : Aspect ratio of the plate panel, defined in Table 3 to be taken as:

$$\alpha = \frac{a}{b}$$

β : Coefficient taken as

$$\beta = \frac{1-\psi}{\alpha}$$

w : Coefficient taken as

$$w = \min(3;\alpha)$$

σ_x : Stress applied on the edge along x axis of the buckling panel, in $\mathrm{N/mm^2}$.

σ_y : Stress applied on the edge along y axis of the buckling panel, in $\mathrm{N/mm^2}$.

σ_1 : Maximum stress, in $\mathrm{N/mm^2}$.

σ_2 : Minimum stress, in $\mathrm{N/mm^2}$.

σ_E : Elastic buckling reference stress, in $\mathrm{N/mm^2}$ to be taken as

- For the application of plate limit state according to [2.2.1]

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_p}{b}\right)^2$$

- For the application of curved plate panels according to [2.2.6]

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_p}{d}\right)^2$$

τ : Applied shear stress, in $\mathrm{N/mm^2}$.

τ_c : Buckling strength in shear, in $\mathrm{N/mm^2}$, as defined in [2.2.3]

ψ : Edge stress ratio to be taken as

$$\psi = \frac{\sigma_2}{\sigma_1}$$

γ : Stress multiplier factor acting on loads. When the factor is such that the loads reach the interaction formulae, $\gamma = \gamma_c$

γ_c : Stress multiplier factor at failure

γ_{GEB} : Stress multiplier factor of global elastic buckling capacity.

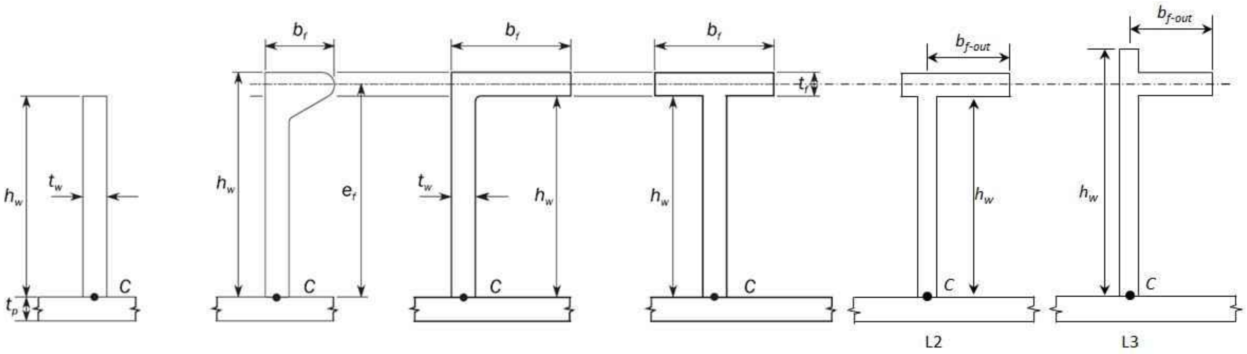


Figure 1 : Stiffener cross sections

1. General

1.1 Scope

1.1.1

This section contains the methods for determination of the buckling capacity of plate panels, stiffeners, primary supporting members, pillars and corrugated bulkheads.

As accepted by the Society, assessment of local plate panel can only be performed in accordance with Sec 4.

1.1.2

For the application of this section, the stresses σ_x, σ_y and τ applied on the structural members are defined in:

- Sec 3 for prescriptive requirements.
- Sec 4 for FE analysis requirements.

1.1.3 Ultimate buckling capacity

The ultimate buckling capacity is calculated by applying the actual stress combination and then increasing or decreasing the stresses proportionally until the interaction formulae defined in [2.1.1], [2.2.1], and [2.3.4] are equal to 1.0.

1.1.4 Buckling utilisation factor

The buckling utilisation factor of the structural member is equal to the highest utilisation factor obtained for the different buckling modes.

1.1.5 Lateral pressure

The lateral pressure is to be considered as constant in the buckling strength assessment.

2. Buckling capacity of plates and stiffeners

2.1 Overall stiffened panel capacity

2.1.1

The elastic stiffened panel limit state is based on the following interaction formula, which sets a precondition for the buckling check of stiffeners in accordance with [2.3.4]:

$$\frac{\gamma}{\gamma_{GEB}} = 1$$

where the stress multiplier factor corresponding to global elastic buckling capacity, γ_{GEB}, is to be calculated based on the following formulae:

$\gamma_{GEB} = \gamma_{GEB,bi+\tau}$ for $\tau \neq 0$ and $(\sigma_x > 0$ or $\sigma_y > 0)$

$\gamma_{GEB} = \gamma_{GEB,bi}$ for $\tau = 0$ and $(\sigma_x > 0$ or $\sigma_y > 0)$

$\gamma_{GEB} = \gamma_{GEB,\tau}$ for $\tau \neq 0$and $(\sigma_x \leq 0$ and $\sigma_y \leq 0)$

where $\gamma_{GEB,bi+\tau}$, $\gamma_{GEB,bi}$ and $\gamma_{GEB,\tau}$ are stress multiplier factors for different load combinations as defined in [2.1.2], [2.1.3] and [2.1.4], respectively. For the calculation of $\gamma_{GEB,bi+\tau}$, $\gamma_{GEB,bi}$ and $\gamma_{GEB,\tau}$, neither σ_x nor σ_y shall be taken less than 0.

σ_x, σ_y : Applied normal stresses to the plate panel, in $\mathrm{N/mm^2}$, to be taken as defined in [2.2.7].

τ : Applied shear stress, in $\mathrm{N/mm^2}$, to be taken as defined in [2.2.7].

2.1.2

The stress multiplier factor $\gamma_{GEB,bi}$ for the stiffened panel subjected to biaxial loads is taken as:

$$\gamma_{GEB,bi} = \frac{\pi^2}{L_{B1}^2 L_{B2}^2} \frac{\left[D_{11} L_{B2}^4 + 2(D_{12} + D_{33}) n^2 L_{B1}^2 L_{B2}^2 + n^4 D_{22} L_{B1}^4\right]}{L_{B2}^2 N_x + n^2 L_{B1}^2 N_y}$$

where:

N_x : Load per unit length applied on the edge along x axis of the stiffened panel, in $\mathrm{N/mm}$, taken as

$N_x = \sigma_{x,av}(A_p + A_s)/s$

For stiffened panels fitted with U-type stiffeners, stiffener spacing s is taken as:

$s = b_1 + b_2$

where b_1 and b_2 are as defined in Figure 2.

N_y : Load per unit length applied on the edge along y axis of the stiffened panel, in $\mathrm{N/mm}$, taken as:

$N_y = c\,\sigma_y t_p$

L_{B1} : Stiffener span, in mm, equal to spacing between primary supporting members, i.e. $L_{B1} = \ell$

For vertically stiffened side shell of single side skin bulk carriers, $L_{B1} = 0.8\ell$

L_{B2} : Width of the stiffened panel, in mm, taken as 6 times of the stiffener spacing, i.e. $6s$

n : Number of half waves along the direction perpendicular to the stiffener axis. The factor $\gamma_{GEB,bi}$ is to be minimized with respect to the wave parameter n, i.e. to be taken as the smallest value larger than zero.

c : Factor taking into account the stresses in the attached plating acting perpendicular to the stiffener axis:

$c = 0.5(1 + \psi)$ for $0 \leq \psi < 1$

$c = \dfrac{1}{2(1-\psi)}$ for $\psi < 0$

ψ : Edge stress ratio for case 2 according to Table 3.

$\sigma_{x,av}$: Average stress, in $\mathrm{N/mm^2}$, for both plate and stiffener with Poisson correction, taken as:

$\sigma_{x,av} = \sigma_x - \nu c \sigma_y A_s/(A_p + A_s) \geq 0$ for $\sigma_x > 0$ and $\sigma_y > 0$

$\sigma_{x,av} = \sigma_x$ for $\sigma_x \leq 0$ or $\sigma_y \leq 0$

D_{11}, D_{12}, D_{22}, D_{33} : Bending stiffness coefficients, in Nmm, of the stiffened panel, defined in general as:

$$D_{11} = \frac{EI_{eff}10^4}{s}$$

$$D_{12} = \frac{Et_p^3\nu}{12(1-\nu^2)}$$

$$D_{22} = \frac{Et_p^3}{12(1-\nu^2)}$$

$$D_{33} = \frac{Et_p^3}{12(1+\nu)}$$

For stiffened panels fitted with U-type stiffeners, D_{12} and D_{22} are defined as:

$$D_{22} = \frac{E\,t_p^3}{12(1-\nu^2)}\left[1.2+4.8\times Min\left(1.0,\ \frac{b_1^2}{h_w(b_1+b_2)}\right)\times Min\left(1.0,\left(\frac{t_w}{t_p}\right)^3\right)\right]$$

$$D_{12} = \nu D_{22}$$

h_w : Breadth of U-type stiffener web, in mm, as defined in Figure 2.

I_{eff} : Moment of inertia, in cm^4, of the stiffener including effective width of attached plating, the same as I defined in [2.3.4].

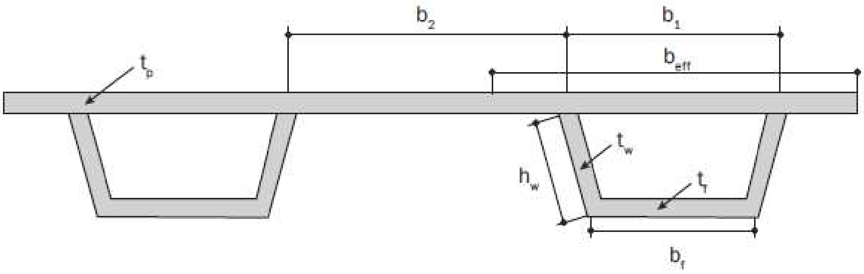


Figure 2 : Example of hatch cover fitted with U-type stiffener

2.1.3

The stress multiplier factor $\gamma_{GEB,\tau}$ for the stiffened panel subjected to pure shear load is taken as:

$$\gamma_{GEB,\tau} = \frac{\sqrt[4]{D_{11}^3 D_{22}}}{(L_{B1}/2)^2 N_{xy}}\left[8.125+5.64\sqrt{\frac{(D_{12}+D_{33})^2}{D_{11}D_{22}}}-0.6\frac{(D_{12}+D_{33})^2}{D_{11}D_{22}}\right] \quad \text{for } D_{11}D_{22} \geq (D_{12}+D_{33})^2$$

$$\gamma_{GEB,\tau} = \frac{\sqrt{2D_{11}(D_{12}+D_{33})}}{(L_{B1}/2)^2 N_{xy}}\left[8.3+1.525\frac{D_{11}D_{22}}{(D_{12}+D_{33})^2}-0.493\frac{D_{11}^2 D_{22}^2}{(D_{12}+D_{33})^4}\right] \quad \text{for } D_{11}D_{22} < (D_{12}+D_{33})^2$$

where

$N_{xy} = \tau t_p$

2.1.4

The stress multiplier factor $\gamma_{GEB,bi+\tau}$ for the stiffened panel subjected to combined loads is taken as:

$$\gamma_{GEB,bi+\tau} = \frac{1}{2}\gamma_{GEB,\tau}^2\left[-\frac{1}{\gamma_{GEB,bi}}+\sqrt{\frac{1}{\gamma_{GEB,bi}^2}+4\frac{1}{\gamma_{GEB,\tau}^2}}\right]$$

where $\gamma_{GEB,bi}$ and $\gamma_{GEB,\tau}$ are as defined in [2.1.2] and [2.1.3], respectively.

2.2 Plate panel

2.2.1 Plate limit state

The plate limit state is based on the following interaction formulae:

$$\left(\frac{\gamma_{c1}\sigma_x S}{\sigma_{cx}^{'}}\right)^{e_0} - B\left(\frac{\gamma_{c1}\sigma_x S}{\sigma_{cx}^{'}}\right)^{e_0/2}\left(\frac{\gamma_{c1}\sigma_y S}{\sigma_{cy}^{'}}\right)^{e_0/2} + \left(\frac{\gamma_{c1}\sigma_y S}{\sigma_{cy}^{'}}\right)^{e_0} + \left(\frac{\gamma_{c1}|\tau|S}{\tau_c^{'}}\right)^{e_0} = 1.0$$

$$\left(\frac{\gamma_{c2}\sigma_x S}{\sigma_{cx}^{'}}\right)^{2/\beta_p^{0.25}} + \left(\frac{\gamma_{c2}|\tau|S}{\tau_c^{'}}\right)^{2/\beta_p^{0.25}} = 1.0 \qquad \text{for } \sigma_x \geq 0$$

$$\left(\frac{\gamma_{c3}\sigma_y S}{\sigma_{cy}^{'}}\right)^{2/\beta_p^{0.25}} + \left(\frac{\gamma_{c3}|\tau|S}{\tau_c^{'}}\right)^{2/\beta_p^{0.25}} = 1.0 \qquad \text{for } \sigma_y \geq 0$$

$$\frac{\gamma_{c4}|\tau|S}{\tau_c^{'}} = 1.0$$

with

$$\gamma_c = \min(\gamma_{c1}, \gamma_{c2}, \gamma_{c3}, \gamma_{c4})$$

where:

σ_x, σ_y : Applied normal stress to the plate panel, in $\mathrm{N/mm^2}$, to be taken as defined in [2.2.7].

τ : Applied shear stress to the plate panel, in $\mathrm{N/mm^2}$.

$\sigma_{cx}^{'}$: Ultimate buckling stress, in $\mathrm{N/mm^2}$ in direction parallel to the longer edge of the buckling panel as defined in [2.2.3]

$\sigma_{cy}^{'}$: Ultimate buckling stress, in $\mathrm{N/mm^2}$ in direction parallel to the shorter edge of the buckling panel as defined in [2.2.3]

$\tau_c^{'}$: Ultimate buckling shear stress, in $\mathrm{N/mm^2}$, as defined in [2.2.3]

$\gamma_{c1}, \gamma_{c2}, \gamma_{c3}, \gamma_{c4}$: Stress multiplier factors at failure for each of the above different limit states. γ_{c2} and γ_{c3} are only to be considered when $\sigma_x \geq 0$ and $\sigma_y \geq 0$ respectively.

B : Coefficient given in Table 1.

e_0 : Coefficient given in Table 1.

β_p : Plate slenderness parameter taken as:

$$\beta_p = \frac{b}{t_p}\sqrt{\frac{R_{eH\_P}}{E}}$$

Table 1 : Definition of coefficients B and e_0

Applied Stress	B	e_0
$\sigma_x \geq 0$ and $\sigma_y \geq 0$	$0.7 - 0.3\beta_p/\alpha^2$	$2/\beta_p^{0.25}$
$\sigma_x < 0$ or $\sigma_y < 0$	1.0	2.0

2.2.2 Reference degree of slenderness

The reference degree of slenderness is to be taken as:

$$\lambda = \sqrt{\frac{R_{eH\_P}}{K\sigma_E}}$$

where:

K : Buckling factor, as defined in **Table 3** and **Table 4**.

2.2.3 Ultimate buckling stresses

The ultimate buckling stress of plate panels, in $\mathrm{N/mm^2}$, is to be taken as:

$$\sigma_{cx}^{'} = C_x R_{eH\_P}$$

$$\sigma_{cy}^{'} = C_y R_{eH\_P}$$

The ultimate buckling stress of plate panels subject to shear, in $\mathrm{N/mm^2}$, is to be taken as:

$$\tau_c^{'} = C_\tau \frac{R_{eH-P}}{\sqrt{3}}$$

where:

C_x, C_y, C_τ : Reduction factors, as defined in **Table 3**.

- For the 1st Equation of [2.2.1], when $\sigma_x < 0$ or $\sigma_y < 0$, the reduction factors are to taken as:

  $C_x = C_y = C_\tau = 1.0$
- For the other cases;
  - For SP-A and UP-A, C_y is calculated according to **Table 3** by using

    $c_1 = \left(1 - \frac{1}{\alpha}\right) \geq 0$
  - For SP-B and UP-B, C_y is calculated according to **Table 3** by using

    $c_1 = 1$
  - For corrugation of corrugated bulkheads, C_y is calculated according to **Table 3** by using

    $c_1 = \left(1 - \frac{1}{\alpha}\right) \geq 0$

The boundary conditions for plates are to be considered as simply supported, see cases 1, 2 and 15 of **Table 3**. If the boundary conditions differ significantly from simple support, a more appropriate boundary condition can be applied according to the different cases of **Table 3** subject to the agreement of the Society.

2.2.4 Correction factor F_{long}

The correction factor, F_{long} depending on the edge stiffener types on the longer side of the buckling panel is defined in **Table 2**. An average value of F_{long} is to be used for plate panels having different edge stiffeners. For stiffener types other than those mentioned in **Table 2**, the value of c is to be agreed by the Society. In such a case, value of c higher than those mentioned in **Table 2** can be used, provided it is verified by buckling strength check of panel using non-linear FE analysis and deemed appropriate by the Society.

2.2.5 Correction factor F_{tran}

The correction factor F_{tran} is to be taken as:

- For the attached plate of a U-type stiffener fitted on a hatch cover:

$$F_{tran} = Max(3-0.08(F_{tran0}-6)^2, 1.0) \leq 2.25$$

where,

$$F_{tran0} = Min\left(\frac{b_2}{b_1}+\frac{6b_2^2}{\pi^2 h_w(b_1+b_2)}\left(\frac{t_w}{t_p}\right)^3, 6\right) \qquad \text{for EPP } b_2$$

$$F_{tran0} = Min\left(\frac{b_1}{b_2}+\frac{6b_1^2}{\pi^2 h_w(b_2+b_1)}\left(\frac{t_w}{t_p}\right)^3, 6\right) \qquad \text{for EPP } b_1$$

with b_1, b_2 and h_w as defined in **Sec 5, Figure 2**

Coefficient F defined in **Case 2** of **Table 3** is to be replaced by the following formula:

$$F=\left[1-\left(\frac{K_y}{0.91F_{tran}}-1\right)/\lambda_p^2\right]c_1 \geq 0$$

- For other cases: $F_{tran}=1$

Table 2 : Correction Factor F_{long}

Structural element types			F_{long}	c
Unstiffened Panel			1.0	N/A
Stiffened Panel	Stiffener not fixed at both ends		1.0	N/A
	Stiffener fixed at both ends	Flat bar(1)	$F_{long}=c+1$ for $\frac{t_w}{t_p}>1$ $F_{long}=c\left(\frac{t_w}{t_p}\right)^3+1$ for $\frac{t_w}{t_p}\leq 1$	0.10
		Bulb profile		0.30
		Angle, L2 and L3 profile		0.40
		T profile		0.30
		Girder of high rigidity (e.g. bottom transverse)	1.4	N/A
		U-type profile fitted on hatch cover(2)	• Plate on which the U-type profile is fitted, including EPP b_1 and EPP b_2 • For $b_2 < b_1$: $F_{long}=1$ • For $b_2 \geq b_1$: $F_{long}=\left(1.55-0.55\frac{b_1}{b_2}\right)\left[1+c\left(\frac{t_w}{t_p}\right)^3\right]$ • Other plate of the U-type profile : $F_{long}=1$	0.20

(1) t_w is the net web thickness, in mm, without the correction defined in **[2.3.2].**

(2) b_1, b_2 and t_w as defined in **Sec 5, Figure 2**

Table 3 : Buckling Factor and reduction factor for plane plate panels

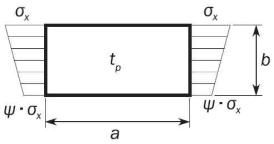
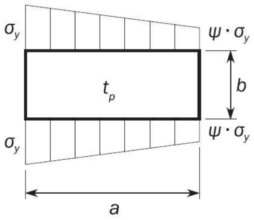
Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
1.  	$1 \geq \psi \geq 0$		$K_x = F_{long}\frac{8.4}{\psi+1.1}$	When $\sigma_x \leq 0$: $C_x = 1$ When $\sigma_x > 0$: $C_x = 1$ for $\lambda \leq \lambda_c$ $C_x = c\left(\frac{1}{\lambda}-\frac{0.22}{\lambda^2}\right)$ for $\lambda > \lambda_c$ where : $c = (1.25-0.12\psi) \leq 1.25$ $\lambda_c = \frac{c}{2}\left(1+\sqrt{1-\frac{0.88}{c}}\right)$
	$0 > \psi > -1$		$K_x = F_{long}[7.63-\psi(6.26-10\psi)]$	
	$\psi \leq -1$		$K_x = F_{long}[5.975(1-\psi)^2]$	
2.  	$1 \geq \psi \geq 0$		$K_y = F_{tran}\frac{2\left(1+\frac{1}{\alpha^2}\right)^2}{1+\psi+\frac{(1-\psi)}{100}\left(\frac{2.4}{\alpha^2}+6.9f_1\right)}$	When $\sigma_y \leq 0$: $C_y = 1$ when $\sigma_y > 0$: $C_y = c\left(\frac{1}{\lambda}-\frac{R+F^2(H-R)}{\lambda^2}\right)$ where : $c = (1.25-0.12\psi) \leq 1.25$ $R = \lambda(1-\lambda/c)$ for $\lambda < \lambda_c$ $R = 0.22$ for $\lambda \geq \lambda_c$ $\lambda_c = 0.5c\left(1+\sqrt{1-0.88/c}\right)$ $F = \left[1-\left(\frac{K}{0.91}-1\right)/\lambda_p^2\right]c_1 \geq 0$ $\lambda_p^2 = \lambda^2-0.5$ for $1 \leq \lambda_p^2 \leq 3$ c_1 as defined in [2.2.3] $H = \lambda-\frac{2\lambda}{c\left(T+\sqrt{T^2-4}\right)} \geq R$ $T = \lambda+\frac{14}{15\lambda}+\frac{1}{3}$
		$\alpha \leq 6$	$f_1 = (1-\psi)(\alpha-1)$	
		α 〉6	$f_1 = 0.6\left(1-\frac{6\psi}{\alpha}\right)\left(\alpha+\frac{14}{\alpha}\right)$, But not greater than $14.5-\frac{0.35}{\alpha^2}$	

Table 3 : Buckling Factor and reduction factor for plane plate panels

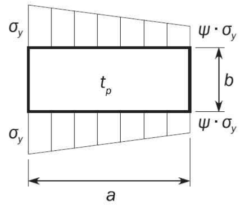
Case	Stress ratio ψ	Stress ratio ψ and Buckling factor K	Reduction factor C
2.  	$0 > \psi \geq 1 - \frac{4\alpha}{3}$	$K_y = \frac{200\, F_{tran}(1+\beta^2)^2}{(1-f_3)(100+2.4\beta^2+6.9\, f_1+23f_2)}$	
		Stress ratio ψ : $\alpha \rangle 6(1-\psi)$	
		$f_1 = 0.6\left(\frac{1}{\beta} + 14\beta\right)$, But not greater than $14.5 - 0.35\beta^{\ 2}$ $f_2 = f_3 = 0$	
		Stress ratio ψ : $3(1-\psi) \leq \alpha \leq 6(1-\psi)$	
		$f_1 = \frac{1}{\beta} - 1$ $f_2 = f_3 = 0$	
		Stress ratio ψ : $1.5(1-\psi) \leq \alpha < 3(1-\psi)$	
		$f_1 = \frac{1}{\beta} - (2 - w\beta)^4 - 9\,(w\beta - 1)\left(\frac{2}{3} - \beta\right)$ $f_2 = f_3 = 0$	
		Stress ratio ψ : $1-\psi \leq \alpha < 1.5(1-\psi)$	
		• For $\alpha > 1.5$: $f_1 = 2\left(\frac{1}{\beta} - 16\left(1 - \frac{\omega}{3}\right)^4\right)\left(\frac{1}{\beta} - 1\right)$ $f_2 = 3\beta - 2$ $f_3 = 0$ • For $\alpha \leq 1.5$: $f_1 = 2\left(\frac{1.5}{1-\psi} - 1\right)\left(\frac{1}{\beta} - 1\right)$ $f_2 = \frac{\psi(1-16f_4^2)}{1-\alpha}$ $f_3 = 0$ $f_4 = (1.5 - \mathrm{Min}(1.5;\alpha))^2$	
		Stress ratio ψ : $0.75(1-\psi) \leq \alpha < 1-\psi$	
		$f_1 = 0$ $f_2 = 1 + 2.31(\beta-1) - 48(4/3-\beta)f_4^2$ $f_3 = 3f_4(\beta-1)\left(\frac{f_4}{1.81} - \frac{\alpha-1}{1.31}\right)$ $f_4 = (1.5 - \mathrm{Min}(1.5;\alpha))^2$	
	$\psi < 1 - \frac{4\alpha}{3}$	$K_y = 5.972F_{tran}\frac{\beta^2}{1-f_3}$ $f_3 = f_5\left(\frac{f_5}{1.81} + \frac{1+3\psi}{5.24}\right)$ $f_5 = \frac{9}{16}(1 + \mathrm{Max}(-1;\psi))^2$	

Table 3 : Buckling Factor and reduction factor for plane plate panels (continued)

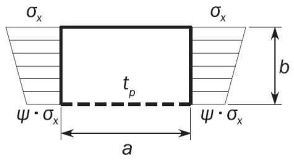
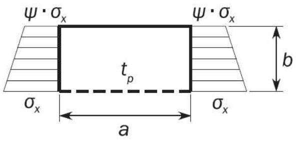
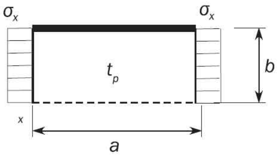
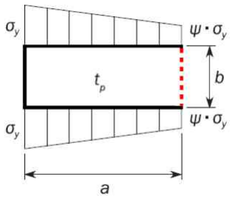
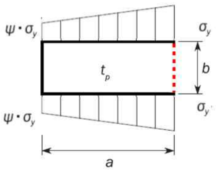
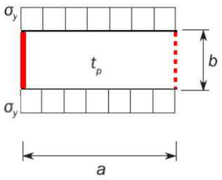
Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
3. 	$1 \geq \psi \geq 0$		$K_x = \frac{4(0.425+1/\alpha^2)}{3\psi+1}$	For UP-A: $C_x = 1$ for $\lambda \leq 0.75$ $C_x = \frac{0.75}{\lambda}$ for $\lambda > 0.75$ For UP-B: $C_x = 1$ for $\lambda \leq 0.7$ $C_x = \frac{1}{\lambda^2+0.51}$ for $\lambda > 0.7$
	$0 > \psi \geq -1$		$K_x = 4(0.425+1/\alpha^2)(1+\psi)-5\psi(1-3.42\psi)$	
4. 	$1 \geq \psi \geq -1$		$K_x = \left(0.425+\frac{1}{\alpha^2}\right)\frac{3-\psi}{2}$	
5. 	–	$\alpha \geq 1.64$	$K_x = 1.28$	
		$0 < \alpha < 1.64$	$K_x = \frac{1}{\alpha^2} + 0.56 + 0.13\alpha^2$	
6. 	$1 \geq \psi \geq 0$		$K_y = \frac{4(0.425+\alpha^2)}{(3\psi+1)\alpha^2}$	For UP-A: $C_y = 1$ for $\lambda \leq 0.75$ $C_y = \frac{0.75}{\lambda}$ for $\lambda > 0.75$ For UP-B: $C_y = 1$ for $\lambda \leq 0.7$ $C_y = \frac{1}{\lambda^2+0.51}$ for $\lambda > 0.7$
	$0 > \psi \geq -1$		$K_y = 4(0.425+\alpha^2)(1+\psi)\frac{1}{\alpha^2}-5\psi(1-3.42\psi)\frac{1}{\alpha^2}$	
7. 	$1 \geq \psi \geq -1$		$K_y = (0.425+\alpha^2)\frac{(3-\psi)}{2\alpha^2}$	
8. 	–		$K_y = 1+\frac{0.56}{\alpha^2}+\frac{0.13}{\alpha^4}$	

Table 3 : Buckling Factor and reduction factor for plane plate panels (continued)

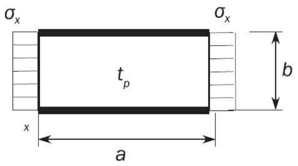
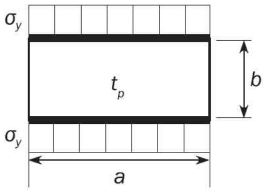
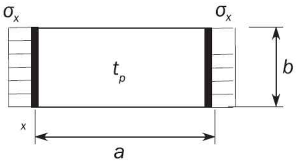
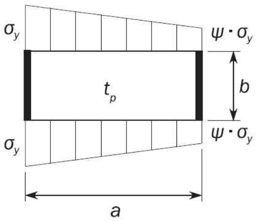
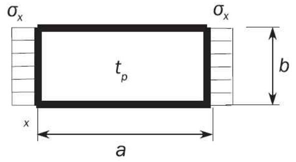
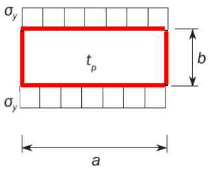
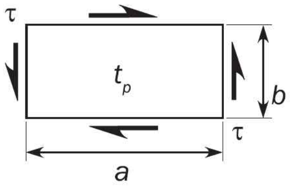
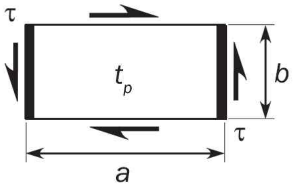
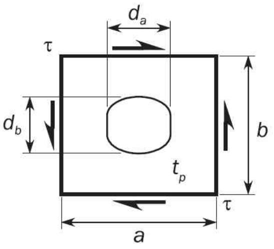
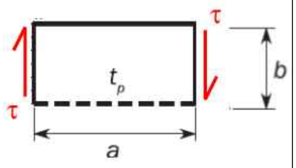
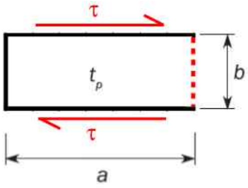
<table>
<tr><th>Case</th><th>Stress ratio ψ</th><th>Aspect ratio α</th><th>Buckling factor K</th><th>Reduction factor C</th></tr>
<tr><td>9.
 </td><td>–</td><td colspan="2">$K_x = 6.97$</td><td rowspan="2">$C_x = 1$
for $\lambda \le 0.83$
$C_x = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$
for $\lambda > 0.83$</td></tr>
<tr><td>10.
 </td><td>–</td><td colspan="2">$K_y = 4 + \frac{2.07}{\alpha^2} + \frac{0.67}{\alpha^4}$</td></tr>
<tr><td rowspan="2">11.
 </td><td rowspan="2">–</td><td>$\alpha \ge 4$</td><td>$K_x = 4$</td><td>$C_x = 1$
for $\lambda \le 0.83$</td></tr>
<tr><td>$\alpha < 4$</td><td>$K_x = 4 + 2.74\left[\frac{4-\alpha}{3}\right]^4$</td><td>$C_x = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$
for $\lambda > 0.83$</td></tr>
<tr><td>12.
 </td><td>–</td><td colspan="2">$K_y = K_y$ determined as per case 2</td><td>$C_y = C_{y2}$
for $\alpha < 2$
$C_y = \left(1.06 + \frac{1}{10\alpha}\right)C_{y2}$
for $\alpha \ge 2$
where:
C_{y2} : C_y determined as per case 2</td></tr>
<tr><td rowspan="2">13.
 </td><td rowspan="2">–</td><td>$\alpha \ge 4$</td><td>$K_x = 6.97$</td><td rowspan="2">$C_x = 1$
for $\lambda \le 0.83$
$C_x = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$
for $\lambda > 0.83$</td></tr>
<tr><td>$\alpha < 4$</td><td>$K_x = 6.97 + 3.1\left[\frac{4-\alpha}{3}\right]^4$</td></tr>
<tr><td>14.
 </td><td>–</td><td colspan="2">$K_y = \frac{6.97}{\alpha^2} + \frac{3.1}{\alpha^2}\left(\frac{4-1/\alpha}{3}\right)^4$</td><td>$C_y = 1$
for $\lambda \le 0.83$
$C_y = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$
for $\lambda > 0.83$</td></tr>
</table>

Table 3 : Buckling Factor and reduction factor for plane plate panels (continued)

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
15. 	–		$K_\tau = \sqrt{3}\left[5.34 + \frac{4}{\alpha^2}\right]$	$C_\tau = 1$ for $\lambda \le 0.84$ $C_\tau = \frac{0.84}{\lambda}$ for $\lambda > 0.84$
16. 	–		$K_\tau = \sqrt{3}\left\{5.34 + Max\left[\frac{4}{\alpha^2}; \frac{7.15}{\alpha^{2.5}}\right]\right\}$	
17. 	–		$K_\tau = K_{\tau case15} r$ $K_{\tau case15}$: K_τ according to case 15 r : opening reduction factor taken as $r = \left(1 - \frac{d_a}{a}\right)\left(1 - \frac{d_b}{b}\right)$ with $\frac{d_a}{a} \le 0.7$ and $\frac{d_b}{b} \le 0.7$	
18. 	–		$K_\tau = 3^{0.5}(0.6 + 4/\alpha^2)$	
19. 	–		$K_\tau = 8$	

Edge boundary conditions :

---------- Plate edge free.

——— Plate edge simply supported.

——— Plate edge clamped.

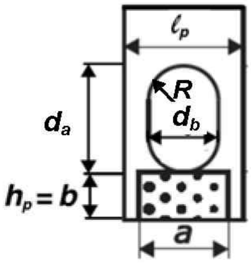
Notes:

1) Cases listed are general cases. Each stress component(σ_x, σ_y) is to be understood in local coordinates.

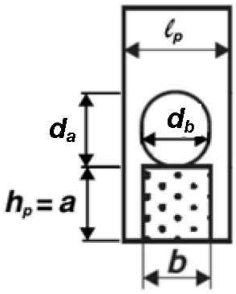
2) Unsupported edge of plane plate panels in way of openings

If the length of a regular opening is longer than half the width of the plate panel ($d_a > 0.5\ell_p$, $\ell_0 > 0.5\ell_p$) the length of the unsupported edge of a plane plate panel in way of a regular opening may be shortened for the buckling assessment as follows:

Table 3 : Buckling Factor and reduction factor for plane plate panels (continued)



Case 3 ($\ell_\sigma = a$) and
Case 18 ($\ell_\tau = a$)



Case 6 ($\ell_\sigma = b$) and
Case 19 ($\ell_\tau = b$)

d_b : width, in mm, of the opening.
d_a : height, in mm, of the opening.
ℓ_0 : length, in mm, of opening, as defined in Ch 7, Sec 2, [2.4.8].
ℓ_p : width, in mm, of plate panel.
h_p : height, in mm, of plate panel.
R : radius, in mm of opening.
R_c : corrected radius, in mm, of opening to be taken as:

$$R_c = \max\left(d_b - \frac{4}{3}R, \frac{2}{9}\ell_p\right)$$

For Cases 3 and 6, normal stresses:

Corrected length of free edge, in mm, to be taken as:

$$\ell_\sigma = \min\left(\ell_p, 100\frac{R_c}{\ell_p}t_p\sqrt{\frac{2h_p}{d_a}+1}\right)$$

If $\ell_\sigma \geq h_p$, Case 3 is to be applied with $a = \ell_\sigma$, $b = h_p$ and σ_x as normal stress.

If $\ell_\sigma < h_p$, Case 6 is to be applied with $a = h_p$, $b = \ell_\sigma$ and σ_y as normal stress.

For small openings, when the reduction factor for Case 3, C_x, or the reduction factor for Case 6, C_y, exceeds the reduction factor for the plate without opening, C_y for Case 2 is applicable.

For Cases 18 and 19, shear stresses:

Corrected length of free edge, in mm, to be taken as:

$$\ell_\tau = \min\left(\ell_p, 2.1R_c\sqrt{\frac{2h_p}{d_a}+1}\right)$$

If $\ell_\tau \geq h_p$, Case 18 is to be applied with $a = \ell_\tau$, $b = h_p$ and τ as shear stress.

If $\ell_\tau < h_p$, Case 19 is to be applied with $a = h_p$, $b = \ell_\tau$ and τ as shear stress.

For small openings, the reduction factor C_τ for Case 17 is applicable.

2.2.6 Curved plate panels

This requirement for curved plate limit state is applicable when $R/t_p \le 2500$. Otherwise, the requirement for plate limit state given in [2.2.1] is applicable.

The curved plate limit state is based on the following interaction formula:

$$\left(\frac{\gamma_c \sigma_{ax} S}{C_{ax} R_{eH\_p}}\right)^{1.25} - 0.5\left(\frac{\gamma_c \sigma_{ax} S}{C_{ax} R_{eH\_p}}\right)\left(\frac{\gamma_c \sigma_{tg} S}{C_{tg} R_{eH\_p}}\right) + \left(\frac{\gamma_c \sigma_{tg} S}{C_{tg} R_{eH\_p}}\right)^{1.25} + \left(\frac{\gamma_c \tau \sqrt{3}\, S}{C_\tau R_{eH\_p}}\right)^{2} = 1.0$$

where:

σ_{ax} : Applied axial stress to the cylinder corresponding to the curved plate panel, in $\mathrm{N/mm^2}$. In case of tensile axial stresses, $\sigma_{ax} = 0$.

σ_{tg} : Applied tangential stress to the cylinder corresponding to the curved plate panel, in $\mathrm{N/mm^2}$. In case of tensile tangential stresses, $\sigma_{tg} = 0$.

C_{ax}, C_{tg}, C_τ : Reduction factor of the curved plate panel, as defined in Table 4.

The stress multiplier factor, γ_c of the curved plate panel needs not be taken less than the stress multiplier factor, γ_c for the expanded plane panel according to [2.2.1].

2.2.7 Applied normal and shear stresses to plate panels

The normal stresses, σ_x and σ_y, in $\mathrm{N/mm^2}$, to be applied for the overall stiffened panel capacity and the plate panel capacity calculations, as given in [2.1.1] and [2.2.1] respectively, are to be taken as follows:

- For FE analysis, the reference stresses as defined in Sec 4, [2.4]
- For prescriptive assessment of the overall stiffened panel capacity and the plate panel capacity, the axial or transverse compressive stresses calculated according to Sec 3, [2.2.1], at load calculation points of the considered stiffener or the considered elementary plate panel, as defined in Ch 3, Sec 7, [3] and Ch 3, Sec 7, [2] respectively. However, in case of transverse stiffening arrangement, the transverse compressive stress used for the assessment of the overall stiffened panel capacity is to be taken as the compressive stress calculated at load calculation points of the stiffener attached plating, as defined in Ch 3, Sec 7, [2].
- For grillage analysis where the stresses are obtained based on beam theory, the stresses taken as:

$$\sigma_x = \frac{\sigma_{xb} + \nu \sigma_{yb}}{1 - \nu^2}$$

$$\sigma_y = \frac{\sigma_{yb} + \nu \sigma_{xb}}{1 - \nu^2}$$

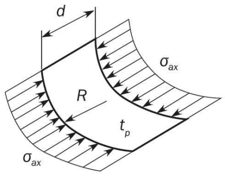
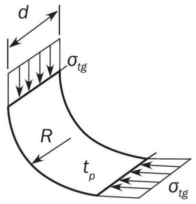
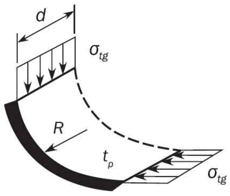
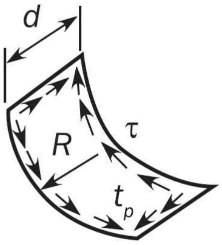
where:

σ_{xb}, σ_{yb} : Stress, in $\mathrm{N/mm^2}$, from grillage beam analysis respectively along x or y axis of the plate attached to the PSM web.

The shear stress τ, in $\mathrm{N/mm^2}$, to be applied for the overall stiffened panel capacity and the plate panel capacity calculations, as given in [2.1.1] and [2.2.1] respectively, are to be taken as follows

- For FE analysis, the reference shear stresses as defined in Ch 8, Sec 4, [2.4].
- For prescriptive assessment of the plate panel capacity, the shear stresses calculated according to Sec 3, [2.2.1], at load calculation points of the considered elementary plate panel, as defined in Ch 3, Sec 7, [2].
- For prescriptive assessment of the overall stiffened panel capacity, the shear stresses calculated according to Sec 3, [2.2.1], at the following load calculation point:
  - At the middle of the full span, ℓ, of the considered stiffener.
  - At the intersection point between the stiffener and its attached plating.
- For grillage beam analysis, $\tau = 0$ in the plate attached to the PSM web.

Table 4 : Buckling Factor and reduction factor for curved plate panel with $R/t_p \le 2500$

Case	Aspect ratio	Buckling factor K	Reduction factor C
1. 	$\frac{d}{R} \le 0.5\sqrt{\frac{R}{t_p}}$	$K = 1 + \frac{2}{3}\frac{d^2}{Rt_p}$	For general application: $C_{ax} = 1$ for $\lambda \le 0.25$ $C_{ax} = 1.233 - 0.933\lambda$ for $0.25 < \lambda \le 1$ $C_{ax} = 0.3/\lambda^3$ for $1 < \lambda \le 1.5$ $C_{ax} = 0.2/\lambda^2$ for $\lambda > 1.5$ For curved single fields, e.g. bilge plating, which are bounded by plane panels as shown in Ch 6, Sec 4, Figure 1: $C_{ax} = \frac{0.65}{\lambda^2} \le 1.0$
	$\frac{d}{R} > 0.5\sqrt{\frac{R}{t_p}}$	$K = 0.267\frac{d^2}{Rt_p}[3 - \frac{d}{R}\sqrt{\frac{t_p}{R}}] \ge 0.4\frac{d^2}{Rt_p}$	
2 	$\frac{d}{R} \le 1.63\sqrt{\frac{R}{t_p}}$	$K = \frac{d}{\sqrt{Rt_p}} + 3\frac{(Rt_p)^{0.175}}{d^{0.35}}$	For general application: $C_{tg} = 1$ for $\lambda \le 0.4$ $C_{tg} = 1.274 - 0.686\lambda$ for $0.4 < \lambda \le 1.2$ $C_{tg} = 0.65/\lambda^2$ for $\lambda > 1.2$ For curved single fields, e.g. bilge plating, which are bounded by plane panels as shown in Ch 6, Sec 4, Figure 1: $C_{tg} = 0.8/\lambda^2 \le 1.0$
	$\frac{d}{R} > 1.63\sqrt{\frac{R}{t_p}}$	$K = 0.3\frac{d^2}{R^2} + 2.25\left(\frac{R^2}{dt_p}\right)^2$	
3 	$\frac{d}{R} \le \sqrt{\frac{R}{t_p}}$	$K = \frac{0.6d}{\sqrt{Rt_p}} + \frac{\sqrt{Rt_p}}{d} - 0.3\frac{Rt_p}{d^2}$	As in load case 2.
	$\frac{d}{R} > \sqrt{\frac{R}{t_p}}$	$K = 0.3\frac{d^2}{R^2} + 0.291\left(\frac{R^2}{dt_p}\right)^2$	
4. 	$\frac{d}{R} \le 8.7\sqrt{\frac{R}{t_p}}$	$K = \sqrt{3}\sqrt{28.3 + \frac{0.67d^3}{R^{1.5}t_p^{1.5}}}$	$C_\tau = 1$ for $\lambda \le 0.4$ $C_\tau = 1.274 - 0.686\lambda$ for $0.4 < \lambda \le 1.2$ $C_\tau = 0.65/\lambda^2$ for $\lambda > 1.2$
	$\frac{d}{R} > 8.7\sqrt{\frac{R}{t_p}}$	$K = \sqrt{3}\frac{0.28d^2}{R\sqrt{Rt_p}}$	
Explanations for boundary conditions: - - - - - - - - - - Plate edge free. ——— Plate edge simply supported. ━━━ Plate edge clamped.			

2.3 Stiffeners

2.3.1 Buckling modes

The following buckling modes are to be checked:

a) Stiffener induced failure (SI)

b) Associated plate induced failure (PI)

2.3.2 Web thickness of flat bar

For accounting the decrease of the stiffness due to local lateral deformation, the effective web thickness of flat bar stiffener, in mm, is to be used in [2.1] and [2.3.4] for the calculation of the net sectional area, A_s, the net section modulus, Z, and the moment of inertia, I, of the stiffener and is taken as:

$$t_{w-red} = t_w\left(1-\frac{2\pi^2}{3}\left(\frac{h_w}{s}\right)^2\left(1-\frac{b_{eff1}}{s}\right)\right)$$

2.3.3 Idealisation of bulb profile

Bulb profiles may be considered as equivalent angle profiles, as defined in Ch 3, Sec 7, [1.4.1].

2.3.4 Ultimate buckling capacity

When $\sigma_a+\sigma_b+\sigma_w>0$ while initially setting $\gamma=1$, the ultimate buckling capacity for stiffeners is to be checked according to the following interaction formula:

$$\frac{\gamma_c\sigma_a+\sigma_b+\sigma_w}{R_{eH}}S=1$$

where:

σ_a : Effective axial stress, in $\mathrm{N/mm^2}$, at mid-span of the stiffener, acting on the stiffener with its attached plating.

$$\sigma_a=\sigma_x\frac{st_p+A_s}{b_{eff1}t_p+A_s}$$

σ_x : Nominal axial stress, in $\mathrm{N/mm^2}$, acting on the stiffener with its attached plating.

- For FE analysis

  σ_x is the FE corrected stress as defined in [2.3.6] in the attached plating in the direction of the stiffener axis.

- For prescriptive assessment

  σ_x is the axial stress calculated according to Sec 3, [2.2.1] at load calculation point of the stiffener, as defined in Ch 3, Sec 7, [3].

- For grillage beam analysis

  σ_x is the stress acting along the x-axis of the attached buckling panel.

R_{eH} : Specified minimum yield stress of the material, in $\mathrm{N/mm^2}$:

$R_{eH}=R_{eH-S}$ for stiffener induced failure (SI)

$R_{eH}=R_{eH-P}$ for plate induced failure (PI)

σ_b : Bending stress in the stiffener, in $\mathrm{N/mm^2}$:

$$\sigma_b=\frac{M_0+M_1+M_2}{1000Z}$$

Z : Net section modulus of stiffener, in cm3, including effective width of plating according to [2.3.5], to be taken as:

- The section modulus calculated at the top of stiffener flange for stiffener induced failure (SI).
- The section modulus calculated at the attached plating for plate induced failure (PI).

C_{PI} : Plate induced failure pressure coefficient:

$C_{PI}=1$ if the lateral pressure is applied on the side opposite to the stiffener.

$C_{PI}=-1$ if the lateral pressure is applied on the same side as the stiffener.

C_{SI} : Stiffener induced failure pressure coefficient:

$C_{SI}=-1$ if the lateral pressure is applied on the side opposite to the stiffener.

$C_{SI}=1$ if the lateral pressure is applied on the same side as the stiffener.

M_1 : Bending moment, in Nmm, due to the lateral load P

$$M_1=C_i\frac{|P|s\ell^2}{24\times 10^3} \quad \text{for continuous stiffener}$$

$$M_1=C_i\frac{|P|s\ell^2}{8\times 10^3} \quad \text{for sniped stiffener}$$

$$M_1=C_i\frac{|P|s\ell^2}{14.2\times 10^3} \quad \text{for stiffeners sniped at one end and continuous at other end.}$$

P : Lateral load, in $\mathrm{kN/m^2}$.

- For FE analysis, P is the average pressure as defined in Sec 4, [2.5.2] in the attached plating.
- For prescriptive assessment, P is the pressure calculated at load calculation point of the stiffener, as defined in Ch 3, Sec 7, [3].

C_i : Pressure coefficient:

$C_i=C_{SI}$ for stiffener induced failure (SI).

$C_i=C_{PI}$ for plate induced failure (PI).

M_0 : Bending moment, in Nmm, due to the lateral deformation w of stiffener:

$$M_0=F_E C_{sl}\frac{\gamma}{\gamma_{GEB}-\gamma}w_0 \text{ with precondition } \gamma_{GEB}-\gamma>0$$

where γ_{GEB} is the stress multiplier factor of global elastic buckling capacity as defined in [2.1].

C_{sl} : Deformation reduction factor to account for global slenderness, to be taken as:

$$C_{sl}=1-\frac{1}{12}\lambda_G^4 \quad \text{for } \lambda_G\le 1.56$$

$$C_{sl}=3/\lambda_G^4 \quad \text{for } \lambda_G>1.56$$

λ_G : The reference degree of global slenderness of the stiffened panel, to be taken as

$$\lambda_G=\sqrt{\frac{\gamma_{R_{eH}}}{\gamma_{GEB}}}$$

$$\gamma_{R_{eH}}=\frac{\min(R_{eH-P},R_{eH-S})}{\sqrt{\sigma_{x,av}^2+\sigma_y^2-\sigma_{x,av}\sigma_y+3\tau_{xy}^2}}$$

F_E : Ideal elastic buckling force of the stiffener, in N.

$$F_E=\left(\frac{\pi}{\ell}\right)^2 EI\,10^4$$

I : Moment of inertia, in $\mathrm{cm^4}$, of the stiffener including effective width of attached plating according to [2.3.5]. I is to comply with the following requirement:

$$I\ge\frac{s\,t_p^3}{12\times 10^4}$$

t_p : Net thickness of plate, in mm, to be taken as

- For prescriptive requirements, the mean thickness of the two attached plating panels,
- For FE analysis, the thickness of the considered EPP on one side of the stiffener.

w_0 : Assumed imperfection, in mm, taken equal to:

$w_0 = \ell / 1000$

M_2 : Bending moment, in Nmm, due to eccentricity of sniped stiffeners, to be taken as

$M_2 = 0$ for continuous stiffeners

$M_2 = C_{snip} \mathrm{w}_{na} \gamma \sigma_{\mathrm{x}} (\mathrm{A_p} + \mathrm{A_s})$ for stiffeners sniped at one or both ends

C_{snip} : Coefficient to account for the end effect of the stiffener sniped at one or both ends, to be taken as

$C_{snip} = -1.2$ for stiffener induced failure (SI)

$C_{snip} = 1.2$ for plate induced failure (PI)

w_{na} : Distance from the mid-point of attached plating to the neutral axis of the stiffener calculated with the effective width of the attached plating according to [2.3.5].

σ_w : Stress due to torsional deformation, in $\mathrm{N/mm^2}$, to be taken as:

- For stiffener induced failure (SI)
  - For $\sigma_a > 0$

$$\sigma_w = E y_w \left(\frac{t_f}{2} + h_w \right) \Phi_0 \left(\frac{m_{tor} \pi}{\ell_{tor}} \right)^2 \left(\frac{1}{1 - \frac{\gamma \sigma_a}{\sigma_{ET}}} - 1 \right)$$

with precondition $\sigma_{ET} - \sigma_a > 0$

  - For $\sigma_a \le 0$

$$\sigma_w = 0$$

- For plate induced failure (PI)

$\sigma_w = 0$

ℓ_{tor} : Stiffener span, distance equal to spacing between primary supporting members, i.e. $\ell_{tor} = \ell$. When the stiffener is supported by tripping brackets, ℓ_{tor} should be taken as the maximum spacing between the adjacent primary supporting members and fitted tripping brackets.

y_w : Distance, in mm, from centroid of stiffener cross-section to the free edge of stiffener flange, to be taken as:

$y_w = \frac{t_w}{2}$ for flat bar

$y_w = b_f - \frac{h_w t_w^2 + t_f b_f^2}{2A_s}$ for angle and bulb profiles

$y_w = b_{f-out} + 0.5 t_w - \frac{h_w t_w^2 + t_f (b_f^2 - 2 b_f d_f)}{2A_s}$ for L2 profile

$y_w = b_{f-out} + 0.5 t_w - \frac{(h_w - t_f) t_w^2 + t_f (b_f + t_w)^2}{2A_s}$ for L3 profile

$y_w = \frac{b_f}{2}$ for Tee profile

Φ_0 : Coefficient taken as:

$$\Phi_0 = \frac{\ell_{tor}}{m_{tor} h_w} 10^{-4}$$

σ_{ET} : Reference stress for torsional buckling, in $\mathrm{N/mm^2}$, to be taken as:

$$\sigma_{ET}=\frac{E}{I_p}\left[\left(\frac{m_{tor}\pi}{\ell_{tor}}\right)^2 I_w \bullet 10^2+\frac{1}{2(1+\nu)}I_T+\left(\frac{\ell_{tor}}{m_{tor}\pi}\right)^2\epsilon \bullet 10^{-4}\right]$$

I_P : Net polar moment of inertia of the stiffener, in $\mathrm{cm^4}$, about point C as shown in **Figure 1**, as defined in **Table 5**.

I_T : Net St. Venant's moment of inertia of the stiffener, in $\mathrm{cm^4}$, as defined in **Table 5**.

I_w : Net sectorial moment of inertia of the stiffener, in $\mathrm{cm^6}$, about point C as shown in **Figure 1**, as defined in **Table 5**.

m_{tor} : Number of half waves within ℓ_{tor} , taken as a positive integer so as to give smallest reference stress for torsional buckling.

ϵ : Degree of fixation, in $\mathrm{mm^2}$, to be taken as:.

$$\epsilon=\left(\frac{3b}{t_p^3}+\frac{2h_w}{t_w^3}\right)^{-1}$$ for bulb, angle, L2, L3 and T profiles

$$\epsilon=\frac{t_p^3}{3b}$$ for flat bars

A_w : Net web area, in $\mathrm{mm^2}$.

A_f : Net flange area, in $\mathrm{mm^2}$.

Table 5 : Moments of inertia

	Flat bars(1)	Bulb, angle, L2, L3 and T profiles
I_p	$\frac{h_w^3 t_w}{3\times 10^4}$	$\left(\frac{A_w(e_f-0.5t_f)^2}{3}+A_f e_f^2\right)10^{-4}$
I_T	$\frac{h_w t_w^3}{3\times 10^4}\left(1-0.63\frac{t_w}{h_w}\right)$	$\frac{(e_f-0.5t_f)t_w^3}{3\times 10^4}\left(1-0.63\frac{t_w}{e_f-0.5t_f}\right)+\frac{b_f t_f^3}{3\times 10^4}\left(1-0.63\frac{t_f}{b_f}\right)$
I_w	$\frac{h_w^3 t_w^3}{36\times 10^6}$	For bulb angle, L2 and L3 profiles(2). $\frac{A_f^3+A_w^3}{36\times 10^6}+\frac{e_f^2}{10^6}\Big[\frac{A_f b_f^2+A_w t_w^2}{3}-\frac{(A_f(b_f-2d_f)+A_w t_w)^2}{4(A_f+A_w)}-A_f d_f(b_f-d_f)\Big]\Big]\Big\}$ For T profiles $\frac{b_f^3 t_f e_f^2}{12\times 10^6}$

(1) t_w is the net web thickness, in mm, $t_{\mathrm{w-red}}$ as defined in **[2.3.2]** is not to be used in this table.

(2) d_f is to be taken as 0 for bulb and angle profiles.

2.3.5 Effective width of the attached plating, b_{eff}

The effective width of the attached plating of a stiffener, b_{eff} in mm, is to be taken as:

- For $\sigma_x > 0$:
  - For FE analysis,

    $b_{eff} = \min(C_x b, \chi_s s)$
  - For prescriptive assessment,

    $$b_{eff} = \min\left(\frac{C_{x1}b_1 + C_{x2}b_2}{2}, \chi_s s\right)$$
- For $\sigma_x \le 0$:
  - $b_{eff} = \chi_s s$

where:

χ_s : Effective width coefficient to be taken as:

$$\chi_s = Min\left[\frac{1.12}{1 + \frac{1.75}{\left(\frac{\ell_{eff}}{s}\right)^{1.6}}} ; 1.0\right] \quad \text{for} \quad \frac{\ell_{eff}}{s} \ge 1$$

$$\chi_s = 0.407\frac{\ell_{eff}}{s} \quad \text{for} \quad \frac{\ell_{eff}}{s} < 1$$

ℓ_{eff} : The effective length of the stiffener, in mm, taken as:

$\ell_{eff} = \frac{\ell}{\sqrt{3}}$ for stiffener fixed at both ends.

$\ell_{eff} = 0.75\ell$ for stiffener simply supported at one end and fixed at the other

$\ell_{eff} = \ell$ for stiffener simply supported at both ends.

2.3.6 FE corrected stresses for stiffener capacity

When the reference stresses σ_x and σ_y obtained by FE analysis according to Sec 4, [2.4] are both compressive, σ_x is to be corrected according to the following formula:

- If $\sigma_x < \nu\sigma_y$:

  $\sigma_{xcor} = 0$
- If $\sigma_x \ge \nu\sigma_y$:

  $\sigma_{xcor} = \sigma_x - \nu\sigma_y$

2.4 Primary supporting members

2.4.1 Web plate in way of openings

The web plate of primary supporting members with openings is to be assessed for buckling based on the combined axial compressive and shear stresses.

The web plate adjacent to the opening on both sides is to be considered as individual unstiffened plate panels as shown in Table 6.

The interaction formulae of [2.2.1] are to be used with:

- $\sigma_x = \sigma_{av}$
- $\sigma_y = 0$
- $\tau = \tau_{av}$

where:

σ_{av} : Weighted average compressive stress, in $\mathrm{N/mm^2}$, in the area of web plate being considered, i.e. P_1, P_2 or P_3 as shown in Table 6.

For the application of the Table 6, the weighted average shear stress is to be taken as:

- Opening modelled in primary supporting members:

  τ_{av} : Weighted average shear stress, in $\mathrm{N/mm^2}$, in the area of web plate being considered, i.e. P_1, P_2 or P_3 as shown in Table 6.

- Opening not modelled in primary supporting members:

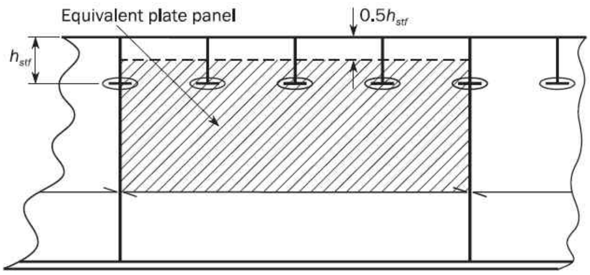
  τ_{av} : Weighted average shear stress, in $\mathrm{N/mm^2}$, given in Table 6.

2.4.2 Reduction factors of web plate in way of openings

The reduction factors, C_x or C_y in combination with, C_τ of the plate panel(s) of the web adjacent to the opening is to be taken as shown in Table 6.

2.4.3

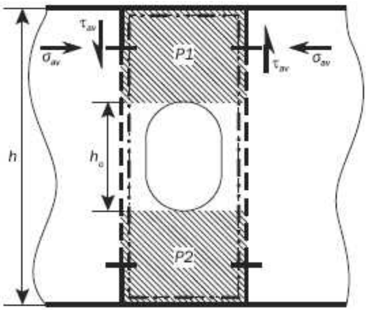
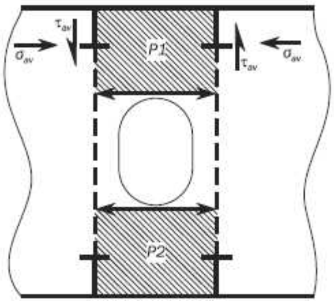
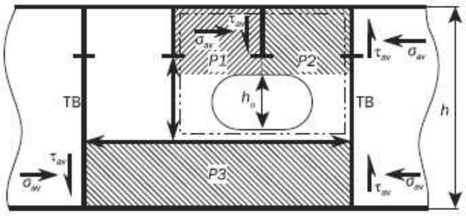
The equivalent plate panel of web plate of primary supporting members crossed by perpendicular stiffeners is to be idealised as shown in Figure 3.



The correction of panel breadth is applicable for other slot configurations provided that the web or collar plate is attached to at least one side of the passing stiffener.

Figure 3 : Web plate idealisation

Table 6 : Reduction factors

Configuration[(1)]	C_x, C_y	C_τ Opening modelled in PSM	C_τ Opening not modelled in PSM
(a) Without edge reinforcements:[(2)]  	Separate reduction factors are to be applied to areas P_1 and P_2 using **case** 3 or **case** 6 in **Table 3**, with edge stress ratio: $\psi = 1.0$	Separate reduction factors are to be applied to areas P_1 and P_2 using **case** 18 or **case** 19 in **Table 3**.	When **case** 17 of **Table** 3 is applicable: A common reduction factor is to be applied to areas P_1 and P_2 using **case** 17 in **Table** 3 with: $\tau_{av} = \tau_{av}(web)$ When **case** 17 of **Table** 3 is not applicable: Separate reduction factors are to be applied to areas P_1 and P_2 using **case** 18 or **case** 19 in **Table** 3 with: $\tau_{ay} = \tau_{av}(web)\dfrac{h}{(h-h_0)}$
(b) With edge reinforcements:  	Separate reduction factors are to be applied for areas P_1 and P_2 using C_x for **case** 1 or C_y for **case** 2 in **Table** 3 with stress ratio: $\psi = 1.0$	Separate reduction factors are to be applied for areas P_1 and P_2 using **case** 15 in **Table** 3.	Separate reduction factors are to be applied to areas P_1 and P_2 using **case** 15 in **Table** 3 with: $\tau_{ay} = \tau_{av}(web)\dfrac{h}{(h-h_0)}$
(c) Example of hole in web:  		Panels P_1 and P_2 are to be evaluated in accordance with (**a**). Panel P_3 is to be evaluated in accordance with (**b**).	

Where:

h : Height, in m, of the web of the primary supporting member in way of the opening.

h_0 : Height, in m, of the opening measured in the depth of the web.

$\tau_{av}(web)$: Weighted average shear stress, in $\mathrm{N/mm^2}$ over the web height h of the primary supporting member.

Note (1) : Web panels to be considered for buckling in way of openings are shown shaded and numbered P_1, P_2, etc.

Note (2) : For a PSM web panel with opening and without edge reinforcements as shown in configuration (**a**), the applicable buckling assessment method depends on its specific boundary conditions. If one of the long edges along the face plate or along the attached plating is not subject to "inline support", i.e. the edge is free to pull in, Method B should be applied. In other cases, typically such as when the short plate edge is attached to the plate flanges, Method A is applicable.

3. Buckling capacity of other structures

3.1 Pillars

3.1.1 Buckling utilisation factor

The buckling utilisation factor, η, for axially compressed pillars is to be taken as:

$$\eta_{pillar} = \frac{\sigma_{av}}{\sigma_{cr}}$$

where:

σ_{av} : Average axial compressive stress in the member, in $\mathrm{N/mm^2}$.

σ_{cr} : Minimum critical buckling stress, in $\mathrm{N/mm^2}$, taken as:

$$\sigma_{cr} = \sigma_E \qquad \text{for } \sigma_E \le 0.5R_{eH-S}$$

$$\sigma_{cr} = \left(1 - \frac{R_{eH-S}}{4\sigma_E}\right)R_{eH-S} \qquad \text{for } \sigma_E > 0.5R_{eH-S}$$

σ_E : Minimum elastic compressive buckling stress, in $\mathrm{N/mm^2}$, according to [3.1.2] to [3.1.4].

R_{eH-S} : Specified minimum yield stress of the considered member, in $\mathrm{N/mm^2}$. For built up members, the lowest specified minimum yield stress is to be used.

3.1.2 Elastic column buckling stress

The elastic compressive column buckling stress, σ_{EC} in $\mathrm{N/mm^2}$ of members subject to axial compression is to be taken as:

$$\sigma_{EC} = \pi^2 E f_{end} \frac{I}{A\,\ell_{pill}^2} 10^{-4}$$

where:

I : Net moment of inertia about the weakest axis of the cross section, in $\mathrm{cm^4}$.

A : Net cross sectional area of the member, in $\mathrm{cm^2}$.

ℓ_{pill} : Length of the member, in m, taken as:

- For pillar : unsupported length of the member

f_{end} : End constraint factor, taken as:

- For pillar
  - $f_{end} = 1.0$ where both ends are simply supported.
  - $f_{end} = 2.0$ where one end is simply supported and the other end is fixed.
  - $f_{end} = 4.0$ where both ends are fixed.

A pillar end may be considered fixed when brackets of adequate size are fitted. Such brackets are to be supported by structural members with greater bending stiffness than the pillar.

3.1.3 Elastic torsional buckling stress

The elastic torsional buckling stress, σ_{ET} in $\mathrm{N/mm^2}$, with respect to axial compression of members is to be taken as:

$$\sigma_{ET} = \frac{GI_{sv}}{I_{pol}} + \frac{\pi^2 f_{end} E c_{warp}}{I_{pol}\ell_{pill}^2} 10^{-4}$$

where:

I_{sv} : Net St. Venant's moment of inertia, in cm^4, see Table 7 for examples of cross sections.

I_{pol} : Net polar moment of inertia about the shear centre of cross section, in cm^4.

$$I_{pol} = I_y + I_z + A(y_0^2 + z_0^2)$$

c_{warp} : Warping constant, in cm^6, see Table 7 for examples of cross sections.

ℓ_{pill} : Length of the member, in m as defined in [3.1.2].

y_0 : Transverse position of shear centre relative to the cross sectional centroid, in cm, see Table 7 for examples of cross sections.

z_0 : Vertical position of shear centre relative to the cross sectional centroid, in cm, see Table 7 for examples of cross sections.

A : Net cross sectional area, in cm^2, as defined in [3.1.2].

I_y : Net moment of inertia about y axis, in cm^4.

I_z : Net moment of inertia about z axis, in cm^4.

3.1.4 Elastic torsional / column buckling stress

For cross sections where the centroid and the shear centre do not coincide, the interaction between the torsional and column buckling mode is to be examined. The elastic torsional / column buckling stress, σ_{ETF}, with respect to axial compression is to be taken as:

$$\sigma_{ETF} = \frac{1}{2\zeta}[(\sigma_{EC} + \sigma_{ET}) - \sqrt{(\sigma_{EC} + \sigma_{ET})^2 - 4\zeta\,\sigma_{EC}\sigma_{ET}}]$$

where:

ζ : Coefficient taken as:

$$\zeta = 1 - \frac{(y_0^2 + z_0^2)A}{I_{pol}}$$

y_0 : Transverse position of shear centre relative to the cross sectional centroid, in cm, as defined in [3.1.3].

z_0 : Vertical position of shear centre relative to the cross sectional centroid, in cm, as defined in [3.1.3].

A : Net cross sectional area, in cm^2, as defined in [3.1.2].

I_{pol} : Net polar moment of inertia about the shear centre of cross section, in cm^4 as defined in [3.1.3].

σ_{EC} : Elastic column compressive buckling stress, as defined in [3.1.2].

σ_{ET} : Elastic torsional buckling stress, as defined in [3.1.3].

3.2 Corrugated bulkhead

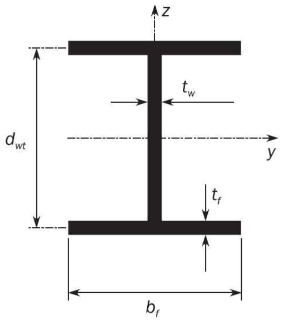
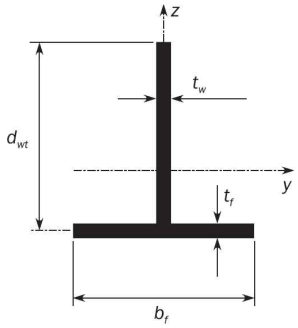
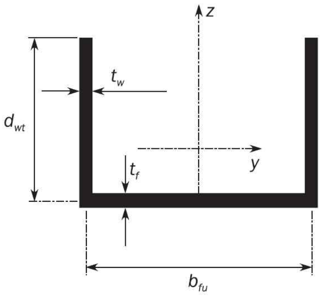
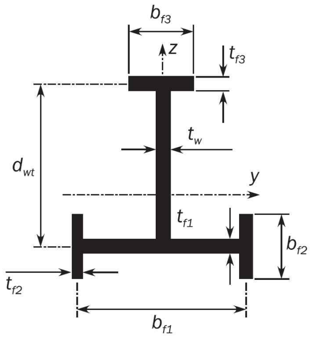
3.2.1

The buckling utilisation factor of flange and web of corrugation of corrugated bulkheads is based on the combination of in plane stresses and shear stress.

The interaction curve of [2.2.1] is to be used with the following coefficients:

- $\alpha = 2$
- $\psi_x = \psi_y = 1$

Table 7 : Cross sectional properties

	$I_{sv} = \frac{1}{3}(2b_f t_f^3 + d_{wt} t_w^3)10^{-4}$	cm^4
	$c_{warp} = \frac{d_{wt}^2 b_f^3 t_f}{24} 10^{-6}$	cm^6
	$I_{sv} = \frac{1}{3}(b_f t_f^3 + d_{wt} t_w^3)10^{-4}$	cm^4
	$y_0 = 0$	cm
	$z_0 = -\frac{0.5 d_{wt}^2 t_w}{d_{wt} t_w + b_f t_f} 10^{-1}$	cm
	$c_{warp} = \frac{b_f^3 t_f^3 + 4 d_{wt}^3 t_w^3}{144} 10^{-6}$	cm^6
	$I_{sv-n50} = \frac{1}{3}(b_{fu} t_f^3 + 2 d_{wt} t_w^3)10^{-4}$	cm^4
	$y_0 = 0$	cm
	$z_0 = -\frac{d_{wt}^2 t_w 10^{-1}}{2d_{wt} t_w + b_{fu} t_f} - \frac{0.5 d_{wt}^2 t_w 10^{-1}}{d_{wt} t_w + b_{fu} t_f/6}$	cm
	$c_{warp} = \frac{b_{fu}^2 d_{wt}^3 t_w (3 d_{wt} t_w + 2 b_{fu} t_f)}{12(6 d_{wt} t_w + b_{fu} t_f)} 10^{-6}$	cm^6
	$I_{sv} = \frac{1}{3}(b_{f1} t_{f1}^3 + 2 b_{f2} t_{f2}^3 + b_{f3} t_{f3}^3 + d_{wt} t_w^3)10^{-4}$	cm^4
	$y_0 = 0$	cm
	$z_0 = z_s - \frac{(b_{f3} d_{wt} t_{f3} + 0.5 d_{wt}^2 t_w)\,10^{-1}}{d_{wt} t_w + b_{f1} t_{f1} + 2 b_{f2} t_{f2} + b_{f3} t_{f3}}$	cm
	$c_{warp} = \left(I_{f1} z_0^2 + \frac{I_{f2} b_{f1}^2}{200} + I_{f3}\left(\frac{d_{wt}}{10} - z_s\right)^2\right)$	cm^6
	$I_{f1} = \left(\frac{(b_{f1} - t_{f2})^3 t_{f1}}{12} + \frac{b_{f2} t_{f2} b_{f1}^2}{2}\right) 10^{-4}$	cm^4
	$I_{f2} = \frac{b_{f2}^3 t_{f2}}{12} 10^{-4}$	cm^4
	$I_{f3} = \frac{b_{f3}^3 t_{f3}}{12} 10^{-4}$	cm^4
	$z_s = \frac{I_{f3} d_{wt}}{I_{f1} + I_{f3}} 10^{-1}$	cm

Note 1: All dimensions are in mm

Note 2: Cross sectional properties are given for typical cross sections. Properties for other cross sections are to be determined by direct calculation.

Section 6 Stress Based Reference Stresses

Symbols

For symbols not defined in this section, refer to Ch 1, Sec 4.

a : Length, in mm, of the longer side of the plate panel as defined in Sec 5.

b : Length, in mm, of the shorter side of the plate panel as defined in Sec 5.

A_i : Area, in mm^2, of the i–th plate element of the buckling panel.

n : Number of plate elements in the buckling panel.

σ_{ix} : Actual stress, in $\mathrm{N/mm}^2$, at the centroid of the i–th plate element in x direction, applied along the shorter edge of the buckling panel.

σ_{iy} : Actual stress, in $\mathrm{N/mm}^2$, at the centroid of the i–th plate element in y direction, applied along the longer edge of the buckling panel.

ψ : Edge stress ratio as defined in Sec 5.

τ_i : Actual membrane shear stress, in $\mathrm{N/mm}^2$, at the centroid of the i–th plate element of the buckling panel.

1. Stress based method

1.1 Introduction

1.1.1

This section provides a method to determine stress distribution along edges of the considered buckling panel by 2nd order polynomial curve, by linear distribution using least square method and by weighted average approach. This method is called Stress based Method.

The reference stress is the stress components at centre of plate element transferred into the local system of the considered buckling panel.

1.1.2 Definition

A regular panel is a plate panel of rectangular shape. An irregular panel is plate panel which is not regular, as detailed in Sec 4, [2.3.1].

1.2 Stress application

1.2.1 Regular panel

The reference stresses are to be taken as defined in [2.1] for a regular panel when the following conditions are satisfied:

a) At least, one plate element centre is located in each third part of the long edge a of a regular panel and
b) This element centre is located at a distance in the panel local x direction not less than $a/4$ to at least one of the element centres in the adjacent third part of the panel.

Otherwise, the reference stresses are to be taken as defined in [2.2] for an irregular panel.

1.2.2 Irregular panel and curved panel

The reference stresses of an irregular panel or of a curved panel are to be taken as defined in [2.2].

2. Reference stresses

2.1 Regular panel

2.1.1 Longitudinal stress

The longitudinal stress σ_x applied on the shorter edge of the buckling panel is to be calculated as follows:

a) For plate buckling assessment, the distribution of $\sigma_x(x)$ is assumed as 2nd order polynomial curve as:

$$\sigma_x(x) = C \cdot x^2 + D \cdot x + E$$

The best fitting curve $\sigma_x(x)$ is to be obtained by minimising the square error Π considering the area of each element as a weighting factor.

$$\Pi = \sum_{i=1}^{n} A_i [\sigma_{ix} - (Cx_i^2 + Dx_i + E)]^2$$

The unknown coefficients C, D and E must yield zero first derivatives, $\partial \Pi$ with respect to C, D and E respectively.

$$\begin{cases} \dfrac{\partial \Pi}{\partial C} = 2\sum_{i=1}^{n} A_i x_i^2 [\sigma_{ix} - (Cx_i^2 + Dx_i + E)] = 0 \\ \dfrac{\partial \Pi}{\partial D} = 2\sum_{i=1}^{n} A_i x_i [\sigma_{ix} - (Cx_i^2 + Dx_i + E)] = 0 \\ \dfrac{\partial \Pi}{\partial C} = 2\sum_{i=1}^{n} A_i [\sigma_{ix} - (Cx_i^2 + Dx_i + E)] = 0 \end{cases}$$

The unknown coefficients C, D and E can be obtained by solving the 3 above equations.

$$\sigma_{x1} = \frac{1}{b}\int_0^b \sigma_x(x)dx = \frac{b^2}{3}C + \frac{b}{2}D + E$$

$$\sigma_{x2} = \frac{1}{b}\int_{a-b}^{a} \sigma_x(x)dx = (a^2 - ab + \frac{b^2}{3})C + (a - \frac{b}{2})D + E$$

If $-D/2C < b/2$ or $-D/2C > a - b/2$, σ_{x3} is to be ignored. Otherwise, σ_{x3} is taken as:

$$\sigma_{x3} = \frac{1}{b}\int_{xmin}^{xmax} \sigma_x(x)dx = \frac{b^2}{12}C - \frac{D^2}{4C} + E$$

where:

$$x_{\min} = -\frac{b}{2} - \frac{D}{2C}$$

$$x_{\max} = \frac{b}{2} - \frac{D}{2C}$$

The longitudinal stress is to be taken as:

$$\sigma_x = \max(\sigma_{x1}; \sigma_{x2}; \sigma_{x3})$$

The edge stress ratio is to be taken as:

$$\psi_x = 1$$

b) For overall stiffened panel buckling and stiffener buckling assessments, $\sigma_x(x)$ applied on the shorter edge of the attached plate is to be taken as:

$$\sigma_x = \frac{\sum_1^n A_i \sigma_{ix}}{\sum_1^n A_i}$$

The edge stress ratio ψ_x for the stress σ_x is equal to 1.0.

2.1.2 Transverse stress

The transverse stress σ_y applied along the longer edges of the buckling panel is to be calculated by extrapolation of the transverse stresses of all elements up to the shorter edges of the considered buckling panel.

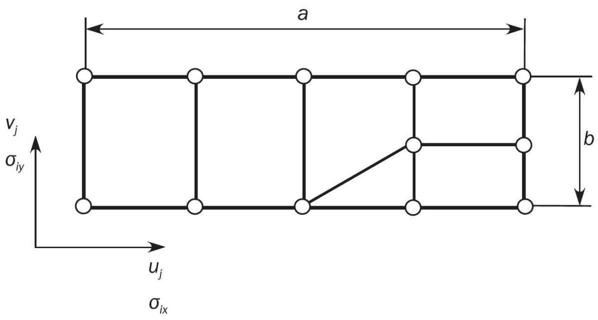


Figure 1 : Buckling panel

The distribution of $\sigma_y(x)$ is assumed as straight line. Therefore:

$\sigma_y(x) = A + Bx$

The best fitting curve $\sigma_y(x)$ is to be obtained by the least square method minimising the square error Π considering area of each element as a weighting factor.

$$\Pi = \sum_{i=1}^n A_i [\sigma_{iy} - (A + Bx_i)]^2$$

The unknown coefficients A and B must yield zero first partial derivatives, $\partial \Pi$ with respect to A and B, respectively.

$$\begin{cases} \dfrac{\partial \Pi}{\partial A} = 2\sum_{i=1}^n A_i [\sigma_{iy} - (A + Bx_i)] = 0 \\ \dfrac{\partial \Pi}{\partial B} = 2\sum_{i=1}^n A_i x_i [\sigma_{iy} - (A + Bx_i)] = 0 \end{cases}$$

The unknown coefficients A and B are obtained by solving the 2 above equations and are given as follow:

$$\begin{cases} A = \dfrac{\left(\sum_{i=1}^n A_i \sigma_{iy}\right)\left(\sum_{i=1}^n A_i x_i^2\right) - \left(\sum_{i=1}^n A_i x_i\right)\left(\sum_{i=1}^n A_i x_i \sigma_{iy}\right)}{\left(\sum_{i=1}^n A_i\right)\left(\sum_{i=1}^n A_i x_i^2\right) - \left(\sum_{i=1}^n A_i x_i\right)^2} \\ B = \dfrac{\left(\sum_{i=1}^n A_i\right)\left(\sum_{i=1}^n A_i x_i \sigma_{iy}\right) - \left(\sum_{i=1}^n A_i x_i\right)\left(\sum_{i=1}^n A_i \sigma_{iy}\right)}{\left(\sum_{i=1}^n A_i\right)\left(\sum_{i=1}^n A_i x_i^2\right) - \left(\sum_{i=1}^n A_i x_i\right)^2} \end{cases}$$

$$\sigma_y = \max(A, A+Ba)$$

$$\psi_y = \frac{\min(A, A+Ba)}{\max(A, A+Ba)} \quad \text{for } \sigma_y \geq 0$$

$$\psi_y = 1 \quad \text{for } \sigma_y < 0$$

2.1.3 Shear stress

The shear stress τ is to be calculated using a weighted average approach, and is to be taken as:

$$\tau = \frac{\sum_1^n A_i \tau_i}{\sum_1^n A_i}$$

2.2 Irregular panel and curved panel

2.2.1 Reference stresses

The longitudinal, transverse and shear stresses are to be calculated using a weighted average approach. They are to be taken as:

$$\sigma_x = \frac{\sum_1^n A_i \sigma_{xi}}{\sum_1^n A_i}$$

$$\sigma_y = \frac{\sum_1^n A_i \sigma_{yi}}{\sum_1^n A_i}$$

$$\tau = \frac{\sum_1^n A_i \tau_i}{\sum_1^n Ai}$$

The edge stress ratios are to be taken as:

$$\psi_x = 1$$

$$\psi_y = 1$$ ⚓

Chapter 9

Fatigue

Section 1 General Considerations

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

T_{DF} : Design fatigue life, in year, specified by the designer, but not to be taken less than 25 years.

1. Rule Application for Fatigue Requirements

1.1 Scope

1.1.1 General

This chapter provides requirements applicable to ships having rule length L between 150 m and 500 m to evaluate fatigue strength of the ship's structural details considering an operation time in North Atlantic or worldwide environment equal to the design fatigue life, T_{DF}.

1.1.2 Assessed area

Fatigue assessment is performed for structural details located in the ship's cargo hold region in order to prevent the following types of fatigue failure:

- Fatigue cracks initiating from the toe of the weld and propagating into the plate.
- Fatigue cracks initiating from free edge of non-welded details.

1.1.3 Structural details to be assessed

The structural details required for fatigue assessment are given in **Ch 9, Sec 2**:

- Structural details to be checked are listed in:
  - **Ch 9, Sec 2, [1]** for simplified stress analysis according to **Ch 9**, **Sec 4**, or
  - **Ch 9, Sec 2, [2]** for finite element stress analysis according to **Ch 9**, **Sec 5**.

Additional specific details may be requested to be checked on a case-by-case basis by the Society.

1.1.4 Detail design standard

Detail design standard given in **Ch 9, Sec 6** provides welding requirement at critical structural details in order to prevent the following types of fatigue failure:

a) Fatigue cracks initiating from the weld toe into the base material.
b) Fatigue cracks initiating from the weld root and propagating into the plate section under the weld.
c) Fatigue cracks initiating from the weld root and propagating through the weld throat.
d) Fatigue cracks initiating from surface irregularity or notch at the free edge into the base material.

1.1.5 Material

The fatigue assessment is applicable for steel material with specified minimum yield stress less than or equal to 390 N/mm^2. For steel with specified minimum yield stress value higher than 390 N/mm^2 and for steels with improved fatigue performance, the S-N curves to be used are considered by the Society on a case-by-case basis.

1.1.6 Wave loads

Fatigue assessment is based on quasi-static wave loads.

1.1.7 Loads other than wave loads

Fatigue induced by low cycle loads such as cargo variations or impact loads such as sloshing in partially filled tanks which may induce fatigue damage is disregarded in this chapter.

2. Definition

2.1 Hot spots

2.1.1

Hot spots are locations in the structure where fatigue cracks may initiate due to the combined effect of nominal structural stress fluctuation and stress raising effects due to the weld geometry or similar effects due to notch in the base material.

Hot spots may be located at:

- Weld toe.
- Weld root of partial penetration or fillet weld.
- Base material at free edge of plate.

2.2 Nominal stress

2.2.1

Nominal stress is the stress in a structural component taking into account macro-geometric effect but disregarding the stress concentration due to structural discontinuities and the presence of welds. Nominal stress is to be obtained either using coarse or fine mesh FE analysis, as required in **Ch 9, Sec 5** or using analytical calculation based on beam theory, as required in **Ch 9, Sec 4.**

2.3 Hot spot stress

2.3.1

Hot spot stress is the stress at the weld toe taking into account the stress concentration due to structural discontinuities and presence of welded attachments but disregarding the non-linear stress peak caused by the notch at the weld toe. The hot spot stresses to be considered correspond to the two principal stresses on the surface plating at the weld toe. The first principal stress acts within ±45°, perpendicular to the weld and the second principal stress acts outside ±45°.

The hot spot stress is to be obtained by multiplying the nominal stress by a Stress Concentration Factor (SCF), according to **Ch 9, Sec 4, [5]** or directly by a very fine mesh FE analysis, according to **Ch 9, Sec 5, [3]** and **Ch 9, Sec 5, [4].**

2.4 Local stress at free edge

2.4.1

Local stress at free edge is the stress at the plate free edge derived using finite element analysis according to **Ch 9, Sec 5, [3.2].**

2.5 Fatigue stress

2.5.1

Fatigue stress is the stress relevant for fatigue assessment purpose, i.e.:

- Maximum of the two principal hot spot stress for weld toe with the mean stress effect and thickness effect corrections.
- Local stress at free edge with corrections due to the base material surface finishing, mean stress effect, thickness effect and material strength.

3. Assumptions

3.1 General

3.1.1

The following assumptions are made in the fatigue assessment:

a) A linear cumulative damage model, i.e. Palmgren-Miner's Rule, given in **Ch 9, Sec 3, [5]**, has been used in connection with the design S-N curves, given in **Ch 9, Sec 3, [4]**.

b) Design fatigue life, T_{DF}, is taken not less than 25 years.

c) Rule quasi-static wave induced loads are based on North Atlantic wave environment. They are determined at 10^{-2} probability level of exceedance by the Equivalent Design Wave (EDW) concept.

d) Net thickness, t_{n50}, is used for simplified stress analysis and gross thickness, t_{gr}, is used for finite stress analysis respectively.

e) Type of stress used for crack initiating at the weld toe is the hot spot stress. Type of stress used for crack initiating at free edge of non-welded details is local stress at free edge.

f) Fatigue stress range $\Delta\sigma_{FS}$ may be calculated by simplified stress analysis or by finite element stress analysis for details with more complex geometry.

g) Long term distribution of stress range of a structural detail is assumed to follow a two-parameter Weibull distribution. Weibull shape parameter ξ is equal to 1.0 and the fatigue stress range $\Delta\sigma_{FS}$ is given at the reference probability level of exceedance equal to 10^{-2}.

h) The acceptance criteria for fatigue checking are the total fatigue damage D to be less than 1.0 for the design fatigue life, as required in **Ch 9, Sec 3, [2]**.

4. Methodology

4.1 Principles

4.1.1 General

Appropriate fatigue strength of structural details is ensured by use of:

- Detail design standards given in **Ch 9, Sec 6**, providing specific design requirements.
- Fatigue strength assessment by fatigue life calculation, based on two different methods for hot spot stress calculation: simplified stress analysis and very fine mesh finite element stress analysis.

4.2 Simplified stress analysis

4.2.1

Procedure based on simplified stress analysis, required in **Ch 9, Sec 4**, is used to determine the hot spot stress at weld toe of longitudinal stiffener end connections, given in **Ch 9, Sec 2, [1.1]**.

Nominal stresses are calculated by using analytical method based on beam theory according to **Ch 9, Sec 4, [3]** and **Ch 9, Sec 4, [4]**. Hot spot stresses are obtained by multiplying nominal stresses by stress concentration factors (SCF) of the considered detail according to **Ch 9, Sec 4, [5.2]**.

4.3 Finite element stress analysis

4.3.1

Procedure based on finite element stress analysis, required in **Ch 9, Sec 5,** is used to determine hot spot stress at weld toe of specified structural details, from very fine mesh models.

The hot spot stress is generally highly dependent on the finite element model used for representing the structure.

General procedure for the calculation of hot spot stress at weld toe for any welded details except for web stiffened cruciform joints is given in **Ch 9, Sec 5, [3.1].** Procedure for the calculation of hot spot stress at the flange connections for web stiffened cruciform joints is given in **Ch 9, Sec 5, [4]**. Calculation of local stress for non-welded area is provided in **Ch 9, Sec 5, [3.2].**

A list of details for which the fatigue assessment is to be made through a compulsory very fine mesh finite element analysis if a very fine mesh finite element analysis is omitted, is given respectively in **Ch 9, Sec 2, Table 1** and **Ch 9, Sec 2, Table 3.**

4.4 Fatigue design standards

4.4.1

Detail design standards given in **Ch 9, Sec 6** are provided to ensure improved fatigue performance of critical structural details. Alternative detail design configurations may be accepted subject to demonstration of satisfactory fatigue performance.

5. Corrosion Model

5.1 Net or Gross thickness

5.1.1 General

The fatigue assessment by simplified method should be performed based on net thicknesses according to **Ch 3, Sec 2.** When accessing the fatigue strength by finite stress analysis, it shall be performed based on gross thicknesses.

5.1.2 Stress correction

The hull girder stresses for simplified stress analysis is to be corrected by multiplying the calculated stress by f_c, correction factor taken as:

f_c = 0.95

6. Loading Conditions

6.1 Description

6.1.1

Fatigue analyses are to be carried out for representative loading conditions according to the intended ship’s operation as given in **[6.2].**

6.2 Loading conditions

6.2.1

The loading conditions to be considered and corresponding fraction of time for each loading condition, $\alpha_{(j)}$, are defined in **Table 1.** The standard loading conditions for fatigue assessment are provided in **Ch 4, Sec 8, [3].**

Table 1 : Fraction of time in each loading condition

Loading conditions		$\alpha_{(j)}$
Full Load	Ballast Tank - Full	0.7 [1]
	Ballast Tank - Empty	0.3 [1]

[1] Two loading conditions, a minimum and maximum hogging condition, shall be checked. For each loading condition, the ballast tank shall be considered as full (to the tank top) 70% and empty 30% of the time, and the fatigue damage shall be calculated as the sum of these two contributions.

7. Load Case

7.1 Assumptions

7.1.1

The load cases to be considered for fatigue assessment are given in **Ch 4, Sec 2, [3].**

The design load scenario for fatigue assessment is defined in **Ch 4, Sec 7, Table 3.**

For each loading condition defined in **[6]**, all fatigue load cases are to be considered to generate the combination of dynamic loads for fatigue assessment.

7.1.2 Predominant load case

The predominant load case for each loading condition (j) is defined as load case where the fatigue stress range for the critical location is the maximum among all fatigue load cases.

Section 2 Structural Details to be Assessed

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

1. Simplified Stress Analysis

1.1 Structural details to be assessed

1.1.1

Critical structural details to be checked over the full extent of the cargo region for fatigue assessment by simplified stress analysis according to **Ch 9, Sec 1** are:

- End connections of longitudinal stiffeners to transverse bulkheads,
- End connections of longitudinal stiffeners to floors and web frames.

2. Finite Element Analysis

2.1 Structural details to be assessed

2.1.1 General

Critical structural details to be checked for fatigue by finite element analysis according to **Ch 9, Sec 5** are given in **[2.1.2].** Additional fatigue assessment may be required for other locations where deemed necessary by Society.

Table 2 give the list of hot spots for structural details.

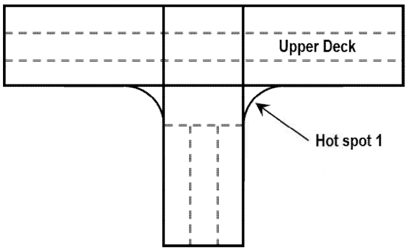
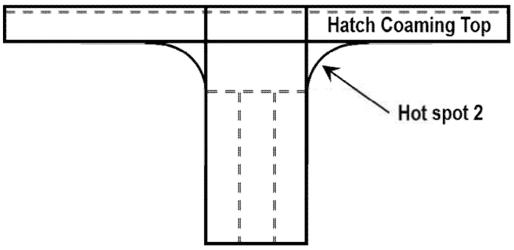
2.1.2 Details to be checked by very fine mesh analysis

Critical structural details to be assessed for fatigue by very fine mesh analysis according to **Ch 9, Sec 5, [1]** to **Ch 9, Sec 5, [4]** are provided in **Table 1.**

Table 1 : Structural details to be assessed by very fine mesh analysis

No	Critical detail	Applicability
1	Typical hatch corner in the midship	Container Hold 1)
1) Cargo hold located closest to the midship.		

Table 2 : Hot spots for deck plating and hatch corner

Hot spot location	Procedure for calculation of hot spot stress
Hot spot 1 : Upper deck corner radiused edge Hot spot 2 : Hatch coaming top corner radiused edge	**Ch 9, Sec 5, [3.2]**
	

Section 3 Fatigue Evaluation

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

(i) : Suffix which denotes load case HSM, FSM, BSR-P, BSR-S, BSP-P, BSP-S, OST-P or OST-S specified in **Ch 4, Sec 2, [3].**

'$i1$' denotes load case: HSM-1, FSM-1, BSR-1P, BSR-1S, BSP-1P, BSP-1S, OST-1P or OST-1S.

'$i2$' denotes load case: HSM-2, FSM-2, BSR-2P, BSR-2S, BSP-2P, BSP-2S, OST-2P or OST-2S.

(j) : Suffix which denotes loading condition:

Loading conditions as defined in **Ch 9, Sec 1, [6.2].**

T_C : Time in corrosive environment, in years, according to **Table 5.**

T_D : Design life, in years, to be taken as 25 years.

T_{DF} : Design fatigue life, in year, as defined in **Ch 9, Sec 1.**

T_F : Fatigue life, in year, calculated according to **[5].**

m : Inverse slope of the design S-N curve, as given in **Table 2** for in-air environment and in **Table 3** for corrosive environment.

The inverse slope for S-N curves in-air environment changes from m to m+2 at N = 10^7 cycles.

n_{LC} : Number of applicable loading conditions, as defined in **Ch 9, Sec 1, [6.2].**

f_c : Correction factor as defined in **Ch 9, Sec 1, [5.1.2].**

f_{thick} : Correction factor for plate thickness effect given in **[3.3].**

$f_{mean,i(j)}$: Correction factor for mean stress effect given in **[3.2].**

f_e : Environmental factor, to be taken as:

f_e=1.0	for North Atlantic wave environment
f_e=0.8	for Worldwide wave environment

1. Fatigue Analysis Methodology

1.1 Cumulative damage

1.1.1

The fatigue assessment of the structure is based on the application of the Palmgren-Miner cumulative damage D taken as:

$$D = \sum_{i=1}^{n_{tot}} \frac{n_i}{N_i}$$

where:

n_i : Number of cycles at stress range $\Delta\sigma_i$.

N_i : Number of cycles to failure at stress range $\Delta\sigma_i$.

n_{tot} : Total number of stress range blocks.

i : Stress range block index.

1.1.2

As the long term stress range distribution of a structural detail in a ship can be described by a two-parameter Weibull distribution, as given in **Ch 9, Sec 1, [3.1.1]**, fatigue damage can be obtained by means of a closed-form equation, as given in **[5]**.

1.2 Fatigue strength assessment

1.2.1

Assessment of the fatigue strength of structural members according to **[2]** includes the following three steps:

a) Calculation of stress ranges, according to **[3]**.
b) Selection of the design S-N curve, according to **[4]**.
c) Calculation of the cumulative damage and the fatigue life calculation, according to **[5]**.

2. Acceptance Criteria

2.1 Fatigue life and acceptance criteria

2.1.1

The calculated fatigue life, T_F, is to comply with the following formula:

$$T_F \geq T_{DF}$$

3. Reference Stresses for Fatigue Assessment

3.1 Fatigue stress range

3.1.1

The fatigue stress range for each load case of each loading condition is defined in **[3.1.2]** for welded joints and in **[3.1.3]** for base material free edge.

The stress range of each loading condition (j) to be considered is the stress range obtained from the predominant load case, according to **Ch 9, Sec 1, [7.1.2]**.

$$\Delta\sigma_{FS,(j)} = \max_i(\Delta\sigma_{FS,i(j)})$$

where:

$\Delta\sigma_{FS,i(j)}$: Fatigue stress range, in N/mm², for load case (i) of loading condition (j), as defined in **[3.1.2]** for welded joints and in **[3.1.3]** for base material free edge.

3.1.2 Welded joints

For welded joints, the fatigue stress range, $\Delta\sigma_{FS,i(j)}$ in N/mm², corrected for mean stress effect, thickness effect and warping effect, is taken as:

- For simplified stress analysis:
  $$\Delta\sigma_{FS,i(j)} = f_{mean,i(j)} \cdot f_{thick} \cdot f_{warp} \cdot f_e \cdot \Delta\sigma_{HS,i(j)}$$
- For FE analysis:
  - For web-stiffened cruciform joints:
    $$\Delta\sigma_{FS,i(j)} = f_W \cdot f_S \cdot \max(\Delta\sigma_{FS1,i(j)}, \Delta\sigma_{FS2,i(j)})$$
  - For other joints:
    $$\Delta\sigma_{FS,i(j)} = \max(SideL, SideR)[\max(\Delta\sigma_{FS1,i(j)}, \Delta\sigma_{FS2,i(j)})]$$

where:

f_W : Correction factor for the effect of stress gradient along weld line given as 0.96

f_S : Correction factor for the effect of supporting member given as 0.95

$\Delta\sigma_{HS,i(j)}$: Hot spot stress range, in N/mm^2, due to dynamic loads in load case (i) of loading condition (j) given in **Ch 9, Sec 4, [2.1.1].**

$\Delta\sigma_{FS1,i(j)}$: Fatigue stress range, in N/mm^2, due to the principal hot spot stress range $\Delta\sigma_{HS1,i(j)}$

$$\Delta\sigma_{FS1,i(j)} = f_{mean,i(j)} \cdot f_{thick} \cdot f_c \cdot f_e \cdot \Delta\sigma_{HS1,i(j)}$$

$\Delta\sigma_{FS2,i(j)}$: Fatigue stress range, in N/mm^2, due to the principal hot spot stress range $\Delta\sigma_{HS2,i(j)}$

$$\Delta\sigma_{FS2,i(j)} = 0.9 \cdot f_{mean2,i(j)} \cdot f_{thick} \cdot f_c \cdot f_e \cdot \Delta\sigma_{HS2,i(j)}$$

$SideL, SideR$: Left and right side respectively of the line A-A as shown in **Ch 9, Sec 5, Figure 7** and **Ch 9, Sec 5, Figure 8.**

$f_{mean1,i(j)}$: Correction factor for mean stress effect given in **[3.2].**

$f_{mean2,i(j)}$: Correction factor for mean stress effect given in **[3.2].**

f_{warp} : Correction factor due to warping effect, taken as:

- f_{warp} = 1.07 for the deck longitudinal stiffener, the closest to the longitudinal hatch coaming in way of the hatch corner as shown in **Figure 1**, except f_{warp} = 1.0 when OST is not the dominant load case for all loading conditions,
- f_{warp} = 1.04 for following deck longitudinal stiffeners, except f_{warp} = 1.0 when OST is not the dominant load case for all loading conditions:
  - The closest stiffener to the longitudinal hatch coaming at one web frame away from the hatch corner, in way of the hatch opening as shown in **Figure 1**,
  - The second closest stiffener away from the longitudinal hatch coaming in way of the hatch corner as shown in **Figure 1**,
- f_{warp} = 1.0 for the other cases.

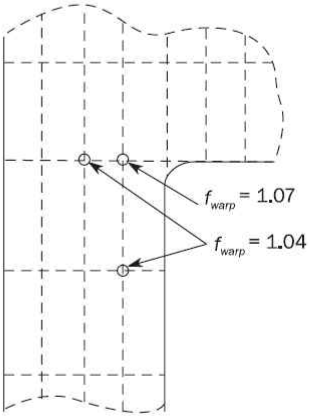


Figure 1 : Warping effect on deck longitudinal stiffeners

$\Delta\sigma_{HS1,i(j)}$: Principal hot spot stress ranges, in N/mm^2, due to dynamic loads for load case (i) of loading condition (j) which acts within ±45° of the perpendicular to the weld toe, determined in **Ch 9, Sec 5, [3.1.2]**, **Ch 9, Sec 5, [3.3.2]** and **Ch 9, Sec 5, [4.2.3]** for the two types of shell elements (4-node or 8-node).

$\Delta\sigma_{HS2,i(j)}$: Principal hot spot stress ranges, in N/mm^2, due to dynamic loads for load case (i) of loading condition (j) which acts outside ±45° of the perpendicular to the weld toe, determined in **Ch 9, Sec 5, [3.1.2]** and **Ch 9, Sec 5, [4.2.3]** for the two types of shell elements (4-node or 8-node).

3.1.3 Base material free edge

For base material free edge, the fatigue stress range, $\Delta\sigma_{FS,i(j)}$ in N/mm², is taken as the local stress range at free edge, $\Delta\sigma_{BS,i(j)}$, as defined in **Ch 9, Sec 1, [2.4]** with correction factors:

$$\Delta\sigma_{FS,i(j)} = K_{sf} \cdot f_{material} \cdot f_{mean,i(j)} \cdot f_{thick} \cdot f_c \cdot \Delta\sigma_{BS,i(j)}$$

where:

K_{sf} : Surface finishing factor for base material given in **[4.2.3].**

$f_{material}$: Correction factor for material strength, taken as:

$$f_{material} = \frac{1200}{965 + R_{eH}}$$

$\Delta\sigma_{BS,i(j)}$: Local stress range, in N/mm^2, due to dynamic loads in load case (i) of loading condition (j) taken as:

$$\Delta\sigma_{BS,i(j)} = \left|\sigma_{BS,i1(j)} - \sigma_{BS,i2(j)}\right|$$

$\sigma_{BS,i1(j)}, \sigma_{BS,i2(j)}$: Local stress, in N/mm², in load case '$i1$' and '$i2$' of loading condition (j), obtained by very fine mesh FE analysis specified in **Ch 9, Sec 5.**

3.2 Mean stress effect

3.2.1 Correction factor for mean stress effect

The mean stress correction factor to be considered for each principal hot spot stress range of welded joint, $\Delta\sigma_{HS,i(j)}$, or for local stress range at free edge, $\Delta\sigma_{BS,i(j)}$, is taken as:

a) For welded joint:

$$f_{mean,i(j)} = \begin{cases} \min\left[1.0,\ 0.9 + 0.2\dfrac{\sigma_{mCor,i(j)}}{2\Delta\sigma_{HS,i(j)}}\right] & \text{for } \sigma_{mCor,i(j)} \geq 0 \\ \max\left[0.3,\ 0.9 + 0.8\dfrac{\sigma_{mCor,i(j)}}{2\Delta\sigma_{HS,i(j)}}\right] & \text{for } \sigma_{mCor,i(j)} < 0 \end{cases}$$

b) For base material:

$$f_{mean,i(j)} = \begin{cases} \min\left[1.0,\ 0.8 + 0.4\dfrac{\sigma_{mCor,i(j)}}{2\Delta\sigma_{BS,\ i(j)}}\right] & \text{for } \sigma_{mCor,i(j)} \geq 0 \\ \max\left[0.3,\ 0.8 + \dfrac{\sigma_{mCor,i(j)}}{2\Delta\sigma_{BS,i(j)}}\right] & \text{for } \sigma_{mCor,i(j)} < 0 \end{cases}$$

where:

$$\sigma_{mCor,i(j)} = \begin{cases} \sigma_{mean,i(j)} & \text{for } \sigma_{\max} \leq R_{eEq} \\ R_{eEq} - \sigma_{\max} + \sigma_{mean,i(j)} & \text{for } \sigma_{\max} > R_{eEq} \end{cases}$$

$$\sigma_{\max} = \begin{cases} \max_{i,\ (j)}\left(\Delta\sigma_{HS,i(j)} + \sigma_{mean,i(j)}\right) & \text{for weledjoint} \\ \max_{i,\ (j)}\left(\Delta\sigma_{BS,i(j)} + \sigma_{mean,i(j)}\right) & \text{for basematerial} \end{cases}$$

$$R_{eEq} = \max(315; R_{eH})$$

$\sigma_{mean,i(j)}$: Fatigue mean stress, in N/mm², for base material according to **[3.2.2]** or welded joint calculated according to **[3.2.3]** or **[3.2.4]** as applicable.

3.2.2 Mean stress for base material free edge

The fatigue mean stress for base material free edge, $\sigma_{mean,i(j)}$ in N/mm^2, due to static and dynamic loads case '$i1$' and '$i2$' of loading condition (j) is calculated by the following formula based on local stress:

$$\sigma_{mean,i(j)} = \frac{\sigma_{BS,i1(j)} + \sigma_{BS,i2(j)}}{2}$$

3.2.3 Mean stress for simplified method

The fatigue mean stress to be considered for welded joint assessed by the simplified stress analysis is to be obtained from **Ch 9, Sec 4, [2.2].**

3.2.4 Mean stress for FE analysis

The fatigue mean stresses for welded joint due to static and dynamic loads, $\sigma_{mean,i(j),pX}$ and $\sigma_{mean,i(j),pY}$, in N/mm^2, for load cases '$i1$' and '$i2$' of loading condition (j), belonging to the two principal hot spot stress range directions, pX and pY, is calculated by the following formula based on hot spot stress components as defined in **Ch 9, Sec 5, [3.1.2]** and **Ch 9, Sec 5, [4.2.3]:**

$$\sigma_{mean,i(j)pX} = \frac{\left(\sigma_{HS,i1(j)}\right)_{xx} + \left(\sigma_{HS,i2(j)}\right)_{xx} + \left(\sigma_{HS,i1(j)}\right)_{yy} + \left(\sigma_{HS,i2(j)}\right)_{yy}}{4}$$

$$+\left(\frac{\left(\sigma_{HS,i1(j)}\right)_{xx} + \left(\sigma_{HS,i2(j)}\right)_{xx} - \left(\sigma_{HS,i1(j)}\right)_{yy} - \left(\sigma_{HS,i2(j)}\right)_{yy}}{4}\right) \bullet \cos 2\theta + \left(\frac{\left(\sigma_{HS,i1(j)}\right)_{xy} + \left(\sigma_{HS,i2(j)}\right)_{xy}}{2}\right) \bullet \sin 2\theta$$

$$\sigma_{mean,i(j)pY} = \frac{\left(\sigma_{HS,i1(j)}\right)_{xx} + \left(\sigma_{HS,i2(j)}\right)_{xx} + \left(\sigma_{HS,i1(j)}\right)_{yy} + \left(\sigma_{HS,i2(j)}\right)_{yy}}{4}$$

$$-\frac{\left(\sigma_{HS,i1(j)}\right)_{xx} + \left(\sigma_{HS,i2(j)}\right)_{xx} - \left(\sigma_{HS,i1(j)}\right)_{yy} - \left(\sigma_{HS,i2(j)}\right)_{yy}}{4} \bullet \cos 2\theta - \left(\frac{\left(\sigma_{HS,i1(j)}\right)_{xy} + \left(\sigma_{HS,i2(j)}\right)_{xy}}{2}\right) \bullet \sin 2\theta$$

θ : Angle between the direction x of the element coordinate system and the principal direction pX of the principal hot spot stress range coordinate system (**Ch 9, Sec 5, [3.1.2], Ch 9, Sec 5, [4.2.3]**). The direction x of the element coordinate system is defined as the normal to the weld toe.

The one of the two mean stresses $\sigma_{mean,i(j),pX}$ and $\sigma_{mean,i(j),pY}$ which has a principal stress direction with an absolute value less than 45° is defined as $\sigma_{mean1,i(j)}$, belonging to $\Delta\sigma_{HS1,i(j)}$. The other mean stress is defined as $\sigma_{mean2,i(j)}$ belonging to $\Delta\sigma_{HS2,i(j)}$.

3.3 Thickness effect

3.3.1

Plate thickness primarily influences the fatigue strength of welded joints through the effect of geometry, and through-thickness stress distribution. The correction factor, f_{thick}, for plate thickness effect is taken as:

- For simplified stress analysis
  f_{thick} = 1.0 for $t_{n50} \leq 22.0$ mm
  f_{thick} = $(t_{n50}/22.0)^n$ for $t_{n50} > 22.0$ mm
- For finite stress analysis
  f_{thick} = 1.0 for $t_{gr} \leq 22.0$ mm
  f_{thick} = $(t_{gr}/22.0)^n$ for $t_{gr} > 22.0$ mm

where:

t_{n50} : Net thickness of the considered member in way of the hot spot for welded joints or base material free edge, in mm, for simplified stress analysis.

- The net thickness to be considered for stiffeners is as follows:
  - Flat bar and Bulb profile: no correction,
  - Angle bar and T-bar: flange net thickness.

t_{gr} : Gross thickness of the considered member in way of the hot spot for welded joints or base material free edge where the crack is likely to initiate and propagate, in mm, for FE analysis.

- For 90° attachments, i.e. cruciform welded joints, transverse T-joints and plates with transverse attachment, the gross thickness to be considered is to be taken as:

$$t_{gr} = \min\left(\frac{d}{2}, t_{1-gr}\right)$$

n : Thickness exponent provided in **Table 1** and **Table 4** respectively for welded and non-welded joints.

n is to be selected according to the considered stress direction. For this selection, $\Delta\sigma_{HS1}$ and $\Delta\sigma_{HS2}$ are considered perpendicular and parallel to the weld respectively.

d : Toe distance, in mm, as shown in **Figure 2**, taken as:

$$d = t_{2-gr} + 2\ell_{leg}$$

t_{1-gr} : Gross thickness, in mm, of the continuous plate as shown in **Figure 2.**

t_{2-gr} : Gross thickness, in mm, of the transverse attach plate where the hot spot is assessed, as shown in **Figure 2.**

ℓ_{leg} : Fillet weld leg length, in mm.

When post-weld treatment methods are applied to improve the fatigue life of considered welded joint, the thickness exponent is provided in **[6].**

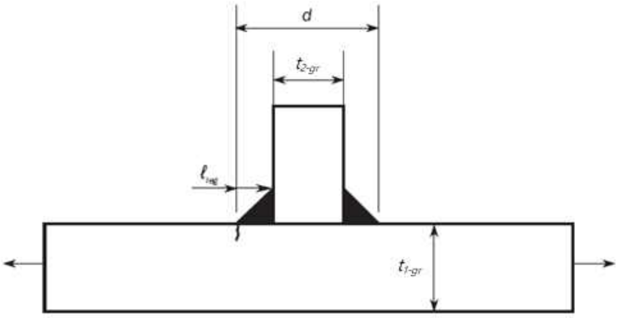
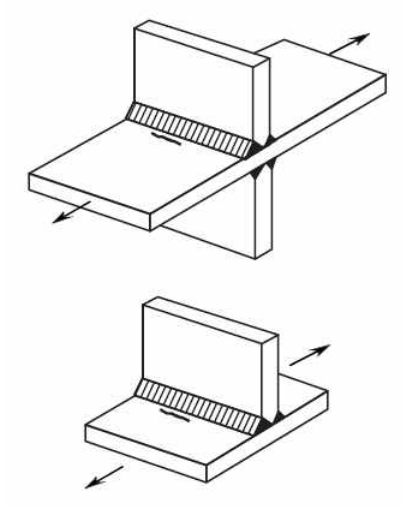
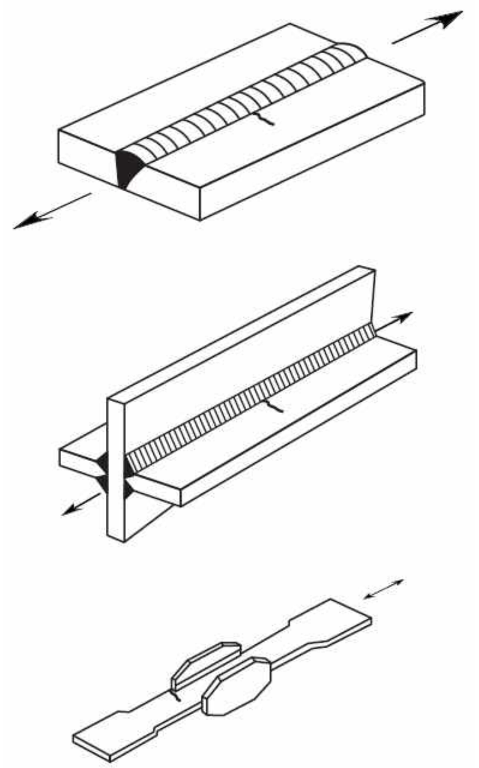
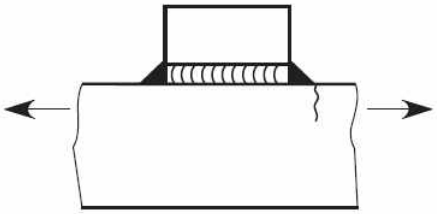
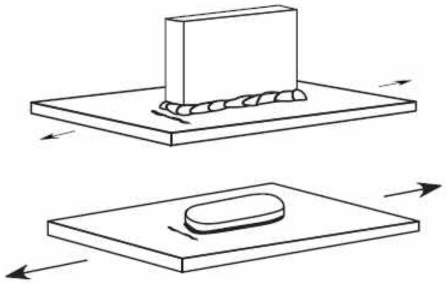
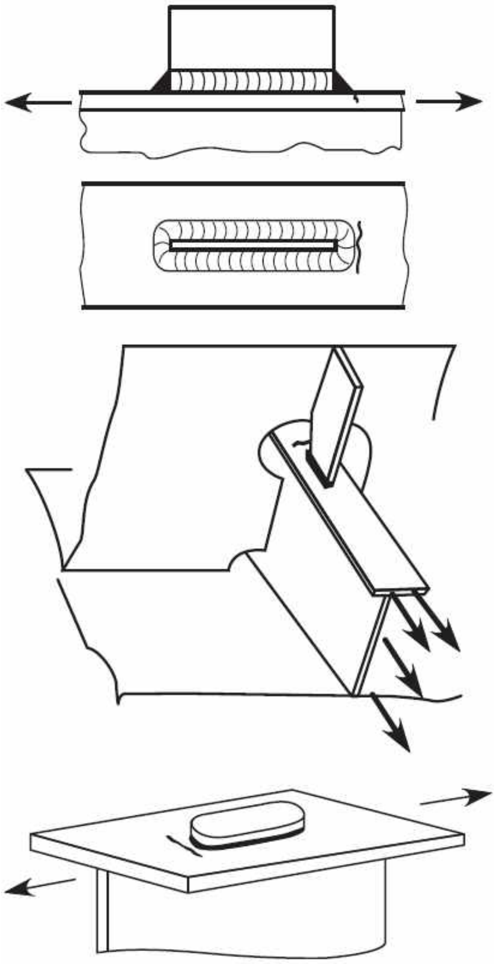


Figure 2 : Toe distance for cruciform welded joints, transverse T-joints and plates with transverse attachment

Table 1 : Welded joints: thickness exponents

No	Joint category description	Geometry	Condition	n
1	Cruciform joints, transverse T-joints, plates with transverse attachments		As-welded	0.25
			Weld toe treated by post-weld improvement method	0.2
2	Transverse butt welds		As-welded	0.2
			Ground flush or weld toe treated by post-weld improvement method	0.1
3	Longitudinal welds or attachments to plate edges		Any	0.1
			Weld toe treated by post-weld improvement method	0.1

No	Joint category description	Geometry	Condition	n
4	Longitudinal attachments on the flat bar or bulb profile		Any	0.0
			Weld toe treated by post-weld improvement method (1)	0.0
5	Longitudinal attachments and doubling plates		As-welded	0.2
			Weld toe treated by post-weld improvement method	0.1
6	Longitudinal attachments and doubling plates supported longitudinally		As-welded	0.1
			Weld toe treated by post-weld improvement method (1)	0.0

(1) No benefit applicable for post-weld treatment of longitudinal end connections.

4. S-N Curves

4.1 Basic S-N curves

4.1.1 Capacity

The capacity of welded steel joints and steel base material with respect to fatigue strength is defined by S-N curves which provide the relationship between the stress range applied to the detail and the number of constant amplitude load cycles to failure.

4.1.2 Design S-N curves

The fatigue assessment is based on use of S-N curves which are obtained from fatigue tests. The design S-N curves are established at two standard deviations below the mean S-N curves corresponding to 50 % of probability of survival for relevant experimental data. Design S-N curves given in **Table 2** and **Table 3** correspond to a probability of survival of 97.7 %.

4.1.3 S-N curve scope of application

The S-N curves are applicable to normal and high strength steels up to a specified minimum yield stress equal to 390 N/mm^2.

4.1.4 In-air environment

The basic design curves in-air environment shown in **Figure 3** are represented by linear relationships between log ($\Delta\sigma$) and log (N) as follows:

$$\log(N) = \log(K_2) - m \cdot \log(\Delta\sigma)$$

where:

$$\log(K_2) = \log(K_1) - 2 \cdot \log(\delta)$$

K_1 : Constant related to mean S-N curve, as given in **Table 2.**

K_2 : Constant related to design S-N curve, as given in **Table 2.**

δ : Standard deviation of log (N), as given in **Table 2.**

$\Delta\sigma_q$: Stress range at N = 10^7 cycles related to design S-N curve, in N/mm^2, as given in **Table 2.**

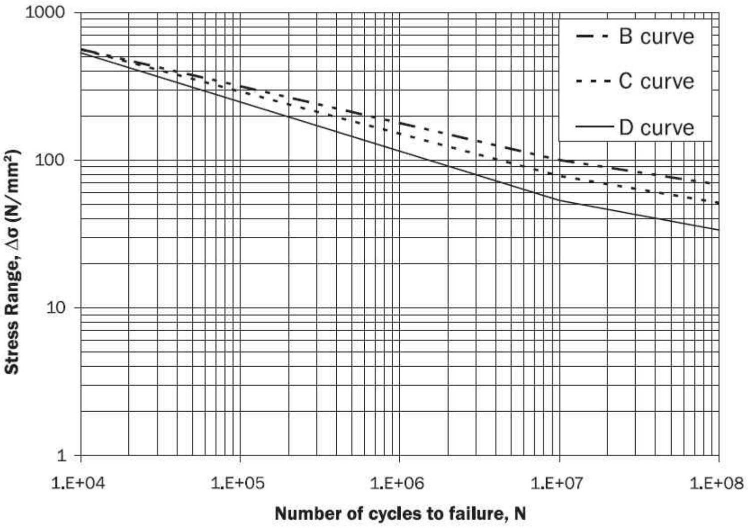


Figure 3 : Basic design S-N curves, in-air environment

Table 2 : Basic S-N curve data, in-air environment

Class	K_1		m	Standard deviation δ	K_2	Design stress range at 10^7 cycles	Design stress range at 2×10^6 cycles
	K_1	$\log_{10}K_1$		$\log_{10}\delta$	K_2	$\Delta\sigma_q$ N/mm^2	N/mm^2
B	2.343E15	15.3697	4.0	0.1821	1.01E15	100.2	149.9
C	1.082E14	14.0342	3.5	0.2041	4.23E13	78.2	123.9
D	3.988E12	12.6007	3.0	0.2095	1.52E12	53.4	91.3

4.1.5 Corrosive environment

The basic design curves for corrosive environment shown in **Figure 4** are represented by linear relationships between log($\Delta\sigma$) and log(N) as follows:

$$\log(N) = \log(K_2) - m \cdot \log(\Delta\sigma)$$

N : Predicted number of cycles to failure under stress range $\Delta\sigma$.

K_2 : Constant related to design S-N curve as given in **Table 3.**

Table 3 : Basic S-N curve data, corrosive environment

Class	K_2	m	Design stress range at 2×10^6 cycles, N/mm^2
B_{corr}	5.05×10^{14}	4.0	126.1
C_{corr}	2.12×10^{13}	3.5	101.6
D_{corr}	7.60×10^{11}	3.0	72.4

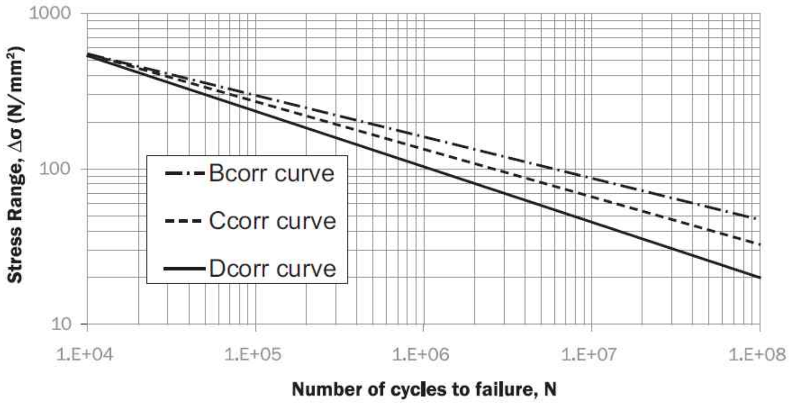


Figure 3 : Basic design S-N curves, corrosive environment

4.2 Selection of S-N curves

4.2.1 Welded joints

For fatigue assessment of welded joints exposed to in-air environment, S-N curve D as defined in **Table 2** is to be used. For corrosive environment, S-N curve D_{corr} as defined in **Table 3** is to be used.

4.2.2 Base material free edge

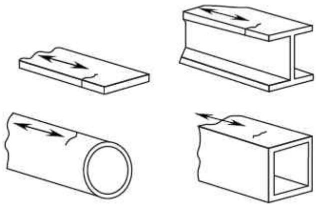
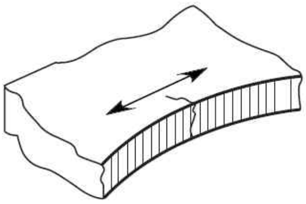
For fatigue assessment of base material at free edge exposed to in-air environment, S-N curves B or C as defined in **Table 2** are to be used. For corrosive environment, S-N curves B_{corr} or C_{corr} as defined in **Table 3** are to be used.

4.2.3 Surface finishing factor

The S-N curve C is applicable to most of non-welded locations taking into account the likelihood of some notching from corrosion, wear and tear in service with surface finishing factor as given in **Table 4.**

Higher surface finishing quality may be applied in using S-N curve B as given in **Table 4,** provided adequate protective measures are taken against wear, tear and corrosion and finite element analysis according to **Ch 9, Sec 5, [2]** is carried out.

Table 4 : Non-welded joints: thickness exponent and surface finishing factor

Joint configuration, fatigue crack location and stress direction		Edge cutting process	Edge treatment	Surface finishing	n	k_{sf}	S-N curve
1	Rolled or extruded plates and sections as well as seamless pipes, no surface or rolling defects 	N/A	N/A	No surface nor roll defect$^{(1)(2)}$	0.0	0.94	B
2	Cut edges 	Machine cutting e.g. by a thermal process or sheared edge cutting	Cutting edges chamfered or rounded by means of smooth grinding, groove direction parallel to the loading direction	Smooth surface free of cracks and notches$^{(1)(2)}$	0.1	1.00	B
			Cutting edges broken or rounded	Smooth surface free of cracks and notches$^{(1)(2)}$	0.1	1.07	B
			No edge treatment	Surface free of cracks and severe notches (inspection procedure)$^{(1)(2)}$	0.1	1.00	C
		Manually thermally cut e.g. by flame cutting	No edge treatment	Surface free of cracks and severe notches (inspection procedure)$^{(1)(2)}$	0.1	1.24	C

(1) Stress increase due to geometry of cut-outs to be considered.
(2) Fine mesh FE analysis according to **Ch 9, Sec 5, [2]**.

5. Fatigue Damage Calculation

5.1 General

5.1.1

The design fatigue life is divided into a number of time periods due to different loading conditions and due to limitation of the corrosion protection.

It is assumed that the corrosion protection (i.e. coating system) is only effective for a limited number of years during which the structural details are protected, i.e. in-air environment. During the remaining part of the design life as specified in **Table 5,** the structural details are unprotected i.e. exposed to corrosive environment.

5.1.2

The elementary fatigue damage, given in **[5.2],** is the damage accumulated during a specific loading condition (j) associated with a specific environmental condition either protected condition, i.e. in-air environment, or unprotected condition, i.e. corrosive environment.

The combined fatigue damage, given in **[5.3],** is the combination of damage accumulated for a specific loading condition (j) for the in-air and corrosive environment time.

Total fatigue damage, given in **[5.4],** is the sum of the combined fatigue damages obtained for all loading conditions.

5.2 Elementary fatigue damage

5.2.1

The elementary fatigue damage for each fatigue loading condition (j) is to be calculated independently for both protected in-air environment and unprotected corrosive environment, based on the fatigue stress range obtained for the predominant load case as follows:

$$D_{E(j)} = \frac{\alpha_{(j)} \bullet N_D}{K_2} \frac{\Delta\sigma^m_{FS,(j)}}{(\ln N_R)^{m/\xi}} \bullet \mu_{(j)} \bullet \Gamma(1+\frac{m}{\xi})$$

where:

N_D : Total number of wave cycles experienced by ship during the design fatigue life, taken as:

$N_D = 31.557 \times 10^6 (f_0\, T_D) / (4 \log L)$

f_0 : Factor taking into account time in seagoing operations excluding time in loading and unloading, repairs, etc.

$f_0 = 0.85$.

$\alpha_{(j)}$: Fraction of time in each loading condition given in **Ch 9, Sec 1, Table 1.**

$\Delta\sigma_{FS,(j)}$: Fatigue stress range at the reference probability level of exceedance of 10^{-2}, in N/mm^2.

N_R : Number of cycles corresponding to the reference probability of exceedance of 10^{-2}.

$N_R = 100$.

ξ : Weibull shape parameter,

$\xi = 1.0$.

$\Gamma(x)$: Complete Gamma function.

K_2 : Constant of the design S-N curve, as given in **Table 2** for in-air environment and in **Table 3** for corrosive environment.

$\mu_{(j)}$: Coefficient taking into account the change of inverse slope of the S-N curve, m,

- For in-air environment:

$$\mu_{(j)} = 1 - \frac{\left\{\gamma\left(1+\frac{m}{\xi}, \nu_{(j)}\right) - \nu_{(j)}^{-\Delta m/\xi} \bullet \gamma\left(1+\left(\frac{m+\Delta m}{\xi}\right), \nu_{(j)}\right)\right\}}{\Gamma\left(1+\frac{m}{\xi}\right)}$$

$$\nu_{(j)} = \left(\frac{\Delta\sigma_q}{\Delta\sigma_{FS,(j)}}\right)^{\xi} In\, N_R$$

- For corrosive environment:

$$\mu_{(j)} = 1.0$$

$\gamma(a,x)$: Incomplete Gamma function.

$\Delta\sigma_q$: Stress range, in N/mm^2, corresponding to the intersection of the two segments of design S-N curve at N = 10^7 cycles, as given in **Table 2.**

Δm : Change in inverse slope of S-N curve at N = 10^7 cycles.

$$\Delta m = 2$$

5.3 Combined fatigue damage

5.3.1

The combined fatigue damage in protected in-air environment and unprotected corrosive environment for each loading condition (j) is to be calculated as follows:

$$D_{(j)} = D_{E,air\ (j)} \bullet \frac{T_D - T_C}{T_D} + D_{E,corr(j)} \bullet \frac{T_C}{T_D}$$

where:

$D_{E,air\ (j)}$: The elementary fatigue damage for in-air environment for loading condition (j) given in **[5.2.1].**

$D_{E,corr(j)}$: The elementary fatigue damage for corrosive environment for loading condition (j) as calculated in **[5.2.1].**

Table 5 : Time in corrosive environment, T_C

Location of weld joint or structural detail	Time in corrosive environment T_C , in years
Water ballast tank	5
Cargo hold	0
Void space	
Other areas	

5.4 Total fatigue damage

5.4.1

The total fatigue damage for all applicable loading conditions is calculated as follows:

$$D = \sum_{j=1}^{n_{LC}} D_{(j)}$$

where:

$D_{(j)}$: Combined fatigue damage for each applicable loading condition, as given in **[5.3].**

5.5 Fatigue life calculation

5.5.1

The fatigue life, T_F, is taken as:

$$T_F = \frac{T_D}{D_{air}} \qquad \text{if } \frac{T_D}{D_{air}} \leq (T_D - T_C)$$

$$T_F = T_D - T_C + \left(\frac{T_D}{D_{air}} - T_D + T_c\right)\frac{D_{air}}{D_{corr}} \qquad \text{otherwise.}$$

where:

D_{air} : Total fatigue damage for all loading conditions in-air environment taken as:

$$D_{air} = \sum_{j=1}^{n_{LC}} D_{E,air\,(j)}$$

D_{corr} : Total fatigue damage for all loading conditions in corrosive environment taken as:

$$D_{corr} = \sum_{j=1}^{n_{LC}} D_{E,corr\,(j)}$$

6. Weld Improvement Methods

6.1 General

6.1.1

Post-weld fatigue strength improvement methods are to be considered as a supplementary means of achieving the required fatigue life, and subjected to quality control procedures and corrosion protection in accordance with **Ch 3, Sec 4**.

6.1.2 Limitation of the benefit of post-weld treatment

For structural details where the benefit of post-weld treatment is applicable, the calculated fatigue life at the design stage for the considered structural detail excluding the post-weld treatment effects, is not to be less than T_{DF} / 1.47.

Note 1: When T_{DF} is taken equal to 25 years, the calculated fatigue life at the design stage for the considered structural detail excluding the post-weld treatment effects, is not to be less than 17 years.

6.1.3 Post-weld treatment at fabrication stage

There is one basic post-weld treatment method considered in these Rules to improve fatigue strength at the fabrication stage, i.e. weld geometry control and defect removal method by burr grinding.

6.1.4 Weld toe

The improvement method is applied to the weld toe. Thus, it is intended to increase the fatigue life of the weld from the viewpoint of a potential fatigue failure arising at the weld toe. The possibility of failure initiation at other locations is always to be considered. If the failure is shifted from the weld toe to the root by applying post-weld treatment, there may be no significant improvement in the overall fatigue performance of the joint. Improvements of the weld root cannot be expected from treatment applied to weld toe.

A brief description of the method and the degree of improvement which can be achieved is given in **[6.2]**.

6.1.5 Weld type for post-weld treatment

When weld improvements are planned, full or partial penetration welds with a minimum root face according to **Ch 12, Sec 3, [2.4]** are to be used to mitigate or to eliminate the possibility of cracking at the weld root.

6.2 Weld toe burr grinding

6.2.1

The weld may be machined using a burr grinding tool to produce a favourable shape to reduce stress concentrations and remove defects at the weld toe, see **Figure 5**. In order to eliminate defects, such as intrusions, undercuts and cold laps, the material in way of the weld toe is to be removed. The depth of grinding shall be at least 0.5 mm below the bottom of any visible undercut. The total depth of the burr grinding is not to be greater than the lesser of 2 mm and of 7 % the local gross thickness of the machined plate. Any undercut not complying with this requirement is to be repaired by an approved method.

6.2.2

To avoid introducing a detrimental notch effect due to small radius grooves, the burr diameter is to be scaled to the plate thickness at the weld toe being ground. The diameter is to be in the 10 to 25 mm range for application to welded joints with plate thickness from 10 to 50 mm. The resulting root radius of the groove is to be no less than 0.25 $t_{as-built}$.The weld throat thickness and leg length after burr grinding must comply with the rule requirements or any increased weld sizes as indicated on the approved drawings.

The inspection procedure is to include a check of the weld toe radius, the depth of burr grinding, and confirmation that the weld toe undercut has been removed completely.

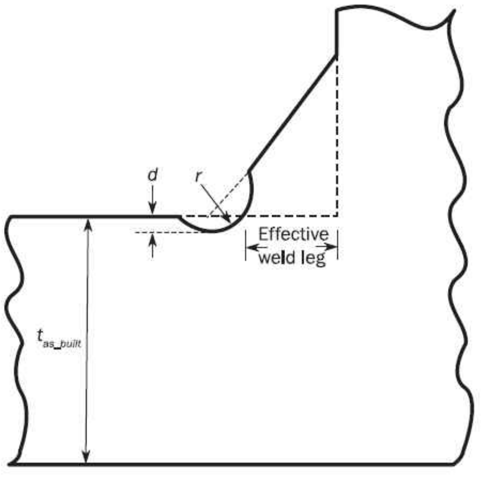


Figure 5 : Details of ground weld toe geometry

6.3 Fatigue improvement factor

6.3.1

The benefit of burr grinding corresponds to an increase in fatigue strength by a factor of 1.3 (i.e. a reduction of the effective stress range by 1.3), reducing the damage in air to D_{air} / 2.2,

where:

D_{air} : Fatigue damage in air as given in **Ch 9, Sec 3, [5.3.1]**.

6.4 Applicability

6.4.1

The application of post-weld improvement and fatigue improvement factor provided in this section is subject to following limitations:

- The weld type complies with **[6.1.5].**
- The weld improvement is effective in improving the fatigue strength of structural details under high cycle fatigue conditions therefore the fatigue improvements factors do not apply to low-cycle fatigue conditions, i.e. when $N \leq 5\times 10^4$, where N is the number of life cycles to failure.
- Unless otherwise specifically stated, the fatigue improvement factor is to be used for welds, joining steel plates which are between 6.0 and 50.0 mm thick.
- Fatigue improvement factor is to be applied to as-welded transverse butt welds, as-welded T-joint and cruciform welds and as-welded longitudinal attachment welds excluding longitudinal end connections.
- In way of areas prone to mechanical damage, fatigue improvement may only be granted if these are adequately protected.
- Treatment of inter-bead toes is required for large multi-pass welds as shown in **Figure 6.**
- The builder is to provide the list of details and their locations on the ship for which the post-weld treatment has been applied.

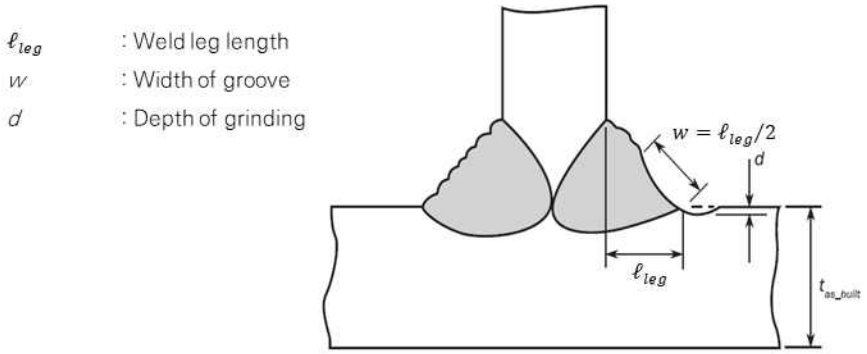


Figure 6 : Extent of weld toe burr grinding to remove inter-bead toes on weld face

7. Workmanship

7.1 Application

7.1.1

In general, the fatigue performance of structural details can be improved by adopting enhanced workmanship standards, which include building alignment and weld control.

7.2 Workmanship control for construction details

7.2.1 Building alignment and tolerance control

Building alignment exceeding construction tolerance could introduce additional stress concentration for structural details, reducing the fatigue performance. The builder is responsible to comply with the construction requirements given in **Ch 12, Sec 1.**

7.2.2 Weld profile control

Poor weld geometry could introduce additional stress concentration; therefore special attention should be given to achieving a favourable geometry and smooth transition at the weld toe. Weld profile control, i.e. enhanced workmanship may be required by the Society in way of critical weld toe locations.

The weld notch stress concentration is a direct function of the weld flank angle and the weld toe radius.

The validity of the aforementioned S-N curves is based on a weld flank angle with a maximum mean value of 50 ° and on a weld toe radius with a minimum mean value of 0.5 mm. Welding details may be requested to be submitted for approval for some critical areas considering the calculated fatigue life.

7.2.3 Post-weld treatment methods

Post-weld treatment methods may be used to improve fatigue resistance of structural detail, as specified in **[6].**

At the design stage, the calculated fatigue life should not generally take into account any benefit that may be derived from such treatment. This benefit should only be considered in exceptional cases when the design fatigue life can not reasonably be achieved by adopting alternative design measures such as improvement of the shape of the cut-outs, soft brackets toes, local increase in thickness or other changes in geometry of the structural detail. This is to be considered on a case-by-case basis by the Society.

Section 4 Simplified Stress Analysis

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

(i) : Suffix which denotes dynamic load case HSM, FSM, BSR-P, BSR-S, BSP-P, BSP-S, OST-P or OST-S specified in **Ch 4, Sec 2, [3.1].**

‘$i1$’ denotes dynamic load case HSM-1, FSM-1, BSR-1P, BSR-1S, BSP-1P, BSP-1S, OST-1P or OST-1S.

‘$i2$’ denotes dynamic load case HSM-2, FSM-2, BSR-2P, BSR-2S, BSP-2P, BSP-2S, OST-2P or OST-2S.

(j) : Suffix which denotes loading condition:

‘Full load’, as defined in **Ch 9, Sec 1, [6.2].**

ℓ_{bdg} : Effective bending span of stiffener, in m, as defined in **Ch 3, Sec 7.**

I_{y-n50} : Net vertical hull girder moment of inertia, at the longitudinal position being considered, in m^4.

I_{z-n50} : Net horizontal hull girder moment of inertia, at the longitudinal position being considered, in m^4.

y : Transverse coordinate of the load calculation point under consideration, in m.

z : Vertical coordinate of the load calculation point under consideration, in m.

z_n : Distance from the baseline to the horizontal neutral axis, in m.

f_c : Correction factor as defined in **Ch 9, Sec 1, [5.1.2].**

K_a : Geometrical stress concentration factor for stress due to axial load given in **[5.2].**

K_b : Geometrical stress concentration factor for stress due to lateral pressure given in **[5.2].**

K_n : Stress concentration factor due to unsymmetrical stiffener geometry, as defined in **[5.1].**

1. General

1.1 Application

1.1.1

This section defines the procedure for a simplified stress assessment which is to be used to evaluate the fatigue strength of the longitudinal stiffener end connections.

1.1.2

The hot spot stress ranges and hot spot mean stresses in way of each end connection of longitudinal stiffener, as shown in **Figure 1** are to be evaluated at the flange of the longitudinal stiffener in the following locations:

a) Transverse webs or floors other than those located
    - At transverse bulkhead of cargo hold

  such that additional hot spot stress due to the relative displacement is not to be considered.

b) Transverse webs or floors located
    - At transverse bulkhead of cargo hold

  such that additional hot spot stress due to the relative displacement are to be considered.

Stress concentration factors due to unsymmetrical stiffener geometry according **[5.1]** and due to the stiffener end connection geometry at point ‘A’ and ‘B’ according to **[5.2]** are to be applied.

1.2 Assumptions

1.2.1

The following assumptions are made in the fatigue assessment for longitudinal stiffener end connections:

a) The hot spot stress is based on:
  - Nominal stresses.
  - Stress concentration factors given in **[5]**.
  - Loading conditions specified in **Ch 9, Sec 1, [6]**.

b) The longitudinal stiffener end connection types are described in **[5.2]**.

1.2.2

The end connections given in **[5.2]** are based on typical joint geometry under axial and lateral loadings. When a structural detail is different from those shown in **Table 3**, a finite element analysis is to be used to demonstrate the adequacy of the detail in terms of fatigue strength, according to **[5.3]**.

2. Hot Spot Stress

2.1 Hot spot stress range

2.1.1

The hot spot stress range, in N/mm^2, due to dynamic loads for load case (i) of loading condition (j) is obtained from the following formula:

$$\Delta\sigma_{HS,i(j)} = |(\sigma_{GD,i1(j)} + \sigma_{LD,i1(j)} + \sigma_{dD,i1(j)}) - (\sigma_{GD,i2(j)} + \sigma_{LD,i2(j)} + \sigma_{dD,i2(j)})|$$

where:

$\sigma_{GD,i1(j)}$, $\sigma_{GD,i2(j)}$: Stresses due to global hull girder wave bending moments, in N/mm^2, as defined in **[3.1.1]**.

$\sigma_{LD,i1(j)}$, $\sigma_{LD,i2(j)}$: Stresses due to local dynamic pressure, in N/mm^2, as defined in **[4.1.1]**.

$\sigma_{dD,i1(j)}$, $\sigma_{dD,i2(j)}$: Stresses due to relative displacement in wave, in N/mm^2, as defined in **[4.2.4]**.

2.2 Hot spot mean stress

2.2.1

The hot spot mean stress, in N/mm^2, due to static and dynamic loads for load case (i) of loading condition (j) is obtained from the following formula:

$$\sigma_{mean,i(j)} = \sigma_{GS,(j)} + \sigma_{LS,(j)} + \sigma_{dS,(j)} + \sigma_{mLD,i(j)} + \sigma_{mGD,i(j)}$$

where for the load case (i) of loading condition (j):

$\sigma_{GS,(j)}$: Stress due to still water hull girder bending moment, in N/mm^2, as defined in **[3.2.1]**.

$\sigma_{LS,(j)}$: Stress due to local static pressure, in N/mm^2, as defined in **[4.1.2]**.

$\sigma_{dS,(j)}$: Stress due to relative displacement in still water, in N/mm^2, as defined in **[4.2.6]**.

$\sigma_{mLD,i(j)}$: Mean stress due to local dynamic pressure, in N/mm^2, as defined as:

$$\sigma_{mLD,i(j)} = \frac{\sigma_{LD,i1(j)} + \sigma_{LD,i2(j)}}{2}$$

$\sigma_{LD,i1(j)}$, $\sigma_{LD,i2(j)}$: Stress due to local dynamic pressure, in N/mm^2, as defined in **[4.1.1]**.

$\sigma_{mGD,i(j)}$: Mean stress due to global wave bending moment, in N/mm^2, as defined as:

$$\sigma_{mGD,i(j)} = \frac{\sigma_{GD,i1(j)} + \sigma_{GD,i2(j)}}{2}$$

$\sigma_{GD,i1(j)}$, $\sigma_{GD,i2(j)}$: Stress due to global wave bending moment, in N/mm^2, as defined in **[3.1.1]**.

3. Hull Girder Stress

3.1 Stress due to hull girder wave bending moments

3.1.1

The hull girder hot spot stress, in N/mm^2, for load cases $i1$ and $i2$ of loading condition (j) is obtained from the following formula:

$$\sigma_{GD,iK(j)} = f_c \bullet K_a \left(\frac{M_{wv-LC,ik}}{I_{y-n50}} (z - z_n) - \frac{M_{wh-LC,ik}}{I_{Z-n50}} y \right) 10^{-3}$$

where:

$M_{wv-LC,ik}$: Vertical wave bending moment, in kNm, of the considered dynamic load case, as defined in **Ch 4, Sec 4,** at the hull girder load calculation point of the considered longitudinal position for the loading condition (j) for iK being equal to $i1$ and $i2$.

$M_{wh-LC,ik}$: Horizontal wave bending moment, in kNm, of the considered dynamic load case, as defined in **Ch 4, Sec 4,** at the hull girder load calculation point of the considered longitudinal position for the loading condition (j) for iK being equal to $i1$ and $i2$.

3.2 Stress due to still water hull girder bending moment

3.2.1

The hull girder hot spot stress due to still water bending moment, in N/mm^2, in loading condition (j) is obtained from the following formula:

$$\sigma_{GS,(i)} = \frac{f_c \bullet K_a \bullet \beta_{(j)} \bullet M_{sw} \bullet (z - z_n)}{I_{y-n50}} 10^{-3}$$

where:

M_{sw} : Permissible still water vertical bending moment, in kNm, as defined in **Ch 4, Sec 4** at the hull girder load calculation point of the considered longitudinal position.

$\beta_{(j)}$: Fraction of permissible still water vertical bending moment, as defined in **Table 1.**

Table 1 : Fraction of permissible still water vertical bending moments, $\beta_{(j)}$

Loading conditions			$\beta_{(j)}$
Loading Pattern		SWBM	
Full Load	Ballast Tank - Full	Max. Hogging	0.9 in hogging condition
	Ballast Tank - Empty		
Full Load	Ballast Tank - Full	Min. Hogging	0.1 in hogging condition [1]
	Ballast Tank - Empty		
[1] $M_{sw,\min}$ is a minimum design hogging moment taken from the loading manual. If $M_{sw,\min}$ is larger (hogging positive) than 0.1 M_{sw-h}, then $M_{sw,\min}$ shall replace 0.1M_{sw-h}			

4. Local Stiffener Stress

4.1 Stress due to stiffener bending

4.1.1 Stress due to dynamic pressure

The hot spot stress, in N/mm^2, due to local dynamic pressure in load case $i1$ and $i2$ for loading condition (j) is obtained from the following formula:

$$\sigma_{LD,ik\,(j)} = \frac{K_b K_n S \ell_{bdg}^2 \left(\eta_w f_{NL} P_{w,ik\,(j)} + \eta_{\ell d} P_{\ell d,ik\,(j)}\right)\left(1 - \frac{6x_e}{\ell_{bdg}} + \frac{6x_e^2}{\ell_{bdg}^2}\right)}{12\, Z_{eff-n50}}$$

where:

$P_{W,ik(j)}$: Dynamic wave pressure, at the mid span, in kN/m^2, specified in **Ch 4, Sec 5, [1.4]**, in load case $i1$ and $i2$ for loading condition (j).

$P_{\ell d,ik(j)}$: Dynamic liquid tank pressure, at the mid span, in kN/m^2, as specified in **Ch 4, Sec 6, [1.1.1]**, in load case $i1$ and $i2$ for loading condition (j).

Pressure acting on both sides of the stiffener, i.e. applied on the attached plate on stiffener side or on opposite side to the stiffener, could be simultaneously considered if relevant in the loading condition.

η_W, $\eta_{\ell d}$: Pressure normal coefficients, taken as:

$\eta = 1$ when the considered pressure is applied on the stiffener side,

$\eta = -1$ otherwise.

f_{NL} : Correction factor for the non-linearity of the wave pressure taken as:

$f_{NL} = 1.0$ for $z > T_{LC} + 2h_w$

$f_{NL} = 2.5\frac{z - T_{LC}}{h_w} - 4$ for $T_{LC} + 1.8h_w < z \le T_{LC} + 2h_w$

$f_{NL} = 0.5\frac{z - T_{LC}}{h_w} - 0.4$ for $T_{LC} + 1.6h_w < z \le T_{LC} + 1.8h_w$

$f_{NL} = 0.4$ for $T_{LC} + 1.2h_w < z \le T_{LC} + 1.6h_w$

$f_{NL} = 0.7 - 0.25\frac{z - T_{LC}}{h_w}$ for $T_{LC} + 0.6h_w < z \le T_{LC} + 1.2h_w$

$f_{NL} = 1 - 0.75\frac{z - T_{LC}}{h_w}$ for $T_{LC} - 0.2h_w < z \le T_{LC} + 0.6h_w$

$f_{NL} = 0.1875\frac{z - T_{LC}}{h_w} + 1.1875$ for $T_{LC} - h_w < z \le T_{LC} - 0.2h_w$

$f_{NL} = 1.0$ for $z \le T_{LC} - h_w$

h_w : Water head equivalent to the pressure at waterline, in m, as defined in **Ch 4, Sec 5.**

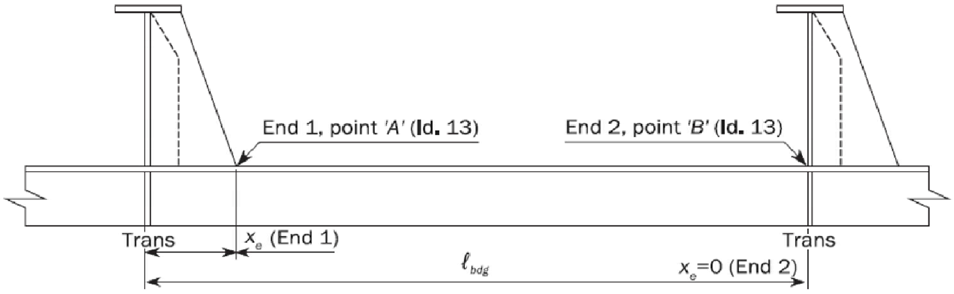
x_e : Distance, in m, to the hot spot from the closest end of the span ℓ_{bdg}, as defined in **Figure 1.**

$Z_{eff-n50}$: Net section modulus, in cm^3, of the considered stiffener calculated considering an effective breadth b_{eff} of attached plating.

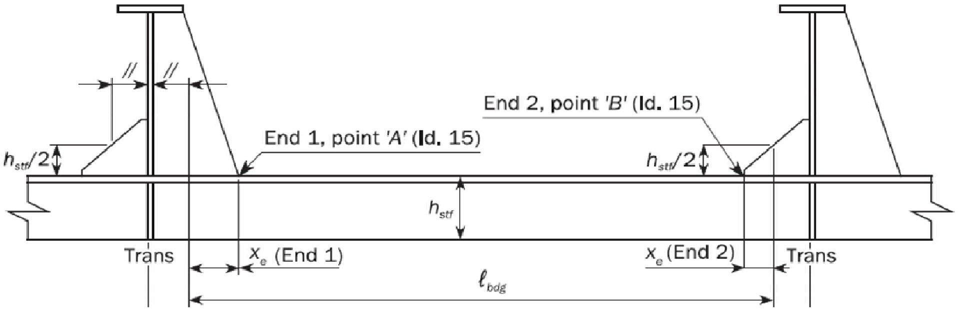
b_{eff} : Effective breadth, in mm, of attached plating specified at the ends of the span and in way of end brackets and supports, taken as:

$$b_{eff} = s \cdot \min\left(\frac{1.04}{1 + \frac{3}{\left(\frac{l_{bdg}}{s}\left(1 - \frac{1}{\sqrt{3}}\right) \cdot 10^3\right)^{1.35}}} ; 1.0\right) \quad \text{for } \frac{\ell_{bdg}}{s}\left(1 - \frac{1}{\sqrt{3}}\right) \times 10^3 \ge 1$$

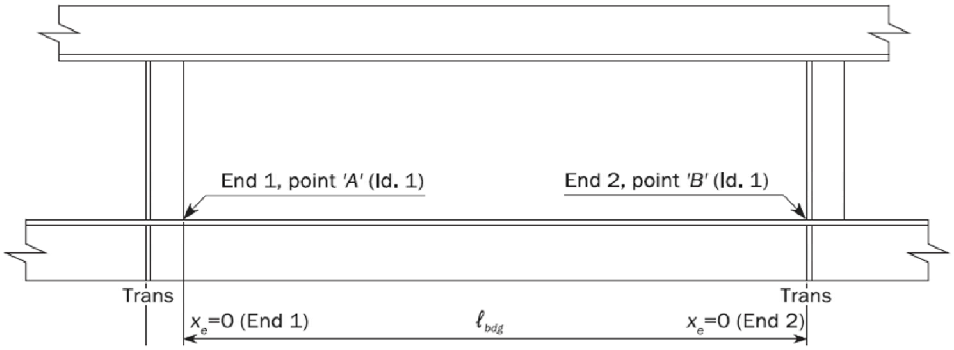
$$b_{eff} = 0.26\, \ell_{bdg}\left(1 - \frac{1}{\sqrt{3}}\right) \times 10^3 \quad \text{for } \frac{\ell_{bdg}}{s}\left(1 - \frac{1}{\sqrt{3}}\right) \times 10^3 < 1$$



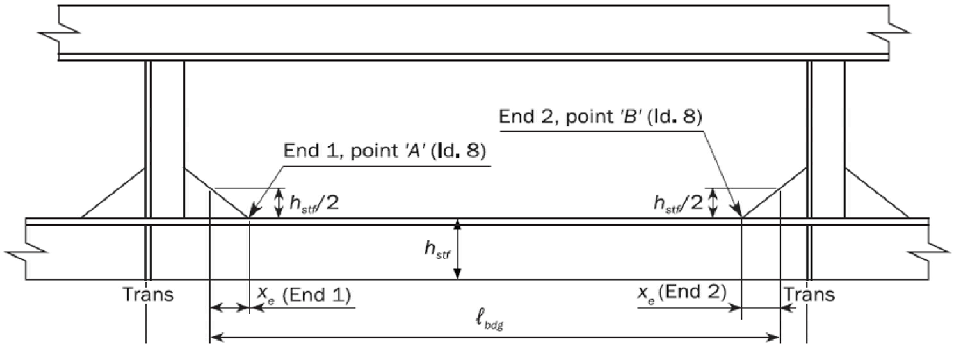
Supported by free flange transverses



Supported by free flange transverses



Supported by double skin/transverse bulkheads



Supported by double skin/transverse bulkheads

Figure 1 : Definition of effective span and x_e for hot spot

4.1.2 Stress due to static pressure

The hot spot stress due to local static pressure, in N/mm^2, for loading condition (j) is obtained from the following formula:

$$\sigma_{LS,(j)} = \frac{K_b K_n s \ell_{bdg}^2 \left(\eta_s P_{S,(j)} + \eta_{ls} P_{ls,(j)}\right)\left(1 - \frac{6x_e}{\ell_{bdg}} + \frac{6x_e^2}{\ell_{bdg}^2}\right)}{12 Z_{eff-n50}}$$

where:

$P_{S,(j)}$: Static external pressure, in kN/m^2, in loading condition (j) specified in **Ch 4, Sec 5, [1.2]**.

$P_{ls,(j)}$: Static liquid tank pressure, in kN/m^2, in loading condition (j) specified in **Ch 4, Sec 6, [1.1.1]**.

Pressure acting on both sides could be simultaneously considered if relevant in the loading condition.

η_S, η_{ls} : Pressure normal coefficients, taken as:

$\eta = 1$ when the considered pressure is applied on the stiffener side,

$\eta = -1$ otherwise.

4.2 Stress due to relative displacement

4.2.1 General

For longitudinal stiffener end connections fitted on transverse web or floor located

- At transverse bulkhead of cargo hold,

the additional hot spot stress due to the relative displacement is to be considered.

4.2.2 Relative displacement definition

The relative displacement is defined as follows.

- For longitudinals, the relative displacement is defined as the displacement of the longitudinal measured at the first transverse web frame (or floor) forward (Fwd) or afterward (Aft) relative to the displacement of the longitudinal at the transverse bulkhead.

4.2.3 Sign convention

Where the stress at the hot spot location, i.e. at the flange of longitudinal, due to relative displacement is in tension, the sign of the relative displacement is positive.

4.2.4 Container ship

The additional hot spot stress due to relative displacement for load case $i1$ and $i2$ of loading condition (j) for a container ship is to be calculated using finite element method as described in **[4.2.5]**.

4.2.5 Stress due to relative displacement derived using FE method

The following procedure is based on a cargo hold model complying with **Ch 7, Sec 2, [2]** to calculate the stress due to relative displacements. The stress due to relative displacements, in N/mm^2, for load case $i1$ and $i2$ of loading condition (j) for both locations “a” and “f” is to be calculated directly using the following expression:

$$\sigma_{dD,ik(j)} = \begin{cases} K_b \sigma_{dFwd-a,ik(j)} + K_b \sigma_{dAft-a,ik(j)} & \text{for location a} \\ \mathrm{K_b} \sigma_{\mathrm{dFwd-f,ik(j)}} + \mathrm{K_b} \sigma_{\mathrm{dAft-f,ik(j)}} & \text{for location f} \end{cases} \qquad (k = 1, 2)$$

where:

a, f : Suffix which denotes the location as indicated in **Figure 2.**

Aft, Fwd : Suffix which denotes the direction, afterward (Aft) or forward (Fwd), from the transverse bulkhead. as shown in **Figure 2.**

K_b : Stress concentration factor due to bending for the location 'a' or 'f' which may correspond to points 'A' or 'B' as defined in **Table 3.**

$\sigma_{dFwd-a,ik(j)}$, $\sigma_{dAft-a,ik(j)}$, $\sigma_{dFwd-f,ik(j)}$, $\sigma_{dAft-f,ik(j)}$: Additional stress at location 'a' and 'f', in N/mm^2, due to the relative displacement between the transverse bulkhead and the forward (Fwd) and afterward (Aft) transverse web or floor respectively for load case $i1$ and $i2$ of loading condition (j), taken as:

$$\sigma_{dFwd-a,\ ik(j)} = \frac{3.9\delta_{Fwd,\ ik(j)}EI_{Aft-n50}I_{Fwd-n50}}{Z_{Aft-n50}\ell_{Fwd}(\ell_{Aft}l_{Fwd-n50}+\ell_{Fwd}I_{Aft-n50})}(1-1.15\frac{|x_{eAft}|}{\ell_{Aft}})10^{-5}$$

$$\sigma_{dAft-A,\ ik(j)} = [\frac{3.9\delta_{Aft,\ ik(j)}EI_{Aft-n50}I_{Fwd-n50}}{Z_{Aft-n50}\ell_{Aft}(\ell_{Aft}l_{Fwd-n50}+\ell_{Fwd}I_{Aft-n50})}(1-1.15\frac{|x_{eAft}|}{\ell_{Aft}})-\frac{0.9\delta_{Aft,\ ik(j)}EI_{Aft-n50}|x_{eAft}|}{Z_{Aft-n50}\ell^3_{Aft}}]10^{-5}$$

$$\sigma_{dFwd-f,\ ik(j)} = [\frac{3.9\delta_{Fwd,\ ik(j)}EI_{Aft-n50}I_{Fwd-n50}}{Z_{Fwd-n50}\ell_{Fwd}(\ell_{Aft}l_{Fwd-n50}+\ell_{Fwd}I_{Aft-n50})}(1-1.15\frac{|x_{eFwd}|}{\ell_{Fwd}})-\frac{0.9\delta_{Fwd,\ ik(j)}EI_{Fwd-n50}|x_{efFwd}|}{Z_{Fwd-n50}\ell^3_{Fwd}}]10^{-5}$$

$$\sigma_{dAft-f,\ ik(j)} = \frac{3.9\delta_{Aft,\ ik(j)}EI_{Aft-n50}I_{Fwd-n50}}{Z_{Fwd-n50}\ell_{Aft}(\ell_{Aft}l_{Fwd-n50}+\ell_{Fwd}I_{Aft-n50})}(1-1.15\frac{|x_{eFwd}|}{\ell_{Fwd}})10^{-5}$$

$I_{Fwd-n50}$, $I_{Aft-n50}$: Net moment of inertia, in cm^4, of forward (Fwd) and afterward (Aft) longitudinal.

$Z_{Fwd-n50}$, $Z_{Aft-n50}$: Net section modulus of forward (Fwd) and afterward (Aft) stiffener, in cm^3.

ℓ_{Fwd}, ℓ_{Aft} : Span, in m, of forward (Fwd) and afterward (Aft) longitudinal, as shown in **Figure 2.**

x_{eFwd}, x_{eAft} : Distance, in m, as shown in **Figure 1,** to the hot spot in location 'a' or 'f' from the closest end of ℓ_{Fwd} and ℓ_{Aft} respectively.

$\delta_{Fwd,ik(j)}$, $\delta_{Aft,ik(j)}$: Relative displacement in the direction perpendicular to the attached plate, in mm, between the transverse bulkhead and the forward (Fwd) or afterward (Aft) transverse web (or floor) as shown in **Figure 2.**

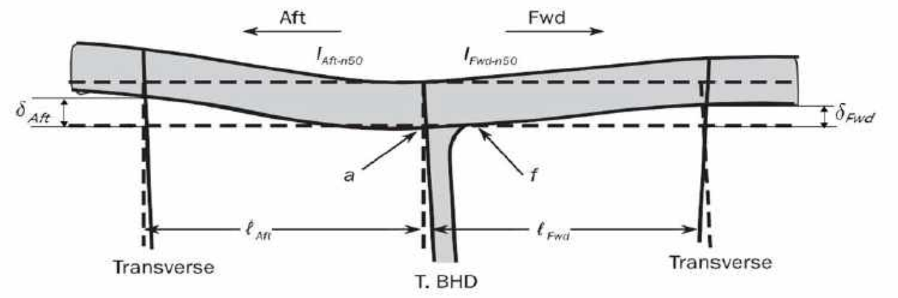


Figure 2 : Definition of the relative displacement (example of the side longitudinal)

4.2.6 Stress due to relative displacement in still water

The additional hot spot stress, in N/mm^2, in still water, due to the relative displacement in the direction perpendicular to the attached plate between the transverse bulkhead and the adjacent transverse web or floor is to be obtained according to procedures of **[4.2.4]**, replacing dynamic local stress σ_{LD} and dynamic pressure with static local stress σ_{LS} and static pressure.

5. Stress Concentration Factors

5.1 Unsymmetrical stiffener

5.1.1

The stress concentration factor K_n for unsymmetrical flange of built-up and rolled angle stiffeners under lateral load, calculated at the web's mid-thickness position, as shown in **Figure 3**, is to be taken as:

$$K_n = \frac{1+\lambda\beta^2}{1+\lambda\beta^2\psi_Z}$$

where:

$$\lambda = \frac{3(1+\frac{\eta}{280})}{1+\frac{\eta}{40}}$$

$$\eta = \frac{\ell_{bdg}^4}{b_{f-n50}^3 \cdot t_{f-n50} \cdot h_{stf-n50}^2 \left(\frac{4h_{stf-n50}}{t_{w-n50}^3} + \frac{s}{t_{p-n50}^3}\right)} 10^{12}$$

$\beta = 1 - \frac{2b_{g-n50}}{b_{f-n50}}$ for built-up profiles.

$\beta = 1 - \frac{t_{w-n50}}{b_{f-n50}}$ for rolled angle profiles.

b_{g-n50} : Eccentricity of the stiffener equal to the distance from flange's edge to web's centreline, in mm, as shown in **Figure 4.**

b_{f-n50} : Net breadth of flange, in mm, as shown in **Figure 4.**

t_{f-n50} : Net flange thickness, in mm, as shown in **Figure 4.**

$h_{stf-n50}$: Net stiffener height, including face plate, in mm, as shown in **Figure 4.**

t_{w-n50} : Net web thickness, in mm, as shown in **Figure 4.**

h_{w-n50} : Net web's height stiffener, in mm, as shown in **Figure 4.**

t_{p-n50} : Net thickness of attached plating, in mm, as shown in **Figure 4.**

ψ_z : Coefficient given as:

$$\psi_z = \frac{h_{w-n50}^2 t_{w-n50}}{4Z_{n50}} 10^{-3}$$

Z_{n50} : Net section modulus, in cm^3, of stiffener with an attached plating breadth equal to the stiffener spacing.

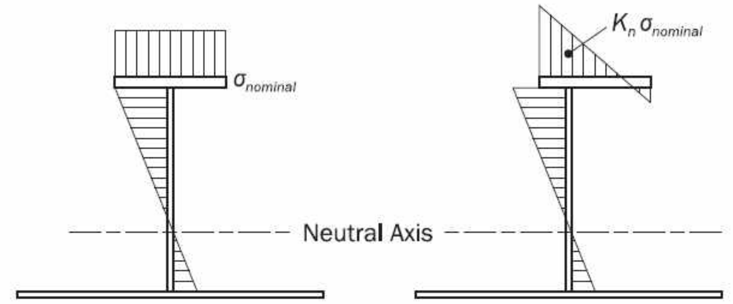


Figure 3 : Bending stress in stiffener with symmetrical and unsymmetrical flange

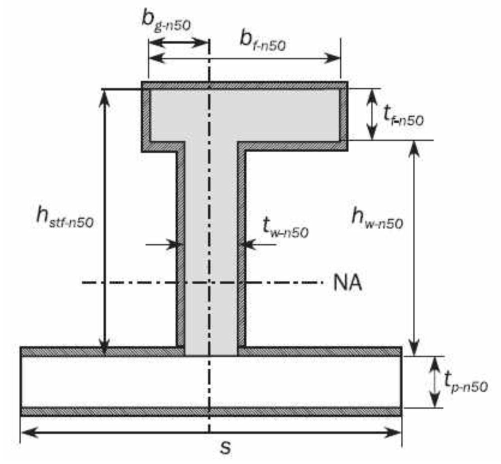


Figure 4 : Stiffener – net scantling

5.1.2 Bulb profiles

For bulb profiles K_n factor is to be calculated using the equivalent built-up profile as shown in **Figure 5.** The flange of the equivalent built-up profile is to have the same properties as the bulb flange, i.e. same cross sectional area and moment of inertia about the vertical axis and neutral axis position.

For HP bulb profiles, examples of the equivalent built up profile dimensions are listed in **Table 2.**

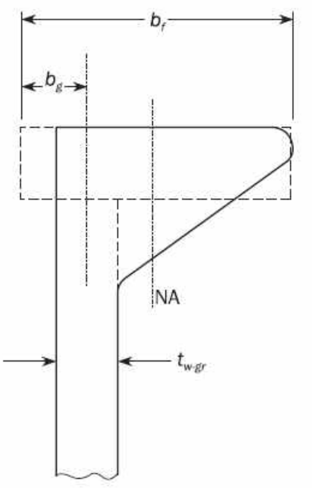


Figure 5 : Bulb profile and equivalent built-up profile

Table 2 : HP equivalent built-up profile dimensions

HP-bulb		Equivalent built-up flange in gross thickness		
Height (mm)	Gross web thickness, t_{w-gr} (mm)	b_f (mm)	t_{f-gr} (mm)	b_g (mm)
200	9 - 13	t_{w-gr} + 24.5	22.9	(t_{w-gr} + 0.9)/2
220	9 - 13	t_{w-gr} + 27.6	25.4	(t_{w-gr} + 1.0)/2
240	10 - 14	t_{w-gr} + 30.3	28.0	(t_{w-gr} + 1.1)/2
260	10 - 14	t_{w-gr} + 33.0	30.6	(t_{w-gr} + 1.3)/2
280	10 - 14	t_{w-gr} + 35.4	33.3	(t_{w-gr} + 1.4)/2
300	11 - 16	t_{w-gr} + 38.4	35.9	(t_{w-gr} + 1.5)/2
320	11 - 16	t_{w-gr} + 41.0	38.5	(t_{w-gr} + 1.6)/2
340	12 - 17	t_{w-gr} + 43.3	41.3	(t_{w-gr} + 1.7)/2
370	13 - 19	t_{w-gr} + 47.5	45.2	(t_{w-gr} + 1.9)/2
400	14 - 19	t_{w-gr} + 51.7	49.1	(t_{w-gr} + 2.1)/2
430	15 - 21	t_{w-gr} + 55.8	53.1	(t_{w-gr} + 2.3)/2

5.2 Longitudinal stiffener end connections

5.2.1

The stress concentration factors K_a and K_b are given in **Table 3** for end connection of stiffeners subjected to axial and lateral loads. The values given in **Table 3** for soft toe are valid provided the toe geometry complies with the requirements given in **[5.2.5]**. The stress concentration factor K_b given for lateral loads are to be used also for stress due to relative displacements.

5.2.2 Other connection types

When connection types other than those given in **Table 3** are proposed, the fatigue strength for the proposed connection type is to be assessed either by performing a very fine mesh FE analysis as described in **Ch 9, Sec 5** to obtain directly the hot spot stress, or by calculating the stress concentration factor using FE analysis according to **[5.3]**.

5.2.3 Overlapped connection

Overlapped connection types for longitudinal stiffeners, i.e. attachments welded to the web of the longitudinals, are not to be used in the cargo hold region.

5.2.4 End stiffener without connection to web stiffener

Where the web stiffener is omitted or not connected to the longitudinal flange in way of:

- Side shell below 1.1 T_{SC}.
- Bottom.
- Inner hull longitudinal bulkhead below 1.1 T_{SC}.
- Inner bottom.

the following is required:

- A complete collar as defined in **Figure 6** (i.e. connection type ID 31 of **Table 3**), or,
- A detail design for cut-outs as described in **Ch 9, Sec 6, [2.1]**.

Equivalence to cut-outs given in **Ch 9, Sec 6, [2.1]** may be accepted provided it is assessed for fatigue by using comparative FE analysis which is based on hot spot stress around the cut-out in the web plate of the primary supporting member inclusive of the collar, as given in **Ch 9, Sec 6, [2.2]**.

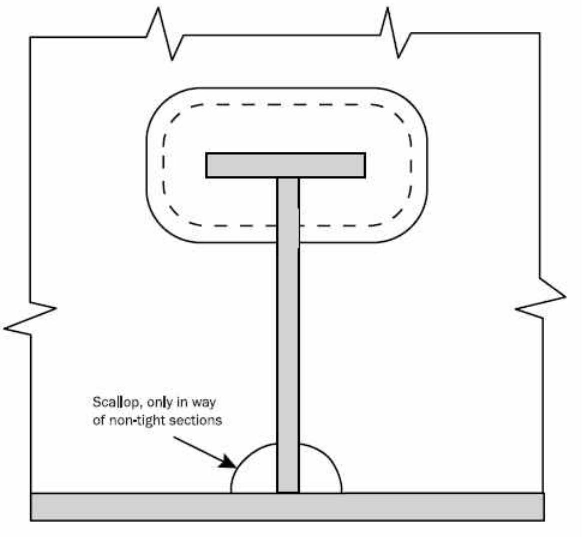


Figure 6 : Complete collar

5.2.5 Soft toe of web stiffener and backing bracket

The toe geometry end connection of web stiffener and backing bracket is to comply with the following:

$\theta \le 20$

$h_{toe} \le \max\,(t_{bkt-gr}\,;15)$

where:

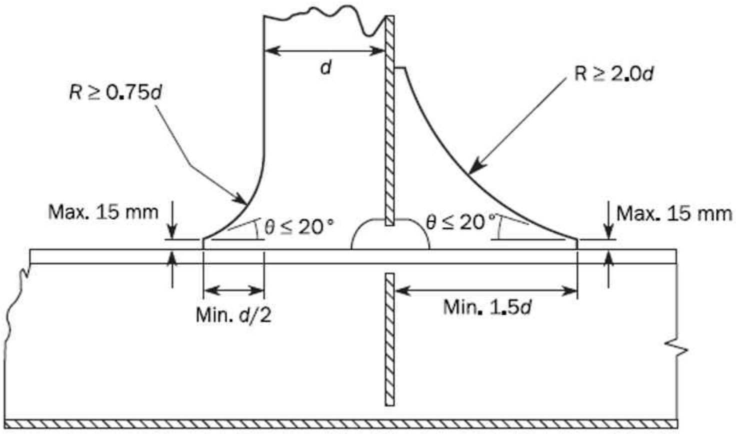
θ : Angle of the toe, in deg, as shown in **Figure 7.**

h_{toe} : Height of the toe, in mm, as shown in **Figure 7.**

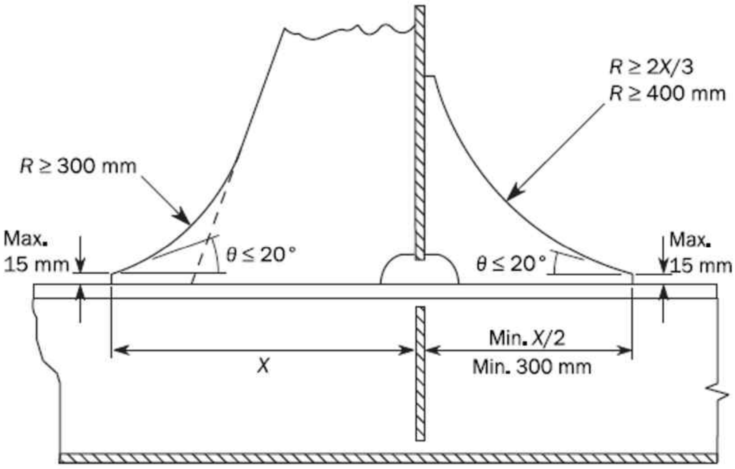
t_{bkt-gr} : Gross thickness of the bracket, in mm.

5.2.6 Recommended detail designs

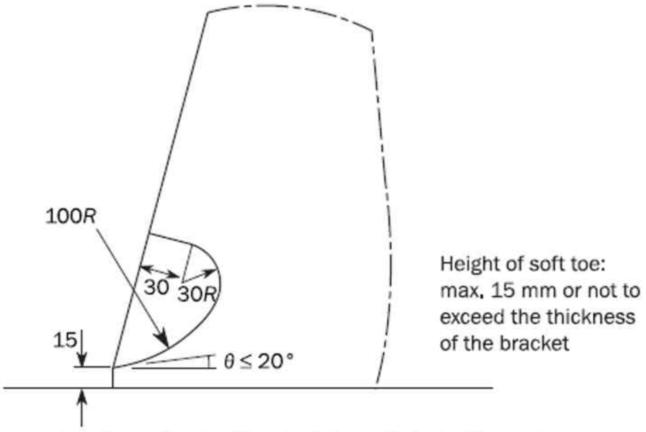
Recommended detail designs for longitudinal end connections with soft toes and backing brackets are given in **Figure 7.**



Recommended design of soft toes and backing bracket of pillar stiffeners



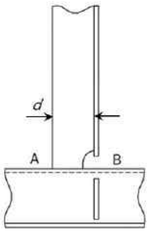
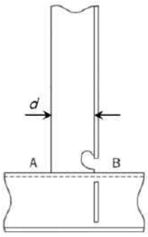
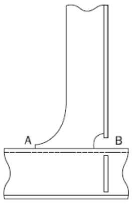
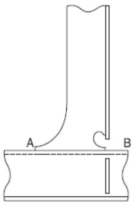
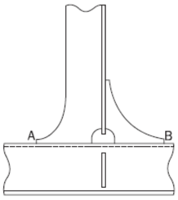
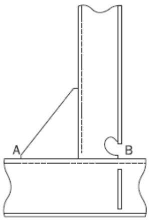
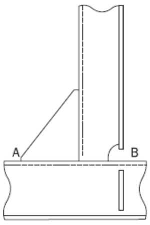
Recommended design of soft toes and backing bracket of tripping brackets

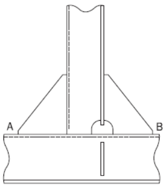
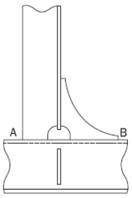
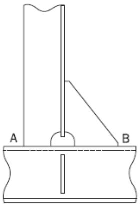
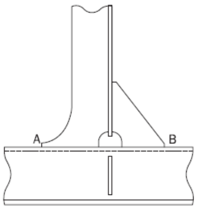
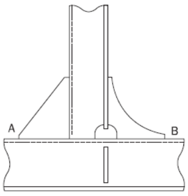
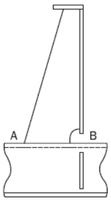
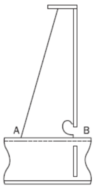


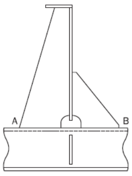
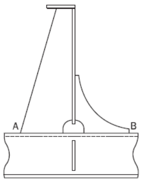
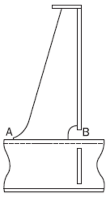
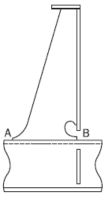
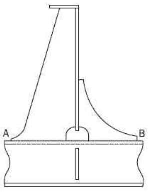
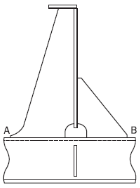
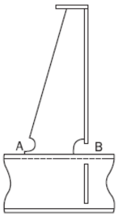
Recommended alternative design of soft toes of tripping brackets

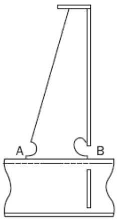
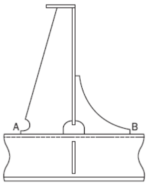
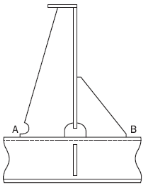
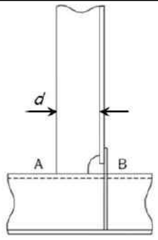
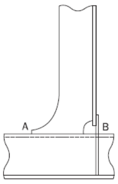
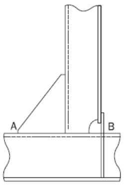
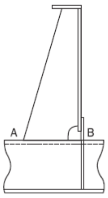
Figure 7 : Detail design for soft toes and backing brackets

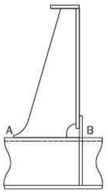
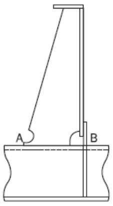
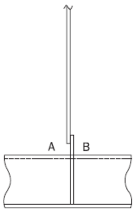
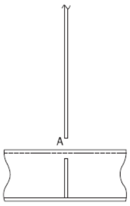
Table 3 : Stress concentration factors

ID	Connection type(2)(3)	Point 'A'		Point 'B'	
		K_a	K_b	K_a	K_b
1(1)		1.28 for $d \le 150$ 1.36 for$150 < d \le 250$ 1.45 for $d > 250$	1.40 for $d \le 150$ 1.50 for $150 < d \le 250$ 1.60 for $d > 250$	1.28 for $d \le 150$ 1.36 for $150 < d \le 250$ 1.45 for $d > 250$	1.60
2(1)		1.28 for $d \le 150$ 1.36 for$150 < d \le 250$ 1.45 for $d > 250$	1.40 for $d \le 150$ 1.50 for $150 < d \le 250$ 1.60 for $d > 250$	1.14 for $d \le 150$ 1.24 for $150 < d \le 250$ 1.34 for $d > 250$	1.27
3		1.28	1.34	1.52	1.67
4		1.28	1.34	1.34	1.34
5		1.28	1.34	1.28	1.34
6		1.52	1.67	1.34	1.34
7		1.52	1.67	1.52	1.67

ID	Connection type(2)(3)	Point 'A'		Point 'B'	
		K_a	K_b	K_a	K_b
8		1.52	1.67	1.52	1.67
9		1.52	1.67	1.28	1.34
10		1.52	1.67	1.52	1.67
11		1.28	1.34	1.52	1.67
12		1.52	1.67	1.28	1.34
13		1.52	1.67	1.52	1.67
14		1.52	1.67	1.34	1.34

ID	Connection type[(2)(3)]	Point 'A'		Point 'B'	
		K_a	K_b	K_a	K_b
15		1.52	1.67	1.52	1.67
16		1.52	1.67	1.28	1.34
17		1.28	1.34	1.52	1.67
18		1.28	1.34	1.34	1.34
19		1.28	1.34	1.28	1.34
20		1.28	1.34	1.52	1.67
21		1.28	1.34	1.52	1.67

ID	Connection type(2)(3)	Point 'A'		Point 'B'	
		K_a	K_b	K_a	K_b
22		1.28	1.34	1.34	1.34
23		1.28	1.34	1.28	1.34
24		1.28	1.34	1.52	1.67
25(1)		1.28 for $d \le 150$ 1.36 for$150 < d \le 250$ 1.45 for $d > 250$	1.40 for $d \le 150$ 1.50 for $150 < d \le 250$ 1.60 for $d > 250$	1.14 for $d \le 150$ 1.24 for $150 < d \le 250$ 1.34 for $d > 250$	1.25 for $d \le 150$ 1.36 for $150 < d \le 250$ 1.47 for $d > 250$
26		1.28	1.34	1.34	1.47
27		1.52	1.67	1.34	1.47
28		1.52	1.67	1.34	1.47

ID	Connection type(2)(3)	Point 'A'		Point 'B'	
		K_a	K_b	K_a	K_b
29		1.28	1.34	1.34	1.47
30		1.28	1.34	1.34	1.47
31(4)		1.13	1.20	1.13	1.20
32 (4)(5)(6)		1.13	1.14	N/A	N/A

(1) The attachment length d, in mm, is defined as the length of the welded attachment on the longitudinal stiffener flange without deduction of scallop.

(2) Where the longitudinal stiffener is a flat bar and there is a web stiffener / bracket welded to the flat bar stiffener, the stress concentration factor listed in the table is to be multiplied by a factor of 1.12 when the thickness of attachment is thicker than the 0.7 times thickness of flat bar stiffener. This also applies to unsymmetrical profiles where there is less than 8.0 mm clearance between the edge of the stiffener flange and the attachment, e.g. bulb or angle profiles where the clearance of 8.0 mm cannot be achieved.

(3) Designs with overlapped connection / attachments, See **[5.2.3].**

(4) ID. 31 and 32 refer to details where web stiffeners are omitted or not connected to the longitudinal stiffener flange. See **[5.2.4].**

(5) For connection type ID. 32 with no collar and/or web plate welded to the flange, the stress concentration factors provided in this table are to be used irrespective of slot configuration.

(6) The fatigue assessment point ‘A’ is located at the connection between the stiffener web and the transverse web frame or lug plate.

5.3 Alternative design

5.3.1 Derivation of alternative stress concentration factors

Upon agreement by the Society, the geometrical stress concentration factors for alternative designs are to be calculated by a very fine mesh FE analysis according to the requirements given in **Ch 9, Sec 5.** Additional requirements for derivation of geometrical stress concentration factors for stiffener end connections using very fine mesh FE analysis are given below:

a) FE model extent: the FE model, as shown in **Figure 8,** is to cover at least four web frame spacings in the longitudinal stiffener direction with the detail to be considered located at the middle frame. The same type of end connection is to be modelled at all the web frames. In the transverse direction, the model may be limited to one stiffener spacing.

b) Load application: in general, two loading cases are to be considered:
- Axial loading by enforced displacement applied to the model ends and
- Lateral loading by unit pressure load applied to the shell plating.

c) Boundary conditions:
- Symmetry conditions are applied along the longitudinal cut of the plate flange, along transverse and vertical cuts on web frames and on top of the web stiffener.
- For lateral pressure loading: the model is to be fixed in all degrees of freedom at both forward and aft ends.
- For axial loading: the model is to be fixed for displacement in the longitudinal direction at the aft end of the model while enforced axial displacement is applied at the forward end, or vice versa.

d) FE mesh density: At the location of the hot spots under consideration, the element size is to be in the order of the thickness of the stiffener flange or 10.0 mm depending on the type of stiffener. In the remaining part of the model, the element size is to be in the order of $s/10$, where s is the stiffener spacing.

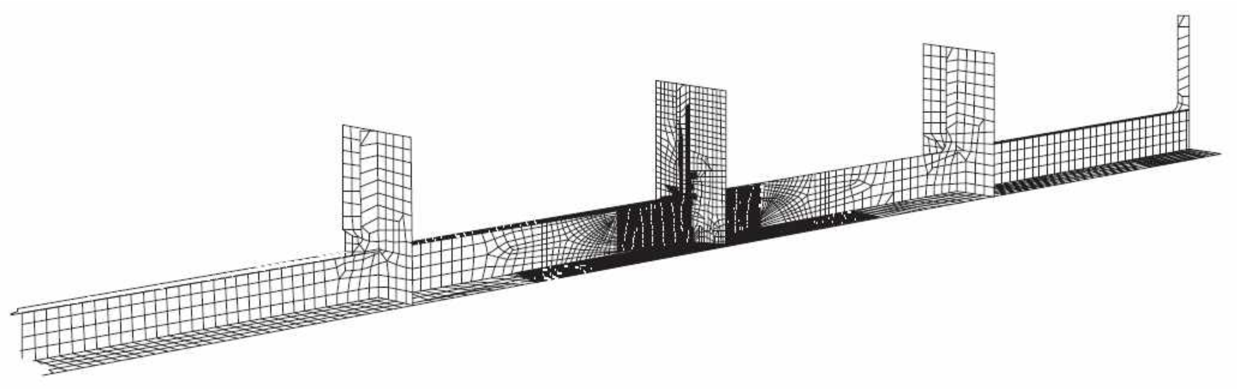


Figure 8 : Fine mesh finite element model for derivation of geometrical stress concentration factor (example of stiffener with flange)

For the 2 loading cases specified above, the stress concentration factors are determined as follows:
- For the axial loading case:

$$K_a = \frac{\sigma_{HSAx}}{\sigma_{Nom\,Ax}}$$

- For the bending loading case:

$$K_b = \frac{\sigma_{HSBd}}{\sigma_{Nom\,Bd}}$$

σ_{HSAx} : Hot spot stress, in N/mm^2, determined at the stiffener flange for the axial load.

$\sigma_{Nom\,Ax}$: Nominal axial stress, in N/mm^2, calculated at the stiffener flange according to **[3.1]** for the axial load applied for the FE calculation.

σ_{HSBd} : Hot spot stress, in N/mm^2, determined at the stiffener flange for the unit pressure load.

$\sigma_{Nom\,Bd}$: Nominal bending stress, in N/mm^2, calculated at the stiffener flange according to **[4.1]** in way of the hot spot for the unit pressure load applied for the FE calculation.

The derivation of geometrical stress concentration factors for alternative designs is to be documented and provided to the Society.

Section 5 Finite Element Stress Analysis

1. General

1.1 Application

1.1.1

This section applies to fatigue assessment by finite element stress analysis. The methods are based on the hot spot stress approach and requirements are given for both welded and non-welded hot spots. The hot spot stress takes into account structural discontinuities due to the structural detail of the welded joint, but not taking into account the notch effect at the weld toe.

1.1.2

The hot spot stress is generally highly dependent on the finite element model used for representation of the structure and the procedure used to calculate the hot spot stress. No other methods than those described in this Section is to be adopted for calculation of FE based hot spot stress.

1.1.3

Two types of hot spots, denoted ‘a’ and ‘b’ are described in **Table 1**. These are defined according to their location on the plate and their orientation to the weld toe as illustrated in **Figure 1.**

Table 1 : Types of hot spots

Type	Description
a	Hot spot at the weld toe on plate surface
b	Hot spot at the weld toe around the plate edge

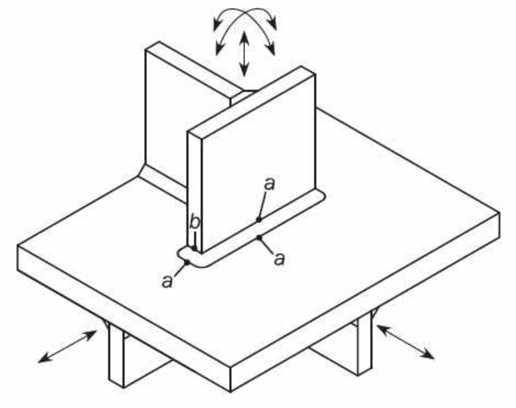


Figure 1 : Types of hot spots

1.1.4

The method for calculation of hot spot stress at weld toe for any welded details is given in **[3.1]** except for web-stiffened cruciform joints. The method for calculation of local stress for non-welded area is given in **[3.2]**.

1.1.5

The method for calculation of hot spot stress at web-stiffened cruciform joints such as transverse bulkhead to inner bottom connection and horizontal stringer heel is given in **[4]**.

1.1.6

Attention is to be given to limitations of the hot spot stress methodology for simple connections given in **[5].**

2. FE Modelling

2.1 General

2.1.1

Evaluation of hot spot stresses for fatigue assessment requires the use of very fine finite element meshes in way of areas of high stress concentration. These very fine mesh zones may be incorporated into the global model as shown in **Figure 2**. The coarse mesh model of the cargo holds is to be made according to **Ch 7, Sec 2, [2.4].** Alternatively, this very fine mesh analysis can be carried out by means of separate local finite element models with very fine mesh zones in conjunction with the boundary conditions obtained from a global model of the cargo holds.

2.1.2 Corrosion model

The very fine mesh finite element models used for fatigue assessment are to be made using gross thickness, t_{gr}, in accordance with **Ch 9, Sec 1, [5.1].**

2.1.3 Separate local FE model

Where a separate local finite element model is used, the 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 be taken at adjacent primary supporting members such as girders, stringers and floors in the cargo hold model as far as practicable. Transverse web frames, stringer plates and girders at the boundaries of the local model need not be represented in the local model.

2.1.4

The evaluation of hot spot stress for 'a' type hot spot is to be based on shell element of mesh size $t_{gr} \times t_{gr}$, where t_{gr} is the gross thickness of the plate in way of the considered hot spot. The evaluation of hot spot stress for a 'b' type hot spot is to be based on shell element of mesh size 10 × 10 mm. The aforementioned mesh size is to be maintained within the very fine mesh zone, extending over at least 10 elements in all directions from the fatigue hot spot position. The transition of element size between the coarser mesh and the very fine mesh zone is to be done gradually and an acceptable mesh quality is to be maintained. This transition mesh is to be such that a uniform mesh with regular shape gradually transitions from smaller elements to larger ones. An example of the mesh transition in way of hatch coaming top and deck plating is shown in **Figure 3.**

2.1.5

Four-node shell elements with adequate bending and membrane properties are to be used inside the very fine mesh zone. The four node element is to have a complete linear field of in-plane stresses and hence pure in-plane bending of the element can be exactly represented. In case of steep stress gradients, 8 node thin shell elements are to be used if deemed practical. The shell elements are to represent the mid plane of the plating. For practical purposes, adjoining plates of different thickness may be assumed to be median line aligned, i.e. no staggering in way of thickness change is required. The geometry of the weld and construction misalignment is not required to be modelled.

2.1.6

All structure in close proximity to the very fine mesh zones is to be modelled explicitly with shell elements. Triangular elements are to be avoided where 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.

2.1.7

Where stresses are to be evaluated on a free edge, such as cut-outs for stiffener connections at web frames, edge of plating and hatch corners, beam elements having the same depth as the adjoining plate thickness and negligible width is to be used to obtain the required local edge stress values.

2.2 Hatch coaming top and deck plating

2.2.1

In addition to the general requirements in **[2.1]**, the modelling requirements in this sub-article are applicable to the modelling of hatch coaming top / deck plating. The selection of hatch coaming top / deck plating for fatigue analysis is to be determined based on the level of stresses obtained from the cargo hold FE analysis.

2.2.2

Where separate local finite element models are used, the model extents are to be according to the following:

a) Transversely, over the half-breadth of the ship,

b) Longitudinally, from the midpoint of the cargo hold in which the concerned hatch coaming top / deck plating is located to the adjacent cargo hold up to and including the midpoint of the cargo hold nearest to the concerned hatch coaming top / deck plating.

c) Vertically, from the top plate of coaming to the intersection of the side stringer with the inner hull.

2.2.3

The hatch coaming top and deck plating are to be represented by shell finite elements having both membrane and bending properties. **Figure 4** shows a typical FE model of hatch coaming and the deck plating with the very fine mesh zone having $t_{gr} \times t_{gr}$ mesh size.

2.2.4

The level of FE mesh refinement is to be such as to enable stress concentrations arising from the hatch corner geometry to be captured in the hot spot stress. The free edge of hatch coaming top and deck plating are to be assessed. Beam elements having the same depth as the adjoining plate thickness and negligible width are to be used at a free edge of the hatch coaming top and free edge of the deck plating to obtain the required local edge stress values as outlined in **[2.1.7]**.

2.2.5

The local structural geometry, particularly in the areas of concern, is to be represented. The hatch corner area is to be meshed using elements with a sufficiently small size to capture the local stress on the edge. In general, a minimum of 15 elements in a 90 degree arc are to be used to describe the curvature of the hatchway radius plating for a rounded corner (see **Figure 5**). For an elliptical or parabolic corner, a minimum of 15 elements are to be used from the inboard radius end to a point on the edge located at half the longitudinal distance of the semi- major axis. A total of 20 elements are to be used at the elliptical edge of the hatch corner (see **Figure 6**). However, the element edge dimensions along the free edge of the radius need not be less than the thickness of the plating being represented and also should not be greater than 5 times the thickness of the plating being represented.

2.3 Boundary conditions

2.3.1 Cargo hold model

The boundary conditions to be applied to the ends of the cargo hold model are to be in accordance with **Ch 7, Sec 2, [2.5]**.

2.3.2 Separate local finite element model

Where a separate local finite element model is used for evaluating the hot spot stress range, the boundary conditions and application of loads are to be in accordance with **Ch 7, Sec 3, [4.2]**.

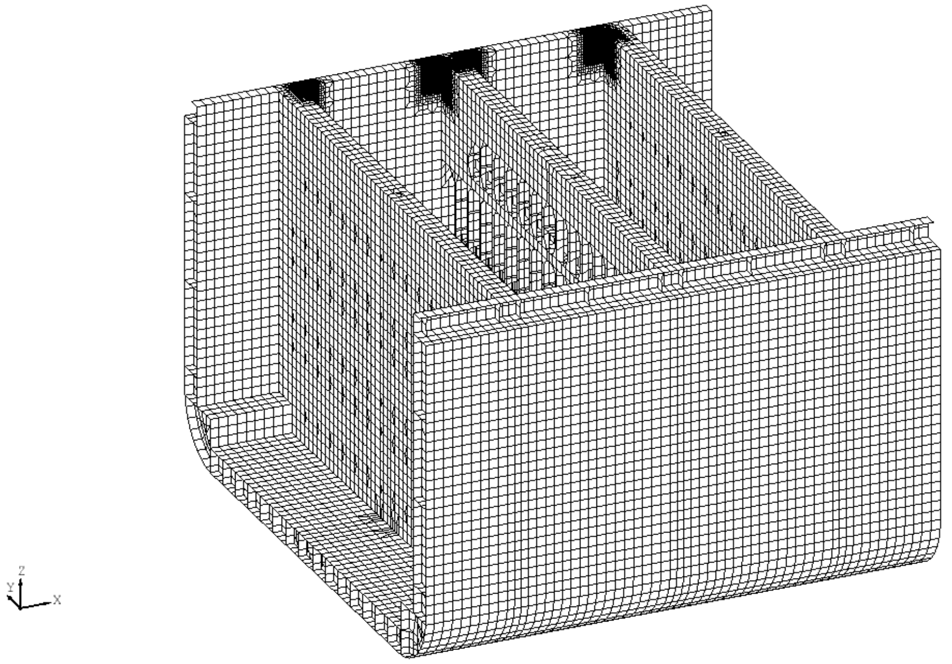


Figure 2 : Very fine mesh areas incorporated directly into the cargo hold model

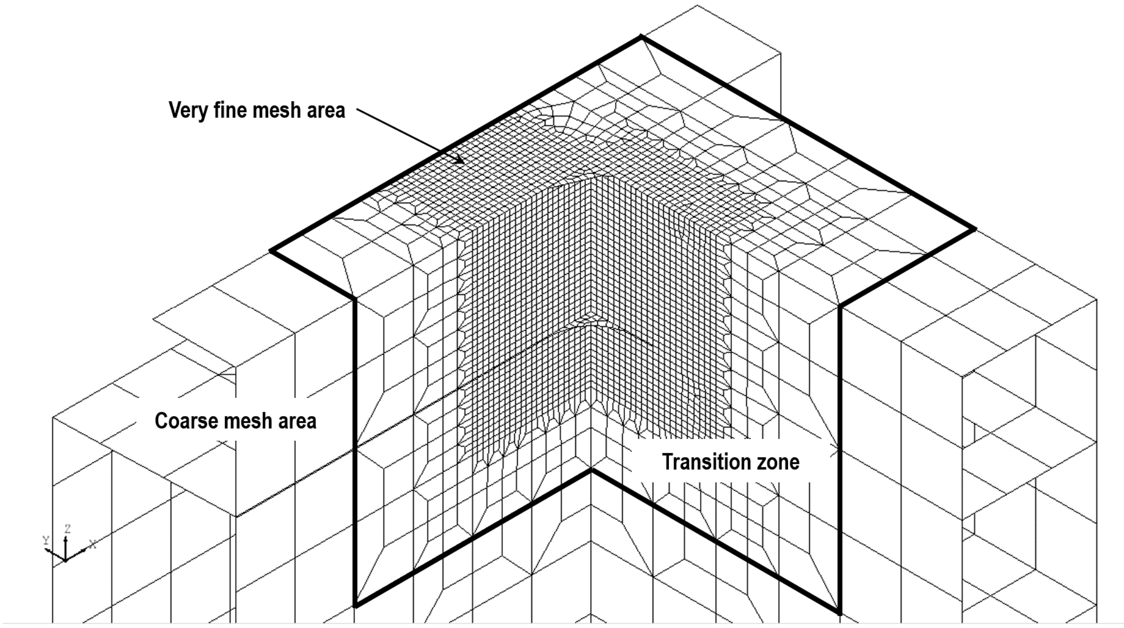


Figure 3 : Transition area between coarse and very fine mesh

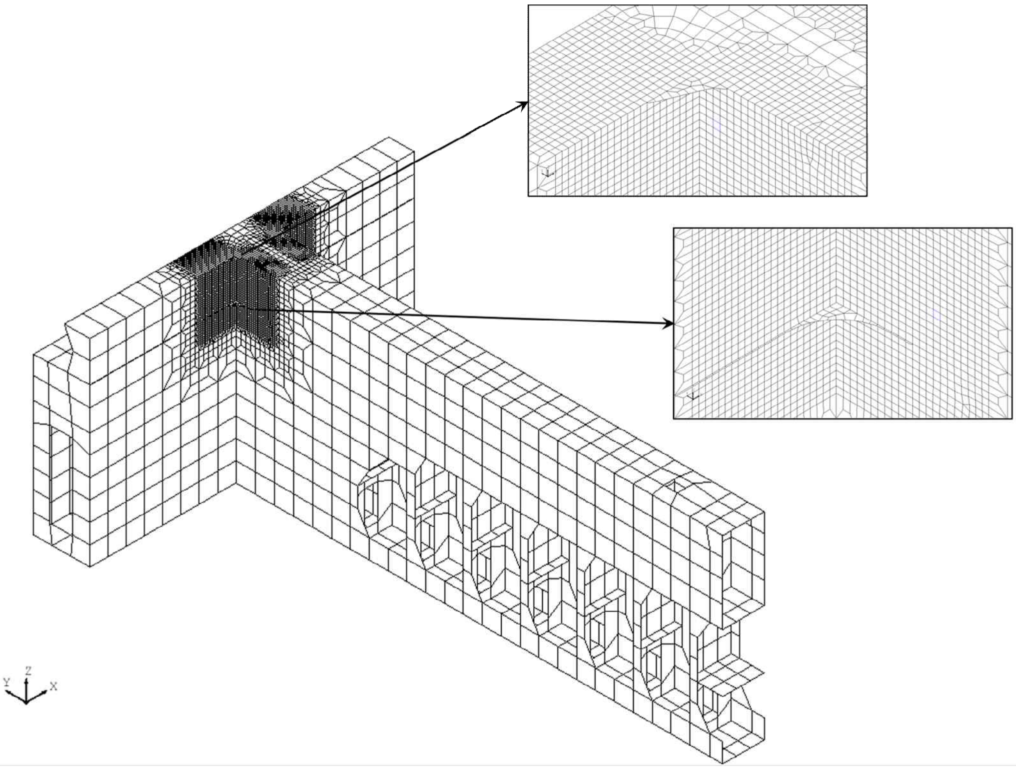


Figure 4 : Local FE model of hatch coaming top and deck plating with very fine mesh zone, $t_{gr} \times t_{gr}$ mesh

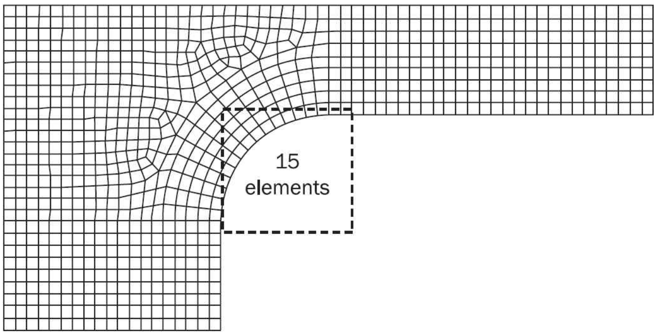


Figure 5 : Mesh density for rounded hatch corner

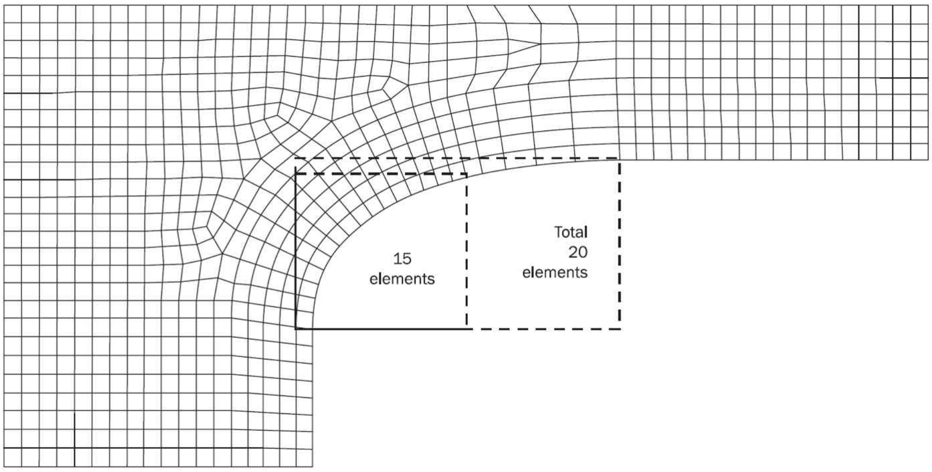


Figure 6 : Mesh density for elliptical hatch corner

3. Hot Spot Stress for Details Different from Web-Stiffened Cruciform Joints

3.1 Welded details

3.1.1

For hot spot type ‘a’, the structural hot spot stress, σ_{HS}, is calculated from a finite element analysis with $t_{gr} \times t_{gr}$ mesh density and is obtained by the following formula:

$\sigma_{HS} = 1.12 \cdot \sigma$

where:

σ : Surface principal stress, in N/mm^2, read out at a distance $t_{gr} / 2$ away from the intersection line.

t_{gr} : Plate gross thickness, in mm, in way of the weld toe.

At structural details where the hot spot type ‘a’ is classified as a web-stiffened cruciform joint, the stress read out procedure of **[4.2]** is to be applied.

For hot spot type ‘b’, the stress distribution is not dependent on the plate thickness; the structural hot spot stress, σ_{HS}, is derived from a finite element analysis with mesh density 10 × 10 mm and is obtained by the following formula:

$\sigma_{HS} = 1.12 \cdot \sigma$

where:

σ : Surface principal stress, in N/mm^2, read out at an absolute distance from the intersection line of 5 mm.

3.1.2 Stress read out methods

Depending on the element type, one of the following stress read out method is to be used:

- With 4-node shell element:

  Element surface stress components at the centre points are linearly extrapolated to the line A-A as shown in **Figure 7** to determine the stress components for load case ‘$i1$’ and ‘$i2$’ at the stress read out point located at a distance $t_{gr} / 2$ from the intersection line for type 'a' hot spot. Two principal hot spot stress ranges are determined at the stress read out point from the stress components tensor differences (between load case ‘$i1$’ and ‘$i2$’) calculated from each side (side L, side R) of line A-A. The angle θ between the direction x of the element co-ordinate system and the principal direction pX of the principal hot spot stress range co-ordinate system has to be determined.

- With 8-node shell element:

  With a $t_{gr} \times t_{gr}$ element mesh using 8-node element type, the element mid-side node is located on the line A-A at a distance $t_{gr} / 2$ for type 'a' hot spots. This node coincides with the stress read out point. The element surface stress components for load case ‘$i1$’ and ‘$i2$’ can be used directly without extrapolation within each adjacent element located on each side (side L, side R) of the line A-A as illustrated in **Figure 8.** Two principal hot spot stress ranges are determined at the stress read out point from the stress components tensor difference (between load case ‘$i1$’ and ‘$i2$’) calculated from each side of line A-A. The angle θ between the direction x of the element coordinate system and the principal direction pX of the principal hot spot stress range coordinate system has to be determined.

For fatigue assessment of type ‘b’ hot spots, a beam element is to be used to obtain the fatigue stress range. The stress range is to be based on axial and bending stress in the beam element. The beam element is to have the same depth as the connecting plate thickness while the in-plane width is negligible.

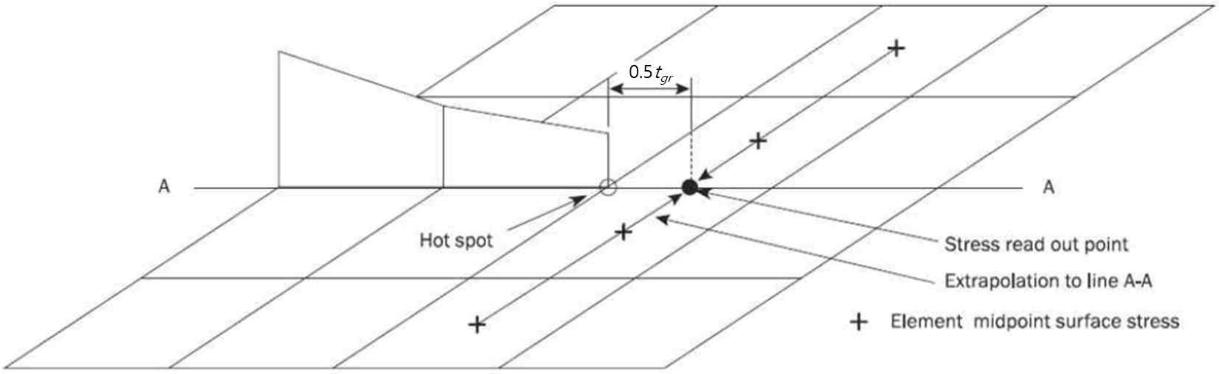


Figure 7 : Determination of stress read out points and hot spot stress for 4-node element

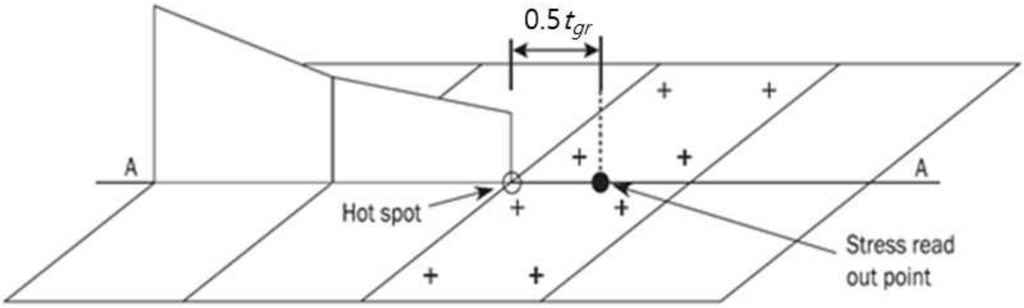


Figure 8 : Determination of stress read out points and hot spot stress for 8-node element

3.1.3

The above read out procedure is based on element surface stresses. Generally, in FE software the element stresses are calculated at the Gaussian integration points located inside the element. Depending on the element type implemented in the FE software, it may be necessary to perform several interpolations in order to determine the actual stress at the considered stress read out point at the surface of the element mid-point or element edge.

3.2 Base material

3.2.1

For fatigue assessment at a free plate edge, a beam element is to be used to obtain the fatigue stress range. The beam element is to have the same depth as the connecting plate thickness while the in-plane width should be negligible.

4. Hot Spot Stress for Web-Stiffened Cruciform Joint

4.1 Applicability

4.1.1

The following structural details are considered as a web-stiffened cruciform joint:

a) Heel of horizontal stringer, shown in **Figure 9.**

b) Longitudinal bulkhead - inner bottom connection.

c) Transverse bulkhead - inner bottom connection.

Two kinds of hot spots relative to the web-stiffened cruciform joints are to be assessed:

- Hot spots at the flange of web-stiffened cruciform joint,
- Hot spots in way of the web of web-stiffened cruciform joint.

4.1.2

The procedure for calculating hot spot stress at flange of web-stiffened cruciform joint is given in **[4.2].**

4.1.3

The procedure for calculating hot spot stress in way of the web of the web-stiffened cruciform joint is given in **[4.3].**

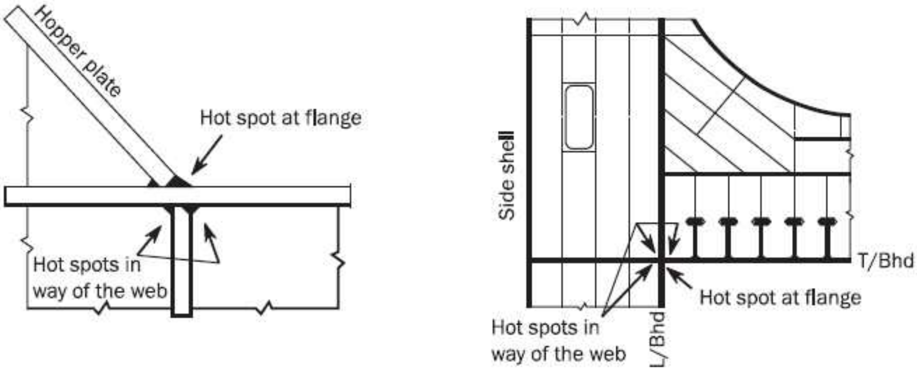


Figure 9 : Web-stiffened cruciform joints

4.2 Calculation of hot spot stress at the flange

4.2.1

For hot spot at the flange of web-stiffened cruciform joints, the surface principal stress is to be read out from a point shifted away from the intersection line between the considered member and abutting member to the position of the actual weld toe and multiplied by 1.12. The intersection line is taken at the mid-thickness of the cruciform joint assuming a median alignment.

The hot spot stress, in N/mm^2, is to be obtained as:

$$\sigma_{HS} = 1.12\,\sigma_{shift}$$

where:

σ_{shift} : Surface principal stress, in N/mm^2, at shifted stress read out position.

The stress read out point shifted away from the intersection line is obtained as:

$$x_{shift} = \frac{t_{1-gr}}{2} + x_{wt}$$

where:

t_{1-gr} : Gross plate thickness of the plate number 1, in mm, as shown in **Figure 10.**

x_{wt} : Extended fillet weld leg length, in mm, as defined in **Figure 10,** not taken larger than t_{1-gr}.

4.2.2

The stress at the shifted position is derived according to the following formula and illustrated in **Figure 11**:

$$\sigma_{shift} = [\sigma_{membrane}(x_{shift}) + 0.60 \cdot \sigma_{bending}(x_{shift})] \cdot \beta$$

where:

$\sigma_{bending}(x_{shift})$: Bending stress, in N/mm², at the shifted position taken as:

$$\sigma_{bending}(x_{shift}) = \sigma_{surface}(x_{shift}) - \sigma_{membrane}(x_{shift})$$

$\sigma_{surface}(x_{shift})$: Total surface stress at x_{shift} position (including membrane stress and bending stress), in N/mm².

$\sigma_{membrane}(x_{shift})$: Membrane stress at x_{shift} position, in N/mm².

β : Plate angle hot spot stress correction factor, taken as:

- For $\alpha = 135°$:

$$\beta = 0.96 - 0.13\frac{x_{wt}}{t_{1-gr}} + 0.20\,(\frac{x_{wt}}{t_{1-gr}})^2$$

- For $\alpha = 120°$:

$$\beta = 0.97 - 0.14\frac{x_{wt}}{t_{1-gr}} + 0.32(\frac{x_{wt}}{t_{1-gr}})^2$$

- For $\alpha = 90°$:

$$\beta = 0.96 + 0.031\frac{x_{wt}}{t_{1-gr}} + 0.24(\frac{x_{wt}}{t_{1-gr}})^2$$

α : Angle, in deg, between the plates forming a web-stiffened cruciform joint as shown in **Figure 11.**

Correction factors for connections with plate angles intermediate to those given should be derived based on a linear interpolation of the above values. The calculated hot spot stress is to be used in conjunction with the hot spot S-N curve for weld toe connections according to **Ch 9, Sec 3, [4.2].**

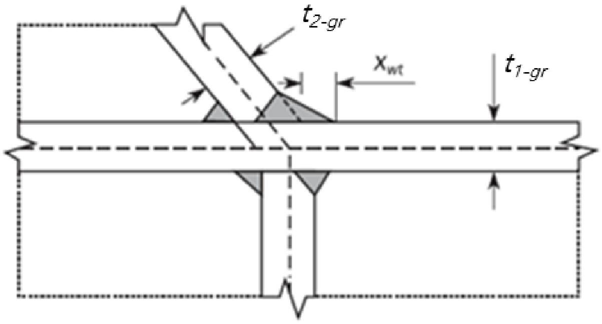


Figure 10 : Geometrical parameters of web-stiffened cruciform connections

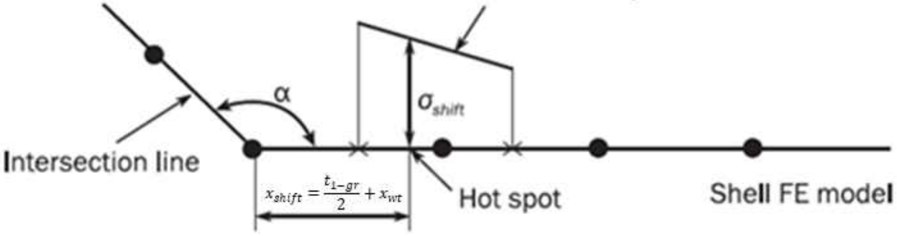


Figure 11 : Procedure for calculation of hot spot stress at web-stiffened cruciform connections

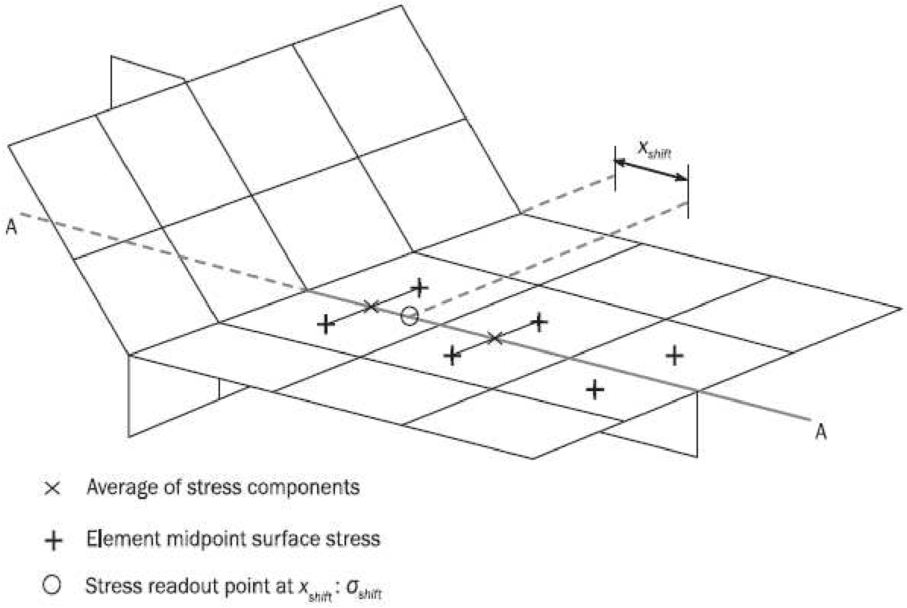


Figure 12 : Determination of stress read out points for web-stiffened cruciform connections

4.2.3

Surface principal stresses at the centre point of the two first elements on left and right side of the line A-A are averaged and taken as the surface principal stresses in way of the web position (line A-A). The surface principal stresses for load case '$i1$' and '$i2$' are linearly interpolated along the line A-A in order to determine hot spot principal stresses at the stress read out point located at the x_{shift} position as shown in **Figure 12**. The two principal hot spot stress ranges are determined at the stress read out point between load case '$i1$' and '$i2$'.

4.3 Calculation of hot spot stress in the web

4.3.1

Hot spots located in way of the web as indicated in **Figure 13** are to be checked with the hot spot stress defined from the maximum principal surface stress at the intersection offset by the distance x_{shift} from the vertical and horizontal element intersection lines as illustrated in **Figure 13**. The intersection line is taken at the mid thickness of the cruciform joint assuming a median alignment. The hot spot stress, in N/mm^2, is to be obtained as:

$$\sigma_{HS} = \sigma_{shift}$$

where:

σ_{shift} : Maximum principal surface stress, in N/mm^2, at the intersection offset by the distance x_{shift}.

The stress read out point at the intersection offset is obtained as:

$$x_{shift} = \frac{t_{3-gr}}{2} + x_{wt}$$

where:

t_{3-gr} : Gross plate thickness of the web, in mm, as shown in **Figure 13.**

x_{wt} : Extended fillet weld leg length, in mm, taken as:

$$x_{wt} = \min(\ell_{leg1}, \ell_{leg2})$$

ℓ_{leg1}, ℓ_{leg2} : Leg length, in mm, of the vertical and horizontal weld lines as shown in **Figure 13.**

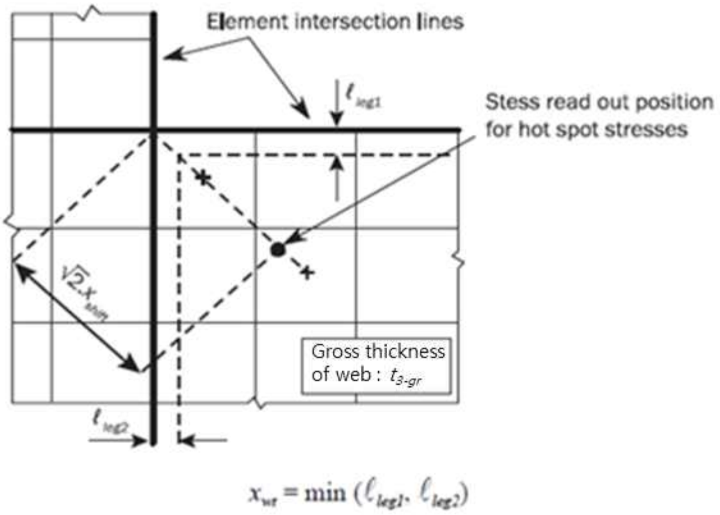


Figure 13 : Hot spots in way of web

5. Limitations of Hot Spot Stress Approach

5.1 Scope of application of hot spot stress approach

5.1.1

The hot spot stress approach given in **Ch 9, Sec 1, [2.3.1]** is not applicable for simple cruciform joints and simple T-joints when the stress flow in direction I as shown in **Figure 14** is considered. For stresses in the direction normal to the weld at hot spot location ‘c’ (direction I) there is no stress flow into the transverse plating as it is represented only by one plane in the shell model. However, it attracts stresses for in-plane direction (direction II) at hot spot location ‘a’.

In situations where a bracket is fitted behind the transverse plate as shown in **Figure 1**, acting with stiffness in the direction normal to the transverse plate, stresses flow also into the transverse plate and the hot spot methodology is considered applicable.

5.1.2

The hot spot stress at position ‘c’ for simple cruciform joints and simple T-joints is to be determined by the stress read out procedure given in **[3.1]** multiplied by a geometrical stress concentration factor of 1.3 and is taken as:

$$\sigma_{HS} = 1.3 \cdot 1.12\,\sigma$$

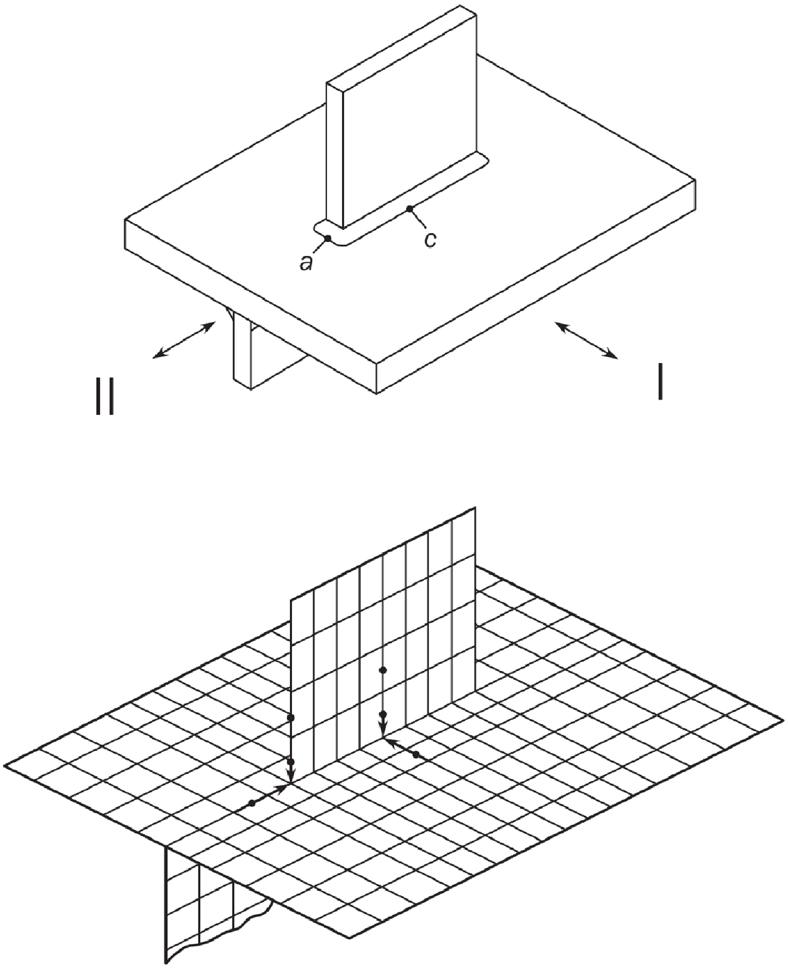


Figure 14 : Illustration of check points in way of a welded attachment under orthogonal applied in plane loads

Section 6 Detail Design Standard

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4**.

1. General

1.1 Purpose

1.1.1

Design standard provides fatigue resistant detail design at an early stage in the structural design process by giving consideration to the following aspects:

- Application of fatigue design principles.
- Construction tolerances and other practical considerations.
- In-service experience and fatigue performance.

1.1.2

The design standard is to be applied to the design of ship structural details in following steps:

- Highlighting potential critical areas within the ship structure.
- Identification of the fatigue hot spot locations for each of the critical structural details.
- Provision of a set of alternative improved configurations from which a suitable solution can be selected.
- Requirements on geometrical configurations, scantlings, welding requirements and construction tolerances.
- Post fabrication method of improving fatigue life, such as weld toe grinding.

1.2 Application

1.2.1

The structural details described in this section are to be designed according to the given design standard but alternative detail design configurations may be accepted subject to demonstration of satisfactory fatigue performance.

2. Stiffener-Frame Connections

2.1 Design standard A

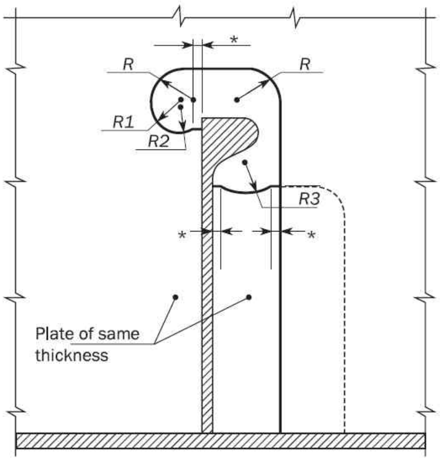
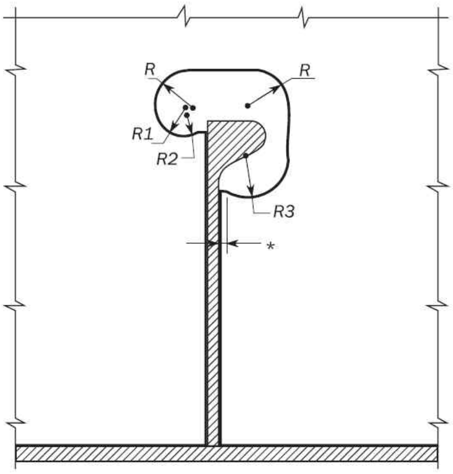
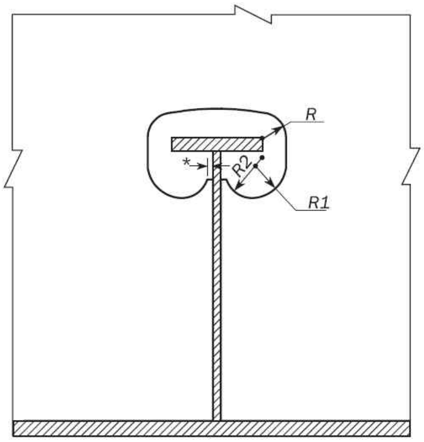
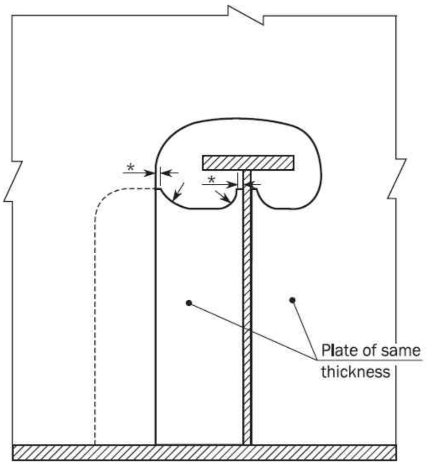
2.1.1

Designs for cut outs in cases where web stiffeners are omitted or not connected to the longitudinals are recommended to adopt tight collar or the improved design standard “A” as shown in **Table 1** or equivalent, for the following members:

- Side shell below 1.1 T_{SC}.
- Bottom.
- Inner hull longitudinal bulkhead below 1.1 T_{SC}.
- Inner bottom.

For designs that are different from those shown in **Table 1**, satisfactory fatigue performance may be demonstrated by, e.g., using comparative FE analysis according to **[2.2]**.

Table 1 : Finite element model for verification of equivalent design

Cut outs for longitudinals in transverse webs where web stiffeners are omitted or not connected to the longitudinal flange	
Design Standard A	
1	2
	
3	4
	
Note 1: Soft toes marked '*' are to be dimensioned to suit the weld leg length such that smooth transition from the weld to the curved part can be achieved. Maximum 15.0 mm or thickness of transverse web / collar plates / lug plates whichever is the greater. Note 2: Configurations 1 and 4 indicate acceptable lapped lug plate connections.	
Critical location	Locations around cut-out with high stress concentration and locations in way of weld terminations.
Detail design standard	Improved slot shape to avoid high stress concentrations in transverse webs due to shear loads and local pressure loads transmitted via welded joints.
Building tolerances	Ensure alignment of all connecting members and accurate dimensional control of cut-outs according to **IACS Recommendation No. 47**.
Welding requirements	A wraparound weld, free of undercut or notches, around the transverse web connection to longitudinal stiffener web.

2.1.2

Designs that are different from those shown in **Table 1** are acceptable subject to demonstration of satisfactory fatigue performance, e.g. by using comparative finite element analysis. The comparative FE analysis is to be performed following the modelling guidance given in **Figure 1**.

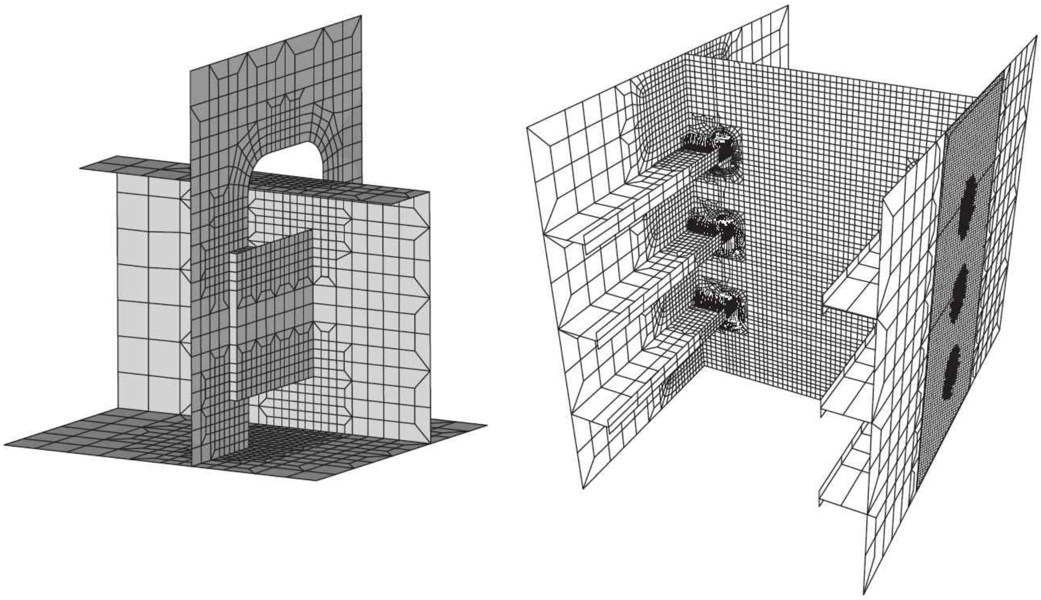


Figure 5 : Finite element model for verification of equivalent design

2.2 Equivalent design of stiffener-frame connections

2.2.1

If the required designs for stiffener-frame connections in **[2.1]** are not followed, the alternative design is to be verified to have equivalent fatigue strength to the design standard "A" or to be verified to have satisfactory fatigue performance. The alternative design is to be verified according to the procedure given in **[2.2.2]** to **[2.2.5]** and documentation of results is to be submitted to the Society.

2.2.2

The procedure of **[2.2.3]** and **[2.2.4]** is provided to verify the alternative design to have equivalent fatigue strength with respect to any position in the transverse ring, i.e. double bottom and double side. The hot spot stress of the alternative design and that of the required design is to be compared to the critical hot spots in way of the cut-out. The critical hot spots depend on the detail design and are to be selected in agreement with the Society. The hot spot stress is to be derived according to **Ch 9, Sec 5, [3.1]** and **Ch 9, Sec 5, [3.2]**. It is to be noted that welded hot spots at the free edge are classified as hot spot type 'b'. Example of typical hot spots for checking is shown in **Ch 9, Sec 2, [2]**.

2.2.3

The very fine mesh finite element models are made to analyse the behaviour in way of double side or double bottom. The models should have an extent of 3 stiffeners in cross section, i.e. 4 stiffener spacings, and the longitudinal extent is to be one half frame spacing in both forward and aft direction. A typical model is shown in **Figure 1.** No cut-outs for access openings are to be included in the models. Connection between the lug or the web-frame to the longitudinal stiffener web, connections of the lug to the web-frame and free edges on lugs and cut-outs in web-frame are to be modelled with elements of gross plate thickness size ($t_{gr} \times t_{gr}$). The mesh with gross plate thickness size should extend at least five elements in all directions. Outside this area, the mesh size may gradually be increased in accordance with the requirements in **Ch 9, Sec 5, [2]**. The eccentricity of the lapped lug plates is to be included in the model. Transverse web and lug plates are to be connected by eccentricity elements (transverse plate elements). The height of eccentricity element is to be the distance between mid-layers of transverse web and lug plates having a thickness equal to 2 times the gross thickness of web-frame plate t_{w-gr}. Eccentricity elements representing fillet welds are shown in **Figure 2**.

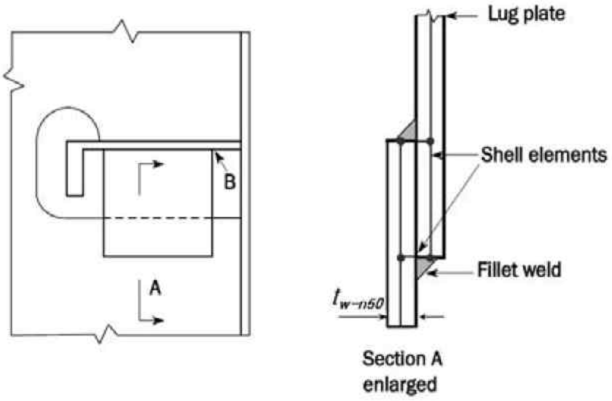


Figure 2 : Modelling of eccentric lug plate by shell elements

2.2.4

Three load cases are to be applied to the models of the design standard and alternative designs:

- External pressure of unit value, fixed boundary conditions at top and bottom of model.
- Shear stress by prescribed unit displacement at the model top and fixed boundary conditions at the model bottom.
- Axial load by prescribed unit displacement at the model top and fixed boundary conditions at the model bottom.

The forward and aft part of the model should have symmetry condition describing the behaviour in a double hull structure. Load application and boundary conditions are provided in **Figure 3**.

2.2.5

The alternative design may also be verified to have satisfactory fatigue performance using sub-modelling technique where a very fine mesh model of the alternative design located at the actual position of the stiffener-frame connection is analysed. The alternative design is considered acceptable if the fatigue acceptance criterion of **Ch 9, Sec 1** is achieved. The fatigue acceptance criterion is checked by applying the methodology described in **Ch 9, Sec 1**, **Ch 9, Sec 3** and **Ch 9, Sec 5**. The alternative design is considered acceptable only for the particular position where it is analysed.

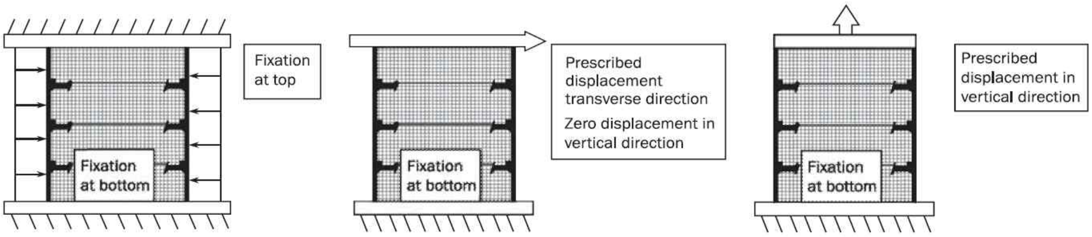


Figure 3 : Load application and boundary conditions - FE model for verification of alternative design

⚓

Chapter 10

Other Structures

Section 1 Fore Part

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

α_p : Correction factor for the panel aspect ratio to be taken as:

$\alpha_p = 1.2 - \frac{b}{2.1a}$ but not to be taken as greater than 1.0.

f_{bdg} : Bending moment factor taken as:

$f_{bdg} = 8\left(1+\frac{n_s}{2}\right)$

n_s : End fixation factor taken as:

$n_s = 0$ for both ends with low end fixity (simply supported).

$n_s = 1$ for one end fixed and one end simply supported.

$n_s = 2$ for continuous members or members with bracketed fitted at both ends.

d_{shr} : Effective web depth of stiffener, in mm, as defined in **Ch 3, Sec 7, [1.4.3]**

P_{SL} : Bottom slamming pressure defined in **Ch 4, Sec 5, [3.3.1]**, in $\mathrm{kN/m^2}$.

P_{FB} : Bow impact pressure defined in **Ch 4, Sec 5, [3.4.1]**, in $\mathrm{kN/m^2}$.

1. General

1.1 Application

1.1.1

The requirements of this section apply to the following structures of the fore part as defined in **Ch 1, Sec 1, [2.4.2]:**

- Fore peak structures.
- Stem.

In addition, the requirements of this section apply to structure subjected to impact loads:

- Flat bottom forward, according to **[3.2]**.
- Bow area, according to **[3.3]**.

2. Structural Arrangement

2.1 Floors and bottom girders

2.1.1 Floors

In case of transverse framing, solid floors are to be fitted at each web frame location.

In case of longitudinal framing, the spacing of solid floors is not to be greater than 3.5 m or four transverse frame spaces, whichever is smaller.

The minimum depth of the floor at the centreline is not to be less than the required depth of the double bottom of the foremost cargo hold. See **Ch 2, Sec 3, [2.3].**

2.1.2 Bottom girders

A supporting structure is to be provided at the centreline either by extending the centreline girder to the stem or by providing a deep girder or centreline bulkhead.

Where a centreline girder is fitted, the minimum depth and thickness is not to be less than that required for the depth of the double bottom in the neighbouring cargo tank region, and the upper edge is to be stiffened.

In case of transverse framing, the spacing of bottom girders is not to exceed 2.5 m.

In case of longitudinal framing, the spacing of bottom girders is not to exceed 3.5 m.

2.1.3 Alternative design verification

This spacing, defined in **[2.1.1]** and **[2.1.2]** may be increased, if the designer performs a verification of the bottom structure by means of grillage analysis or FE analysis and provides their full documentation. The acceptance criteria to be applied are defined in **Ch 6, Sec 6, [3].** A FE analysis is to be performed under consideration of the requirements provided in **Ch 7.**

2.2 Side shell supporting structure

2.2.1 Web frames

The spacing of web frames, S, in m as defined in **Ch 1, Sec 4, Table 5,** is to be taken as:

$S = 2.6 + 0.005L$, but not to be taken greater than 3.5 m.

Perforated flats are to be fitted to limit the effective span of web frames to not greater than 10.0 m.

2.2.2 Stringers

The transverse framing forward of collision bulkhead stringers are to be spaced approximately 3.5 m apart. Stringers are to have an effective span not greater than 10.0 m, and are to be adequately supported by web frame structures.

2.2.3 Alternative design verification

The spacing of web frames and stringers may be increased, if the designer performs a verification of the side shell supporting structure by means of beam analysis or FE analysis and provides their full documentation.

The acceptance criteria to be applied are defined in **Ch 6, Sec 6, [3].** A FE analysis is to be performed under consideration of the requirements provided in **Ch 7.**

2.3 Tripping brackets

2.3.1

For side shell and tank walls, located forward of the collision bulkhead and vertically framed, tripping brackets spaced not more than 2.6 m are to be fitted, according to **Figure 1,** between primary supporting members, decks and / or platforms.

The as-built thickness of the tripping brackets is not to be less than the as-built thickness of the side frame webs to which they are connected.

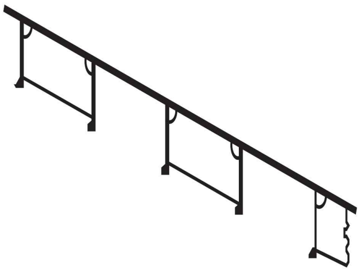


Figure 1 : Tripping brackets

2.4 Bulbous bow

2.4.1 General

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.

2.4.2 Diaphragm plates

At the forward end of the bulb the structure is generally to be supported by horizontal diaphragm plates spaced about 1.0 m apart in conjunction with a deep centreline web.

In general, vertical transverse diaphragm plates are to be arranged in way of the transition from the peak framing to the bulb framing.

2.4.3 Special bulbous bow designs

In way of a wide bulb, additional strengthening in the form of a centreline wash bulkhead is generally to be fitted.

In way of a long bulb, additional strengthening in the form of transverse wash bulkheads or substantial web frames is to be fitted.

2.4.4 Strengthening for anchor and chain cable contact

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 **[4.1.1]**.

3. Structure subjected to impact loads

3.1 General

3.1.1 Application

The requirements of this sub-section cover the strengthening requirements for local impact loads that may occur in the forward structure. The impact loads to be applied in **[3.2]** and **[3.3]** are described in **Ch 4, Sec 5, [3]**.

3.1.2 General scantling requirements

The requirements of **[3.2]** and **[3.3]** are to be applied in addition to applicable scantling requirements in **Ch 6**. Local scantling increases due to impact loads are to be made with due consideration given to details and avoidance of hard spots, notches and other harmful stress concentrations.

3.2 Bottom slamming

3.2.1 Application

Where the minimum draughts forward, T_F, as specified in **Ch 4, Sec 5, [3.2.1]**, are less than 0.045 L, the bottom forward is to be additionally strengthened to resist bottom slamming pressures.

The draughts for which the bottom has been strengthened are to be indicated on the shell expansion plan and loading guidance information, as required in **Ch 1, Sec 5.**

The load calculation point of the primary supporting members is specified in **Ch 3, Sec 7, [4].**

3.2.2 Extent of strengthening

The strengthening is to extend forward of 0.3 L from the FP over the flat of bottom and adjacent plating with attached stiffeners up to a height of 500 mm above the baseline, see **Figure 2.**

Outside the region strengthened to resist bottom slamming the scantlings are to be tapered to maintain continuity of longitudinal and / or transverse strength.

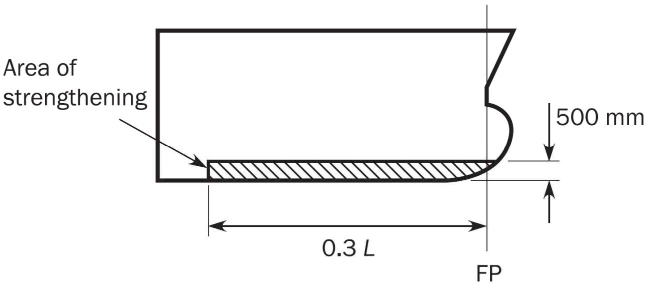


Figure 2 : Extent of strengthening against bottom slamming

3.2.3 Design to resist bottom slamming loads

The design of end connections of stiffeners in the bottom slamming region is to provide end fixity, either by making the stiffeners continuous through supports or by providing end brackets complying with **Ch 3, Sec 6, [3.2].**

Scantlings and arrangements of primary supporting members, including bulkheads in way of stiffeners, are to comply with **[3.2.6].**

3.2.4 Shell plating

The net thickness of the hull envelope plating, t in mm, except for the transversely stiffened bilge plating within the cylindrical part of the ship, is not to be less than:

$$t = \frac{0.0158\,\alpha_p b}{C_d}\sqrt{\frac{P_{SL}}{R_{eH}}}$$

where:

C_d : Plate capacity correction coefficient taken as:

$C_d = 1.3$

3.2.5 Shell stiffeners

The shell stiffeners within the strengthening area defined in **[3.2.2]** are to comply with the following criteria:

a) The net web thickness, t_w in mm, is not to be less than:

$$t_w = \frac{f_{shr} P s \ell_{shr}}{d_{shr}\,\tau_{eH}}$$

b) The net plastic section modulus, Z_{pl} in cm^3, is not to be less than:

$$Z_{pl} = \frac{1.2 P s \ell_{bdg}^2}{f_{bdg} R_{eH}}$$

where:

P : Effective design pressure, in $\mathrm{kN/m^2}$.

$P = 0.5 P_{SL}$

f_{shr} : Shear force distribution factor:

f_{shr}=0.7

3.2.6 Bottom slamming load area for primary supporting members

The scantlings of primary supporting members according to **[3.2.7]** are based on the application of the slamming pressure defined in **Ch 4, Sec 5, [3.2]** to an idealised slamming load area of hull envelope plating, A_{SL}, in m^2, given by:

$$A_{SL} = \frac{1.1 L B C_b}{1000}$$

3.2.7 Primary supporting members

The size and number of openings in web plating of the floors and girders is to be minimised considering the required shear area.

a) Shear area

The shear area, A_{shr}, in cm^2, of each primary supporting member web is not to be less than:

$$A_{shr} = \frac{10 Q_{SL}}{\tau_{eH}}$$

b) Simplified calculation of slamming shear force

For simple arrangements of primary supporting members, where the grillage effect may be ignored, the shear force, Q_{SL}, in kN, is given by:

$Q_{SL} = f_{dist} F_{SL}$

f_{dist} : Factor for the greatest shear force distribution along the span, according to **Figure 3**.

F_{SL} : Patch load, in kN, taken as:

$F_{SL} = P \ell_{SL} b_{SL}$

P : Effective design pressure, in $\mathrm{kN/m^2}$.

$P = 0.4 P_{SL}$

ℓ_{SL} : Extent of slamming load area along the span, in m, taken as:

$\ell_{SL} = \sqrt{A_{SL}}$ but not to be greater than 0.5ℓ_{SL}

b_{SL} : Breadth of impact area supported by primary supporting member, in m, taken as:

$b_{SL} = \sqrt{A_{SL}}$ but not to be greater than S

c) Direct calculation method for slamming shear force

For complex arrangements of primary supporting members, the greatest shear force, Q_{SL}, at any location along the span of each primary supporting member is to be derived by direct calculation in accordance with **Table 1**. The nominal shear stress shall not exceed 0.9τ_{eH} when the stress levels are determined through a grillage analysis.

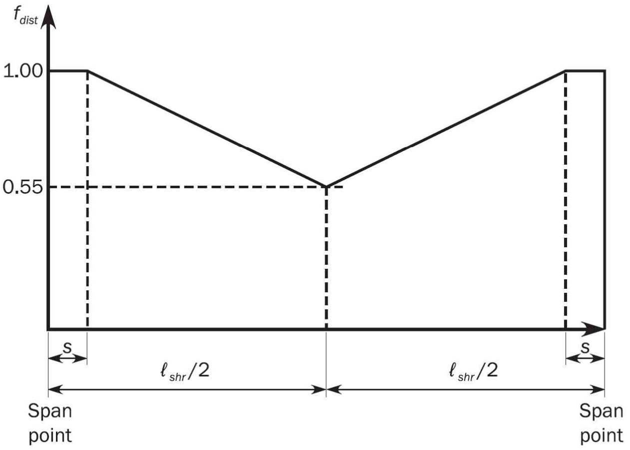


Figure 3 : Distribution of f_{dist} along the span of simple primary supporting members

d) Web thickness of primary supporting member

The net web thickness, t_w, in mm, of primary supporting members adjacent to the shell is not to be less than:

$$t_w = \frac{s_W}{100}\sqrt{\frac{R_{eH}}{235}}$$

s_W : Plate breadth, in mm, taken as the spacing between the web stiffening.

Table 1 : Direct calculation methods for derivation of Q_{SL}

Type of analysis	Model extent	Assumed end fixity of floors
Beam theory	Overall span of member between effective bending supports.	Fixed at ends
Double bottom grillage	Longitudinal extent to be one cargo hold length. Transverse extent to be half breadth of inner bottom	Floors and girders to be fixed at boundaries of the model.
Note 1: The envelope of greatest shear force along each primary supporting member is to be derived by applying the load patch on a square area as defined in **[3.2.6]**, to a number of locations along the span. Note 2: A more extensive model in length and breadth can be considered.		

3.3 Bow impact

3.3.1 Application

The side structure in the ship forward area is to be strengthened against bow impact pressures.

3.3.2 Extent of strengthening

The strengthening is to extend forward of 0.1 L from the FP and vertically above the minimum design ballast draught, T_{BAL}, defined in **Ch 1, Sec 4, [3.1.5]** and forecastle deck if any. See **Figure 4.**

If the flare angle, α as defined in **Ch 4, Sec 5, [3.3.1]**, is greater than 40° at 0.1 L from F.E., the bow impact area shall be extended to 0.15 L from F.E.

Outside the strengthening area the scantlings are to be tapered to maintain continuity of longitudinal and / or transverse strength.

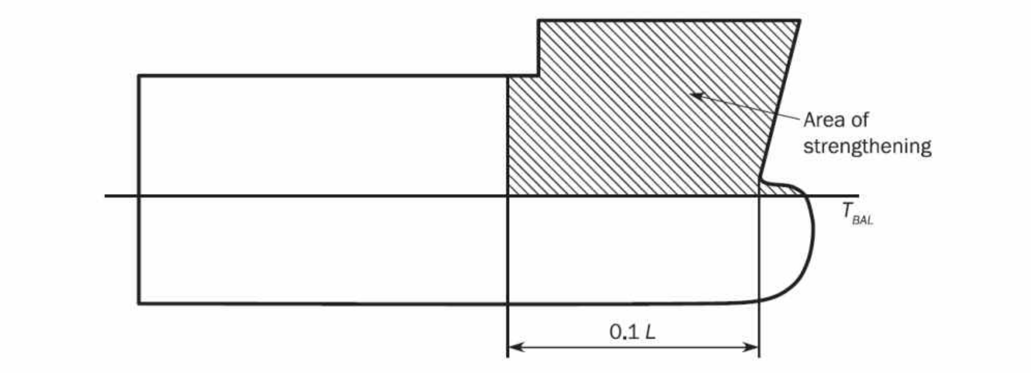


Figure 4 : Extent of strengthening against bow impact

3.3.3 Design to resist bow impact loads

a) In the bow impact strengthening area, longitudinal framing is to be carried as far forward as practicable.

The design of end connections of stiffeners in the bow impact region are to ensure end fixity, either by making the stiffeners continuous through supports or by providing end brackets complying with **Ch 3, Sec 6, [3.2].**

b) Scantlings and arrangements of primary supporting members, including decks and bulkheads, in way of the stiffeners, are to comply with **[3.3.6]**. In areas of the greatest bow impact load, the web stiffeners arranged perpendicular to the hull envelope plating and the double sided lug connections are to be provided.

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.

3.3.4 Side shell plating

The net thickness of the side shell plating, t in mm is not to be less than:

$$t = \frac{0.0158\alpha_p b}{C_d}\sqrt{\frac{P_{FB}}{R_{eH}}}$$

where:

C_d : Plate capacity correction coefficient taken as:

$$C_d = 1.3$$

3.3.5 Side shell stiffeners

The side shell stiffeners within the strengthening area defined in **[3.3.2]** are to comply with the following criteria:

a) The net web thickness, t_w in mm, is not to be less than:

$$t_w = \frac{f_{shr} P s \ell_{shr}}{d_{shr} \tau_{eH}}$$

b) The net plastic section modulus, Z_{pl} in cm^3, is not to be less than:

$$Z_{pl} = \frac{1.2 P s \ell_{bdg}^2}{f_{bdg} R_{eH}}$$

where:

P : Effective design pressure, in $\mathrm{kN/m^2}$.

$$P = 0.5 P_{FB}$$

f_{shr} : Shear force distribution factor:

f_{shr}=0.5 for horizontal stiffeners and upper end of vertical stiffeners

f_{shr}=0.7 for lower end of vertical stiffeners

3.3.6 Primary supporting members

a) Primary supporting members in the bow impact strengthening area are to be configured to provide effective continuity of strength and the avoidance of hard spots.

b) End brackets of primary supporting 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.

c) Tripping brackets are to be fitted at the toes of end brackets and at locations where the primary supporting member flange is knuckled or curved.

d) The net thickness of primary supporting members in way of bow impact strengthening area defined in **[3.3.2]**, t_w in mm, is not to be less than:

$$t_w = \frac{s_W}{75}\sqrt{\frac{R_{eH}}{235}}$$

e) The effective section modulus of each primary supporting member, Z in cm^3, is not to be less than:

$$Z = 1000\frac{P\,S\,\ell_{bdg}^2}{f_{bdg}\,R_{eH}}$$ with f_{bdg} is not to be taken less than 10

f) The effective shear area of the web, A_{shr} in cm^2, of each primary supporting member at the support / toe of end brackets is not to be less than:

$$A_{shr} = 10\frac{f_{shr}\,P\,S\,\ell_{shr}}{\tau_{eH}}$$

where:

P : Effective design pressure, in $\mathrm{kN/m^2}$.

$P = 0.4\,P_{FB}$

f_{shr} : Shear force distribution factor, as defined in **Ch 6, Sec 6, Table 14**.

s_W : Plate breadth, in mm, taken as the spacing between the web stiffening.

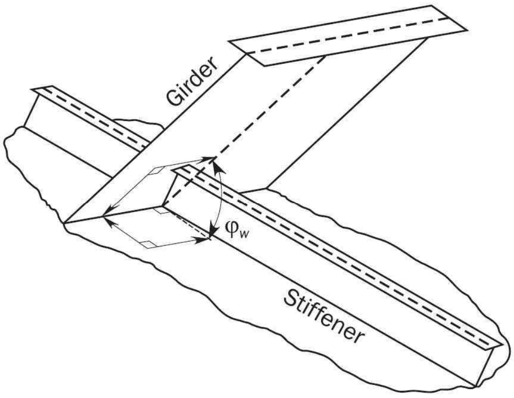


Figure 5 : Angle between shell primary member and shell plate

4. Additional scantling requirements

4.1 Plate stem

4.1.1

The net thickness, t_{Stm} in mm, is not to be less than:

$t_{Stm}=(0.6+0.4S_B)(0.08L+2.7)\sqrt{k}$ but need not be greater than $22\sqrt{k}-1$

where:

S_B : Spacing, in m, between horizontal stringers (partial or not), breasthooks or equivalent horizontal stiffening members.

Starting from 0.6 m above the summer load waterline up to $T_{SC}+C_w$, the net thickness may gradually be reduced to 0.8 t_{Stm}.

4.1.2 Breasthooks and diaphragm plating

The net thickness of breasthooks / diaphragm plates in way of bow impact strengthening area defined in **[3.3.1]**, t_w in mm, is not to be less than:

$$t_w=\frac{s}{70}\sqrt{\frac{R_{eH}}{235}}$$

where:

s : Spacing of stiffeners on the web, as defined in **Ch 1, Sec 4, Table 5**, in mm. Where no stiffeners are fitted, s is to be taken as the depth of the web.

4.2 Thruster tunnel

4.2.1

The net thickness of the tunnel plating, t_{tun} in mm, is not to be less than the net required thickness for the shell plating in the vicinity of the bow thruster.

In addition, t_{tun} is not to be taken less than:

$t_{tun}=0.008d_{tun}+1.8$

where:

d_{tun} : inside diameter of the tunnel, in mm, but not to be taken less than 970 mm.

Where the outboard ends of the tunnel are provided with bars or grids, the bars or grids are to be effectively secured.

Section 2 Machinery Space

1. General

1.1 Application

1.1.1

The requirements of this section apply to the scantlings and arrangement of structures located in the machinery space. It is the shipyard responsibility to design the ship in accordance with the machinery manufacturer's requirements.

2. Machinery space arrangement

2.1 Structural arrangement

2.1.1

Where openings in decks / bulkheads are provided in the machinery space, the arrangements are to support the deck, side, and bottom structure.

2.1.2

All parts of the machinery, shafting, etc, are to be supported to distribute the loads into the ship' structure. The adjacent structure is to be suitably stiffened.

2.1.3

Primary supporting members are to be positioned giving consideration to the provision of through stiffeners and in line pillar supports to achieve an efficient structural design.

2.1.4

The spacing of web frames in way of transversely framed machinery spaces is generally not to exceed five transverse frame spaces. Web frames are to be connected at the top and bottom to members of suitable stiffness, and supported by deck transverses.

2.1.5

End connections of side longitudinals at transverse bulkheads are to provide fixity, lateral support, and when not continuous are to be provided with soft-toe brackets. Brackets lapped onto the longitudinals are not to be fitted.

2.1.6

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. Where fitted, deck transverses are to be arranged in line with web frames to provide end fixity and transverse continuity of strength.

Where a longitudinal framing system is adopted, deck longitudinals are to be supported by deck transverses in line with web frames in association with pillars or pillar bulkheads.

2.1.7

Machinery casings are to be supported by a suitable arrangement of deck transverses and longitudinal girders in association with pillars or pillar bulkheads. In way of particularly large machinery casing openings, cross ties may be required. These are to be arranged in line with deck transverses.

2.1.8

The foundations for main propulsion units, reduction gears, shaft and thrust bearings, and the structure supporting those foundations are to maintain the required alignment and rigidity under all anticipated conditions of loading. Consideration is to be given to the submittal of the following plans to the machinery manufacturer for review:

a) Foundations for main propulsion units.
b) Foundations for reduction gears.
c) Foundations for thrust bearings.
d) Structure supporting a), b) and c).

2.2 Double bottom

2.2.1 Double bottom height

The double bottom height at the centreline, irrespective of the location of the machinery space, is to be not less than the value defined in **Ch 2, Sec 3, [2.3.1].** This depth may need to be considerably increased in relation to the type and depth of main machinery seatings.

The above height is to be increased by the shipyard where the machinery space is very large and where there is a considerable variation in draught between light ballast and full load conditions.

Where the double bottom height in the machinery space differs from that in adjacent spaces, structural continuity of longitudinal members is to be provided by sloping the inner bottom over an adequate longitudinal extent. The knuckles in the sloped inner bottom are to be located in way of floors. Lesser double bottom height may be accepted in local areas provided that the overall strength of the double bottom structure is not thereby impaired.

2.2.2 Centreline girder

The double bottom is to be arranged with a centreline girder. In way of any openings for manholes on the centreline girder, permitted only where absolutely necessary for double bottom access and maintenance, local strengthening is to be arranged.

2.2.3 Side bottom girders

In the machinery space, the number of side bottom girders is to be adequately increased, with respect to the adjacent areas, to provide adequate rigidity of the structure. The side bottom girders in longitudinal stiffened double bottom, are to be a continuation of any bottom longitudinals in the areas adjacent to the machinery space and are generally to have a spacing not greater than 3 times that of longitudinals and in no case greater than 3.0 m.

2.2.4 Girders in way of machinery seatings

Additional side bottom girders are to be fitted in way of machinery seating.

2.2.5 Floors in longitudinally stiffened double bottom

Where the double bottom is longitudinally stiffened, 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.

2.2.6 Floors in transversely framed double bottom

Where the double bottom in the machinery space is transversely stiffened, floors are to be arranged at every frame.

2.2.7 Manholes and wells

The number and size of manholes in floors located in way of seatings and adjacent areas are to be kept to the minimum necessary for double bottom access and maintenance.

In general, manhole edges are to be stiffened with flanges; failing this, the floor plate is to be adequately stiffened with flat bars at manhole sides.

Manholes with perforated portable plates are to be fitted in the inner bottom in the vicinity of wells arranged close to the aft bulkhead of the engine room.

Drainage of the tunnel is to be arranged through a well located at the aft end of the tunnel.

2.2.8 Inner bottom plating

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 19.0 mm. 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' recommendations.

2.2.9 Heavy equipment

Where heavy equipment is mounted directly on the inner bottom, the thickness of the floors and girders is to be suitably increased.

3. Machinery foundations

3.1 General

3.1.1

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.

3.1.2

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 case and the thrust bearing, see Type 1 of **Figure 1.**

3.1.3

For main machinery supported on foundations of Type 2, as shown in **Figure 2,** 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 Type 2 of **Figure 2.**

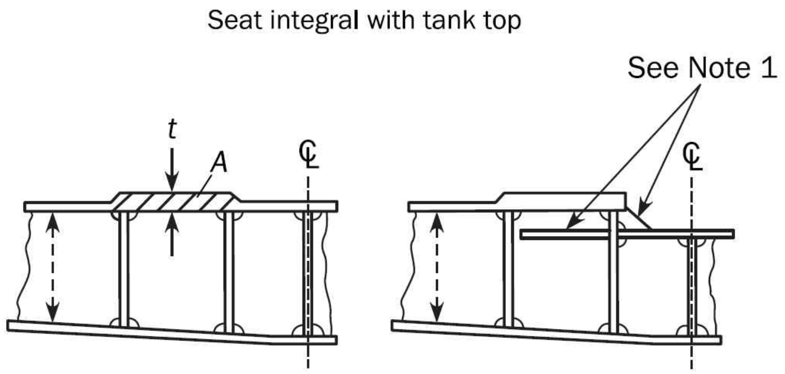


Figure 1 : Machinery foundations Type 1

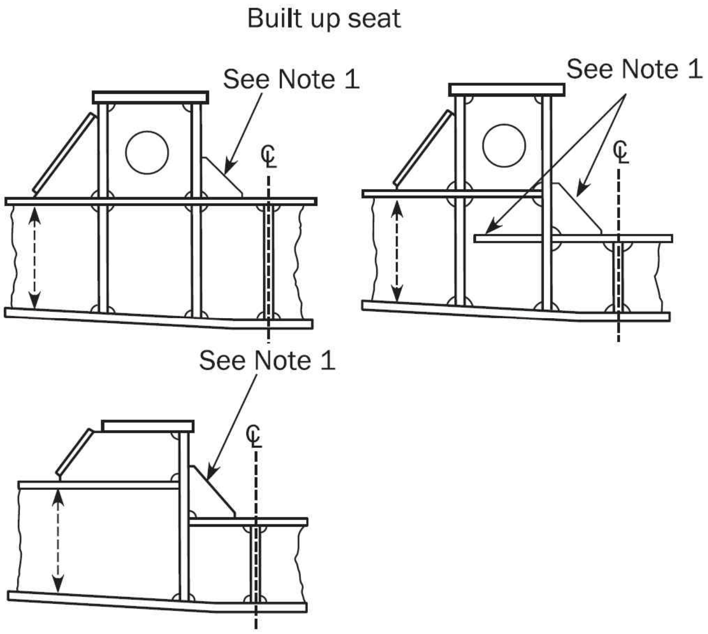


Figure 2 : Machinery foundation Type 2

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.

3.2 Foundations for internal combustion engines and thrust bearings

3.2.1

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 its design characteristics with regard to out of balance forces.

3.2.2

Generally, two girders are to be fitted in way of the foundation for internal combustion engines and thrust bearings.

3.3 Auxiliary foundations

3.3.1

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.

Section 3 Aft Part

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

P_{SS} : Stern slamming pressure defined in **Ch 4, Sec 5, [3.5.1]**, in $\mathrm{kN/m^2}$.

1. General

1.1 Application

1.1.1

The requirements of this section apply for the scantlings and arrangement of structures located aft of the aft peak bulkhead.

2. Aft peak

2.1 Structural arrangement

2.1.1 Floors

Floors are to be fitted 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.

Heavy plate floors are to be fitted 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.

2.1.2 Platforms and side girders

Platforms and side girders within the peak are to be arranged in line with those located in the area immediately forward.

Where this arrangement is not possible due to the shape of the hull and access needs, structural continuity between the peak and the structures of the area immediately forward is to be ensured by adopting wide tapering brackets.

Where the aft peak is adjacent to a machinery space whose side is longitudinally framed, the side girders in the aft peak are to be fitted with tapering brackets.

Where the depth from the peak tank top to the weather deck is greater than 2.6 m and the side is transversely framed, one or more side girders are to be fitted, preferably in line with similar structures existing forward.

2.1.3 Longitudinal bulkheads

A longitudinal non-tight bulkhead is to be fitted on the centreline of the ship, in general in the upper part of the peak, and stiffened at each frame spacing.

Where either the stern overhang is very large or the maximum breadth of the space divided by watertight and wash bulkheads is greater than 20.0 m, additional longitudinal wash bulkheads may be required.

2.1.4 Alternative design verification

The spacing and arrangement requirements, defined in **[2.1.1]**, **[2.1.2]** and **[2.1.3]** may be increased, if the designer performs a verification by means of grillage analysis or FE analysis and provides their full documentation. The acceptance criteria to be applied are defined in **Ch 6, Sec 6, [3].** A FE analysis is to be performed under consideration of the requirements provided in **Ch 7.**

2.2 Stiffening of floors and girders in aft peak

2.2.1

Stiffeners on the floors and girders in aft peak ballast or fresh water tanks above propeller are to be designed in accordance with **[2.2.2]** and **[2.2.3]**. This applies for stiffeners located in an area extending longitudinally between the forward edge of the rudder and the after end of the propeller boss and transversely within the diameter of the propeller.

2.2.2

The height of stiffeners, h_{stf} in mm, on the floors and girders are not to be less than:

$h_{stf} = 80\,\ell_{stf}$ for flat bar stiffeners.

$h_{stf} = 70\,\ell_{stf}$ for bulb profiles and flanged stiffeners.

where:

ℓ_{stf} : Length of stiffener, in m, as shown in **Figure 1**. Length need not be taken greater than 5.0 m.

2.2.3

End brackets are to be provided as follows:

a) Brackets are to be fitted at the lower and upper ends when ℓ_{stf-t} exceeds 4.0 m.

b) Brackets are to be fitted at the lower end when ℓ_{stf-t} exceeds 2.5 m.

where:

ℓ_{stf-t} : Total length of stiffener, in m, as shown in **Figure 1.**

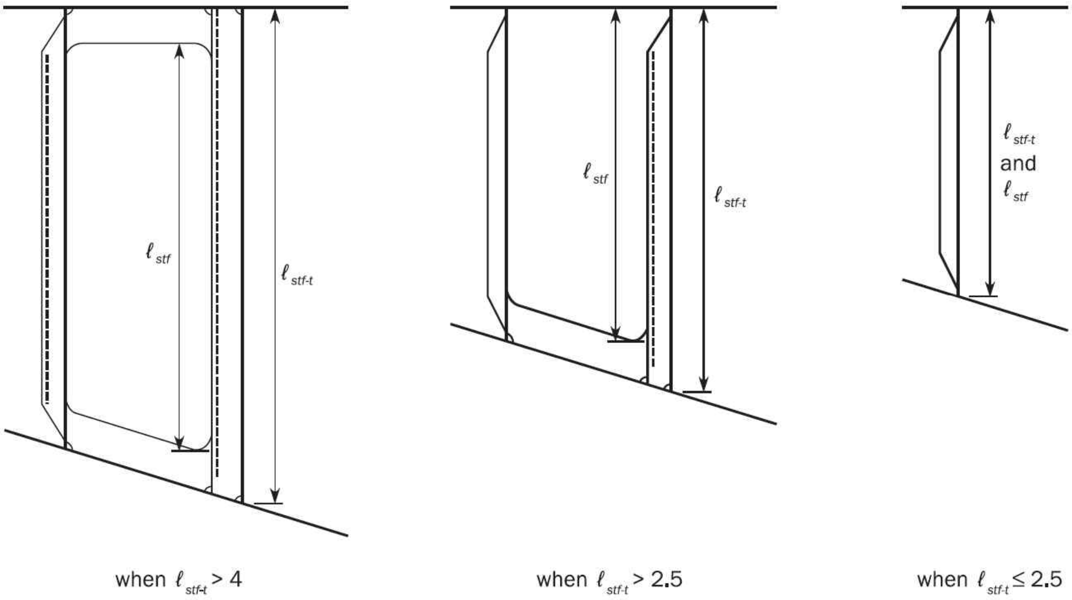


Figure 1 : Stiffening of floors and girders in the aft peak tank

3. Stern frames

3.1 General

3.1.1

Stern frames may be fabricated from steel plates or made of cast steel with a hollow section. For applicable material specifications and steel grades, see **Ch 3, Sec 1.** Stern frames of other material or construction will be specially considered.

3.1.2

Cast steel and fabricated stern frames are to be strengthened by adequately spaced horizontal plates with gross thickness not less than 80 % of required thickness for stern frames. Abrupt changes of section are to be avoided in castings; all sections are to have adequate tapering radius.

3.1.3

In the upper part of the propeller aperture, where the hull form is full and centreline supports are provided, the thickness of stern frames may be reduced to 80 % of the applicable requirement in **[3.2.1]**.

3.2 Propeller posts

3.2.1 Gross scantlings of propeller posts

The gross scantlings of propeller posts are not to be less than those obtained from the formulae in **Table 1** for single screw ships and **Table 2** for twin screw ships.

Scantlings and proportions of the propeller post which differ from **Table 1** and **Table 2** may be considered acceptable provided that the section modulus of the propeller post section about its longitudinal axis is not less than that calculated with the propeller post scantlings in **Table 1** or **Table 2**, as applicable.

Table 1 : Single screw ships – Gross scantlings of propeller posts

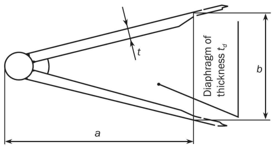
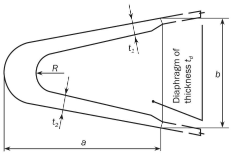
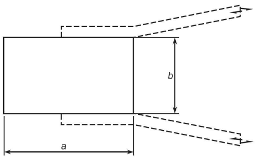
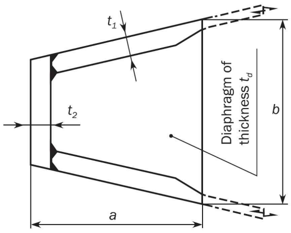
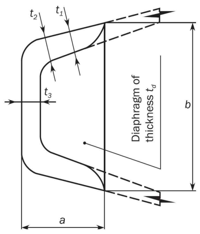
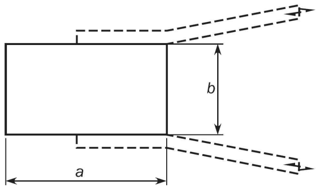
Gross scantlings of propeller posts, in mm	Fabricated propeller post  	Cast propeller post  	Bar propeller post, cast or forged, having rectangular section 
a	$50L_1^{1/2}$	$33L_1^{1/2}$	$10\sqrt{7.2L-256}$
b	$35L_1^{1/2}$	$23L_1^{1/2}$	$10\sqrt{4.6L-164}$
t_1	$2.5L_1^{1/2}$	$3.2L_1^{1/2}$	–
t_2	–	$4.4L_1^{1/2}$	–
t_d	$1.3L_1^{1/2}$	$2.0L_1^{1/2}$	–
R	–	50 mm	–

Table 2 : Twin screw ships – Gross scantlings of propeller posts

Gross scantlings of propeller posts, in mm	Fabricated propeller post 	Cast propeller post 	Bar propeller post, cast or forged, having rectangular section 
a	$25L^{1/2}$	$12.5L^{1/2}$	$2.4L+6$
b	$25L^{1/2}$	$25L^{1/2}$	$0.8L+2$
t_1	$2.5L^{1/2}$	$2.5L^{1/2}$	–
t_2	$3.2L^{1/2}$	$3.2L^{1/2}$	–
t_3	–	$4.4L^{1/2}$	–
t_d	$1.3L^{1/2}$	$2.0L^{1/2}$	–

3.2.2 Propeller shaft bossing

In single screw ships, the thickness of the propeller shaft bossing, included in the propeller post, is not to be less than 60 % of the dimension b required in **[3.2.1]** for bar propeller posts with a rectangular section.

3.3 Connections

3.3.1 Connections with hull structure

Stern frames are to be effectively attached to the aft structure and the required scantling for the lower part of the propeller post is to be extended from the aft end of the propeller post, at the centerline of the propeller shaft, to a length not less than $1500 + 6\,L_2\ \mathrm{mm}$, in order to provide an effective connection with the keel. However, the stern frame need not extend beyond the aft peak bulkhead.

3.3.2 Connection with keel plate

The thickness of the lower part of the stern frames is to be gradually tapered to that of the solid bar keel or keel plate.

Where a keel plate is fitted, the lower part of the stern frame is to be designed to ensure an effective connection with the keel.

3.3.3 Connection with transom floors

Rudder posts and propeller posts are to be connected with transom floors having height not less than that of the double bottom height and a net thickness not less than that obtained, in mm, from the following formula:

$t = 9 + 0.023\,L_1$

3.3.4 Connection with centre keelson

Where the stern frame is made of cast steel, the lower part of the stern frame is to be fitted, as far as practicable, with a longitudinal web for connection with the centre keelson.

4. Special scantling requirements for shell structure

4.1 Shell plating

4.1.1 Shell plating connected with stern frame

The net thickness of shell plating connected with the stern frame is not to be less than that obtained, in mm, from the following formula:

$$t = 0.094(L_2 - 43) + 0.009\,b$$

In way of the boss and heel plate, the net thickness, t, of shell plating, in mm, is not to be less than:

$$t = 0.105(L_2 - 47) + 0.011\,b$$

where:

b : Breadth of plate panel, in mm, as defined in **Ch 3, Sec 7, [2.2.2].**

4.1.2 Heavy shell plates

Heavy shell plates are to be fitted locally in way of the heavy plate floors as required by **[2.1.1].** The net thickness of heavy shell plates is not to be less than the value given in **[4.1.1]**. 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 in mm, is not to be less than:

$$r = 150 + 0.8L_2$$

4.1.3 Thruster tunnel plating

The net thickness of the tunnel plating, t_{tun} in mm, is to comply with the requirements in **Ch 10, Sec 1, [4.2.1].**

5. Structure subjected to impact loads

5.1 General

5.1.1 Application

The requirements of this sub-section cover the strengthening requirements for local impact loads that may occur in the stern bottom structure of the ships with length $L \geq 150\ \mathrm{m}$. The stern slamming loads, P_{SS}, to be applied in **[5.2]** are described in **Ch 4, Sec 5, [3].** The requirements of **[5.2]** are to be applied in addition to applicable scantling requirements in **Ch 6.**

5.2 Stern slamming

5.2.1 Application

The stern bottom structure is to be strengthened against stern slamming pressures.

5.2.2 Extent of strengthening

In general the strengthening is to extend aft of 0.1 L forward of AE and vertically above the minimum design ballast draught, T_{AE}, defined in **Ch 1, Sec 4, Table 2**. Outside the strengthening area the scantlings are to be tapered to maintain continuity of longitudinal and / or transverse strength.

5.2.3 Side shell plating

The net thickness of the side shell plating, t in mm, is not to be less than:

$$t = \frac{0.0158\alpha_p b}{C_d}\sqrt{\frac{P_{SS}}{R_{eH}}}$$

where:

C_d : Plate capacity correction coefficient taken as:

$C_d = 1.3$

5.2.4 Side shell stiffeners

The side shell stiffeners within the strengthening area defined in **[5.2.2]** are to comply with the following criteria:

a) The net web thickness, t_w in mm, is not to be less than:

$$t_w = \frac{f_{shr} P s \ell_{shr}}{d_{shr} \tau_{eH}}$$

b) The net plastic section modulus, Z_{pl} in cm^3, is not to be less than:

$$Z_{pl} = \frac{1.2 P s \ell_{bdg}^2}{f_{bdg} R_{eH}}$$

where:

P : Effective design pressure, in $\mathrm{kN/m^2}$.

$P = 0.5 P_{SS}$

f_{shr} : Shear force distribution factor:

$f_{shr} = 0.7$

5.2.5 Primary supporting members

The size and number of openings in web plating of the floors and girders is to be minimised considering the required shear area as given:

a) Section modulus

The section modulus of each primary supporting member, Z in cm^3, is not to be less than:

$$Z = 1000 \frac{P S \ell_{bdg}^2}{f_{bdg} R_{eH}}$$ with f_{bdg} is not to be taken less than 10

b) Shear area

The shear area, A_{shr} in cm^2, of each primary supporting member web at any position along its span is not to be less than:

$$A_{shr} = 10 \frac{f_{shr} P S \ell_{shr}}{\tau_{eH}}$$

c) Web thickness of primary supporting member

The net thickness of primary supporting members in way of stern slamming strengthening area defined in **[5.2.2]**, t_w in mm, is not to be less than:

$$t_w = \frac{s_W}{75} \sqrt{\frac{R_{eH}}{235}}$$

where:

P : Effective design pressure, in $\mathrm{kN/m^2}$.

$P = 0.4 P_{SS}$

f_{shr} : Shear force distribution factor, as defined in **Ch 6, Sec 6, Table 14**.

s_W : Plate breadth, in mm, taken as the spacing between the web stiffening.

Section 4 Tanks Subject to Sloshing

Symbols

For symbols not defined in this section, refer to **Ch 1, Sec 4.**

α_p : Correction factor for the panel aspect ratio to be taken as:

$$\alpha_p = 1.2 - \frac{b}{2.1a}$$ but not to be taken as greater than 1.0

a : Length of plate panel, in mm, as defined in **Ch 3, Sec 7, [2.1.1].**

b : Breadth of plate panel, in mm, as defined in **Ch 3, Sec 7, [2.1.1].**

ℓ_{bdg} : Effective bending span, as defined in **Ch 3, Sec 7, [1.1.2],** in m.

ℓ_{tk-h} : Effective sloshing length, in m, as defined in **Ch 4, Sec 6, [3.3.2].**

b_{tk-h} : Effective sloshing breadth, in m, as defined in **Ch 4, Sec 6, [3.4.2].**

I_{y-n50} : Net horizontal hull girder moment of inertia, at the longitudinal position being considered, as defined in **Ch 5, Sec 1, [1.5],** in m^4.

M_{sw} : Permissible hull girder hogging and sagging still water bending moment for seagoing operation at the location being considered, in kNm, as defined in **Ch 4, Sec 4, [2.2.2].**

z_n : Distance from the baseline to the horizontal neutral axis, as defined in **Ch 5, Sec 1,** in m.

z : Vertical coordinate of the load calculation point or at the reference point under consideration, in m.

σ_{hg} : Hull girder bending stress, in $\mathrm{N/mm^2}$, calculated at the load calculation point defined in **Ch 3, Sec 7, [2.2]** or in **Ch 3, Sec 7, [3.2],** as the case may be:

$$\sigma_{hg} = \left[\frac{(z - z_n) M_{sw}}{I_{y-n50}} \right] 10^{-3}$$

1. General

1.1 Application

1.1.1

The requirements of this section cover the strengthening requirements for localised sloshing loads that may occur in tanks.

Sloshing loads due to the free movement of liquid in tanks are given in **Ch 4, Sec 6, [3].**

1.2 General requirements

1.2.1 Filling heights of fuel tanks and ballast tanks

The scantlings of all fuel tanks and ballast tanks are to comply with the sloshing requirements given in this section for the following cases:

- unrestricted filling height for ballast tanks.
- unrestricted filling height for fuel tanks with fuel density equal to ρ_L, as defined in **Ch 4, Sec 6**.

1.2.2 Structural details

Local scantling increases due to sloshing loads are to be made with due consideration given to details and avoidance of hard spots, notches and other harmful stress concentrations.

1.3 Application of sloshing pressure

1.3.1 General

The structural members of the following tanks are to be assessed for the design sloshing pressures $P_{slh-\ln g}$ and P_{slh-t} in accordance with **[1.3.4]** and **[1.3.5]**.

a) Fore peak and aft peak ballast tanks.

b) Other tanks which allow free movement of liquid, e.g. ballast tanks, fuel oil bunkering tanks, methanol fuel tanks and fresh water tanks, etc.

Where the effective sloshing length, ℓ_{tk-h} is less than 0.03 L, calculations involving $P_{slh-\ln g}$ are not required and where the effective sloshing breadth b_{tk-h} is less than 0.32 B, calculations involving P_{slh-t} are not required.

1.3.2 Minimum sloshing pressure

The minimum sloshing pressure, $P_{slh-\min}$, as defined in **Ch 4, Sec 6, [3.2]** is to apply to tanks in which the effective sloshing length, ℓ_{tk-h} or breadth b_{tk-h}, is less than defined in **[1.3.1]**.

1.3.3 Structural members to be assessed

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 supporting members located in tanks.

d) Tripping brackets supporting primary supporting members in tanks.

1.3.4 Application of design sloshing pressure due to longitudinal liquid motion

The design sloshing pressure due to longitudinal liquid motion, $P_{slh-\ln g}$, as defined in **Ch 4, Sec 6, [3.3.2]** is to be applied to the following members as shown in **Figure 1**.

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 within a distance from the transverse bulkhead taken as:

- 0.25 ℓ_{tk-h},
- The distance between the transverse bulkhead and the first web frame if located inside the tank at the considered level,

whichever is less.

In addition, the first web frame next to a transverse tight or wash bulkhead if the web frame is located within 0.25 ℓ_{tk-h} from the bulkhead, as shown in **Figure 1**, is to be assessed for the web frame reflected sloshing pressure, P_{slh-wf}, as defined in **Ch 4, Sec 6, [6.3.4]**.

The minimum sloshing pressure, $P_{slh-\min}$, as defined in **Ch 4, Sec 6, [3.2]** is to be applied to all other members.

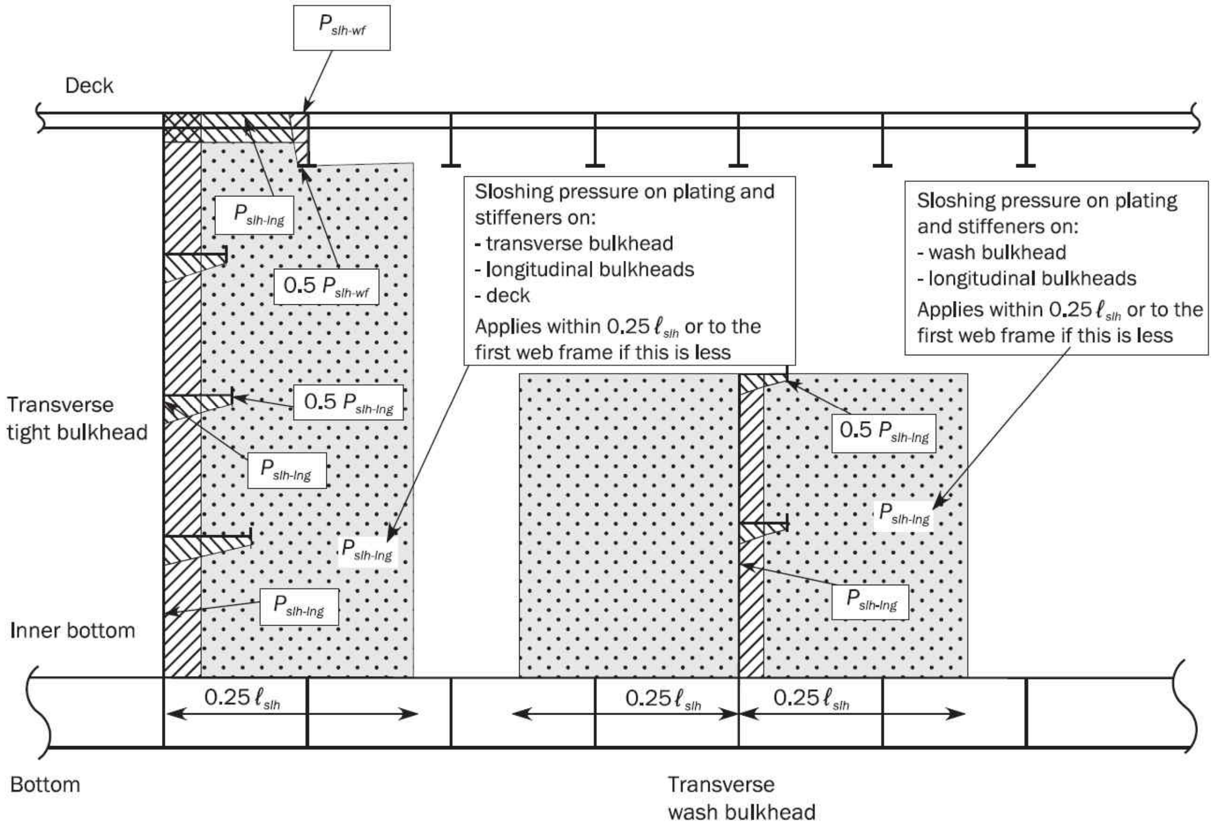


Figure 1 : Application of sloshing loads due to longitudinal liquid motion

1.3.5 Application of design sloshing pressure due to transverse liquid motion

The design sloshing pressure due to transverse liquid motion, P_{shl-t}, as defined in **Ch 4, Sec 6, [3.4.2]**, is to be applied to the following members as shown in **Figure 2.**

a) Longitudinal tight bulkhead.

b) Longitudinal wash bulkhead.

c) Horizontal stringers on longitudinal tight and wash bulkheads.

d) Plating and stiffeners on the transverse tight bulkheads including stringers and deck within a distance from the longitudinal bulkhead taken as:

  - 0.25 b_{tk-h},
  - The distance between the longitudinal bulkhead and the first girder if located inside the tank at the considered level,

  whichever is less.

In addition, the first girder next to the longitudinal tight or wash bulkhead if the girder is located within 0.25 b_{tk-h} from longitudinal bulkhead, as shown in **Figure 2,** is to be assessed for the reflected sloshing pressure, $P_{slh-grd}$ as defined in **Ch 4, Sec 6, [3.4.3].**

The minimum sloshing pressure, $P_{slh-\min}$, as defined in **Ch 4, Sec 6, [3.2]**, is to be applied to all other members.

1.3.6 Combination of transverse and longitudinal fluid motion

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.

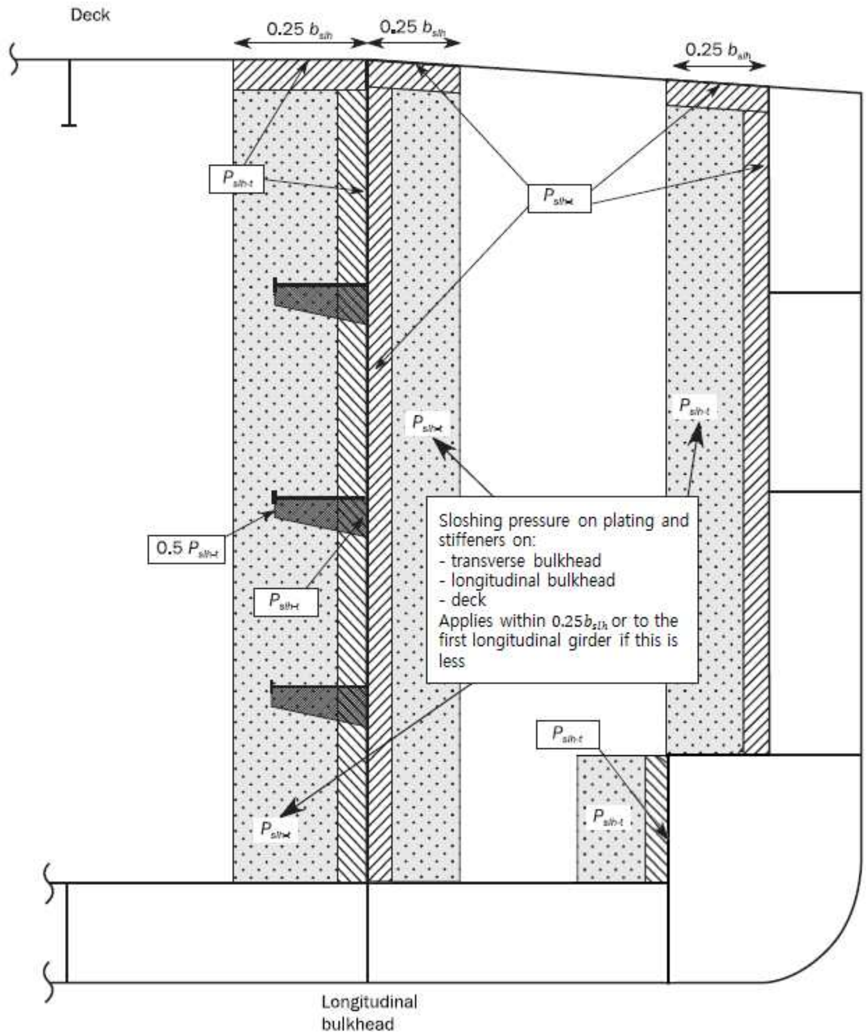


Figure 2 : Application of sloshing loads due to transverse liquid motion

1.3.7 Additional sloshing impact assessment

For tanks with effective sloshing breadth, b_{tk-h}, greater than 0.56 B or effective sloshing length, ℓ_{tk-h}, greater than 0.13 L, an additional sloshing impact assessment is to be carried out in accordance with the individual Society' procedures.

2. Scantling requirements

2.1 Plating

2.1.1 Net thickness

The net thickness of plating, t in mm, subjected to sloshing pressure is not to be less than:

$$t = 0.0158\alpha_p b\sqrt{\frac{P_{slh}}{C_a R_{eH}}}$$

where:

C_a : Permissible bending stress coefficient to be taken as:

$C_a = \beta_a - \alpha_a \frac{|\sigma_{hg}|}{R_{eH}}$ with coefficients defined in **Table 1,** but not to be taken greater than $C_{a-\max}$.

σ_{hg} : Hull girder bending stress, in $\mathrm{N/mm^2}$, corresponding to the greatest of the sagging and hogging bending moment in absolute value.

P_{slh} : The greater of $P_{slh-\ln g}$, P_{slh-t} or $P_{slh-\min}$ as specified in **[1.3].**

Table 1 : Definition β_a, α_a and C_{a-max}

Acceptance criteria set	Structural member		β_a	α_a	C_{a-max}
AC-S	Longitudinal strength members in the cargo hold region including but not limited to: • Deck. • Longitudinal plane bulkhead. • Horizontal corrugated longitudinal bulkhead. • Longitudinal girders and stringers.	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 supporting members outside the cargo hold region.		0.8	0.0	0.8

2.2 Stiffeners

2.2.1 Net section modulus

The net section modulus, Z in $\mathrm{cm^3}$, of stiffeners subjected to sloshing pressure is not to be less than:

$$Z = \frac{P_{slh} s \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

f_{bdg} : Bending moment factor:

$f_{bdg} = 12$, for stiffeners fixed against rotation at each end. This is generally to be applied for scantlings of all continuous stiffeners.

$f_{bdg} = 8$, or stiffeners with one or both ends not fixed against rotation. This is generally to be applied to discontinuous stiffeners.

C_s : Permissible bending stress coefficient to be taken as :

a) For members subject to hull girder stress: coefficient to be taken as defined in **Table 2**.

b) $C_s = C_{s-\max}$ for other cases.

P_{slh} : The greater of $P_{slh-\ln g}$, P_{slh-t} or $P_{slh-\min}$ as specified in **[1.3]**.

$C_{s-\max}$: Coefficient as defined in **Table 3**.

Table 2 : Permissible bending stress coefficient C_s

Sign of hull girder bending stress σ_{hg} (1)	Lateral pressure acting on(2)	Stiffener boundary condition(3)	f_{bdg}	Coefficient C_s
Tension (positive)	Stiffener side	F - F	12	$C_s = \beta_s - \alpha_s \frac{\lvert\sigma_{hg}\rvert}{R_{eH}}$ but not to be taken greater than $C_{s-\max}$
		F - S	8	$C_s = \beta_s - \alpha_s \frac{\lvert\sigma_{hg}\rvert}{R_{eH}}$ but not to be taken greater than $C_{s-\max}$
		S - S	8	$C_s = C_{s-\max}$
	Plate side	F - F	12	$C_s = C_{s-\max}$
		F - S	8	$C_s = C_{s-\max}$
		S - S	8	$C_s = \beta_s - \alpha_s \frac{\lvert\sigma_{hg}\rvert}{R_{eH}}$ but not to be taken greater than $C_{s-\max}$
Compression (negative)	Stiffener side	F - F	12	$C_s = C_{s-\max}$
		F - S	8	$C_s = C_{s-\max}$
		S - S	8	$C_s = \beta_s - \alpha_s \frac{\lvert\sigma_{hg}\rvert}{R_{eH}}$ but not to be taken greater than $C_{s-\max}$
	Plate side	F - F	12	$C_s = \beta_s - \alpha_s \frac{\lvert\sigma_{hg}\rvert}{R_{eH}}$ but not to be taken greater than $C_{s-\max}$
		F - S	8	$C_s = \beta_s - \alpha_s \frac{\lvert\sigma_{hg}\rvert}{R_{eH}}$ but not to be taken greater than $C_{s-\max}$
		S - S	8	$C_s = C_{s-\max}$

(1) σ_{hg} is to be considered for the hogging and sagging situations.
(2) For primary supporting members located inside the considered tank and for wash bulkheads, the sloshing pressure is to be applied both on stiffeners and plate sides.
(3) F - F stands for both ends of the stiffener fixed against rotation.
F - S stands for one end of the stiffener fixed and the other not fixed against rotation.
S - S stands for both ends of the stiffener not fixed against rotation.

Table 3 : Definition β_s, α_s and C_{s-max}

Acceptance criteria set	Structural member		β_s	α_s	C_{s-max}
AC-S	Longitudinal strength members in the cargo hold region including but not limited to: • Deck stiffeners. • Stiffeners on longitudinal bulkheads. • Stiffeners on longitudinal girders and stringers	Longitudinally stiffeners	0.85	1.0	0.75
		Transversely or vertically stiffeners	0.7	0.0	0.7
	Other strength members including: • Stiffeners on transverse bulkheads. • Stiffeners on transverse stringers and web frames. • Stiffeners on tank boundaries and primary supporting members outside the cargo hold region.		0.75	0.0	0.75

2.3 Primary supporting members

2.3.1 Web plating

The web plating net thickness of primary supporting members, t in mm, is not to be less than:

$$t = 0.0158\alpha_p b\sqrt{\frac{P_{slh}}{C_a R_{eH}}}$$

where:

P_{slh} : The greater of $P_{slh-\ln g}$, P_{slh-t}, P_{slh-wf}, $P_{slh-grd}$ and $P_{slh-\min}$ as specified in **[1.3].** The pressure is to be calculated at the load application point, defined in **Ch 3, Sec 7, [4.1],** taking into account the distribution over the height of the member, as shown in **Figure 1** and **Figure 2.**

C_a : Permissible plate bending stress coefficient, as given in **[2.1.1].**

2.3.2 Stiffeners on web plating

The net section modulus, Z in cm^3, of each individual stiffener on the web plating of primary supporting members subjected to sloshing pressures is not to be less than:

$$Z = \frac{P_{slh} s \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

P_{slh} : The greater of $P_{slh-\ln g}$, P_{slh-t}, P_{slh-wf}, $P_{slh-grd}$ and $P_{slh-\min}$ as specified in **[1.3].** The pressure is to be calculated at the load application point, defined in **Ch 3, Sec 7, [3.2],** taking into account the distribution over the height of the member, as shown in **Figure 1** and **Figure 2.**

C_s : Permissible plate bending stress coefficient, as given in **[2.2.1].**

f_{bdg} : Bending moment factor as given in **[2.2.1].**

2.3.3 Tripping brackets supporting primary supporting members

The net section modulus, Z in cm^3, in way of the base within the effective length, d, of tripping brackets and net shear area, A_{shr} in cm^2, after deduction of cut-outs and slots, of tripping brackets supporting primary supporting members is not to be less than:

$$Z = \frac{1000 P_{slh} s_{trip} h^2}{2 C_s R_{eH}}$$

$$A_{shr} = 10 \frac{P_{slh} s_{trip} h}{C_t \tau_{eH}}$$

where:

P_{slh} : The greater of $P_{slh-\ln g}$, P_{slh-t}, P_{slh-wf}, $P_{slh-grd}$ and $P_{slh-\min}$ as specified in **[1.3]**. The average pressure may be calculated at mid point of the tripping bracket taking into account the distribution as shown in **Figure 1** and **Figure 2.**

s_{trip} : Mean spacing, between tripping brackets or other primary supporting members or bulkheads, in m.

h : Height of tripping bracket, see **Figure 3**, in m.

C_s : Permissible bending stress coefficient for tripping brackets to be taken as 0.75.

C_t : Permissible shear stress coefficient for tripping bracket to be taken as 0.75.

The effective breadth of the attached plate to be used for calculating the section modulus of the tripping bracket is to be taken as $h/3$. ⚓

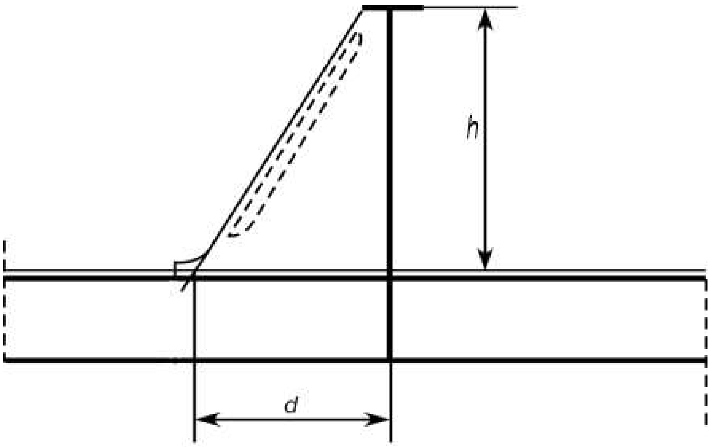


Figure 4 : Effective length of tripping bracket

Chapter 11

Superstructure, Deckhouses and Hull Outfitting

Section 1 Superstructures and Deckhouses

Symbols

For symbols not defined in this Section, refer to **Ch 1, Sec 4.**

P : Pressure applied on the considered superstructure side or deck, in $\mathrm{kN/m^2}$

$P = P_D$ for exposed decks,

$P = P_{dl}$ for unexposed deck,

$P = P_{SI}$ for superstructure side.

P_D : Lateral pressure for exposed decks, in $\mathrm{kN/m^2}$, as defined in **Ch 4, Sec 5, [2]** and in **Ch 4, Sec 5, [4.2]**.

P_{dl} : Lateral pressure for unexposed decks, in $\mathrm{kN/m^2}$, as defined in **Ch 4, Sec 6, [5]**.

P_{SI} : Lateral pressure for superstructure side, in $\mathrm{kN/m^2}$, as defined in **Ch 4, Sec 5, [4.3]**.

P_{FB} : Lateral pressure for side shell plating, in $\mathrm{kN/m^2}$, affected by bow impact requirements according to **Ch 4, Sec 5, [3.3.1]**.

P_A : External pressure for end bulkheads of superstructure and deckhouse walls, in $\mathrm{kN/m^2}$ according to **Ch 4, Sec 5, [4.4.1]**.

C_w : Wave coefficient, as defined in **Ch 4, Sec 4**.

ℓ_{bdg} : Effective bending span, in m, as defined in **Ch 3, Sec 7**.

ℓ_{shr} : Effective shear span, in m, as defined in **Ch 3, Sec 7**.

c : Coefficient taken as:

c = 0.75 for beams, girders and transverses which are simply supported in one or both ends.

c = 0.55 in other cases.

m_a : Coefficient taken as:

$$m_a = 0.204 \frac{s}{1000 l_{bdg}} \left[4 - \left(\frac{s}{1000 l_{bdg}} \right)^2 \right] \text{ with } \frac{s}{1000 \ell_{bdg}} \le 1$$

1. General

1.1 Application

1.1.1

The requirements of this section are applicable to superstructures and deckhouses, made of steel. The scantling requirements are listed in **Table 1**.

Table 1 : Application requirements

Item	Superstructure	Deckhouse
Exposed decks	**[3.1.1]**	**[3.2]**
Unexposed decks	**[3.2.2]** to **[3.2.5]**	**[3.2]**
Side walls	**[3.1.1]**	**[3.2]**
End bulkheads (fore and aft)	**[3.3]**	**[3.2]**

1.1.2

For the application of this section, a superstructure is considered being located aft or forward 0.4 L amidships or having a length of less than 0.15 L.

1.1.3

For the application of this section, the length of a deckhouse located within 0.4 L amidships is considered not exceeding 0.2 L.

1.2 Gross scantlings

1.2.1

With reference to **Ch 3, Sec 2, [1.1.3]**, all scantlings and dimensions referred to in **[3]** are gross.

2. Structural arrangement

2.1 Structural continuity

2.1.1 Bulkheads and sides of deckhouses

The aft, front and side bulkheads are to be effectively supported by under deck structures such as bulkheads, girders and pillars.

Sides and main longitudinal and transverse bulkheads are to be in line in the various tiers of deckhouses. Where such arrangement in line is not possible, other effective support is to be provided.

Arrangements are to be made to minimize the effect of discontinuities in erections. All openings cut in the sides are to be framed and have well-rounded corners. Continuous coamings or girders are to be fitted below and above doors and similar openings.

2.1.2 Deckhouse corners

At the corners where the deckhouse is attached to the strength deck, attention is to be given to the arrangements to transmit load into the under deck supporting structure.

2.2 End connections

2.2.1 Deck stiffeners

Transverse beams are to be connected to side frames by brackets according to **Ch 3, Sec 6, [3.2.1], [3.2.2]** and **[3.2.3]**. Beams crossing longitudinal walls and girders may be attached to the stiffeners of longitudinal walls and the webs of girders respectively by welding without brackets.

2.2.2 Longitudinal and transverse deck girders

Face plates are to be stiffened by tripping brackets according to **Ch 3, Sec 6, [4.3]**.

2.2.3 End connections of superstructure frames

Vertical frames are to be welded to the main frames below, or to the deck under provision of a sufficient supporting structure.

2.3 Local reinforcement on bulkheads

2.3.1

Local reinforcement is to be provided in way of large openings and areas supporting life saving appliances or high loads from other equipment, fittings, etc.

3. Scantlings

3.1 Superstructures sides and decks

3.1.1 Exposed sides and exposed deck plating

When the side of superstructure is part of the side shell, the net scantlings of Eexposed sides and exposed decks plating, stiffeners and primary supporting members **Ch 6**, **Sec 3**, **Ch 6**, **Sec 4**, **Ch 6**, **Sec 5** and **Ch 6**, **Sec 6**, respectively, with the pressure P_D, P_{dl} and P_{SI} defined in this Section. The net scantling approach defined in **Ch 3**, **Sec 2** and the corrosion additions defined in **Ch 3**, **Sec 3**, are to be considered.

When the side of superstructure is not part of the side shell, the exposed sides and exposed deck plating inclusive their supporting structure are to comply with the requirements given in **[3.3]**, **[3.2.1]** and **[3.2.3]** to **[3.2.5]**, respectively.

3.2 Deckhouses decks

3.2.1 Exposed deck plating

The gross thickness of the deckhouses exposed deck plating, $t_{gr-\exp}$ in mm, is not to be less than

$t_{gr-\exp} = 7.5\sqrt{\dfrac{ks}{s_{std}}}$ on first tier.

$t_{gr-\exp} = 7.0\sqrt{\dfrac{ks}{s_{std}}}$ on second tier.

$t_{gr-\exp} = 6.5\sqrt{\dfrac{ks}{s_{std}}}$ on third tier and above.

where:

s_{std} : Standard reference spacing of stiffeners or beams, in mm, taken as:

$$s_{std} = 470 + 1.67\,L_1$$

Where deck is protected by sheathing, the gross thickness of the deck plating may be reduced by 1.5 mm, without being less than 5.0 mm.

Where sheathing other than wood is used, attention is to be paid that the sheathing does not affect the steel. The sheathing is to be effectively fitted to the deck.

3.2.2 Unexposed deck plating

The gross thickness of the deckhouses unexposed deck plating, $t_{gr-unexp}$ in mm, is not to be less than the greater value of:

$t_{gr-unexp} = 0.9\, t_{gr-\mathrm{exp}}$ at the tier considered, and

$t_{gr-unexp} = \left(5.8 \frac{s}{1000} + 1\right)\sqrt{k}$ but not less than 5.5 mm.

3.2.3 Beams and stiffeners

The gross section modulus, Z_{gr} in cm^3, and the gross shear area, A_{gr-sh} in cm^2, of deckhouse deck transverse beams and of stiffeners are not to be less than:

$$Z_{gr} = c\, k\, P \frac{s}{1000} \ell_{bdg}{}^2$$

$$A_{gr-sh} = 0.05\,(1 - 0.817\, m_a)\, k\, P \frac{s}{1000} \ell_{shr}$$

3.2.4 Girders and transverses

The gross section modulus, Z_{gr} in cm^3, and the gross shear area, A_{gr-sh} in cm^2, of deckhouse deck girders and transverses are not to be less than:

$$Z_{gr} = c\, k\, P\, S\, \ell_{bdg}{}^2$$

$$A_{gr-sh} = 0.05\, k\, P\, S\, \ell_{shr}$$

The girder depth is not to be less than $\ell / 25$. The web depth of girders scalloped for continuous deck beams is to be at least 1.5 times the depth of the deck beams.

3.2.5 Alternative grillage analysis for girders and transverses

Where arrangements of deck girders and transverses are such that these members act as a grillage structure, additional analysis may be carried out with a structural model based on the gross scantling.

The resulting stresses are not to exceed the following permissible bending, shear and equivalent stresses, in $\mathrm{N/mm^2}$, taken as:

$$\sigma_b = 150 / k$$

$$\tau = 100 / k$$

$$\sigma_{eqv} = 180 / k$$

3.3 Deckhouses walls and end bulkheads of superstructures

3.3.1 Application

The requirements in **[3.3]** apply to end bulkhead of superstructure and deckhouse walls forming the only protection for openings and for accommodations.

Special consideration may be given to the bulkhead scantlings of deckhouses which do not protect openings in the freeboard deck, superstructure deck or in the top of a lowest tier deckhouse. Special consideration may also be given to the bulkhead scantlings of deckhouses which do not protect machinery casings, provided they do not contain accommodation or do not protect equipment essential to the operation of the ship.

3.3.2 Plate thickness

The gross thickness of the plating, t_{gr} in mm, is not to be less than the greater of:

$$t_{gr} = 0.9 \frac{s}{1000} \sqrt{k P_A} + 1.5$$

$$t_{gr} = \left(5.0 + \frac{L_2}{100}\right) \sqrt{k}$$ for the lowest tier.

$$t_{gr} = \left(4.0 + \frac{L_2}{100}\right) \sqrt{k}$$ for the upper tiers, without being less than 5.0 mm.

3.3.3 Stiffeners

The gross section modulus, Z_{gr} in cm^3, of the stiffeners is not to be less than:

$$Z_{gr} = 0.35\, k\, P_A \frac{s}{1000} \ell^2$$

This requirement assumes the webs of lowest tier stiffeners to be efficiently welded to the decks. Scantlings for other types of end connections are to be specially considered.

The section modulus of deckhouse side stiffeners needs not to be greater than that of side frames on the deck situated directly below, taking account of spacing s and span ℓ.

Section 2 Bulwark, Guard Rails and Breakwater

1. General requirements

1.1 Application

1.1.1

Bulwarks or guard rails are to be provided at the boundaries of exposed freeboard and superstructure decks, at the boundary of first tier of deckhouses and at the ends of superstructures.

1.2 Minimum height

1.2.1

Bulwarks, or guard rails, are to be a minimum of 1.0 m in height, measured above sheathing, and are to be constructed as required in **[2.2]** and **[3.2]**. Where this height would interfere with the normal operation of the ship, a lesser height may be accepted, on the basis of justifying information to be submitted.

2. Bulwarks

2.1 General

2.1.1

Plate bulwarks are to be stiffened at the upper edge by a suitable rail and supported either by stays or plate brackets spaced not more than 2.0 m apart.

The free edge of the stay or the plate bracket is to be stiffened.

2.1.2

Within 0.6 L amidships, bulwarks are to be arranged to ensure that they are free from hull girder stresses.

2.1.3

Bulwarks are to be adequately strengthened and increased in thickness in way of mooring pipes.

Cut-outs in bulwarks for gangways or other openings are to be kept clear of breaks of superstructures.

2.1.4

Bulwark plating and stays are to be adequately strengthened in way of eye plates used for shrouds or other tackles in use for cargo gear operation, as well as in way of hawser holes or fairleads provided for mooring or towing.

2.1.5

Openings in bulwarks are to be arranged so that the protection of the crew is to be at least equivalent to that provided by the horizontal courses in **[3.2.2]**.

For this purpose, vertical rails or bars spaced approximately 230 mm apart may be accepted in lieu of rails or bars arranged horizontally.

2.1.6

Where mooring fittings subject the bulwark to large forces, the stays are to be adequately strengthened.

2.2 Construction of bulwarks

2.2.1 Plating

The gross thickness of bulwark plating, at the boundaries of exposed freeboard and superstructure decks, is not to be less than that given in **Table 1**.

Table 1: Height of bulwark Gross thickness

Height of bulwark	Gross thickness
1.8 m or more	Thickness required for a superstructure side in the same position, obtained from **Ch 11, Sec 1, [3.2.1],** but not to be less than 6.5 mm
1.0 m	6.5 mm
Intermediate height	To be determined by linear interpolation

2.2.2 Stays

The gross section modulus of stays, $Z_{stay-gr}$ in cm^3, is not to be less than:

$$Z_{stay-gr} = 77\, h_{blwk}^2\, s_{stay}$$

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.

In the calculation of the section modulus, only the material connected to the deck is to be included. The bulb or flange of the stay may be taken into account where connected to the deck. Where the bulwark plating is connected to the sheer strake, a width of attached plating, not exceeding 600 mm, may also be included.

2.2.3

Where bulwarks are cut completely, stays or plate brackets of increased strength are to be fitted at the ends of openings.

Bulwark stays are to be supported by, or are to be in line with, suitable under deck stiffening. The stiffening is to be connected by double continuous fillet welds in way of bulwark stay connections.

2.2.4

At the ends of superstructures and for the distance over which their side plating is tapered into the bulwark, the latter is to have the same thickness as the side plating. Where openings are cut in the bulwark at these positions, adequate compensation is to be provided either by increasing the thickness of the plating or by other suitable means.

3. Guard rails

3.1 General

3.1.1

Where superstructures are connected by trunks, open rails are to be fitted for the whole length of the exposed parts of the freeboard deck.

3.2 Construction of guard rails

3.2.1

Stanchions of guard rails are to comply with the following requirements:

a) Fixed, removable or hinged stanchions are to be fitted approximately 1.5 m apart.

b) At least every third stanchion is to be supported by a bracket or stay.

c) Removable or hinged stanchions are to be capable of being locked in the upright position.

d) In the case of ships with rounded sheer strake, the stanchions are to be placed on the flat of the deck.

e) In the case of ships with welded sheer strake, the stanchions are not to be attached to the sheer strake, upstand or a continuous gutter bar.

3.2.2

The size of openings, below the lowest course of rails and the deck or upstand, is to be a maximum of 230 mm. The distance between other courses is not to be greater than 380 mm.

3.2.3

Wire ropes may be accepted, in lieu of guard rails, only in special circumstances and then only in limited lengths. In such cases, they are to be made taut by means of turnbuckles.

3.2.4

Chains may be accepted, in lieu of guard rails, only where they are fitted between two fixed stanchions and/or bulwarks. if the opening is wide, the chains are to be fitted with vertical courses to prevent the horizontal courses from spreading apart.

4. Breakwater

4.1 General

4.1.1 Arrangement

If cargo is intended to be carried on deck forward of 0.85 L, a breakwater or an equivalent protecting structure (e.g. whaleback or turtle deck) is to be installed.

4.1.2 Dimensions of the breakwater

a) The recommended height of the breakwater, in m, is as following.

$h_w = 0.8\,(b\,C_w - z)$ but not less than $h_{w-\min}$

where;

$h_{w-\min} = 0.6(b\,C_w - z)$

z : the vertical distance (m) between the summer load line and the bottom line of the breakwater.

$$b = 1.0 + 2.75\left(\frac{\frac{x}{L} - 0.45}{C_B + 0.2}\right)^2 \qquad \text{with } 0.6 \le C_B \le 0.8$$

x : distance (m) from aft end of L to breakwater

The average height of whalebacks or turtle decks has to be determined analogously according to **Figure 1**.

b) The breakwater has to be at least as broad as the width of the area behind the breakwater, intended for carrying deck cargo.

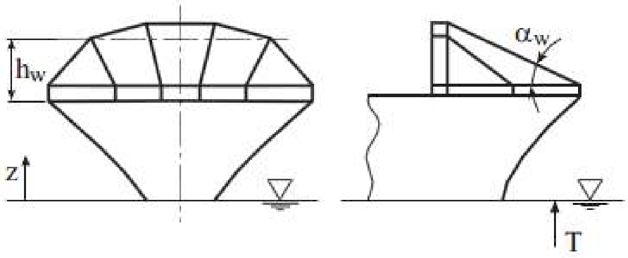


Figure 1 : Whaleback

4.1.3 Cutouts

Cutouts in the webs of primary supporting members of the breakwater are to be reduced to their necessary minimum. Free edges of the cutouts are to be reinforced by stiffeners. If cutouts in the plating are provided to reduce the load on the breakwater, the area of single cutouts should not exceed 0.2 m^2 and the sum of the cutout areas not 3 % of the overall area of the breakwater plating.

4.1.4 Loads

a) The loads for dimensioning, in $\mathrm{kN/m^2}$, are to be determined according to following formula.

$$P_A = nc\,(b\,C_w - z)$$

P_A is not to be less than following values

$25 + \frac{L}{10}$ where $L \le 250$ m

50 where $L > 250$ m

$$n = 10 + \frac{L_2}{20}$$

$$c = \sin \alpha_w$$

where;

α_w : Inclining angle, in deg, of breakwater at centre line

4.1.5 Plate thickness and stiffeners

a) The net thickness of plate, in mm, has to be determined according to following formula.

$t = 0.9\,s\sqrt{P_A k} \cdot 10^{-3}$ but not less than $t_{\min}$

where;

$$t_{\min} = (3.5 + \frac{L_2}{100})\sqrt{k}$$

b) The net section modulus of stiffeners, in cm^3, are to be calculated according to following formula. Stiffeners are to be connected on both ends to the structural members supporting them.

$$Z = 0.07\,\frac{s\,\ell_{bdg}^2\,P_A}{R_{eH}}$$

c) For whalebacks with an inclining angle α_w of less than 20 ° the scantlings of plates and stiffeners are to be in accordance with the discretion of the Society.

4.1.6 Primary supporting members

For primary supporting members of the structure, a stress analysis has to be carried out. The permissible equivalent stress, σ_{vm} in $\mathrm{N/mm^2}$, shall not exceed R_Y.

4.1.7 Proof of buckling strength

Structural members' buckling strength has to be proved according to **Ch 8, Sec 5**.

Section 3 Equipment

1. General

1.1 Application

1.1.1

The anchoring equipment are to be in accordance with relevant chapters of **Pt 4** of the **Rules and Guidance for the Classification of Steel Ships**.

Section 4 Supporting Structure for Deck Equipment and Fittings

1. General

1.1 Application

1.1.1

The supporting structure and foundations for deck equipment and fittings are to be in accordance with relevant chapters of **Pt 4** of the **Rules and Guidance for the Classification of Steel Ships**.

1.1.2

Where deck equipment is subject to multiple load cases, such as operational loads and green sea load, the loads are be applied independently for the evaluation of strength of foundations and support structure.

1.2 Documents to be submitted

1.2.1

The documents to be submitted are indicated in **Ch 1, Sec 3**.

2. Anchoring windlass and chain stopper

2.1 General

2.1.1

The windlass is to be efficiently bedded and secured to the deck.

2.1.2

The builder and the windlass manufacturer are to ensured that the foundation is suitable for the safe operation and maintenance of the windlass equipment.

2.1.3

The supporting structure is to be dimensioned to ensure that for each of the load scenarios specified in **[2.1.5]** and **[2.1.6]**, the stresses do not exceed the permissible values given in **[2.1.12]** to **[2.1.15]**.

2.1.4

These requirements are to be assessed based on net scantlings.

2.1.5

The following load cases are to be examined for the anchoring operation, as appropriate:

a) Windlass where chain stoppers are fitted but not attached to the windlass: 45 % of BS.

b) Windlass where no chain stoppers is fitted or the chain stopper is attached to the windlass: 80 % of BS.

c) Chain stopper: 80 % of BS.

where:

BS : Minimum breaking strength of the chain cable.

2.1.6

The following forces are to be applied in the independent load cases that are to be examined for the design loads due to green sea over the forward 0.25 L, see **Figure 1**:

$P_x = 200\,A_x$ acting normal to the shaft axis, in kN

$P_y = 150\,A_y\,f$ acting parallel to the shaft axis, in kN (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 : Coefficient taken as:

$f = 1 + B_w / H$, but not to be taken greater than 2.5.

B_w : Breadth of windlass measured parallel to the shaft axis, in m, see **Figure 1**.

H : Overall height of windlass, in m, see **Figure 1**.

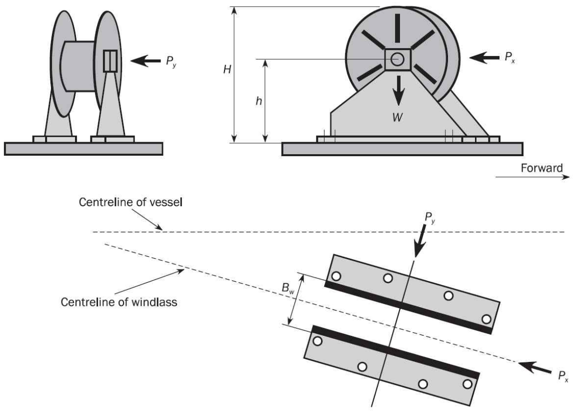


Figure 1 : Directions of forces and weight

2.1.7

Forces resulting from green sea design loads in the bolts, chocks and stoppers securing the windlass to the deck are to be calculated. The windlass is supported by a number of bolt groups, N, each containing one or more bolts. See **Figure 2**.

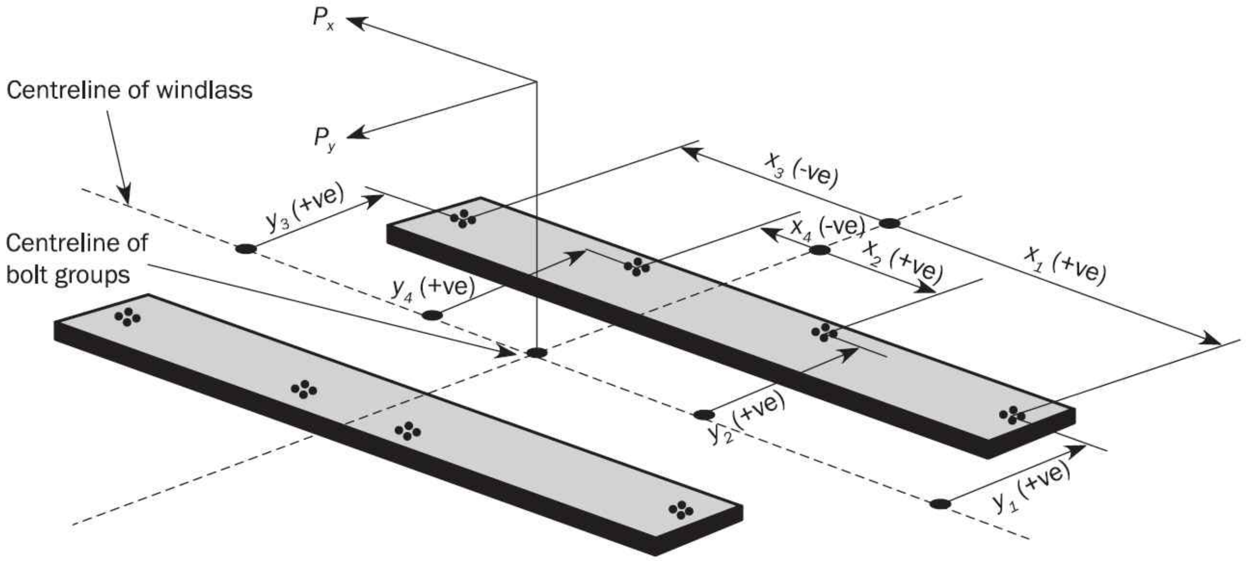


Figure 2 : Bolting arrangements and sign conventions

2.1.8

The axial forces, $R_{x\,i}$ and $R_{y\,i}$, in bolt group (or bolt) i, positive in tension, are given by:

$$R_{x\,i} = P_x\, h\, x_i\, A_i \,/\, I_x$$

$$R_{y\,i} = P_y\, h\, y_i\, A_i \,/\, I_y$$

$$R_i = R_{x\,i} + R_{y\,i} - R_{si}$$

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.

h : Shaft centre height above the windlass mounting, in cm, see **Figure 1.**

x_i, y : 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.

A_i : Cross sectional area of all bolts in group i, in cm^2.

I_x : Inertia in x direction for N bolt groups, in cm^4, taken as:

$$I_x = \sum A_i\, x_i^2$$

I_y : Inertia in y direction for N bolt groups, in cm^4, taken as:

$$I_y = \sum A_i\, y_i^2$$

R_{si} : Static reaction at bolt group i, due to the weight of windlass, in kN.

2.1.9

The shear forces, $F_{x\,i}$ and $F_{y\,i}$, applied to the bolt group i, and the resultant combined force F_i, are given by:

$$F_{x\,i} = (P_x - C_1 m\, g) \,/\, N$$

$$F_{y\,i} = (P_y - C_1 m\, g) \,/\, N$$

$$F_i = \sqrt{F_{x\,i}^{\;2} + F_{y\,i}^{\;2}}$$

where:

C_1 : Coefficient of friction, taken equal to 0.5.

m : Mass of windlass, in t.

g : Acceleration due to gravity, taken equal to 9.81 m/s^2.

N : Number of bolt groups.

2.1.10

The resultant forces from the application of the loads specified in **[2.1.5]** and **[2.1.6]** are to be considered in the design of the supporting structure.

2.1.11

Where a separate foundation is provided for the windlass brake, the distribution of resultant forces is to be calculated on the assumption that the brake is applied for load cases (a) and (b) defined in **[2.1.5]**.

2.1.12

The stresses resulting from anchoring design loads induced in the supporting structure are not to be greater than the following permissible values:

- Normal stress : 1.0 R_{eH}
- Shear stress : 0.6 R_{eH}

2.1.13

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. The load is to be applied in the direction of the chain cable. Where fitted bolts are designed to support shear forces in one or both directions, the von Mises equivalent stresses are not to exceed 50 % of the bolt proof strength.

2.1.14

The horizontal forces resulting from the green sea design loads, F_{xi} and F_{yi} may be supported by shear chocks. Where pourable resins are incorporated in the holding down arrangements, due account is to be taken in the calculation.

2.1.15

The stresses resulting from green sea design loads induced in the supporting structure are not to be greater than the following permissible values:

- Normal stress : 1.0 R_{eH}
- Shear stress : 0.6 R_{eH}

3. DELETED

4. Cranes, derricks, lifting masts and life saving appliances

4.1 General

4.1.1

Supporting structure of life saving appliances and supporting structures of cranes, derricks and lifting masts with a Safe Working Load greater than 30 kN, or a maximum overturning moment to the supporting structure greater than 100 kNm, are to comply with these requirements.

4.1.2

These requirements apply to the connection to the deck and the supporting structure of cranes, derricks and lifting masts. Where the crane, derrick or lifting mast is to be certified by the Society, additional requirements may be applied by the Society.

4.1.3

These requirements do not cover the following items:

a) Supports of lifting appliances for personnel or passengers, except foundation for life saving appliances.
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.

The term ‘lifting appliance’ is defined as a crane, derrick or lifting mast.

4.1.4 SWL definition

The Safe Working Load (SWL) is defined as the maximum load which the lifting appliance is certified to lift at any specified outreach.

4.1.5 Self weight

The self weight is the calculated gross self weight of the lifting appliance, including the weight of any lifting gear.

4.1.6 Overturning moment

The 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.

4.1.7

The crane pedestal and derrick mast are as defined in **Figure 3**.

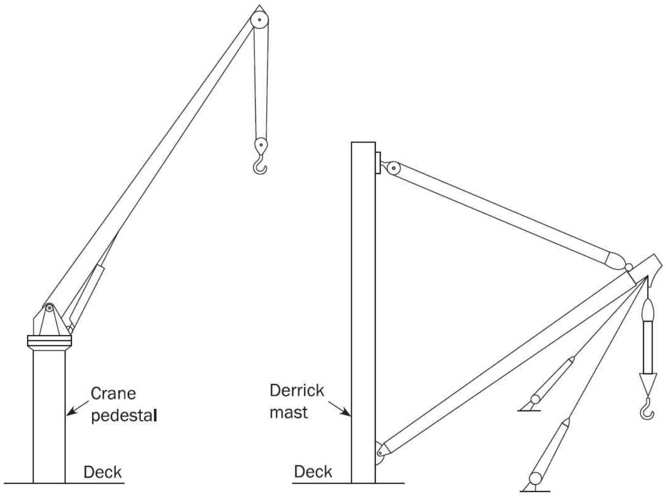


Figure 3 : Crane pedestal and derrick mast

4.1.8

Deck plating and under deck structure is to provide adequate support for derrick masts and crane pedestals against the loads and maximum overturning moment. Where the deck is penetrated, the deck plating is to be suitably strengthened.

4.1.9

Structural continuity of the deck structure is to be maintained.

Under deck members are to be provided to support the crane pedestal and to comply with:

a) Where the pedestal is directly connected to the deck, without above deck brackets, adequate under deck structure directly in line with the crane pedestal is to be provided. Where the crane pedestal is attached to the deck without bracketing or where the 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 suitable full penetration welding. The design of the weld connection is to be adequate for the calculated stress in the welded connection, in accordance with **[4.1.15]**.

b) Where the pedestal is directly connected to the deck with brackets, under deck support structure is to be fitted to ensure a satisfactory transmission of the load, 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 an abrupt 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. The design of the connection is to be adequate for the calculated stress, in accordance with **[4.1.15]**.

4.1.10

Deck plating are to be of a material strength compatible with the crane pedestal. Where necessary, a thicker insert plate is to be fitted. In no case are doublers to be used where structures are subject to tension.

4.1.11

The supporting structure is to be dimensioned to ensure that for the load cases specified in **[4.1.13]** and **[4.1.14]**, the stresses do not exceed those given in **[4.1.15]**.

The capability of the supporting structure to resist buckling failure is to be assured.

4.1.12

These requirements are to be assessed based on gross scantlings.

4.1.13

For lifting appliances which are limited to use in harbour, design load is to be taken equal to 1.3 times SWL added to the lifting appliances self weight.

4.1.14

For life saving appliances, design load is to be taken as 2.2 times SWL.

4.1.15

The stresses induced in the supporting structure are not to exceed the following permissible values:

- Normal stress : 0.67 R_{eH}
- Shear stress : 0.39 R_{eH}

5. DELETED

6. Miscellaneous deck fittings

6.1 Support and attachment

6.1.1

The following requirements are to be considered in the design of the support and attachment of miscellaneous fittings which impose relatively small loads on the ship's structure. The arrangement of such details and their approval is considered on a case-by-case basis by the Society.

6.1.2

Support positions are to be arranged so that the attachment to the ship structure is clear of deck openings and stress concentrations, such as the toes of end brackets. Design of supports is to be such that the attachment to the deck minimises the creation of hard points.

Section 5 Hatchways

1. General

1.1 Application

1.1.1

The hatchways are to be in accordance with relevant chapters of **Pt 4** of the **Rules and Guidance for the Classification of Steel Ships.** ⚓

Chapter 12

Construction

Section 1 Construction and Fabrication

1. General

1.1 Workmanship

1.1.1

All workmanship is to be of commercial marine quality and acceptable to the surveyor. Welding is to be in accordance with the requirements of **Ch 12, Sec 2.** Any defect is to be rectified to the satisfaction of the surveyor before the material is covered with paint, cement or any other composition.

1.2 Fabrication standard

1.2.1

Structural fabrication is to be carried out in accordance with **IACS Recommendation No. 47** or with a recognised fabrication standard which has been accepted by the Society prior to the commencement of fabrication/construction.

1.2.2

The fabrication standard to be used during fabrication / construction is to be made available to the attending representative of the Society prior to the commencement of the fabrication / construction.

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) Cut edges: the slope of the cut edge and the roughness of the cut edges.
b) Flanged stiffeners 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 flat bar stiffeners: the distortion at the free edge line of tripping brackets and flat bar stiffeners.
e) Sub-assembly stiffeners: details of sniped end of face plates and webs.
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, breadth and length of top plate of main engine bed. Where boring out of the propeller boss and stern frame, skeg or solepiece are to be carried out after completing the major part of the welding of the aft part of the ship. Where block boring is used, the shaft alignment is to be carried out using a method and sequence submitted to and recognised by the Society. The fit-up and alignment of the rudder, pintles and axles are to be carried out after completing the major parts 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 profiles, 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: 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, deckhouse 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 of frames.

2. Cut-Outs, Plate Edges

2.1 General

2.1.1

The free edges (cut surfaces) of cut-outs, hatch corners, etc are to be properly prepared and are to be free from notches. As a general rule, cutting draglines, etc are to be smoothly ground. All edges are to be broken or in cases of highly stressed parts, be rounded off.

Free edges on flame or machine cut plates or flanges are not to be sharp cornered and are to be finished off as specified above. This also applies to cutting drag lines, etc, in particular to the upper edge of sheer strake and analogously to weld joints, changes in sectional areas or similar discontinuities.

2.1.2

Corners in hatch opening are to be machine cut.

3. Cold Forming

3.1 Special structural members

3.1.1

For highly stressed components of the hull girder where notch toughness is of particular concern (e.g. items required to be Class III in **Ch 3, Sec 1, Table 3**, such as radius gunwales (bent sheer plates) and bilge strakes), the inside bending radius, in cold formed plating, is not to be less than 10 times the as-built plate thickness for carbon-manganese steels (see **Ch 3, Sec 1**). The allowable inside bending radius may be reduced provided the requirements stated in **[3.3]** are complied with.

3.2 Corrugated bulkheads

3.2.1

For corrugated bulkheads the inside bending radius, in cold formed plating, is not to be less than 4.5 times the as-built plate thickness for carbon-manganese steels (see **Ch 3**, **Sec 1**). The allowable inside bending radius may be reduced provided the requirements stated in **[3.3]** are complied with.

3.3 Low bending radius

3.3.1

When the inside bending radius is reduced below 10 times or 4.5 times the as-built plate thickness according to **[3.1]** and **[3.2]** respectively, supporting data is to be provided. The bending radius is in no case to be less than 2 times the as-built plate thickness. As a minimum, the following additional requirements are to be complied with:

a) For all bent plates:
  - 100 % visual inspection of the bent area is to be carried out.
  - Random checks by magnetic particle testing are to be carried out.

b) In addition to a), for bent plates at boundaries to tanks:
  - The steel is to be of Grade D / DH or higher.
  - The material is impact tested in the strain-aged condition and satisfies the requirements stated herein. The deformation is to be equal to the maximum deformation to be applied during production, calculated by the formula $t_{as-built}/(2r_{bdg}+t_{as-built})$, where $t_{as-built}$ is the as-built 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 at 250°C for one hour then subject to Charpy V-notch testing. The average impact energy after strain ageing is to meet the impact requirements specified for the grade of steel used.

4. Hot Forming

4.1 Temperature requirements

4.1.1

Steel is not to be formed between the upper and lower critical temperatures. If the forming temperature exceeds 650°C for as-rolled, controlled rolled, thermo-mechanical controlled rolled or normalised steels, or is not at least 28°C lower than the tempering temperature for quenched and tempered steels, mechanical tests are to be made to assure that these temperatures have not adversely affected both the tensile and impact properties of the steel. Where curve forming or fairing, by line or spot heating, is carried out in accordance with **[4.2.1]** these mechanical tests are not required.

4.1.2

After further heating, other than specified in **[4.1.1]**, of Thermo-Mechanically Controlled Steels (TMCP plates) for forming and stress relieving, it is to be demonstrated that the mechanical properties meet the requirements specified by a procedure test using representative material.

4.2 Line or spot heating

4.2.1

Curve forming or fairing, by linear or spot heating, is to be carried out using approved procedures in order to ensure that the properties of the material are not adversely affected. Heating temperature on the surface is to be controlled so as not to exceed the maximum allowable limit applicable to the plate grade.

5. Assembly and Alignment

5.1 General

5.1.1

The use of excessive force is to be avoided during the assembly of individual structural components or during the erection of sections. Major distortions of individual structural components are to be corrected before further assembly.

After completion of welding, straightening and aligning are to be carried out in such a manner that the material properties are not influenced significantly. In case of doubt, the Society may require a procedure test or a working test to be carried out.

5.1.2

Structural members are to be aligned following the provisions of **IACS Recommendation No. 47, Table 7** or according to the requirements of a recognised fabrication standard that has been accepted by the Society. In the case of critical components, control drillings are to be made where necessary, which are then to be welded up again on completion.

Section 2 Fabrication by Welding

1. General

1.1 Application

1.1.1

The requirements of this section apply to the preparation, execution and inspection of welded connections in hull structures.

1.2 Limits of application to welding procedures

1.2.1 Weld type, size and materials

The requirements of this section for weld type, size and materials are based on the following considerations:

- Joint type.
- Criticality of the joint.
- Magnitude, type and direction of the stresses in the joint.
- Material properties of the parent and weld material.
- Weld gap size.

1.2.2 Preparation, execution and inspection

The requirements of this section are to be complemented by the general requirements relevant to fabrication by welding and qualification of welding procedures given by the Society when deemed appropriate by the Society.

2. Welding Procedures, Welding Consumables and Welders

2.1 General

2.1.1

All welding is to be carried out by approved welders, in accordance with approved welding procedures, using approved welding consumables, in compliance with **Pt 2.**

Personnel manning automatic welding machines and equipment are to be competent, sufficiently trained and certified by the Society as specified in **Pt 2.**

3. Weld Joints

3.1 General

3.1.1

Welding of connections is to be executed according to the approved plans.

3.1.2

The quality standard adopted by the shipyard is to be submitted to the Society and it applies to all welded connections unless otherwise specified on a case-by-case basis.

3.1.3

Consideration is to be given to the assembly sequence and the effect of the overall shrinkage of plate panels, assemblies, etc, resulting from the welding processes employed. Welding is to proceed systematically, with each welded joint being completed in correct sequence, without undue interruption. When practicable, welding is to commence at the centre of a joint and proceed outwards, or at the centre of assembly and progress outwards towards the perimeter so that each part has freedom to move in one or more directions.

3.1.4

Completed welded joints are to be to the satisfaction of the attending surveyor. Edge preparations and root gaps are to be in accordance with the approved welding procedure. The gap between the members being joined should not exceed the maximum values given in **IACS Recommendation No. 47** or as specified in recognised fabrication standard approved by the Society. Where the gap between members being joined exceeds the specified values, corrective measures are to be taken in accordance with an approved welding procedure specification.

3.1.5

Where small fillets are used to attach heavy plates or sections, welding is to be based on approved welding procedure specifications. Special precautions, such as the use of preheating, low-hydrogen electrodes or low hydrogen welding processes, are accepted.

3.1.6

When heavy structural members are attached to relatively light plating, the weld size and sequence may require modification.

3.1.7

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 minimum specified in **Sec 3, [2.5.2]** and the size of the weld may be determined based on the yield strength of the higher grade welding consumable.

3.1.8

In general, butt joints are to be welded from both sides. Before welding is carried out on the second side, unsound 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.

3.1.9 Arrangements at junctions of welds

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 of stiffening members are to be completed and made flush with the stiffening member before the fillet weld is made. The ends of the flush portion are to run out smoothly without notches or sudden changes of section. Where these conditions can not be complied with, a scallop is to be arranged in the web of the stiffening member. Scallops are to be of the size, and in a position, that a satisfactory return weld can be made.

3.1.10 Leak stoppers

Where structural members pass through the boundary of a tank, leakage into adjacent space could be hazardous or undesirable, and full penetration welding is to be adopted for the members for at least 150 mm on each side of the boundary. Alternatively, a small scallop of suitable shape may be cut in a member close to the boundary outside of the compartment, and carefully welded all around.

4. Non-Destructive Examination(NDE)

4.1 General

4.1.1

The NDE plan to be submitted for approval has to contain the necessary data relevant to the locations and number of examinations, welding procedures applied, method of NDE applied, etc. Visual inspection of finished welds is to be carried out by the shipyard to ensure that all welding has been satisfactory completed. In addition to visual inspection, welded joints are to be examined using any one or a combination of ultrasonic, radiographic, magnetic particle, eddy current, dye penetrant or other acceptable methods appropriate to the configuration of the weld. Above inspections are to be carried out as per the requirements of the Society.

4.1.2

NDE of welding is to be carried out at the positions indicated by the NDE plan in order to ensure that the welds are free from cracks and unacceptable internal defects with regards to the requirements of the Society. NDE is to be carried out by qualified personnel certified by recognised bodies in compliance with recognised standards.

4.2 Hatch coaming

4.2.1

When NDE during construction is to be carried out, NDE is to follow **Sec 4, [2]**.

4.2.2

When periodic NDE after delivery is to be carried out, periodic NDE is to be follow **Sec 4, [3]**.

Section 3 Design of Weld Joints

Symbols

A_{weld} : Effective fillet weld area, in cm^2.

f : Root face, in mm.

f_{weld} : Weld factor.

f_{yd} : Correction factor taking into account the yield strength of the weld deposit as defined in **[2.5.2]**.

ℓ_{dep} : Total length of deposit of weld metal, in mm.

ℓ_{leg} : Leg length of continuous, lapped or intermittent fillet weld, in mm.

ℓ_{weld} : Length of the welded connection in mm.

$R_{eH-weld}$: Minimum yield stress of weld deposit, in $\mathrm{N/mm}^2$.

$t_{as-built}$: As-built thickness of the member being joined, in mm.

t_{gap} : Allowance for fillet weld gap, is to be taken equal to 2.0 mm.

t_{throat} : Throat thickness of fillet weld in mm, as defined in **[2.5.3]**.

1. General

1.1 Application

1.1.1

The requirements of this section apply to the design of welded connections in hull structures and are based on the considerations mentioned in **Sec 2, [1.2.1]**.

1.1.2

Plans and/or specifications showing weld sizes and weld details are to be submitted for approval.

1.1.3

The leg length of welds is to comply with the minimum leg length given in **Table 1.**

1.2 Alternatives

1.2.1

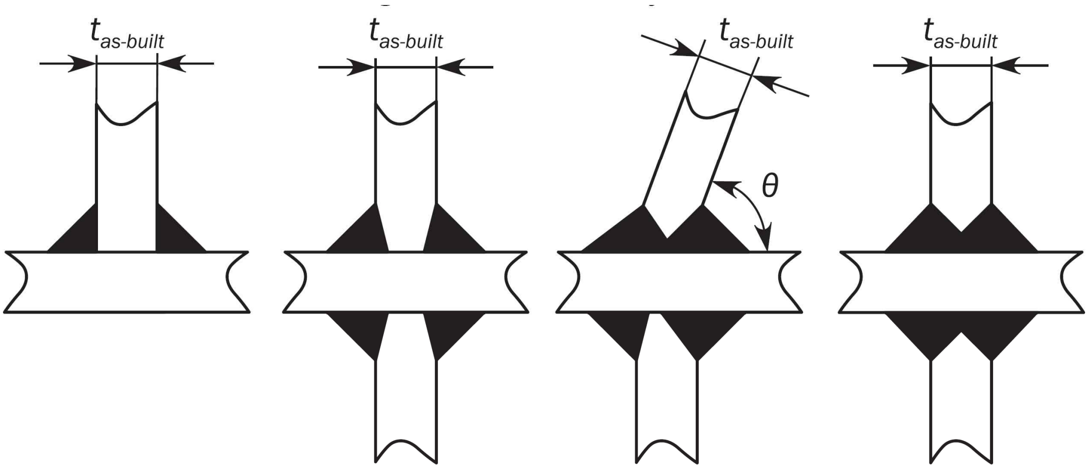
The requirements given in this section are considered minimum for electric-arc welding in hull construction, but alternative methods, arrangements and details will be specially considered for approval.

2. Tee or Cross Joint

2.1 Application

2.1.1

The connection of primary supporting members, stiffener webs to plating as well as the plating abutting on another plating, are to be made by fillet or penetration welding, as shown on **Figure 1.**



$t_{as-built}$: As-built thickness of the member being attached, mm.

θ : Connecting angle, in $\deg$.

Figure 1 : Tee or cross joints

2.1.2

Where the connection is highly stressed or otherwise considered critical, a partial or full penetration weld is to be achieved by bevelling the edge of the abutting plate.

2.2 Continuous fillet welds

2.2.1

Continuous welding is to be adopted in the following locations:

a) Connection of the web to the face plate for all members.
b) All fillet welds where higher strength steel is used.
c) Boundaries of weathertight decks and erections, including hatch coamings, companionways and other openings.
d) Boundaries of tanks and watertight compartments.
e) All structures inside tanks and cargo holds.
f) Stiffeners and primary supporting members at tank boundaries.
g) All structures in the aft peak and stiffeners and primary supporting members of the aft peak bulkhead.
h) All structures in the fore peak.
i) Welding in way of all end connections of stiffeners and primary supporting members, including end brackets, lugs, scallops, and at orthogonal connections with other members.
j) All lap welds in the main hull.
k) Primary supporting members and stiffener members to bottom shell in the 0.3 L forward region.
l) Flat bar longitudinals to plating.
m) The attachment of minor fittings to higher strength steel plating and other connections or attachments.
n) Pillars to heads and heels.
o) Hatch coaming stay webs to deck plating, see **[2.4.5]**.

2.3 Intermittent fillet welds

2.3.1

Where continuous welding is not required, intermittent welding may be applied.

2.3.2

Where beams, stiffeners, frames, etc, are intermittently welded and pass through slotted girders, shelves or stringers, there is to be a pair of matched intermittent welds on each side of every intersection. In addition, the beams, stiffeners and frames are to be efficiently attached to the girders, shelves and stringers.

Where intermittent welding or one side continuous welding is permitted, double continuous welds are to be applied for one-tenth of their shear span at each end, in accordance with **[2.5.2]** and **[2.5.3].**

2.3.3 Deckhouses

One side continuous fillet welding is acceptable in the dry spaces of deckhouses.

2.3.4 Size for one side continuous weld

The size for one side continuous weld is to be of fillet required by **[2.5.2]** for intermittent welding, where f_3 factor is to be taken as 2.0.

2.4 Partial or full penetration welds

2.4.1 High stress area definition

For the application of this section, high stress area means an area where fine mesh finite element analysis is to be carried out and the fine mesh yield utilisation factor in elements adjacent to the weld is more than 90% of the fine mesh permissible utilisation factor, as defined in **Ch 7, Sec 3, [6.2].**

2.4.2 Partial or full penetration welding

In areas with high tensile stresses or areas considered critical, full or partial penetration welds are to be used. In case of full penetration welding, the root face is to be removed, e.g. by gouging before welding of the back side. For partial penetration welds the root face, f, is, to be taken between 3.0 mm and $t_{as-built}/3$.

The groove angle α made to ensure welding bead penetrating up to the root of the groove is usually from 40 ° to 60 °.

The welding bead of the full / partial penetration welds is to cover root of the groove.

Examples of partial penetration welds are given on **Figure 2.** The weld size of partial penetration for extremely thick steel is to satisfy the following equation.

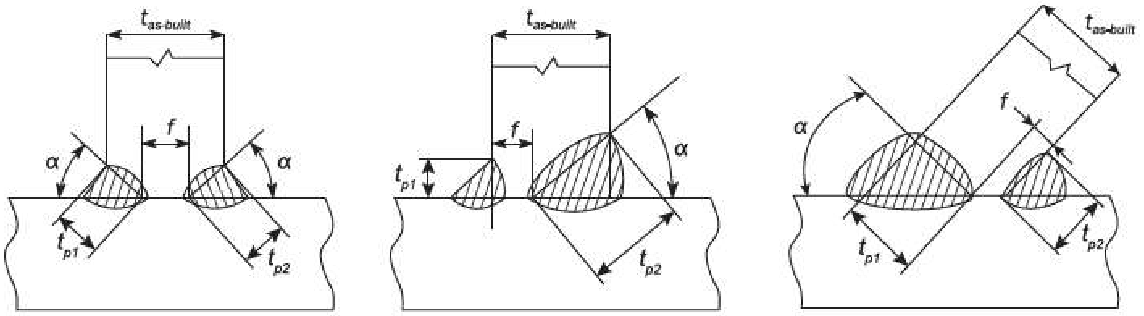


Figure 2 : Partial penetration welds

$t_{p1}+t_{p2} \geq 2(f_{yd} \cdot f_c \cdot f_{ten} \cdot t_{as-built}+t_{gap})$

t_{p1}, t_{p2} : The weld size in **Figure 2**

f_c : Position coefficient, which is 1.1 for ballast tank and bilge well and 1.0 for elsewhere

f_{ten} : welding factor

$$f_{ten}=0.22+0.66\,f\,/\,t_{as-built}$$

2.4.3 One side partial penetration weld

For partial penetration welds with one side bevelling the fillet weld at the opposite side of the bevel is to satisfy the requirements given in **[2.5.2]**.

2.4.4 Extent of full or partial penetration welding

The extent of full or partial penetration welding in each particular location listed in **[2.4.5]** and **[2.4.6]** is to be approved by the Society. However, the minimum extent of full / partial penetration welding from the reference point (i.e. intersection point of structural members, end of bracket toe, etc.) is not to be taken less than 300 mm, unless otherwise specifically stated.

2.4.5 Locations required for full penetration welding

Full penetration welds are to be used in the following locations and elsewhere as required by the rules :

a) Radiused hatch coaming plate at corners to deck.
b) Connection of vertical corrugated bulkhead to the inner bottom plate within the cargo hold region, when the vertical corrugated bulkhead is arranged without a lower stool.
c) Connection of structural elements in the double bottom in line with corrugated bulkhead flanges to the inner bottom plate, when the vertical corrugated bulkhead is arranged without a lower stool.
d) Connection of vertical corrugated bulkhead to top plating of lower stool.
e) Corrugated bulkhead lower stool side plating to lower stool top plate.
f) Corrugated bulkhead lower stool side plating to inner bottom.
g) Edge reinforcement or pipe penetration both to strength deck, sheer strake and bottom plating within 0.6 L amidships, when the dimensions of the opening exceeds 300 mm.
h) Abutting plate panels with as-built thickness less than or equal to 12.0 mm, forming outer shell boundaries below the scantling draught, including but not limited to: sea chests, rudder trunks, and portions of transom.
i) Crane pedestals and associated bracketing and support structure.
j) For toe connections of longitudinal hatch coaming end bracket to the deck plating, full penetration weld for a distance of 0.15 H_c from toe of side coaming termination bracket is required, where H_c is the hatch coaming height.
k) Rudder horns and shaft brackets to shell structure.

2.4.6 Locations required for partial penetration welding

Partial penetration welding as defined in **[2.4.2]**, is to be used in the following locations.

a) Abutting plate panels with as-built thickness greater than 12mm, forming outer shell boundaries below the scantling draught, including but not limited to : sea chests, rudder trunks, and portions of transom.

2.4.7 Fine mesh finite element analysis

In high stress area, at least partial penetration welds as defined in **[2.4.2]** are to be used. The minimum extent of full or partial penetration welding in that case is to be the greater of the following:

a) 150 mm in either direction from the element with the highest yield utilisation factor.
b) The extent covering all elements that exceed the above mentioned yield utilisation factor criteria.

2.5 Weld size criteria

2.5.1

The required weld sizes are to be rounded to the nearest half millimetre.

2.5.2

The leg length, ℓ_{leg} in mm, of continuous, lapped or intermittent fillet welds is not to be taken less than the greater of the following values:

$\ell_{leg} = f_1 f_2 t_w$

$\ell_{leg} = f_{yd} f_{weld} f_2 f_3 t_w + t_{gap}$

ℓ_{leg} as given in **Table 1.**

where:

t_w : Effective thickness of abutting plate in mm

$t_w = t_{as-built}$ for $t_{as-built} \le 25.0$ mm

$t_w = 0.5(25 + t_{as-built})$ for $t_{as-built} > 25.0$ mm

$t_w = 25 + 0.25(t_{as-built} - 25)$ for longitudinals of flat-bar type with $t_{as-built} > 25.0$ mm

f_1 : Coefficient depending on welding type:

f_1 = 0.30 for double continuous welding.

f_1 = 0.38 for intermittent welding.

f_2 : Coefficient depending on the edge preparation:

f_2 = 1.0 for welds without bevelling.

f_2 = 0.70 for welds with one / both side bevelling and $f = t_{as-built}/3$.

f_{yd} : Coefficient not to be taken less than the following:

$$f_{yd} = \left(\frac{1}{k}\right)^{0.5}\left(\frac{235}{R_{eH-weld}}\right)^{0.75}$$

$f_{yd} = 0.71$

$R_{eH-weld}$: Specified minimum yield stress for the weld deposit in N/mm^2, not to be less than:

$R_{eH-weld}$ = 305 N/mm^2 for welding of normal strength steel with R_{eH} = 235 N/mm^2

$R_{eH-weld}$ = 375 N/mm^2 for welding of higher strength steels with R_{eH} from 265 to 355 N/mm^2

$R_{eH-weld}$ = 400 N/mm^2 for welding of higher strength steel with R_{eH} = 390 N/mm^2

$R_{eH-weld}$ = 460 N/mm^2 for welding of higher strength steel with R_{eH} = 460 N/mm^2

f_{weld} : Weld factor dependent on the type of the structural member, see **Table 2, Table 3** and **Table 4.**

k : Material factor of the abutting member.

f_3 : Correction factor for the type of weld:

f_3 = 1.0 for double continuous weld.

$f_3 = s_{ctr}/\ell_{weld}$ for intermittent or chain welding.

s_{ctr} : Distance between successive fillet welds, in mm

2.5.3

The throat size t_{throat}, in mm, as shown in **Figure 3,** is not to be less than:

$$t_{throat} = \frac{\ell_{leg}}{\sqrt{2}}$$

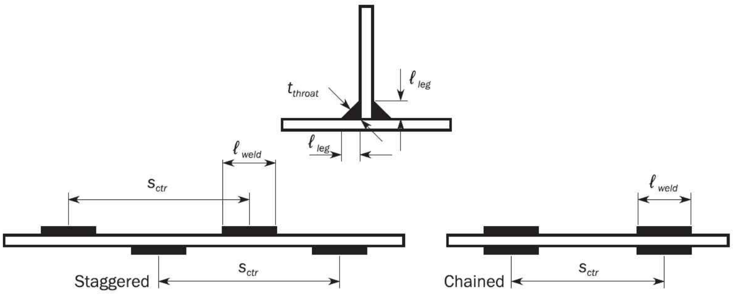


Figure 3 : Weld scantlings definitions

Table 1 : Minimum leg size

Area	Minimum length, in mm
Cargo hold region	4.5
Superstructures and deckhouses	3.5
Other areas	4.5

Table 2 : Weld factors for different structural members

Connection			f_{weld}
Stiffeners in general	At ends (15% of span) on deep tank bulkheads, brackets at ends		0.30
	Other span		0.20
PSM(1) in general	At ends (15% of span), brackets at ends		0.38
	Other span		0.24
	Connection between stiffeners and PSMs, **Figure 4 (a)**		0.30
Watertight boundary	Deep tank, **Figure 4 (b)**		0.48
	Watertight compartments, **Figure 4 (b)**		0.38
Deck	Strength deck,	Within $0.6L$ midship, **Figure 4 (a)**	PPW(3)
		Elsewhere, **Figure 4 (a)**	0.48
	Other deck		0.30
	Hatch coaming(2)	End of hatch corner curvature radius(R.E.) + 100 mm, **Figure 5**	PPW(3)
		Transverse hatch coaming 15% of hatch coaming height(5), **Figure 5**	PPW(3) or 0.38
		Elsewhere	PPW(4) or 0.38
Side and bottom structure in double hull	Girder(1)	At ends(6) (15% of span), **Figure 4 (a)**	0.38
		Center girder	0.30
		Other girders	0.24
	Floor, Stringer, Web frame(1)	At ends(6) (15% of span), **Figure 4 (a)**	0.38
		Other span, **Figure 4 (a)**	0.24
Machinery space	Center girder	To keel and inner bottom	0.38
	Floor	To center girder	0.38
Fore and Aft part	Above waterline		0.20
	Below waterline		0.30
Superstructure, Deckhouse excluding watertight boundary			0.20
Not specified in the table			0.38

(1) Weld factor may be determined based on the shear stress according to **[2.5.7]**

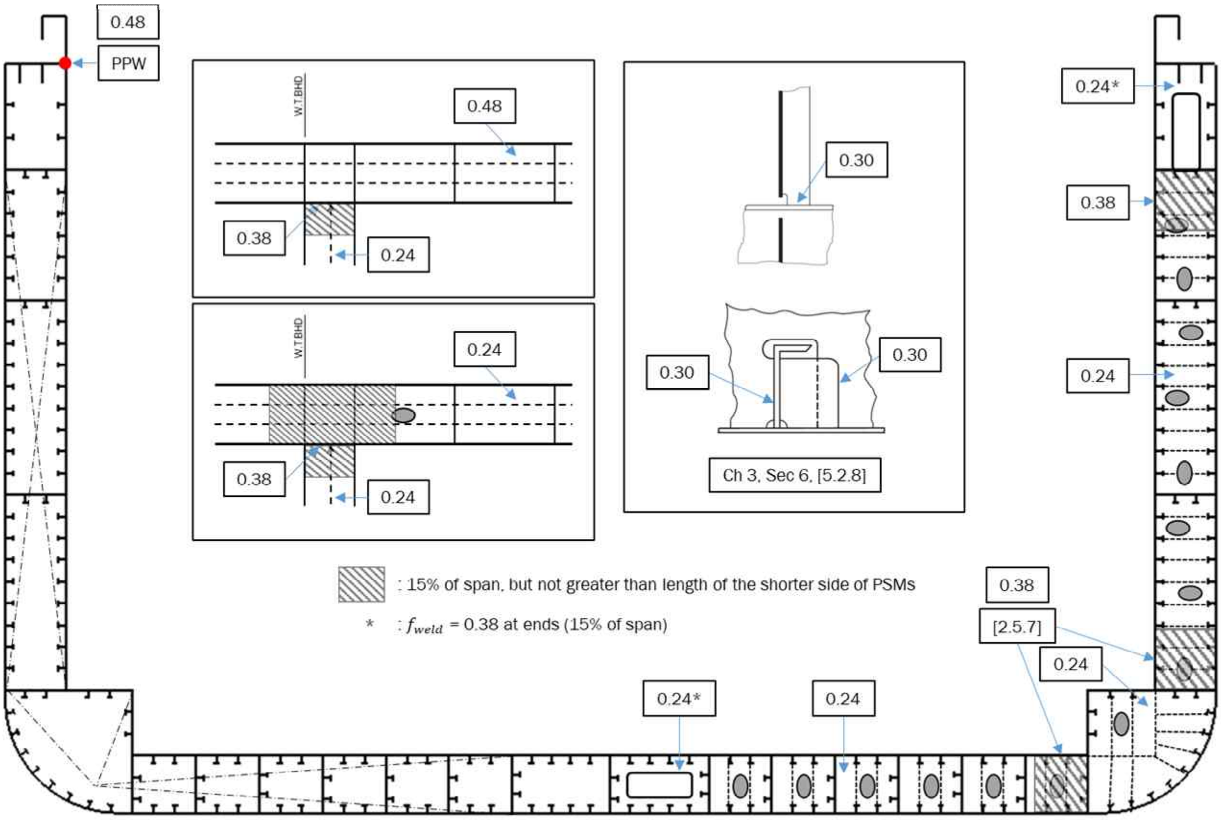
(2) f_{weld} = 0.43 for hatch coaming other than in cargo holds.

(3) PPW : Partial penetration welding in accordance with **[2.4.2]**.

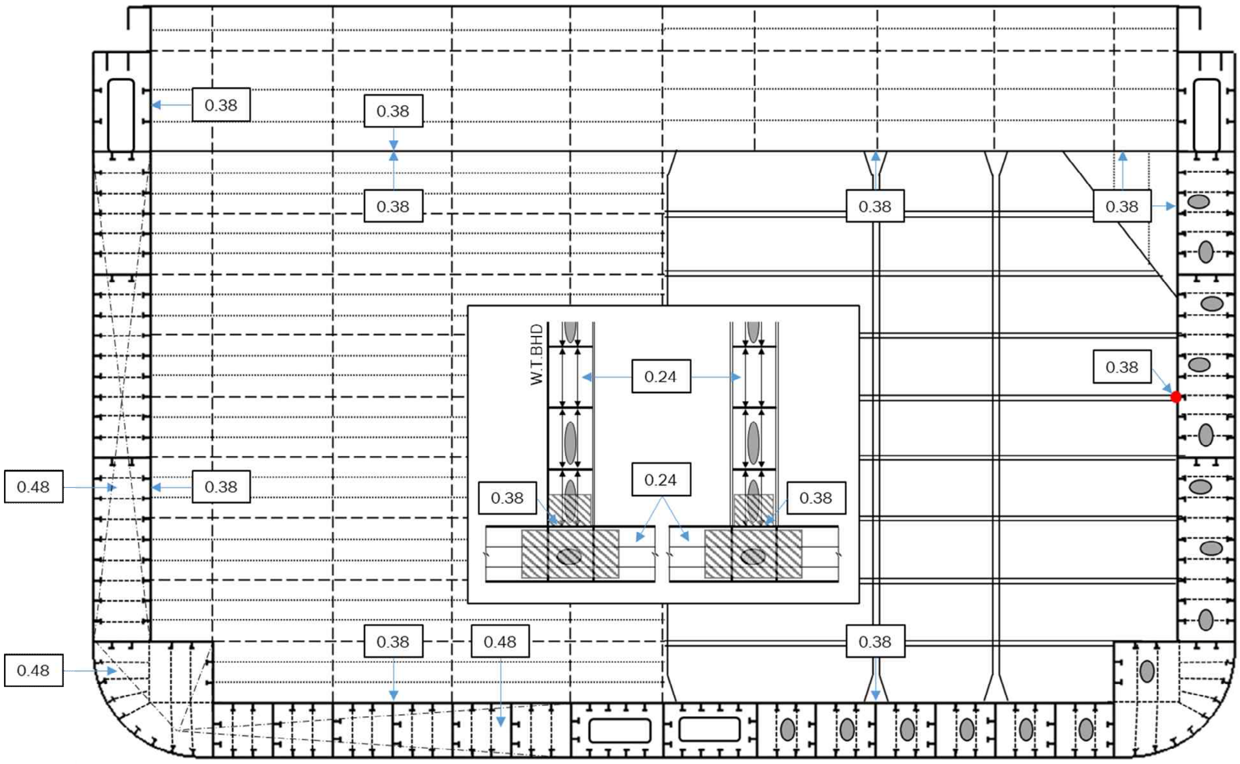
(4) PPW : Partial penetration welding in accordance with **[2.4.2]**, with $f = t_{as-built}/2$

(5) Need not to be taken greater than 250 mm

(6) Need not to be taken greater than length of the shorter side of PSMs

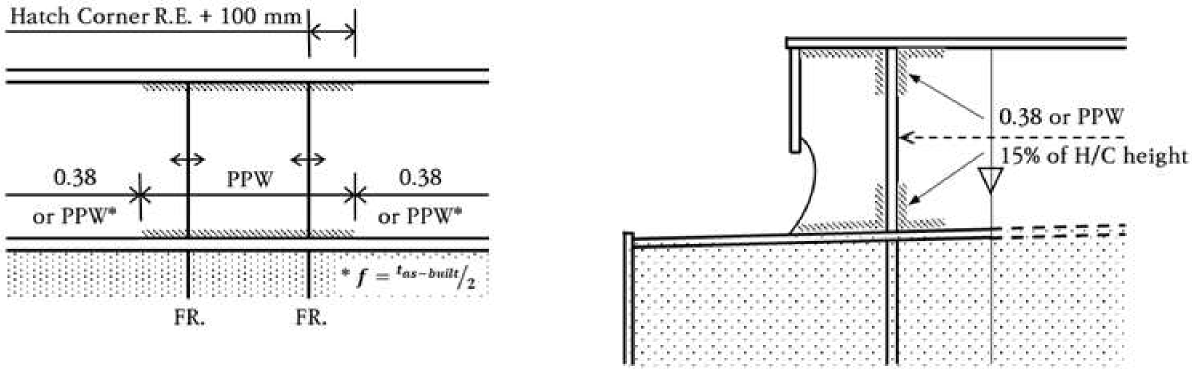


(a) Ordinary and Typical web section



(b) Watertight and Support bulkhead

Figure 4 : Welding of structural members



(a) Longitudinal (b) Transverse

Figure 5 : Welding of hatch coaming

Table 3 : Weld factors for miscellaneous fittings and equipment

Item		Connection to	f_{weld}
Hatch cover	Primary supporting members	At ends(15% of span) of PSM	0.48
		Elsewhere	0.24
	Stiffeners	At ends	0.38
		Elsewhere	0.24
Mast, derrick post, crane pedestal, etc.		Deck / Underdeck reinforced structure	0.43
Deck machinery seat		Deck	0.24
Mooring equipment seat		Deck	0.43
Ring for access hole type cover		Anywhere	0.43
Stiffening of side shell doors and weathertight doors		Anywhere	0.24
Frames of shell and weathertight doors		Anywhere	0.43
Coaming of ventilator and air pipe		Deck	0.43
Ventilators, etc., fittings		Anywhere	0.24
Scupper and discharge		Deck	0.55
Bulwark stay		Deck	0.24
Bulwark plating		Deck	0.43
Guard rail, stanchion		Deck	0.43
Cell guide backing bracket		Bulkhead	0.24
Cone bracket		Deck and Girders	0.43
Lashing bridge, Container stanchion		Deck	PPW(1)
Cleats and fittings		Hatch coaming and hatch cover	0.24(2)

(1) PPW : Partial penetration welding in accordance with **[2.4.2]**.

(2) Minimum weld factor. Where $t_{as-built} > 11.5\text{mm}$, ℓ_{leg} need not exceed $0.62t_{as-built}$. Penetration welding may be required depending on design.

2.5.4 Void

2.5.5

Where the effective thickness of the abutting longitudinal stiffener web, t_w is greater than 15.0 mm and exceeds the thickness of the attached plating, the welding is to be double continuous and the leg length of the weld is not to be less than the largest of the following:

a) 0.30 $t_{as-built}$, where $t_{as-built}$ is the as-built thickness of the attached plating without being taken greater than 30.0 mm.

b) 0.27 $t_{as-built}+1$, where $t_{as-built}$ is the as-built thickness of the abutting member. The leg size resulting of this formula needs not to be taken greater than 8.0 mm.

c) Leg length given in the **Table 1.**

2.5.6

Where the minimum weld size is determined by the requirements of second formula shown in **[2.5.2]**, 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 width of the cut-out exceeds 15 % of the stiffener spacing, the size of weld leg length is to be multiplied by:

$$\frac{0.85\,s}{\ell_w}$$

where:

s : Stiffener spacing, in mm, as shown in **Figure 6.**

ℓ_w : Length of web plating between notches, in mm, as shown in **Figure 6.**

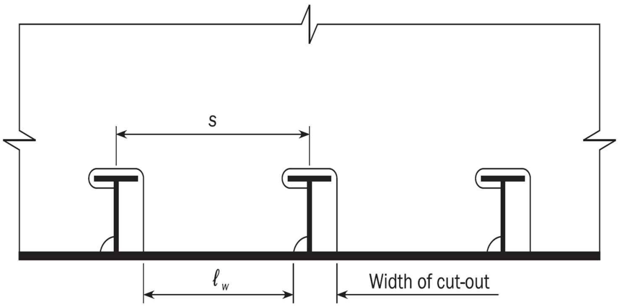


Figure 6 : Effective material in web cut-outs for stiffeners

2.5.7 Shear area of primary supporting member end connections

Welding of the end connections, inclusive 10 % of shear span, of primary supporting members is to be such that the weld area is to be equivalent to the gross cross sectional area of the member. The weld leg length in mm, ℓ_{leg}, is to be taken as:

$$\ell_{leg} = 1.41\, f_{yd} \frac{h_w\, t_{gr-req}}{\ell_{dep}}$$

where:

h_w : Web height of primary supporting members, in mm.

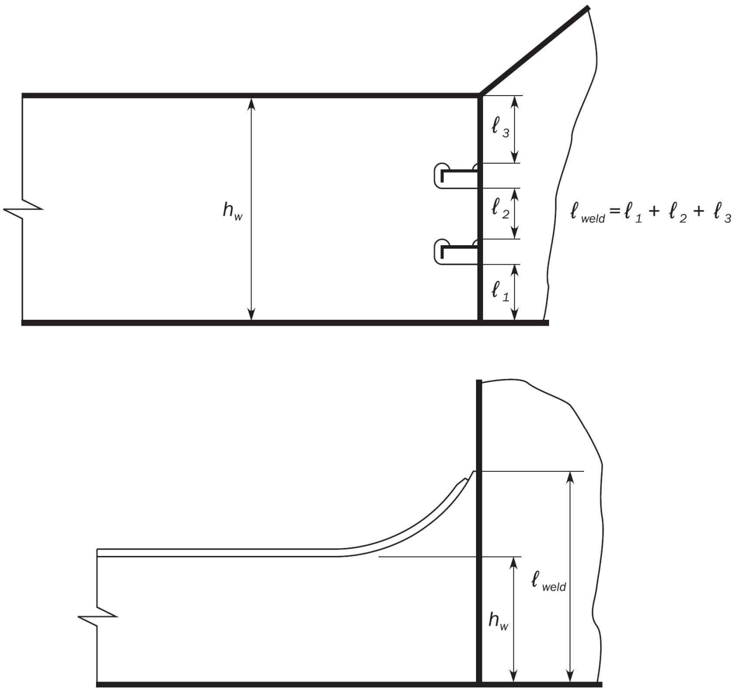
t_{gr-req} : Required gross thickness of the web in way of the end connection, including 10 % of shear span, based on the highest average usage factor for yield from cargo hold FE analysis or the shear area requirement for PSM outside cargo hold region, in mm.

ℓ_{weld} : Length of the welded connection in mm, as shown in **Figure 7.**

ℓ_{dep} : Total length of deposit of weld metal, in mm, see **Figure 7** taken as:

$$\ell_{dep} = 2\, \ell_{weld}$$

The size of weld is not to be less than the value calculated in accordance with **[2.5.2].**



Note 1: The length ℓ_{weld} is the length of the welded connection. The total length of the weld deposit ℓ_{dep} if welded with double continuous fillet welds is twice the length of the welded connection ℓ_{weld}.

Figure 7 : Shear area of primary supporting member

2.5.8 Longitudinals

Welding of longitudinals to plating is to be doubled continuous at the ends of the longitudinals at the extent of 15 % of shear span as defined in **Ch 3, Sec 6, [1.1.3].**

In way of primary supporting members, the length of the double continuous weld is to be equal to the depth of the longitudinal or the end bracket, whichever is greater.

2.5.9 Deck longitudinals

For deck longitudinals, a matched pair of welds is required at the intersection of longitudinals with primary supporting members.

2.5.10 Longitudinal continuity provided by brackets

Where a longitudinal strength member is to cut at a primary supporting structure and the continuity of strength is provided by brackets, the weld area A_{weld} is not to be less than the gross cross sectional area of the member. The weld area, A_{weld} in cm^2, is to be determined by the following formula:

$$A_{weld} = \frac{f_{yd}\, t_{throat}\, \ell_{dep}}{100}$$

2.5.11 Reduced weld size

Where an approved automatic deep penetration procedure is used and quality control facilitates are working to a gap between members of 1.0 mm and less, the weld factors given in **Table 2** may be reduced by 15 % but not more than fillet weld leg size of 1.5 mm. Reductions of up to 20 %, but not more than the fillet weld leg size of 1.5 mm, 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.

2.5.12 Reduced weld size justification

Where any of the methods for reduction of the weld size are adopted, the specific requirements giving justification for the reduction are to be indicated on the drawings. The drawings are to document the weld design and dimensioning requirements for the reduced weld length and the required weld leg length given by **[2.5.2]** without the 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.

3. Butt Joint

3.1 General

3.1.1

Joints in the plate components of stiffened panel structures are generally to be joined by butt welds, see **Figure 8.**

3.2 Thickness difference

3.2.1 Taper

In the case of welding of plates with difference in as-built thickness greater than 4.0 mm, the thicker plate is normally to be tapered. The taper has to have a length of not less than 3 times the difference in as-built thickness.

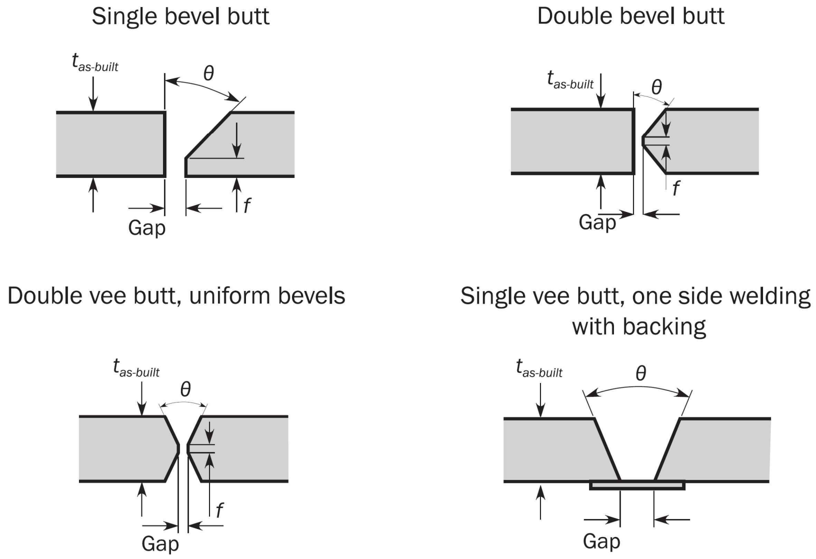


Figure 8 : Typical butt welds

4. Other Types of Joints

4.1 Lapped joints

4.1.1 Areas

Lap joint welds may be adopted in very specific cases subject to the approval of the Society. Lap joint welds may be adopted for the following:

a) Peripheral connections of doublers.

b) Internal structural elements subject to very low stresses.

4.1.2 Overlap width

Where overlaps are adopted, the width of the overlap, W_{lap} in mm, is not to be less than 3 times, but not greater than 4 times the as-built thickness of the plates being joined, see **Figure 9.** Where the as-built thickness of the thinner plate being joined has a thickness of 25.0 mm or more, the overlap will be subject to special consideration.

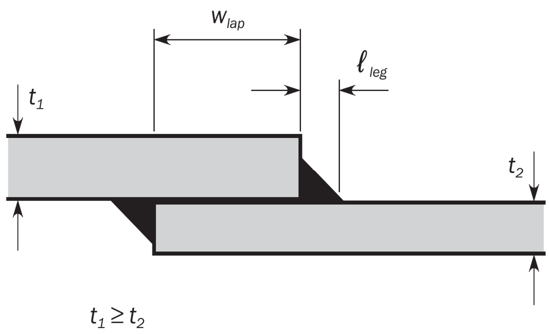


Figure 9 : Fillet weld in lapped joint

4.1.3 Overlaps for lugs

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 3 times the thickness of the lug but not be greater than 50.0 mm.

4.1.4 Lapped end connections

Lapped end connections are to have continuous welds on each edge with leg length, ℓ_{leg} in mm, as shown on **Figure 9** such that the sum of the two leg lengths is not less than 1.5 times the as-built thickness of the thinner plate.

4.2 Slot welds

4.2.1

Slot welds may be adopted in very specific cases subject to the approval of the Society. However, slot welds of doublers on the outer shell and strength deck are not permitted within 0.6 L amidships.

4.2.2

Slots are to be well-rounded and have a minimum slot length, ℓ_{slot} of 75.0 mm and width, W_{slot} of twice the as-built plate thickness. Where used in the body of doublers and similar locations, such welds are in general to be spaced a distance, S_{slot} of 2 ℓ_{slot} to 3 ℓ_{slot} but not greater than 250 mm, see **Figure 10.** The size of the fillet welds is to be determined from second formula shown in **[2.5.2]** using $t_{as-built}$ of the thinner plate and a weld factor of 0.48.

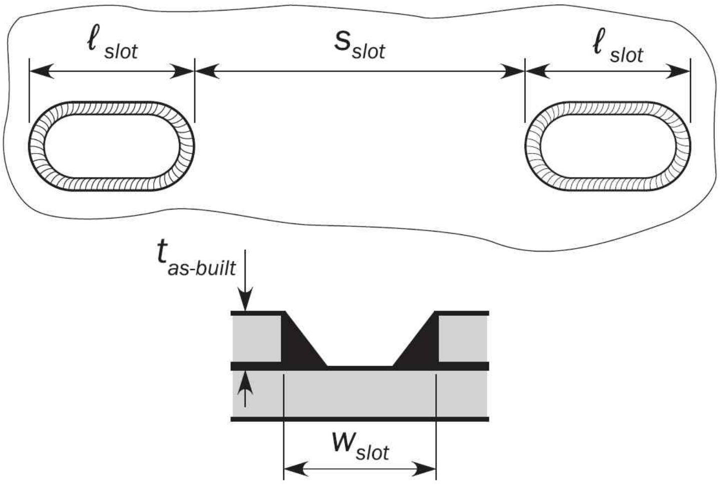


Figure 10 : Slot welds

4.2.3 Closing plates

For the connection of plating to internal webs, where access for welding is not practicable, the closing plating may be attached by slot welds to face plates fitted to the webs.

4.2.4

Slots are to be well-rounded and have a minimum slot length, ℓ_{slot} of 90 mm and a minimum width, W_{slot} of twice the as-built 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 140 mm. Slots are not to be filled with welding.

4.3 Stud and lifting lug welds

4.3.1

Where permanent or temporary studs or lifting lugs are to be attached by welding to main structural parts in areas subject to high stress, the proposed locations are to be submitted for approval.

5. Connection Details

5.1 Bilge keels

5.1.1

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 continuous fillet weld in accordance with **Table 5.**

Table 4 : Connections of bilge keels

Structural items being joined	Leg length of weld, in mm	
	At ends (1)	Elsewhere
Ground bar to the shell	$0.62\,t_{1as-built}$	$0.48\,t_{1as-built}$
Bilge keel web to ground bar	$0.48\,t_{1as-built}$	$0.30\,t_{2as-built}$
$t_{1as-built}$: As-built thickness of ground bar, in mm. $t_{2as-built}$: As-built thickness of web of bilge keel, in mm. (1) : Zone "b" in **Figure 18** and **Figure 19** in **Ch 3 Sec 6** for definition of "ends"		

5.1.2

Butt welds, in the bilge keel and ground bar, are to be well clear of each other and of butts in the shell plating as shown in **Figure 11.** In general, shell butts are to be flush in way of the ground bar and ground bar butts are to be flush in way of the bilge keel. Direct connection between ground bar butt welds and shell plating is not permitted. This may be obtained by use of removable backing.

5.1.3

The ground bar is to be continuously fillet welded with a leg length as given in **Table 5.** At the ends of the ground bar, the leg length is to be increased as given in **Table 5,** without exceeding the as-built thickness of the ground bar as shown in **Figure 11.** The welded transition at the ends of the ground bar to the plating connection should be formed with the weld flank angle of 45° or less.

5.1.4

In general, scallops and cut-outs are not to be used. Crack arresting holes are to be drilled in the bilge keel butt welds as close as practicable to the ground bar. The diameter of the hole is to be greater than the width of the butt weld and is to be a minimum of 25.0 mm. Where the butt weld has been subject to non-destructive examination, the crack arresting hole may be omitted.

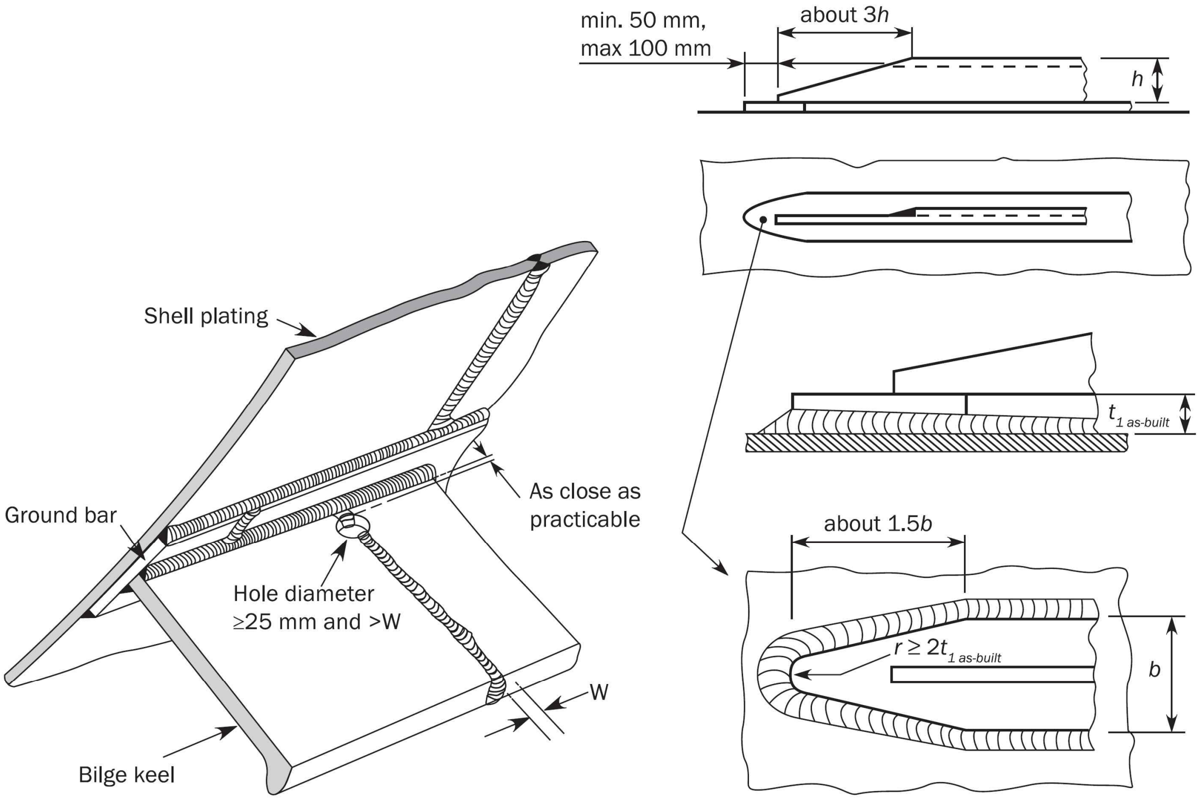


Figure 11 : Bilge keel

5.2 End connections of pillars

5.2.1

The end connections of pillars are to have an effective fillet weld area, A_{weld} in cm^2, (weld throat multiplied by weld length) not less than:

$$A_{weld} = f_3 \left(\frac{235}{R_{eH-weld}}\right)^{0.75} F$$

where:

F : Design load, for the structure under consideration, in kN.

f_3 : Coefficient equal to:

f_3 = 0.05 when pillar is in compression only.

f_3 = 0.14 when pillar is in tension.

5.3 Abutting plates with small angles

5.3.1

Where the angle θ between the abutting plate and the connected plate is less than 75° as shown in **Figure 12**, the size of fillet welds ℓ_θ, in mm, for the side of larger angle is to be increased in accordance with:

$$\ell_\theta = \frac{\ell_{leg}}{\sqrt{2}\sin\frac{\theta}{2}}$$

where:

ℓ_{leg} : Leg length of fillet weld, in mm, as defined in **[2.5.2].**

θ : Connecting angle, in $\deg$, as shown in **Figure 12.**

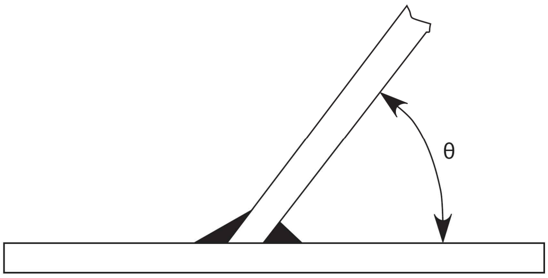


Figure 12 : Connecting angle

5.3.2

Connections of main strength members where θ is less than 45°, see **Figure 12**, may be applied only in dry spaces and voids.

Section 4 Use of Extremely Thick Steel

1. Application

1.1 General

1.1.1

This requirements of this section is to be complied with for container ships incorporating extremely thick steel plates having steel grade and thickness in accordance with **[1.1.2]** and **[1.1.3]** respectively.

1.1.2

The requirements given in this section identifies when measures for prevention of brittle fracture of extremely thick steel plates are required for longitudinal structural members.

1.1.3

This requirements gives the basic concepts for application of extremely thick steel plates to longitudinal structural members in the upper deck region.

1.1.4

This requirements defines the following methods to apply to the extremely thick plates of container ships for preventing the crack initiation and propagation:

a) Non-Destructive Testing(NDT) during construction detailed in **[2]**
b) Welding to increase toughness in **[3]**
c) Brittle crack arrest design detailed in **[4]**

The application of the measures specified in **[2]**, **[3]** and **[4]** of this requirements is to be in accordance with **[5]**.

1.1.5

For the application of this requirements, the upper deck region means the upper deck plating, hatch side coaming plating, hatch coaming top plating and their attached longitudinals.

1.2 Steel Grade

1.2.1

This requirements is to be applied to when any of YP36, YP40 and YP47 steel plates are used for the longitudinal structure members in the upper deck region.

1.2.2

YP36, YP40 and YP47 means the steel plates having the minimum specified yield points of 355, 390 and 460 $\mathrm{N/mm^2}$, respectively.

1.2.3

In case YP47 steel plates are used for longitudinal structural members in the upper deck region, the steel plates are to be EH47 specified in **Pt 2, Ch 1, Sec 3.**

1.3 Thickness

1.3.1

For steel plates with thickness of over 50 mm and not greater than 100 mm, the measures for prevention of brittle crack initiation and propagation specified in **[2]**, **[3]** and **[4]** are to be taken.

1.3.2

For steel plates with thickness exceeding 100 mm, appropriate measures for prevention of brittle crack initiation and propagation are to be taken in accordance with the Society's procedures.

2. Non-Destructive Testing(NDT) during construction(Measure No.1 of [5])

2.1 General

2.1.1

Where NDT during construction is required in **[5]**, the NDT is to be in accordance with **[2.1]** and **[2.2]**. Enhanced NDT as specified in **[4.3.5]** is to be carried out in accordance with an appropriate standard.

2.1.2

Ultrasonic testing (UT) is to be carried out on all block-to-block butt joints of all upper flange longitudinal structural members in the cargo hold region.

2.1.3

Upper flange longitudinal structural members include the topmost strakes of the inner hull/bulkhead, the sheer strake, main deck, coaming plate, coaming top plate, and all attached longitudinal stiffeners. These members are defined in **Figure 1.**

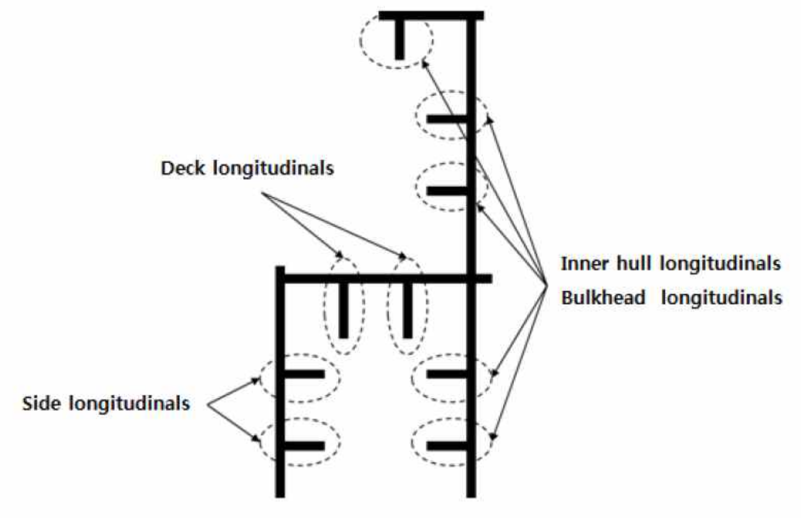


Figure 1 : Upper flange longitudinal structural members

2.1.4

Testing procedure of UT not specified in this requirements are to comply with the requirements in **Pt 2, Annex 2-7** of the Guidance.

a) Scanning has to be performed from at least one surfaces and both sides of the welded seam as shown in **Figure 2.** (Scanning from root face is recommended.)

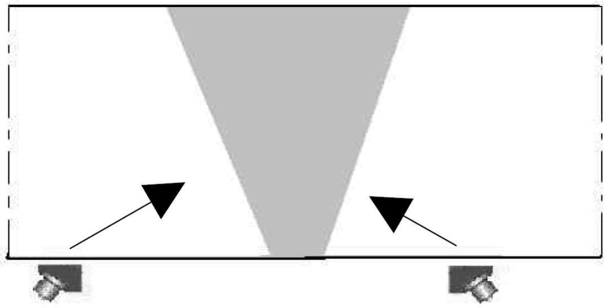


Figure 2 : Scanning from root face and both sides

b) Testing has to be performed with two probes 70° and 45° or 70° and 60° depending on the bevel preparation.

c) Any possible differences in attenuation and surface character between the calibration block and the welded seam to be tested are to be checked in accordance with **KS B 0896** or equivalent.

d) In case where the detected echo signal is suspicious as vertically oriented defect such as lack of fusion(LF) based on the calculation of sound path, the length of the detected echo signal is to be measured by 6 dB drop method and evaluated regardless of echo height.(acceptance criteria ≤ 25.0 mm)

e) For the NDE personnel engaged in UT of extremely thick steel plates welds, the shipyard should give education and training related to the detecting and evaluation of vertically oriented defect.

f) In order to detect transverse defects, scanning to be made with an angle probe angled about 15 degree from weld axis on at least one surface and both sides or with an angle probe along the centre line of the weld as shown in **Figure 3.**

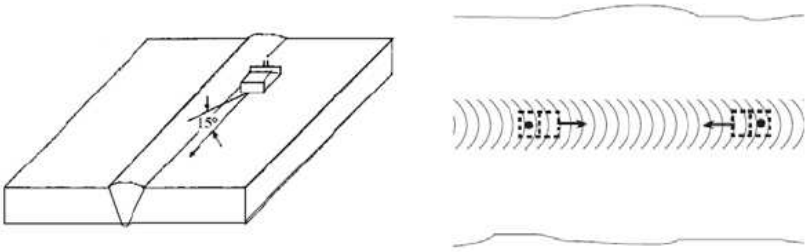


Figure 3 : UT scanning examples for detecting the transverse defects

2.2 Acceptance criteria of UT

2.2.1

Acceptance criteria of UT not specified in this requirements are to comply with the requirements in **Pt 2, Annex 2-7** of the Guidance.

2.2.2

The acceptance criteria may be adjusted under consideration of the appertaining brittle crack initiation prevention procedure and where this is more severe than that found in **Pt 2, Annex 2-7** of the Guidance, the UT procedure is to be amended accordingly to a more severe sensitivity.

3. Welding to increase toughness(Measure No.2 of [5])

3.1

Welding to increase toughness is to be carried out when B option in **[5]** is selected as a safety measure to identify and prevent brittle fracture.

3.2

Impact specimens are to be taken in accordance with **[3.2.1]**.

3.2.1

Impact specimens are to be taken from the weld center “WM”, fusion line “FL”, heat affected zone of 2.0 mm from fusion line, heat affected zone of 5.0 mm from fusion line.

3.3

Impact specimens are to meet the criteria for absorbed energy of base material at impact test temperature of base material.

4. Brittle crack arrest design(Measure No.3, 4 and 5 of [5])

4.1 General

4.1.1

The brittle crack arrest steel method detailed in **[4]** may be used when the **measures No. 3, 4, and 5 of [5]** are applied and the steel grade material of the upper deck is not higher than YP40. Otherwise other means for preventing the crack initiation and propagation shall be agreed with the Society.

4.1.2

Measures for prevention of brittle crack propagation are to be taken within the cargo hold region. A brittle crack arrest design means a design using these measures.

4.1.3

The measures given in this section generally apply to the block-to-block joints but it should be noted that cracks can initiate and propagate away from such joints. Therefore, appropriate measures should also be considered for the cases specified in **[4.2.2.b]**.

4.1.4

Brittle crack arrest steels are defined in **Pt 2, Ch 1, Sec 3**.

4.2 Functional requirements of brittle crack arrest design

The purpose of the brittle crack arrest design is aimed at arresting propagation of a crack at a proper position and to prevent large scale fracture of the hull girder.

4.2.1

The locations of most concern fro brittle crack initiation and propagation are the block-to-block butt weld joints either on hatch side coaming or on upper deck plating. Other locations in block fabrication where joints are aligned may also present higher opportunity for crack initiation and propagation along butt weld joints.

4.2.2

Both of the following cases are to be considered:

a) where the brittle crack runs straight along the butt joint, and

b) where the brittle crack initiates in the butt joint but deviates away from the weld and into the plate, or where the brittle crack initiates from any other weld and propagates into the plate.

c) “Other weld areas” in b) includes the following (refer to **Figure 4**):

- [1] Fillet welds between hatch side coaming plating, including top plating, and longitudinals;
- [2] Fillet welds between hatch side coaming plating, including top plating and longitudinals, and attachments. (e.g. Fillet welds between hatch side top plating and hatch cover pad plating.);
- [3] Fillet welds between hatch side coaming top plating and hatch side coaming plating;
- [4] Fillet welds between hatch side coaming plating and upper deck plating;
- [5] Fillet welds between upper deck plating and inner hull / bulkheads;
- [6] Fillet welds between upper deck plating and longitudinal; and
- [7] Fillet welds between sheer strakes and upper deck plating.

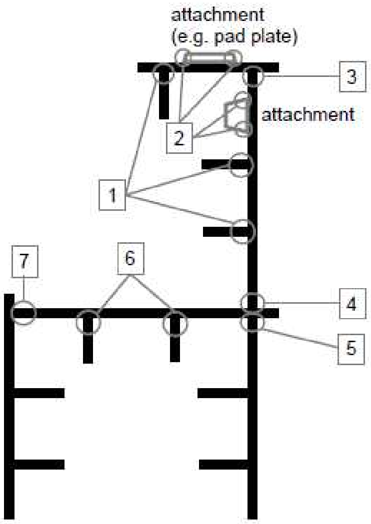


Figure 4 : Other weld areas

4.3 Concept examples of brittle crack arrest design

The followings are considered to be acceptable examples of measures that can be used on a brittle crack arrest-design to prevent brittle crack propagations. The detail design arrangements are to be submitted to the Society for their approval. Other measures may be considered and accepted for review by the Society.

4.3.1 Brittle crack arrest design for [4.2.2.b]:

Brittle crack arresting steel is to be used for the upper deck along the cargo hold region in a way suitable to arrest a brittle crack initiating from the coaming and propagating into the structure below.

4.3.2 Brittle crack arrest design for [4.2.2.a]:

Where the block to block butt welds of the hatch side coaming and those of the upper deck are shifted, this shift is to be greater than or equal to 300 mm. Brittle crack arrest steel is to be provided for the hatch side coaming. (refer to **Figure 5**)

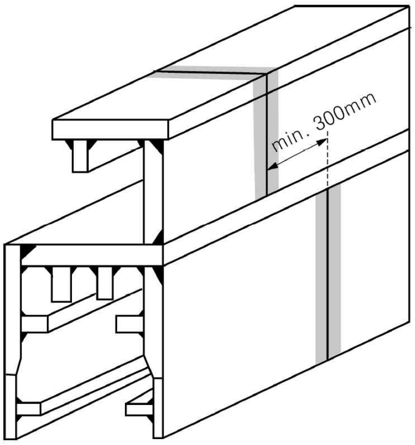


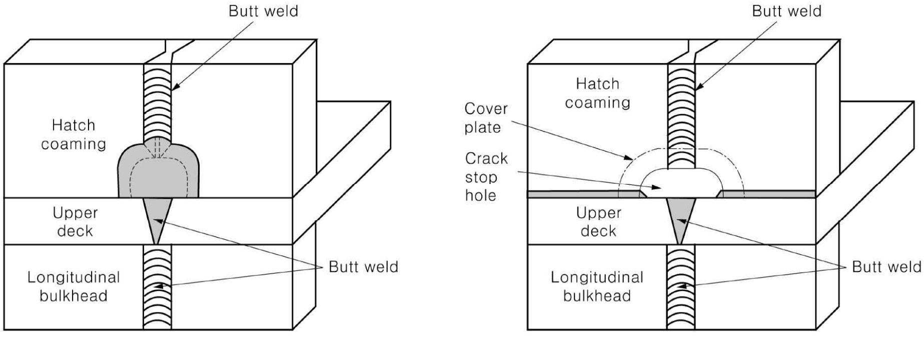
Figure 5 : An example of block to block butt-shift

4.3.3

Where crack arrest holes are provided in way of the block-to-block butt welds at the region where hatch side coaming weld meets the deck weld, the fatigue strength of the lower end of the butt weld is to be assessed. Additional countermeasures are to be taken for the possibility that a running brittle crack may deviate from the weld line into upper deck or hatch side coaming. These countermeasures are to include the application of brittle crack arrest steel in hatch side coaming.

4.3.4

Where Arrest Insert Plates of brittle crack arrest steel or Weld Metal Inserts with high crack arrest toughness properties are provided in way of the block-to-block butt welds at the region where hatch side coaming weld meets the deck weld, additional countermeasures are to be taken for the possibility that a running brittle crack may deviate from the weld line into upper deck or hatch side coaming. These countermeasures are to include the application of brittle crack arrest steel in hatch side coamings.



(a) Arrest welding type **(b) Arrest hole type**

Figure 6 : An example of joint arrangement for arresting the brittle crack propagation

4.3.5

The application of enhanced NDT such as time of flight diffraction (TOFD) technique or phase array (PAUT) using stricter defect acceptance in lieu of standard UT technique specified in **[2]** can be an alternative to **[4.3.2]**, **[4.3.3]** and **[4.3.4]** above.

4.4 Selection of brittle crack arrest steels

4.4.1

The brittle crack arrest steels fitted in the upper deck region of container ships are to comply with **Table 1** where suffixes BCA1 and BCA2 are defined in **Rule Part 2**.

4.4.2

The brittle crack arrest steel property is to be selected for each individual structural member with thickness above 50.0 mm according to **Table 1**.

4.4.3

When brittle crack arrest steels as specified in **Table 1** are used, the weld joints between the hatch coaming side and the upper deck are to be partial penetration weld details approved by the Society.

In the vicinity of ship block joints, alternative weld details may be used for the deck and hatch coaming side connection provided additional means for preventing the crack propagation are implemented and agreed by the Society in this connection area.

Table 1 : Brittle crack arrest steel requirement in function of structural members and thickness

Structural Members plating (1)	Thickness(mm)	Brittle crack arrest steel requirement
Upper deck	$50 < t \le 100$	Steel grade YP36 or 40 with suffix BCA1
Hatch coaming side	$50 < t \le 80$	Steel grade YP40 or 47 with suffix BCA1
	$80 < t \le 100$	Steel grade YP40 or 47 with suffix BCA2

Note;

(1) Excluding their attached longitudinals

5. Measures for Extremely Thick Steel Plates

The thickness and the yield strength shown in the **Table 2** apply to the hatch coaming top plating and side plating, and are the controlling parameters for the application of countermeasures. These controling parameters are not applicable for the upper deck.

If the as built thickness of the hatch coaming top plating and side plating is below the values contained in the **Table 2**, countermeasures are not necessary regardless of the thickness and yield strength of the upper deck plating.

Table 2 : Measures for extremely thick steel plates

Yield Strength (kgf/mm^2)	Thickness (mm)	Option	Measures			
			1	2	3 + 4	5
36	50 〈 t ≤ 85		N.A.	N.A.	N.A.	N.A.
	85 〈 t ≤ 100		O	N.A.	N.A.	N.A.
40	50 〈 t ≤ 85		O	N.A.	N.A.	N.A.
	85 〈 t ≤ 100	A	O	N.A.	O	O
		B	O*	N.A.**	N.A.	O
47 (FCAW)	50 〈 t ≤ 100	A	O	N.A.	O	O
		B	O*	N.A.**	N.A.	O
47 (EGW)	50 〈 t ≤ 100		O	N.A.	O	O

Measures:

No.	Measures
1	NDT other than visual inspection on all target block joints (during construction) **[2]**.
2	Welding to increase toughness(during construction) See **[3]**.
3	Brittle crack arrest design against straight propagation of brittle crack along weld line to be taken (during construction) See **[4.3.2]**, **[4.3.3]** or **[4.3.4]** of this requirements.
4	Brittle crack arrest design against deviation of brittle crack from weldline (during construction) See **[4.3.1]**.
5	Brittle crack arrest design against propagation of cracks from other weld areas such as fillets and attachment welds. (during construction) See **[4.3.1]**.

Symbols:
(a) “O” means “To be applied”.
(b) “N.A.” means “Need not to be applied”.
(c) Selectable from option “A” and “B”.
Note:
* : See **[4.3.5]**
** : See **[3]**.

6. Application of YP47 Steel Plates

These requirements apply to YP47 steel plates specified in **Pt 2, Ch 1, Sec 3, 311**.

6.1 Hull structure(design)

6.1.1

HT factor (Material factor of high tensile steel, k) for the assessment of hull girder strength is to be taken as 0.62.

6.1.2

Butt welds in the hatch side coaming and fillet welded joints for fixing outfitting items are to be set at an adequate distance from the hatch corners so that effects of stress concentration are to be avoided.

6.1.3

The free edge including hatch corner of the hatch side coaming should not have any defects such as notch that could be harmful against fatigue strength. Appropriate edge treatment including treatment of corner edge (as an example, see **Figure 7**) is to be performed so that the edges should have adequate fatigue strength.

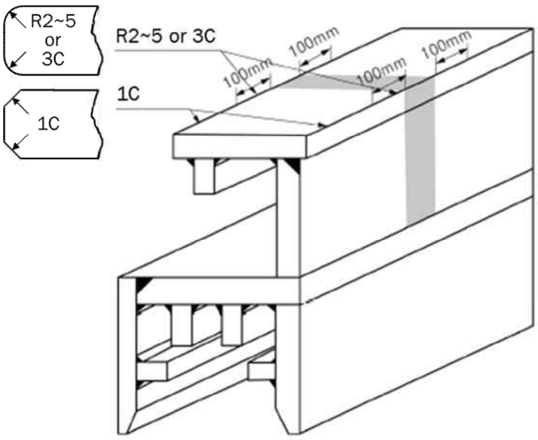


Figure 7 : An example of appropriate edge treatment including corner edge

6.1.4

In case of fitting of outfitting items such as hatch cover pads and container pads, taper is to be provided on the edge of the outfitting item so that a very large difference in rigidity does not occur between outfitting items and the hull structure. Measures such as increasing the thickness of plating at the fitted location are also to be adopted.

6.1.5

Special consideration is to be paid to the construction details where extremely thick steel plates are applied as structural members such as connections between outfitting and hull structures. ⚓

Chapter 13

Ship in Operation – Renewal Criteria

Section 1 Principles and Survey Requirements

1. Principles

1.1 Application

1.1.1

The purpose of this chapter is to provide criteria for the allowable thickness diminution of ships' hull structures.

1.1.2

The criteria apply only to ships in operation that are classed in accordance with these Rules.

1.1.3

Thickness measurement is to be used to assess ships' hull structures against the specified renewal criteria.

1.1.4

The hull survey requirements are those given, as applicable, in **Pt 1, Ch 2, Sec 1, 2, 3** and **4.**

1.2 Corrosion allowance concept

1.2.1 Corrosion allowance

Corrosion allowance is comprised of two aspects: local and global corrosion, as defined in **Ch 3, Sec 2, [1.1.2].**

1.2.2 Assessment

Assessment against both local and global corrosion renewal criteria is required during the operational life of ships.

Assessment against the newbuilding requirements which incorporate corrosion additions, given in **Ch 3, Sec 3,** and which consider all relevant loads and limit states, e.g. yielding, buckling, and fatigue is not required during the operational life of ships, provided that the measured thickness of any structural members remain greater than the renewal thickness specified in **Sec 2, [2].**

1.2.3 Steel renewal

Steel renewal is required if either the local or global corrosion allowance is exceeded.

2. Hull Survey Requirements

2.1 General

2.1.1 Minimum hull survey requirements

The minimum hull survey requirements including thickness measurements for the maintenance of class are given in **Pt 1.** Refer to **[1.1.4].**

Section 2 Acceptance Criteria

Symbols

$t_{as-built}$: As built thickness, in mm.

t_{c-m} : Diminution thickness, in mm

t_{res} : Reserve thickness, taken equal to 0.5 mm.

$t_{vol-add}$: Thickness for voluntary addition, in mm.

1. General

1.1 Application

1.1.1

This section gives requirements for the application of the acceptance criteria.

1.2 Definition

1.2.1 Deck zone

The deck zone includes all the following items contributing to the hull girder strength:

- Strength deck plating.
- Longitudinal hatch coaming
- Sheer strake.
- Side shell plating.
- Inner hull and other longitudinal bulkhead plating, if any.
- Longitudinal stiffeners, girders and stringers connected to the above mentioned plating.

1.2.2 Bottom zone

The bottom zone includes the following items contributing to the hull girder strength:

- Keel plate.
- Bottom plating.
- Bilge plating.
- Bottom girders.
- Inner bottom plating.
- Longitudinal stiffeners connected to the above mentioned plating.
- Side shell plating.

1.2.3 Neutral axis zone

The neutral axis zone includes the following items between the deck zone and the bottom zone, as for example:

- Side shell plating.
- Inner hull plating and longitudinal bulkheads, if any.
- Double hull stringer

For the longitudinal strength members forming the web of the hull girder which are inclined to the vertical, the area of the member to be included in the zone area is to be based on the projected area onto the vertical plane.

2. Renewal Criteria

2.1 Local corrosion

2.1.1 Renewal thickness of local structural elements

Local structural elements include local supporting members and primary supporting members.

Steel renewal is required if the measured thickness, t_m in mm, is less than the renewal thickness, t_{ren} defined as:

$$t_{ren} = t_{as-built} - t_{c-m} - t_{vol-add}$$

where:

$$t_{c-m} = (t_{as-built} - t_{vol-add})\, C_{Wear-limit}$$

$C_{Wear-limit}$: Local wear limit defined in **Table 1**.

Table 1 : Local wear limit, $C_{Wear-limit}$

	Name of member	Wear limit
		Class I
Local Wear Limit	Strength deck plating and Sheer strake including welded longitudinals, Side and bottom shell plating Stringer deck plating Inner bottom plating Longitudinal and Side longitudinal bulkhead plating Bulkhead plating of deep tank Floor and Girder of double bottom Transverse web frame and Side stringer of double side Longitudinal deck girder Web and face of primary supporting member Web, face and brackets of frames in cargo hold	0.2
	Effective deck plating (3) Superstructure deck plating Deck plating inside the line of cargo hatch openings Watertight bulkhead plating other than bulkhead plating of deep tank, Hatch cover(including stiffeners) and Hatch coaming(including stiffeners), Web, face and brackets of secondary stiffener (2)	0.25
	Partial corrosion (e.g pitting)	0.3
	(1) For ships classed through the Classification Survey after Construction, the separate requirements specified by the Society are to be applied. (2) Secondary stiffener refers to the member which is supported by the primary supporting member and does not support another reinforcement member. (3) Definition of effective deck is specified in Pt 3, Ch 5, 103. of the Rules.	

2.1.2 Renewed area

Areas which need to be renewed based on the renewal criteria in **[2.1.1]** are, in general, to be repaired with inserted material which is to have the same or greater grade and yield stress as the original, and to have a thickness, t_{repair} in mm, not less than:

$$t_{repair} = t_{as-built} - t_{vol-add}$$

2.1.3 Alternative solutions

Alternative solutions(Substantial Corrosion) may be adopted in accordance with **Pt 1, Ch 2 202. 1. (31)**, where the measured thickness, t_m is such as:

$$t_{ren} \le t_m < t_{ren} + t_{res}$$

Where both sides of a structural member are in void space or dry space, alternative solutions are not applied.

2.2 Global corrosion

2.2.1 Application

The ship's longitudinal strength is to be evaluated by using the thickness of structural members measured, renewed and reinforced, as appropriate, on and after Special Survey No.3.

2.2.2 Renewal criteria

The hull girder strength criteria are given as detailed below.

a) Deck and bottom zones: The current hull girder section modulus at deck and at bottom determined with the thickness measurements are not to be less than 90 % of the section modulus calculated according to **Ch 5, Sec 1** with the gross offered thickness. Alternatively, the current sectional areas of the bottom zone and of the deck zone which are the sum of the measured item areas of the considered zones are not to be less than 90 % of the sectional area of the corresponding zones determined with the gross offered thickness.

b) Neutral axis zone: The current sectional area of the neutral axis zone, which is the sum of the measured plating areas of this zone, is not to be less than the sectional area of the neutral axis zone calculated with the gross offered thickness minus 0.5 t_c.

If the actual reduction of the gross offered thickness of all items, of a given transverse section, which contribute to the hull girder strength is less than 10 % for the deck and bottom zones and 0.5 t_c for the neutral axis zone, the hull girder strength criteria of this transverse section is satisfied and the calculations of the different zone areas with measured thicknesses need not be carried out.

The gross offered thickness is defined in **Ch 3, Sec 2.** ⚓

Chapter 14

Lashing Equipment

Section 1 Lashing Equipment

Section 1 Lashing Equipment

1. Application

1.1 General

1.1.1

The check of container securing fittings are to be performed according to **Pt 7, Annex 7-2**. ⚓

2024

Guidance Relating to the Rules for the Classification of Steel Ships

Part 14

Structural Rules for Container Ships

GA-14-E

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APPLICATION OF THE GUIDANCE RELATING TO THE RULES

This "Guidance Relating to the Rules for the Classification of Steel Ships" (hereafter called as the Guidance Relating to the Rules) is prepared with the intent of giving details as to the treatment of the various provisions for items required the unified interpretations and items not specified in the Rules, and the requirements specified in the Guidance Relating to the Rules are to be applied, in principle, in addition to the various provisions in the Rules.

As to any technical modifications which can be regarded as equivalent to any requirements in the Guidance Relating to the Rules, their flexible application will be properly considered.

APPLICATION OF PART 14
"STRUCTURAL RULES FOR CONTAINER SHIPS"

1. Unless expressly specified otherwise, the requirements in the Guidance apply to ships for which contracts for construction are signed on or after 1 July 2024.

2. The amendments to the Guidance for 2021 edition and their effective date are as follows;

Effective Date 1 July 2021

〈No revision〉

CONTENTS

Annex 14-1 Strength assessment of flooded condition for fire-fighting

1. General

1.1 Application

1.1.1 Scope

In addition to the Rules, this Annex applies to the strength assessment of container ships with flooding requirements for fire-fighting in cargo holds in accordance with **Pt 8**, **Annex 8-9**, **405**. **5** of **Guidance relating to Rules for the Classification of Steel Ships**.

1.1.2 Limitations

The cargo hold flooding condition is regarded as an accident condition and the design load and acceptance criteria are applied.

The ship is assumed to be intact and upright.

1.2 Loading Manual and Loading Instrument

1.2.1 Loading Manual

The maximum flooding level of each hold is to be specified in the loading manual according to the strength assessment results based on this annex.

It is to be specified in the loading manual to ensure that the permissible vertical bending moment and shear force in **[2.2]** are not exceeded under actual loading conditions and flooding level when filling the cargo hold with water.

1.2.2 Loading instrument

The loading instrument shall be equipped with a function to check the vertical still water bending moment, the vertical still water shear force, and the intact stability at specified read-out points when any cargo hold is completely or partially flooded.

2. Loads

2.1 Application

2.1.1

For requirements not described in this Article, refer to **Ch 4** of the Rules.

2.1.2 Coefficient for strength assessment

For the flooded condition for fire-fighting, the coefficient for strength assessment is to be taken as 0.8.

2.2 Hull girder loads

2.2.1 Permissible vertical still water bending moment in flooded condition for fire-fighting

Permissible vertical still water bending moment, M_{sw-FSC}, in flooded condition for fire-fighting is calculated as:

$$M_{sw-FSC} = M_{sw} + M_{wv}(1 - f_{ps})$$

where:

M_{sw} : Permissible hogging and sagging vertical still water bending moment in seagoing operation, in kNm, at the hull transverse section considered, defined in **Ch 4**, **Sec 4**, **[2.2.2]** of the Rules.

M_{wv} : Vertical wave bending moment in seagoing condition, in kNm, in seagoing operation at the hull transverse section considered, defined in **Ch 4**, **Sec 4**, **[3.2.1]** of the Rules.

f_{ps} : The coefficient for strength assessment in flooded condition for fire-fighting, refer to **[2.1.2]**.

2.2.2 Permissible vertical still water shear force in flooded condition for fire-fighting

Permissible vertical still water shear force, Q_{sw-FSC}, in flooded condition for fire-fighting is calculated as:

$$Q_{sw-FSC} = Q_{sw} + Q_{wv}(1 - f_{ps})$$

where:

Q_{sw} : Permissible positive or negative still water shear force for seagoing operation, in kN, at the hull transverse section considered, as defined in **Ch 4**, **Sec 4**, **[2.3.1]** of the Rules.

Q_{wv} : Vertical wave shear force in seagoing condition, in kN, at the hull transverse section considered, defined in **Ch 4**, **Sec 4**, **[3.3.1]** of the Rules.

f_{ps} : The coefficient for strength assessment in flooded condition for fire-fighting, refer to **[2.1.2]**.

2.3 Internal loads

2.3.1 Pressures for the strength assessment of flooded conditions for fire-fighting

The internal pressure in flooded condition for fire-fighting, in $\mathrm{kN/m^2}$, acting on any load point of the watertight boundary of a hold for the flooded static (S) design load scenarios, given in **[2.4]** is to be taken as:

$$P_{in} = P_{FSC}$$

$$P_{FSC} = \rho g h$$

ρ : Density of seawater, taken equal to 1.025 t/m^3

g : Gravity acceleration, taken equal to 9.81 m/s^2

h : Pressure height, in m, in flooded condition, to be taken as:

$$h = z_{FSC} - z$$

where:

z_{FSC} : Vertical distance from the top of inner bottom plating to the maximum flooding level, in m

z : Vertical distance from the top of inner bottom plating to the load point, in m

2.4 Design load scenarios

2.4.1 Design load scenarios for strength assessment in flooded condition for fire-fighting

The design load scenarios for strength assessment in flooded condition for fire-fighting are given in **Table 1**.

Table 1 : Design load scenarios for strength assessment in flooded condition

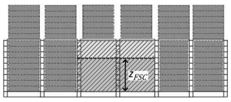
Design load scenario			Flooded condition (for fire-fighting)
Load components			Accidental (A)
Hull Girder	VBM		M_{sw-FSC}
	HBM		-
	VSF		-
	TM		-
Local Loads	P_{ex}	External deck for green sea	-
		Hull envelope	-
	P_{in}	Ballast tanks	-
		Other tanks	-
		Watertight boundaries	P_{FSC}
	F_{con}	Container	-
	P_{dk}	Internal decks for dry spaces	-
		External deck for distributed loads	-
		External deck for heavy units	-

2.5 Loading conditions

2.5.1 Loading condition for cargo hold strength assessment in flooded condition for fire-fighting

The loading condition for strength assessment in flooded condition for fire-fighting is given in **Table 2**.

Table 2 : Loading conditions for cargo holds strength check to cargo hold region

No	Loading Pattern	Still water loads					Dynamic load cases
		Draught	Container load		% of perm. SWBM	% of perm. SWSF	Midship cargo region
			In hold	On deck			
Flooded condition(for fire-fighting)							
A2		T_{SC}	centre: flooded adjacent: 40t/FEU all ballast tanks empty	max 40 ft stack weight	100% (sag. or min. hog.)	-	Static
▦ heavy cargo	░ light cargo	▩ ballast tank	■ fuel oil tank				

3. Hull local scantling

3.1 Application

3.1.1

Hull local scantlings for cargo hold region in flooded condition for fire-fighting are to be evaluated in accordance with **Ch 6** of the Rules.

3.2 Load combination

3.2.1 Design load sets for plating, stiffeners and PSM in flooded condition for fire-fighting

Design load sets for plating, stiffeners and primary supporting members in flooded condition for fire-fighting are given in **Table 3**.

Table 3 : Design load sets in flooded condition for fire-fighting

Structural member	Design load set	Load component	Draught	Design load	Loading condition
Watertight boundaries	FD-2	P_{in}	-	A	Flooded condition (for fire-fighting)

4. Cargo Hold Structural Strength Analysis

4.1 Application

4.1.1

Cargo hold structural strength analysis is to be carried out in accordance with **Ch 7**, **Sec 1** and **2** of the Rules.

4.2 Design load combinations

4.2.1

The loading condition for cargo hold structural strength analysis in flooding condition for fire-fighting is in accordance with **Table 2**.

4.3 Internal loads

4.3.1 Internal pressure in flooded condition

The internal pressure is calculated according to **[2.3.1]** for the design load scenarios in flooded condition for fire-fighting in **Table 1**.

4.4 Hull girder loads

4.4.1

The hull girder loads is to be taken as the still water vertical bending moment according to **Table 2**.

4.4.2 Target hull girder vertical bending moment in flooded condition for fire-fighting

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

$$M_{v-targ} = M_{sw-FSC}$$

where:

M_{sw-FSC} : Permissible still water bending moments in kNm, at the considered longitudinal position in flooded condition for fire-fighting as defined in **[2.2.1]**.

The values of M_{v-targ} are taken as the maximum hull girder bending moment within the mid-hold(s) for each individual cargo hold for each given FE load combination as defined in **Table 2**.

4.5 Alternative methods

4.5.1 Strength assessment for PSM in flooded condition for fire-fighting

In evaluating the strength of the primary supporting members in flooded condition for fire-fighting, a method that considers the plasticity of the material using nonlinear finite element analysis can be used as an alternative evaluation method. In this case, evaluation procedures and methods are to be submitted to the Society for consultation in advance. ⚓

Rules for the Classification of Steel Ships
Guidance Relating to the Rules for the Classification of Steel Ships

PART 14 STRUCTURAL RULES FOR CONTAINER SHIPS

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