IACS

Common Structural Rules for

Bulk Carriers and Oil Tankers

01 January 2024 Release

COMMON STRUCTURAL RULES FOR BULK CARRIERS AND OIL TANKERS

TECHNICAL BACKGROUND RULE REFERENCE

This document is an updated version of the Technical Background Rule Reference for Common Structural Rules for Bulk Carriers and Oil Tankers following the publication of the 01 Jan 2024 Rules.

The document was updated on the basis of Technical Background for Rule Change Notice 1 to 01 Jan 2023 version.

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PART 1
GENERAL HULL REQUIREMENTS

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PART 1 CHAPTER 1

RULE GENERAL PRINCIPLES

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1 SCOPE OF APPLICATION

1.1 General

1.1.1

These regulations clearly define the application of harmonised Common Structural Rules (CSR-H) for bulk carriers and oil tankers.

1.1.2

These regulations give the typical structural arrangement of the ships concerned by the Rules.

1.1.3

Technical background is not considered necessary.

1.2 Scope of application for bulk carriers

1.2.1

The Rules apply to bulk carriers of length 90m and greater of typical arrangement fitted with a double bottom structure and side structure of single skin or double skin construction and constructed generally with a single deck and, in the cargo holds, with topside tanks and bilge hopper tanks.

The word “generally” means that ships fitted with top side and hopper tanks have a typical bulk carrier arrangement, but CSR are applicable to other arrangements, for example hybrid type bulk carriers.

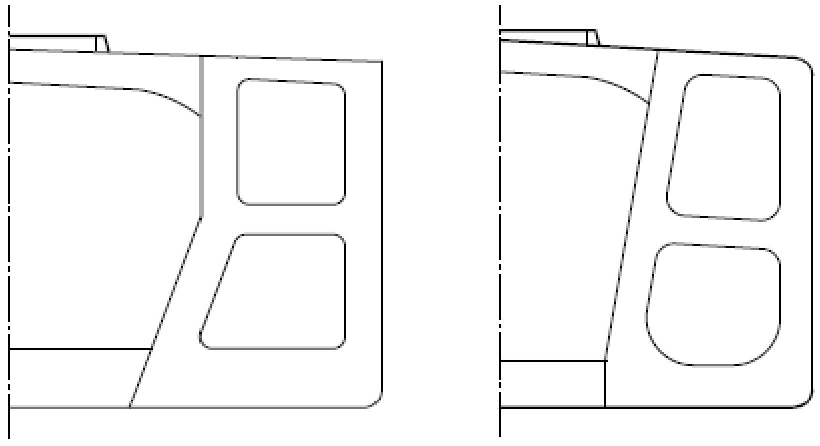
A hybrid bulk carrier is a bulk carrier where at least one cargo hold is constructed with hopper tank and topside tank. It clearly means that these Rules apply to bulk carriers without topside nor hopper tanks in some holds and having hopper tank and top side tank in remaining hold.

This is in line with the interpretation of the expression “constructed generally with single deck, top-side tanks and hopper side tanks in cargo area“, which means, according to MSC Res. 277(85), that ships are not considered outside the definition of bulk carriers only on the grounds that they lack some or all of the specified constructional features.

The expression “intended primarily to carry dry cargoes in bulk” is to be understood in the same way as MSC Res. 277(85). The text of MSC Res. 277(85) says: ““primarily to carry dry cargo in bulk” means primarily designed to carry dry cargoes in bulk and to transport cargoes which are carried, and loaded or discharged, in bulk, and which occupy the ship’s cargo spaces exclusively or predominantly”.

Ore carriers and combination carriers are excluded from the scope of application of the Rules due to their typical arrangement (see Figure 1).

Figure 1: Typical structural arrangement for Ore Carriers



The Rules also exclude from its scope of application the following ship types:

- Woodchip carrier.
- Cement, fly ash and sugar carriers provided that loading and unloading is not carried out by grabs heavier than 10 tons, power shovels and other means which may damage cargo hold structure.
- Ships with inner bottom construction adapted for self-unloading.

The same ship types are excluded from MSC Res. 277(85).

The definition of bulk carriers covered by the Rules is in accordance with the International Convention for Safety of Life at Sea (SOLAS) and MSC Res. 277(85), excepted for the pure ore carriers and combination carriers due to their typical structural arrangement as mentioned above.

The references to SOLAS and MSC Res. 277(85), adopted on 28 November 2008 are given for reference.

1.3 Scope of application of oil tankers

1.3.1 Length and structural arrangement application

Technical background is not considered necessary.

1.3.2 Cargo temperature application

This requirement is in accordance with CSR OT (July 2010) Sec 2, 3.1.8.4. Ships with cargo design temperature outside the range (0°C to 80°C) are subject to additional requirements as specified by the Society.

2 RULE APPLICATION

2.1 Rule description

2.1.1 Rule structure

Technical background is not considered necessary.

2.1.2 Numbering

Technical background is not considered necessary.

2.2 Rule Requirements

2.2.1 Part 1

Technical background is not considered necessary.

2.2.2 Part 2

Technical background is not considered necessary.

2.2.3 Application of the Rules

Technical background is not considered necessary.

2.2.4 General criteria

Technical background is not considered necessary.

2.3 Structural requirements

2.3.1 Materials and welding

The rule requirements associated with the selection of materials for structural components are based on the location, design temperature, through thickness stress, and criticality of the component, see Sec 2, [3.4.4] and Ch 3, Sec 1.

The rule requirements are based on the assumption that the material is manufactured in accordance with the rolling tolerances specified in IACS UR W13 (Rev 5, February 2012).

2.4 Ship parts

2.4.1 General

Technical background is not considered necessary.

2.4.2 Fore part

The structure in the forward part is defined as structure forward of the collision bulkhead in principle, but the scope of applicability of the structural regulations for slamming of the forward bottom and bow flare extends also to the structural parts aft of the collision bulkhead. To avoid duplication and for convenience, the regulations are included in those for the forward part.

2.4.3 Cargo area

Technical background is not considered necessary.

2.4.4 Machinery space

The pump room is included in machinery space for strength assessment purpose although SOLAS Ch II-1, Reg. 3.16, as amended; considers the pump room as part of the cargo area. The reference to SOLAS is given for information.

2.4.5 Aft part

Technical background is not considered necessary.

2.4.6 Superstructures and deckhouses

Technical background is not considered necessary.

2.5 Limits of application to lifting appliances

2.5.1 Definition

This requirement specifies the fixed parts of lifting appliances considered as an integral part of the hull, to be checked under the CSR requirements.

2.5.2 Rule application for lifting appliances

Technical background is not considered necessary.

2.5.3 Structures supporting fixed lifting appliances

Technical background is not considered necessary.

2.6 Novel designs

2.6.1

Technical background is not considered necessary.

3 CLASS NOTATIONS

3.1 Class notation CSR

3.1.1 Application

This requirement defines the class notation CSR. Ships complying with the requirements of these Rules will have the notation CSR placed in the ships public class. Mandatory or voluntary procedures which previously resulted in class notations that are made redundant by these Rules will no longer be applied to ships covered by the notation CSR. Additionally, current notations from the Societies that indicate compliance with specific guides or requirements that augment this standard will also be added to the ships public class records.

3.2 Class notation for bulk carriers

3.2.1 Additional service features BC-A, BC-B and BC-C

This incorporates the requirements of IACS UR S25.3 (which is no longer in force). For improvement and transparency, the additional service feature {Block loading} is included when the ship is intended to operate in alternate block load condition.

3.2.2 Additional class notation GRAB [X]

The External Advisory Group IACS used for consultation during harmonisation of CSR-BC and CSR-OT, advised that GRAB(20), the design basis in CSR-BC, is too low for larger vessels carrying iron ore and coal, compared to actual grabs used at terminals. The IACS Hull Panel followed up this feedback by collecting information on actual grab weight from owners association and IACS members and the following feedback were noted :

Source	Extract of information received (Grab weights refer to weight of empty grabss)
Class 1	Most heavy grabs are found in Rotterdam and are 37t . Grabs with weight 22-28 t are quite common.
Industry org. 1	Max weight is 42.7t for ore and 43.7t for coal
Industry org. 2	Max weights are 36-38 t
Class 2 (investigation from 1991)	In Europe max weight is 37t and average weight is 19t In Japan/Taiwan max deadweight is 31t and average 21t

The bulk carriers shall be designed for the most extreme grab weight that can be expected during ship life and it is assumed that larger vessels are more likely to encounter the largest grabs as they will more frequently carry coal and iron ore than handy size ships.

It is recognised that there are significant uncertainties related to scantlings needed to ensure satisfactory robustness for cargo handling. Reduction of inner bottom and hopper scantlings compared to CSR BC is therefore considered not acceptable. The minimum grab weights are chosen to ensure inner bottom thicknesses similar to what used on the reference vessels.

The minimum mass of the grab is taken as 35t for vessels with length exceeding 250m , 30t for ships between 200m and 250m and 20t for smaller vessels. The increased design grab weight for larger vesseels is intended to take into account large grabs commonly used for iron ore. The strength requirement for impact load of grab specified in Pt 2, Ch 1, Sec6 of the Rules shall be satisfied.

Please refer to HSRTB2_Ch01_Sec06 for details about technical background and scantling impact.

4 APPLICATION OF THE RULES OF THE SOCIETY

4.1 Structural parts not covered by these Rules

4.1.1

Technical background is not considered necessary.

1 GENERAL

1.1 Rule objectives

1.1.1

The objectives of the Rules are to mitigate the risks of structural failure in relation to safety of life, environment and property and to ensure adequate durability of the hull structure for its intended life, see Figure 1. The Rule Objectives were categorised as given below.

- Safety objectives:

The overall safety of the hull structure and hence structural requirements are specified in such a way so that:

(a) The ship's structural strength and watertight integrity are adequate for the intended service of the ship.

(b) The minimum state of the structure is specified so that the minimum acceptable structural safety level is adequate and the status of the structure with regard to renewal criteria is known throughout the ship's life.

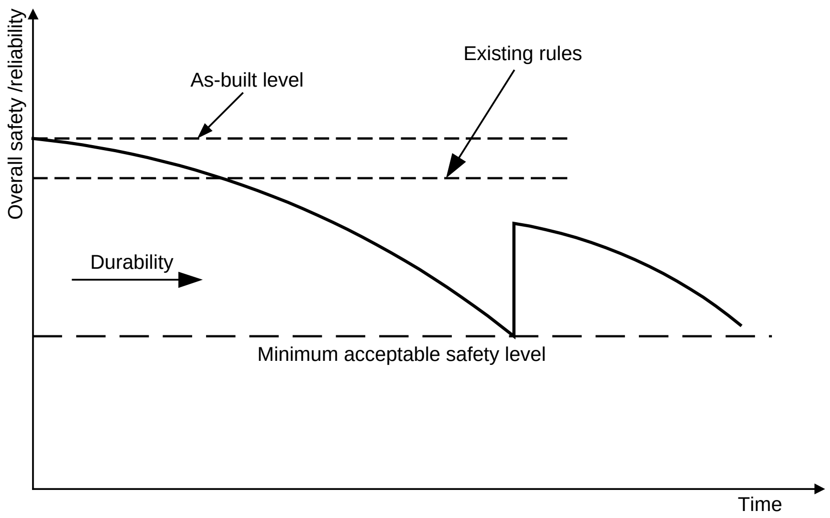
- Performance and durability objectives:

The Rules include structural requirements related to the satisfactory durability of the ship. This implies that:

(a) The ship is capable of carrying the intended cargo with the required flexibility in operation to fulfil its design role.

(b) The structure has sufficient durability in terms of corrosion margin and fatigue endurance.

Figure 1: Structural safety and durability



1.1.2

Technical background is not considered necessary.

2 GENERAL ASSUMPTIONS

2.1 International and national regulations

2.1.1

Ships are designed, constructed and operated in a complex regulatory framework laid down by IMO and implemented by flag states or by classification societies on their behalf. Statutory requirements set the standard for statutory aspects to ships, such as life saving, subdivisions, stability, fire protection, etc. These requirements influence the operational and cargo carrying arrangements of the ship and may therefore affect its structural design.

2.1.2

The intent of the 2.1.2 text is to state that the design submitted by a designer is to comply with the statutory requirements stated in National Regulations and/or IMO Instruments.

The compliance of the design with the CSR Rules does not necessarily imply compliance with the Statutory requirements.

The structural requirements of National and International Regulations which are mentioned or referenced in the Rules are not to be considered as Classification requirements.

Such requirements are to be considered as a part of Classification requirements, only when they are either re-stated or clearly mentioned as CSR requirements.

The CSR requirements do not replace the corresponding National and International Regulations but are additional requirements that must be complied with.

The attention of the designers is especially drawn to the principal SOLAS regulations typically applicable to CSR ships as given below for information:

- Ch II-1, Construction - structure, subdivision and stability, machinery and electrical installations:
  - (a) Reg. 3-2, Protective coatings of dedicated seawater ballast tanks in all types of ships and double-side skin spaces of bulk carriers.
  - (b) Reg. 3-3, Safe access to tanker bows.
  - (c) Reg. 3-4, Emergency towing arrangements and procedures.
  - (d) Reg. 3-6, Access to and within spaces in, and forward of, the cargo area of oil tankers and bulk carriers.
  - (e) Reg. 12, Peak and machinery space bulkheads, shaft tunnels, etc.
  - (f) Reg. 15, Openings in the shell plating below the bulkhead deck of passenger ships and the freeboard deck of cargo ships.
  - (g) Reg. 16, Construction and initial tests of watertight doors, sidescuttles, etc.
  - (h) Reg. 16-1, Construction and initial tests of watertight decks, trunks, etc.
- Ch V, Safety of Navigation:
  - (a) Reg. 22, Navigation bridge visibility.

2.2 Application and implementation of the Rules

2.2.1

Technical background is not considered necessary.

2.2.2

This section identifies what the primary responsibilities of each party is in the design and construction of a ship. In particular, it should be noted that industry also set requirements which affect the structural design and the responsibility to implement these requirements is between the owners and designers/shipbuilders.

IACS Recommendation No. 132 is referred to as a repository of optional additional considerations to add an element of ergonomics to the vessel design. Alternative ergonomic standards accepted by the Society are also referenced to account for cases where other standards are preferred.

3 DESIGN BASIS

3.1 General

3.1.1

Technical background is not considered necessary.

3.1.2

This regulation corresponds to the functional requirements specified in the Tier II.3 of Goal Based Standards, GBS.

3.1.3 Residual strength

This regulation corresponds to the functional requirements specified in the Tier II.5 of Goal Based Standards, GBS.

3.1.4 Finite element analysis

Technical background is not considered necessary.

3.1.5 Fatigue life

Technical background is not considered necessary.

3.1.6

Technical background is not considered necessary.

3.1.7

Technical background is not considered necessary.

3.2 Hull form limit

3.2.1

Technical background is not considered necessary.

3.3 Design life

3.3.1

The design life is the nominal period that the ship is assumed to be exposed to operating and/or environmental conditions and/or the corrosive environment and is used for selecting appropriate ship design parameters. The ship's actual service life may be longer or shorter depending on the actual operating conditions and maintenance of the ship throughout its life cycle.

The relationship between the design life that is specified for a ship at the time of design and construction and the actual safe working life is dependent on the operational history and the maintenance regime. It follows that two identical ships that are operated differently or maintained under different maintenance regimes may have different actual lives.

3.4 Environmental conditions

3.4.1 North Atlantic wave environment

To cover worldwide trading operations and also to deal with the uncertainty in the future trading pattern of the ship and the corresponding wave conditions that will be encountered, a severe wave environment is used for the design assessment.

3.4.2 Wind and current

Technical background is not considered necessary.

3.4.3 Ice

Technical background is not considered necessary.

3.4.4 Design temperatures

Technical background is not considered necessary.

3.4.5 Thermal loads

Technical background is not considered necessary.

3.5 Operating conditions

3.5.1

Technical background is not considered necessary.

3.5.2

For avoiding sloshing and impact loads, the ballast cargo hold is not to be partly filled in seagoing operations. Ballasting and deballasting operations are not to be performed in unfair weather condition to avoid sloshing and impact loads in the ballast cargo hold.

3.6 Operating draughts

3.6.1

It is only required that the scantling draft is required to be greater than the draft corresponding to the specified freeboard. The purpose of the operational limitations for minimum draughts forward (at FP) is to control the design slamming loads.

The scantlings are to be approved for minimum draught forward, at FP applicable for all sea-going conditions of which for the following cases:

- T_{F-e} in m, with any of double bottom ballast tanks in bottom slamming area empty.
- T_{F-f} in m, with all double bottom ballast tanks in bottom slamming area.

3.7 Internal environment

3.7.1 Oil cargo density for strength assessment

The objective with the strength assessment is to ensure satisfactory structural behaviour for a "worst case scenario" and a value equal to seawater density is to be used unless a higher value is specified by designer/owner.

3.7.2 Oil cargo density for fatigue assessment

The reason for having a different value of SG (specific gravity) for fatigue and strength assessment lies in the way that the fatigue and strength assessment capacities are evaluated.

The objective with the fatigue assessment is to capture an average value for the entire trading life of a ship; hence a conservative mean SG value of 0.9 is selected for this purpose. The specified cargo SG of 0.9 for fatigue assessment is a minimum value. A higher value may be specified by the owner or designer.

3.7.3 Dry cargo density

Technical background is not considered necessary.

3.7.4 Water ballast density

Technical background is not considered necessary.

3.8 Structural construction and inspection

3.8.1

Technical background is not considered necessary.

3.8.2

This regulation corresponds to the functional requirements specified in the Tier II.11 of Goal Based Standards, GBS.

3.8.3

Technical background is not considered necessary.

3.8.4

Technical background is not considered necessary.

3.8.5

Technical background is not considered necessary.

3.9 Maximum service speed

3.9.1

Technical background is not considered necessary.

3.10 Owner's extras

3.10.1

Technical background is not considered necessary.

4 DESIGN PRINCIPLES

4.1 Overall principles

4.1.1 Introduction

Technical background is not considered necessary.

4.1.2 General

Technical background is not considered necessary.

4.1.3 Limit state design principles

Technical background is not considered necessary.

4.2 Loads

4.2.1 Design load scenarios

Technical background is not considered necessary.

4.3 Structural capacity assessment

4.3.1 General

The structural capacity models used in the Rules are classified according to limit state principles. The criticality class as identified in the systematic review for each structural component is applied to link the specified design load scenario to the structural requirement.

Yielding and buckling are controlled explicitly by the application of structural strength criteria. Rupture is controlled implicitly by limits applied to the yielding failure modes. Brittle fracture is controlled implicitly by the selection of suitable materials associated with location of the structural component.

Fatigue cracks are caused by cyclic loads and are controlled explicitly by the application of fatigue strength criteria for selected critical structural elements. The nature of fatigue cracking is different to the strength failure modes and consequently assessed using different capacity models.

4.3.2 Capacity models for ULS, SLS and ALS

The strength failure modes are controlled by means of structural capacity models. Capacity models are considered to include two related parts:

(a) Selection of structural response model. The means of determination of stresses and deformations are related to the selected strength assessment method and the magnitude of the design loads.

(b) Selection of strength assessment criteria. The strength assessment method is capable of analysing the failure mode in question to a suitable degree of accuracy. The assessment method for the various rule requirements may be different, even for the same failure mode, as the degree of utilisation of the capacity may differ.

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

- Whether the structural member is also assessed at a higher level in the hierarchy and/or at a later stage by more accurate methods or by more accurate response calculations.

- Simplified capacity models where some of the stress components are neglected are always give conservative results.
- Appropriate methodology to assess the failure mode.
- Probability level of the load.
- Capability of response calculations to represent the physical behaviour of the structure up to the given load level.
- Complexity of structure.
- Complexity of loads.
- Criticality of the structural member. This will primarily have an impact on the assessment criteria, but needs to be considered in conjunction with selection of the appropriate methodology for structural assessment.

The ultimate capacity of the hull girder or structural member is assessed by methods that are capable of determining the structural capacity beyond the elastic response range. This implies that these methods account for redistribution of forces, large deformations and non-linearities. The acceptance criteria regulate the permissible extent of plasticity and deformation.

Other methods used are capable of assessing the structure beyond the elastic range, but not to the full utilisation of the capacity. The acceptance criteria regulate the permissible extent of plasticity and force redistribution.

The load effects in terms of structural responses are determined by analytical methods on a prescriptive format or by direct calculations. Direct calculations usually refer to 3D analysis based on linear finite element methods. The method adopted to determine the structural response matches the requirements given by the assessment methods.

4.3.3 Capacity models for FLS

The accumulated damage caused by the cyclic loads over the entire design life is considered. The fatigue life depends on the local hot spot stress and hence is related to the design of structural details and quality of workmanship.

The fatigue assessment method is based on the expected number of cyclic loads and structural response from trading based on the design life in the design external environment (25 years in the North Atlantic environment). The method is based on a linear cumulative damage theorem (i.e. Palmgren-Miner's rule) in combination with S-N curves, a characteristic stress range and an assumed long-term stress distribution curve. The long-term stress distribution range curve is assumed to follow a Weibull probability distribution.

The method accounts for the combined effect from global and local loads.

4.3.4 Net scantling approach

Technical background is not considered necessary.

4.3.5 Intact structure

Technical background is not considered necessary.

5 RULE DESIGN METHODS

5.1 General

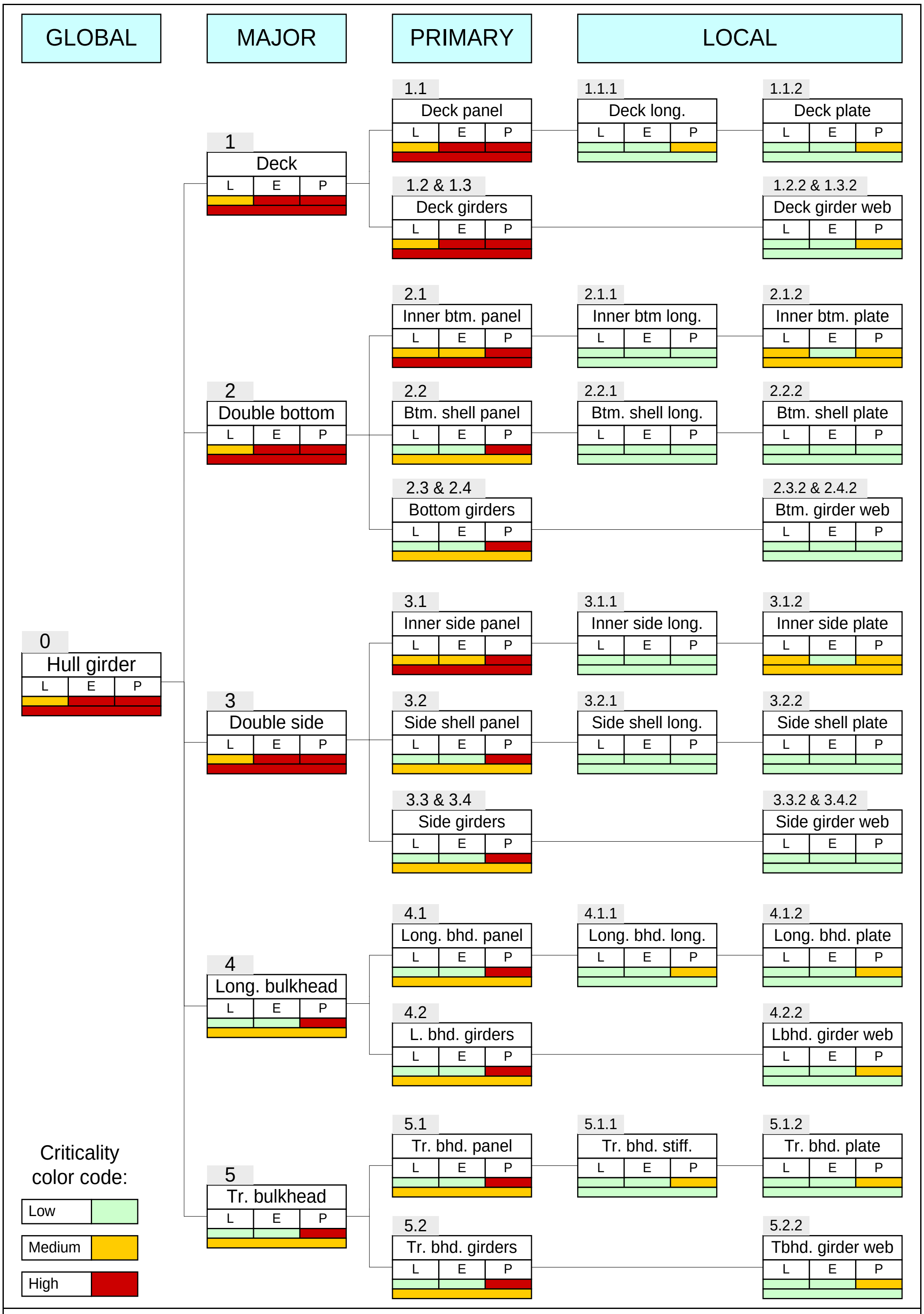
5.1.1 Design methods

The purpose of the various design methods is to ensure satisfactory levels of safety, serviceability and durability. To verify this, calculations are performed according to a chosen design method. The safety margins for the various elements reflect the consequence of a failure.

The classification of the criticality of each structural component with respect to the consequences to Life, Environment and Property in the hierarchical tree allowed each structural component to be assigned a "criticality class". This facilitated the selection of acceptance criteria and capacity models such that the more critical elements have stricter requirements and hence a lower probability of failure than less critical elements.

A schematic diagram of the "criticality class" for all structural elements in the cargo region is shown in Figure 2. A "top-down" approach is used; i.e. starting at the top level (hull girder) of the hierarchy (i.e. the hull girder) and working downwards through all levels of the hierarchy to the plates and stiffeners. The criticality at the next higher level is always set to be equal to or higher than the level below.

Figure 2: Criticality class of structural elements in the cargo region



Symbols:

L Life

E Environment

P Property

The following design methods are considered in the Rules:

(a) The working stress design (WSD) method, also known as the permissible or allowable stress method.

(b) The partial safety factor (PSF) method, also known as load and resistance factor design method (LRFD).

The PSF method separates the influence of uncertainties and variability originating from different causes by means of partial factors for each load and capacity component. The WSD method addresses the same limit states as the PSF method but accounts for the influence of uncertainty by a single usage factor as an allowable stress or similar such criteria. The PSF method allows for a more flexible and optimal design assessment when complex load and structural models are employed.

The working stress design (WSD) format is used as the main method to verify the structural design in the Rules. Both the WSD and PSF methods have to ensure a consistent and acceptable safety level for all combinations of static and dynamic load effects. The acceptance criteria for both the WSD method and PSF method were calibrated for the various rule requirements such that a consistent and acceptable safety level for all combinations of “S” (static) and “S+D” (static plus dynamic) load effects were achieved.

5.2 Minimum requirements

5.2.1

Technical background is not considered necessary.

5.3 Load-capacity based requirements

5.3.1 General

Technical background is not considered necessary.

5.3.2 Design loads for SLS, ULS and ALS

Technical background is not considered necessary.

5.3.3 Design loads for FLS

Technical background is not considered necessary.

5.3.4 Structural response analysis

Technical background is not considered necessary.

5.4 Acceptance criteria

5.4.1 General

Technical background is not considered necessary.

5.4.2 Acceptance Criteria

Technical background is not considered necessary.

5.5 Design verification

5.5.1 Design verification – hull girder ultimate strength

Technical background is not considered necessary.

5.5.2 Design verification – global finite element analysis

Technical background is not considered necessary.

5.5.3 Design verification – fatigue assessment

Technical background is not considered necessary.

5.5.4 Relationship between prescriptive scantling requirements and FE analysis

Technical background is not considered necessary.

1 GENERAL

1.1 Newbuilding

1.1.1

Technical background is not considered necessary.

1.1.2

The requirement defines the items that the Society carries out during construction, which have been done in order to verify the compliance for new building in a conventional manner.

1.1.3

Technical background is not considered necessary.

1.1.4

Refer to TB [1.1.2].

1.1.5

Technical background is not considered necessary.

1.2 Ships in service

1.2.1

Technical background is not considered necessary.

2 DOCUMENTS TO BE SUBMITTED

2.1 Documentation and data requirements

2.1.1 Loading information

Technical background is not considered necessary.

2.1.2 Calculation data and results

Further detailed requirements for information to be submitted to support the calculations can be found in the relevant chapter of the Rules.

2.2 Submission of plans and supporting calculations

2.2.1 Plans and supporting calculations are to be submitted for approval

Plans, documents and calculation data necessary for the approval and the follow up of the fabrication/construction of the ship shall be submitted to the plan approval office for approval process.

2.2.2 Plans to be submitted for information

Plans to be submitted for approval process are listed in TB [2.2.1].

2.2.3 Plans or instruments to be supplied onboard the ship

One key requirement is for provision of steel renewal thickness information on the plans, except the plans of casing, superstructures and deckhouses of which the required scantlings are based on gross scantling, provided to the Shipowner for retention onboard the ship. Note the need also to provide hull girder sectional properties. This is to enable the consistent application of the net thickness concept throughout the life of the ship. In addition, in cases where post-weld fatigue strength improvement methods have been taken into consideration to achieve the calculated fatigue life of 25 years according to Pt. 1, Ch. 9, Sec. 3, [6], the location of structural details where the benefit of post-weld treatment is applied is to be informed to the owner and class so that the structural details will be properly dealt with during operation and maintenance, and have better follow-up of the coating condition during the ship's life.

3 SCOPE OF APPROVAL

3.1 General

3.1.1

Technical background is not considered necessary.

3.1.2

Technical background is not considered necessary.

3.1.3

Technical background is not considered necessary.

3.2 Requirement of international and national regulations

3.2.1 Responsibility

The responsibilities are clearly defined to describe the current position and to avoid any ambiguity.

4 WORKMANSHIP

4.1 Requirements to be complied with by the manufacturer

4.1.1

This regulation corresponds to the functional requirements specified in the Tier II.11 of Goal Base Standards, GBS.

4.2 Quality control

4.2.1

This regulation is based on the functional requirements specified in the Tier II.11 of Goal Based Standards, GBS.

5 STRUCTURAL DETAILS

5.1 Details in manufacturing documents

5.1.1

This regulation is based on the functional requirements specified in the Tier II.11 of Goal Based Standards, GBS.

6 EQUIVALENCE PROCEDURES

6.1 Rule applications

6.1.1

Technical background is not considered necessary.

6.1.2

Technical background is not considered necessary.

6.2 Novel designs

6.2.1

Technical background is not considered necessary.

6.2.2

Technical background is not considered necessary.

6.2.3

Technical background is not considered necessary.

6.2.4

Technical background is not considered necessary.

6.3 Alternative calculation methods

6.3.1

Technical background is not considered necessary.

1 PRIMARY SYMBOLS AND UNITS

1.1 General

1.1.1

Definitions of primary symbols and units used in the Rules are specified.

2 SYMBOLS

2.1 Ship's main data

2.1.1

Definitions of ship main data are specified.

2.2 Materials

2.2.1

Definitions of symbols used for the characteristics of materials are specified.

2.3 Loads

2.3.1

Definitions of symbols used for loads are specified.

2.4 Scantlings

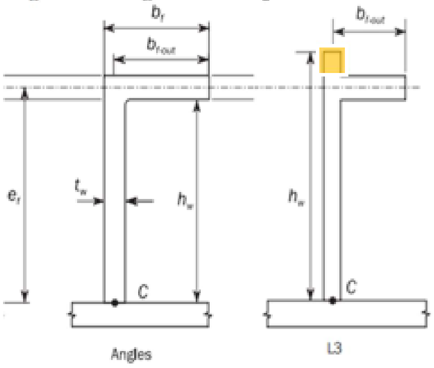
2.4.1

Definitions of symbols used for scantlings are specified.

Based on investigation of industry practice, it is understood that L3 profile is used purely for the purpose of easy manufacturing instead of further strengthening with extra web material beyond flange plate. Accordingly, in RCN 1 to CSR 01 Jan 2021 it is suggested to remove requirements related to L3 profile stiffeners from the rule. Hence, respective L3 profile symbol '*de*' has been removed from Table 5.

However, for rule strength assessment purpose, as a common practice and due to marginal effect, it is suggested to simply take L3 profile as a standard Angle bar disregarding the extra part of the web height which is purely used for fabrication purpose (the yellow shaded part as shown in Figure 1), instead of using actual shape.

Figure 1. Angle and L3 profile stiffeners



3 DEFINITIONS

3.1 Principle Particulars

3.1.1 *L*, Rule length

The definition is in accordance with IACS UR S2 (Rev 1, May 2010), however "measured on the summer load waterline" has been changed to "scantling draught", which is the maximum permissible draught with respect to hull scantlings. This definition avoids that a ship may be assigned with different rule lengths depending of freeboard selected.
L is to be used for CSR requirements originated from IACS.

3.1.2 L_{LL}, freeboard length

The definition is in accordance with International Convention on Load Lines (ICLL), as amended by the 1988 Protocol by Res. MSC.143(77) in 2003, and further amended in 2008, Annex I, Ch I, Reg. 3(1), given here for information.
L_{LL} is to be used for statutory related CSR requirements and other relative requirements, which may not come from statutory requirements, for harmonious rule application.

3.1.3 Moulded breadth

Technical background is not considered necessary.

3.1.4 Moulded depth

Technical background is not considered necessary.

3.1.5 Draughts

Technical background is not considered necessary.

3.1.6 Moulded displacement

Technical background is not considered necessary.

3.1.7 Maximum service speed

Technical background is not considered necessary.

3.1.8 Block coefficient

The definition is in accordance with IACS UR S2 (as amended).

3.1.9 Lightweight

Technical background is not considered necessary.

3.1.10 Deadweight

Technical background is not considered necessary.

3.1.11 Fore end

Technical background is not considered necessary.

3.1.12 Aft end

Technical background is not considered necessary.

3.1.13 Midship

Technical background is not considered necessary.

3.1.14 Midship part

Technical background is not considered necessary.

3.1.15 Forward freeboard perpendicular

Technical background is not considered necessary.

3.1.16 After freeboard perpendicular

Technical background is not considered necessary.

3.2 Position 1 and Position 2

3.2.1 Position 1

The definition is in accordance with International Convention on Load Lines (ICLL), as amended by the 1988 Protocol by Res. MSC.143(77) in 2003, Annex I, Ch II, Reg. 13, given here for information.

3.2.2 Position 2

The definition is in accordance with International Convention on Load Lines (ICLL), as amended by the 1988 Protocol by Res. MSC.143(77) in 2003, Annex I, Ch II, Reg. 13, given here for information.

3.3 Standard height of superstructure

3.3.1

The definition is in accordance with International Convention of Load Line (ICLL), as amended by the 1988 Protocol by Res. MSC.143(77) in 2003, Annex I, Ch III, Reg. 33, given here for information.

3.3.2

The definition of tier is taken from CSR OT Sec 11, [1.4.3.3].

3.4 Type A and Type B freeboard ships

3.4.1 Type A ship

The definition is in accordance with International Convention of Load Line (ICLL), as amended by the 1988 Protocol by Res. MSC.143(77) in 2003, and further amended in 2012, Annex I, Ch III, Reg. 27, given here for information.

3.4.2 Type B ship

The definition is in accordance with International Convention of Load Line (ICLL), as amended by the 1988 Protocol by Res. MSC.143(77) in 2003, and further amended in 2012, Annex I, Ch III, Reg. 27, given here for information.

3.4.3 Type B-60 ship

The definition is in accordance with International Convention of Load Line (ICLL), as amended by the 1988 Protocol by Res. MSC.143(77) in 2003, and further amended in 2012, Annex I, Ch III, Reg. 27, given here for information.

3.4.4 Type B-100 ship

The definition is in accordance with International Convention of Load Line (ICLL), as amended by the 1988 Protocol by Res. MSC.143(77) in 2003, and further amended in 2012, Annex I, Ch III, Reg. 27, given here for information.

3.5 Operation definition

3.5.1 Multiport

This definition is added for avoiding the ship sails on long trips during long time which could have impact on the fatigue strength.

3.5.2 Sheltered water

Technical background is not considered necessary.

3.6 Reference coordinate system

3.6.1

Technical background is not considered necessary.

3.7 Naming convention

3.7.1 Structural nomenclature

Nomenclature is in accordance with IACS Rec 82 (July 2003), "Surveyor's Glossary - hull terms and hull survey terms".

3.8 Glossary

3.8.1 Definition of terms

Terminology is in general in accordance with IACS Rec 82 (July 2003), "Surveyor's Glossary - hull terms and hull survey terms". Additional terms and definitions have been added when needed.

1 GENERAL REQUIREMENTS

1.1 Application

1.1.1
TB is not considered necessary.

1.1.2
The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

1.1.3
The regulation is based on IACS UR S25 (which no more in force).

1.1.4
Technical background is not considered necessary.

1.2 Annual and class renewal survey

1.2.1
The regulation is based on IACS UR S1.1.3 (Rev 7, May 2010).

1.2.2
The regulation is based on IACS UR S1.1.3 (Rev 7, May 2010).

1.2.3
The regulation is based on IACS UR S1.1.3 (Rev 7, May 2010).

2 LOADING MANUALS

2.1 General requirements

2.1.1 Definition
The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

2.1.2 Condition of approval
The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

2.1.3 Loading conditions
The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

2.1.4 Operational limitations
The regulation lists major design limits used as the basis for the standard rule requirements and that may have an impact on operational flexibility. These operational limitations are used in the rule structural design process. If there is a wish/need to exceed these limits during operation of the vessel the extended limits are to be specified and included in the design assessment and are therefore required to be included in the loading manual.

2.2 Requirements specific to oil tankers

2.2.1
Technical background is not considered necessary.

2.3 Requirements specific to bulk carriers

2.3.1
Technical background is not considered necessary.

2.3.2
The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

2.3.3
The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

3 LOADING INSTRUMENT

3.1 General requirements

3.1.1 Definition
The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

3.1.2 Conditions of approval of loading instruments
The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

3.2 Requirements specific to bulk carriers

3.2.1 General
The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

3.2.2 Conditions of approval

4 LOADING SPECIFIC TO BULK CARRIERS

4.1 Guidance for loading/unloading sequences

4.1.1 Scope of application
Technical background is not considered necessary.

4.1.2
The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

4.1.3
The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

4.1.4
The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

4.1.5
The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

4.1.6

The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

4.1.7

The regulation is based on IACS UR S1 (Rev 7, May 2010) and S1A (Rev 6, May 2010).

PART 1 CHAPTER 2

GENERAL ARRANGEMENT DESIGN

Table of Contents

1 GENERAL

1.1 General

1.1.1

Technical background is not considered necessary.

1.1.2

Technical background is not considered necessary.

1.1.3

Technical background is not considered necessary.

1 WATERTIGHT BULKHEAD ARRANGEMENT

1.1 Number and disposition of watertight bulkheads

1.1.1

This requirement is based on Ch II-1, Reg. 12 of the SOLAS Convention 1974, given here for information.

1.1.2

To give ships with an electrical propulsion plant the safety level as same as other type of ships, both the generator room and engine room are to be enclosed by watertight bulkheads.

1.1.3

The bulkheads in the cargo area are to be fitted taking into account the floodability and damage stability in accordance with the requirements in the SOLAS Convention and other relevant International (as request in Ch 1, Sec 2, [2.1.2]) and National regulations.

1.1.4

This requirement is based on SOLAS, Ch II-1, Reg 12 (as amended), given here for information but the number of bulkhead comes from RINA Rules.

1.1.5

Technical background is not considered necessary.

1.2 DELETED

2 COLLISION BULKHEAD

2.1 Extent and position of collision bulkhead

2.1.1

The requirement is based on Ch II-1, Reg. 12.1 of the SOLAS Convention (as amended) given as Classification requirements.

2.1.2

The requirement is based on Ch II-1, Reg. 12.3 of the SOLAS Convention (as amended by the 2017 SOLAS Amendments) given as Classification requirements.

2.2 Arrangement of collision bulkhead

2.2.1

This requirement is based on Ch II-1, Reg. 12.4 of the SOLAS Convention (as amended) given as Classification requirements.

2.2.2

This requirement is based on Ch II-1, Reg. 12.5 of the SOLAS convention (as amended) given as Classification requirements.

3 AFT PEAK BULKHEAD

3.1 General

3.1.1

The aft peak bulkhead is required in this rule, although SOLAS require it only for passenger ships in Ch II-1, Reg. 12.10 (as amended).

3.1.2

This requirement is based on Ch II-1, Reg. 12.10 of the SOLAS Convention (as amended), which is for passenger ships and cargo ships. This IMO requirement is considered as a part of the Classification requirement.

As stated in Ch II-1, Reg. 12.10 of the SOLAS Convention (as amended), the afterpeak bulkhead may be stepped below the bulkhead deck or the freeboard deck, provided the degree of safety of the ship as regards subdivision is not thereby diminished.

According to explanatory notes for Reg. 12.10 the following guidance is given:

"In cargo ships with a raised quarter deck, it may be impracticable to extend the afterpeak bulkhead to the freeboard deck as the freeboard deck does not extend to the aft perpendicular. Provided that the afterpeak bulkhead extends above the deepest load line, and that all rudderstock bearings are housed in a watertight compartment without open connection to spaces located in front of the afterpeak bulkhead, termination of the afterpeak bulkhead on a watertight deck lower than the freeboard deck can be accepted by the Administration."

For the WT integrity, all rudderstock bearings below the steering gear flat need to be separated from the steering gear by a WT sealing at the rudderstock.

This means that for conventional cargo ship arrangements, as for bulk carrier as and oil tankers, termination of the watertight aft E/R bulkhead will be permitted at the steering gear flat if the water tight steering gear flat is located above the deepest load line (typ. scantling draught). In order to provide a watertight steering gear flat a watertight sealing of the rudder stock shall be fitted in way of the steering gear flat or above.

3.1.3

Technical background is not considered necessary.

3.1.4

Refer to TB [3.1.2].

1 COFFERDAMS

1.1 Definition

1.1.1

This requirement is based on CSR BC (July 2010), Ch 2, Sec 2, [1.1.1] (based on the Reg 2, Sec 1, Ch 2, Pt A of the RINA Rules, January 2013).

1.2 Arrangement of cofferdams

1.2.1

This requirement is based on CSR BC (July 2010), Ch 2, Sec 2, [2.1.1] (based on 2.1.1, Sec 2, Ch 2, Pt B of the RINA Rules, January 2013).

1.2.2

This requirement is based on CSR BC (July 2010), Ch 2, Sec 2, [2.1.3] (based on the first sentence of 2.1.3, Sec 2, Ch 2, Pt B of the RINA Rules, January 2013).

1.2.3

This requirement is based on CSR BC (July 2010), Ch 2, Sec 2, [2.1.4] (based on 2.1.4, Sec 2, Ch 2, Pt B of the RINA Rules, January 2013).

2 DOUBLE BOTTOM

2.1 General

2.1.1

Technical background is not considered necessary.

2.2 Extent of double bottom

2.2.1

For bulk carriers, this requirement is based on Ch II-1, Reg 9.1 of the SOLAS Convention (as amended), which is for passenger ships and cargo ships other than tankers. For oil tankers, this requirement is based on Annex I, Ch 4, Reg 22 of MARPOL (as amended).

2.2.2

This requirement is based on Ch II-1, Reg 9.2 of the SOLAS Convention (as amended), which is for passenger ships and cargo ships other than tankers.

2.3 Height of double bottom

2.3.1

For bulk carriers, this requirement is based on Ch II-1, Reg 9.2 of the SOLAS Convention (as amended).

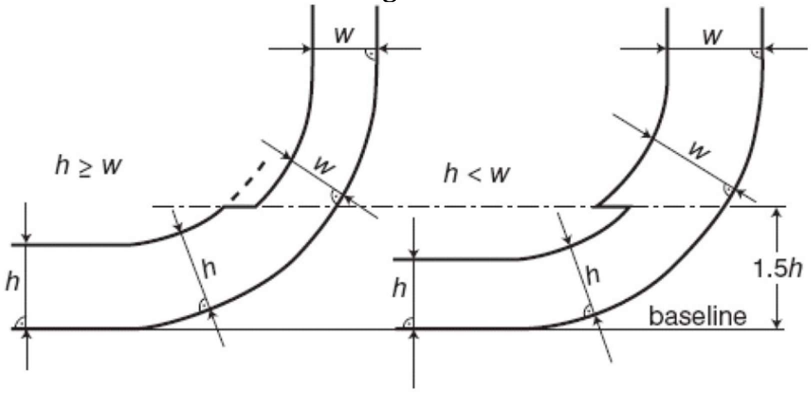
The measurement of double bottom height for tanker is based on MARPOL Annex I Regulation 19.3.2, Figure 1. This requirement applies to the whole range in double bottom up to 1.5h above the base line for turn of the bilge area or at locations without a clearly defined turn of bilge.

At any cross-section, the depth of each double bottom tank or space shall be such that the distance h between the bottom of the cargo tanks and the moulded line of the bottom shell plating measured at right angles to the bottom shell plating as shown in Figure 1 is not less than specified below:

h = B/15 (m) or
h = 2.0 m, whichever is the lesser

The minimum value of h = 1.0 m

Figure 1



2.4 Small wells in double bottom tank

2.4.1

This requirement is based on Ch II-1, Reg 9.3 of the SOLAS Convention (as amended), which is for passenger ships and cargo ships other than tankers.

3 DOUBLE SIDE

3.1 Double side width

3.1.1 Oil tanker

This requirement is based on Annex I, Ch 4, Reg 19.3.1 of MARPOL (as amended).

3.1.2 Bulk carriers

This requirement is based on Ch XII, Reg 1.4 of the SOLAS Convention (as amended). The minimum double side width is in accordance with SOLAS, Ch XII, Reg 6 (as amended).

3.2 Minimum clearance inside the double side

3.2.1 Definition

This requirement is based on Ch XII, Reg 6.2.2.5 of the SOLAS Convention (as amended).

3.2.2 Minimum clearance dimensions

This requirement is based on Ch XII, Reg 6.2.2 of the SOLAS Convention (as amended).

4 FORE END COMPARTMENTS

4.1 General

4.1.1

This requirement is based on Ch II-2, Reg 4.2.2.3.1 of the SOLAS Convention (as amended).

5 FUEL OIL TANKS

5.1 Arrangement of fuel oil tanks

5.1.1

This requirement is based on SOLAS, Ch II-2, Reg 4.2 (as amended) and MARPOL, Annex I, Ch 3, Reg 12A (as amended).

6 AFT END COMPARTMENTS

6.1 Sterntube

6.1.1

This requirement is based on Ch II-1, Reg 12.10 of the SOLAS Convention (as amended).

7 BALLAST TANKS

7.1 Capacity and disposition of ballast tanks

7.1.1

For bulk carriers, this requirement is based on UR S25 (which no more in force). For oil tankers, this requirement is based on Annex I, Ch 4, Reg 18 of MARPOL (as amended).

1 ENCLOSED SPACES

1.1 General

1.1.1 Special considerations

The first paragraph is generally introductory in nature, but again alludes to the use of Rec.132, or other standards accepted by the Society, for additional ergonomic considerations. The second paragraph is to draw attention to the fact that there may be spaces on board where additional requirements for access exist and these may, in some instances, create conflict with the content of the CSR. Therefore, this clause offers a pragmatic approach of identifying such conflicts at an early stage so that they may be suitably considered by the Society.

1.1.2 Enclosed spaces

Technical background is not considered necessary.

1.1.3 Spaces not explicitly covered by SOLAS

Technical background is not considered necessary.

1.1.4 Ventilation of normally unmanned spaces

This requirement is based on the content of Rec. 132.

1.1.5 Permanent means of access to normally unmanned spaces

This paragraph reiterates that PMA requirements for 'normally unmanned' spaces are to be in accordance with SOLAS, Ch II-1, Reg. 3-6.

The text goes on to extend this SOLAS regulation to spaces that are not currently covered by the same regulation. However, it is noted that it may not be practicable to apply such regulations to some smaller or isolated spaces, therefore the requirements are to be applied 'as far as practicable' in the eyes of the Society. This is a pragmatic approach that provides an adequate level of prescription with a proven solution (SOLAS) but also allows for alternative approaches, so long as such are acceptable to the Society, e.g., application of MSC.1/Circ.1455 considering mitigation of risk to levels analogous to those associated with PMA of the spaces covered by SOLAS, Ch II-1, Reg. 3-6 with compliant PMA arrangements.

2 CARGO AREA AND FORWARD SPACES

2.1 General

2.1.1 Means of access

GBS is applicable to ships above 150 m in length. This requirement is based on SOLAS, Ch II-1, Reg. 3-6 (as amended) considered for the Classification and includes in addition the application to bulk carriers of less than 20,000 GT but having a length of 150m and above to avoid a gap between SOLAS Reg II-1, Reg. 3-6 and CSR.

2.1.2

Technical background is not considered necessary.

PART 1 CHAPTER 3

STRUCTURAL DESIGN PRINCIPLES

Table of Contents

1 GENERAL

1.1 Standard of material

1.1.1

Since regulations related to material standards, material tests, and manufacturing methods exist in the rules of every Society, general regulations have been specified to refer to them.

1.1.2

Technical background is not considered necessary.

1.2 Testing of materials

1.2.1

Refer to TB [1.1.1].

1.3 Manufacturing process

1.3.1

Refer to TB [1.1.1].

2 HULL STRUCTURAL STEEL

2.1 General

2.1.1 Young's modulus and Poisson's ratio

Technical background is not considered necessary.

2.1.2 Steel material grades and mechanical properties

This regulation is in accordance with IACS UR W11 (Corr. 1, February 2009). The term "normal" was adopted in IACS UR W11 (Corr. 1, February 2009) and it is used here.

2.1.3

This regulation is in accordance with IACS UR W11 (Corr. 1, February 2009).

2.1.4 High tensile steel

This regulation is in accordance with IACS UR W11 (Corr. 1, February 2009).

2.1.5 Onboard documents

Technical background is not considered necessary.

2.2 Material factor, *k*

2.2.1

This regulation is in accordance with IACS UR S4 (Rev 3, May 2010).

2.3 Steel grades

2.3.1

This regulation is in accordance with IACS UR S6.1 (Rev 9, Corr.1 Mar 2021).

2.3.2

This regulation is in accordance with IACS UR S6.1 (Rev 9, Corr.1 Mar 2021).

2.3.3

This regulation is in accordance with IACS UR S6.1 (Rev 9, Corr.1 Mar 2021).

2.4 Structures exposed to low air temperature

2.4.1

It has been decided to apply the Rules for Material of each Society for the requirements concerning the material of structures exposed to low air temperature. The reference low air temperature is equal to -10°C since IACS UR S6.1 (Rev 9, Corr.1 Mar 2021) was developed based on worldwide service using a lowest mean daily average temperature of -10°C.

2.5 Through thickness property

2.5.1

This requirement is from CSR OT, Sec 6/1.1.5.1 (July 2010).

2.6 Stainless steel

2.6.1

Technical background is not considered necessary.

3 STEELS FOR FORGING AND CASTING

3.1 General

3.1.1

This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 3.1.1 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 3.1.1).

3.1.2

This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 3.1.2 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 3.1.2).

3.1.3

This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 3.1.3 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 3.1.3).

3.2 Steels for forging

3.2.1

This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 3.2.1 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 3.2.2).

3.3 Steels for casting

3.3.1

This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 3.3.1 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 3.3.1).

3.3.2
This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 3.3.2 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 3.3.3).

4 ALUMINIUM ALLOYS

4.1 General

4.1.1
This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 4.1.1 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 4.1.1).

4.1.2
This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 4.1.2 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 4.1.2).

4.1.3
This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 4.1.3 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 4.1.3).

4.1.4
Technical background is not considered necessary.

4.2 Extruded plating

4.2.1
This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 4.2.1 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 4.2.1).

4.2.2
This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 4.2.2 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 4.2.2).

4.2.3
This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 4.2.3 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 4.2.3).

4.2.4
This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 4.2.4 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 4.2.4).

4.3 Mechanical properties of weld joints

4.3.1
This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 4.3.1 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 4.3.1).

4.3.2
This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 4.3.2 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 4.3.2).

4.3.3

This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 4.3.3 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 4.3.3).

4.4 Material factor, *k*

4.4.1

This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 4.4.1 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 4.4.1).

4.4.2

This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 4.4.2 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 4.4.2).

4.5 Others

4.5.1

This requirement is from CSR OT (July 2010), Sec 6/1.3.2 (based on LR Rules (January 2013), Pt 4, Ch 9, 2.3.1).

4.5.2

This requirement is from CSR OT (July 2010), Sec 6/1.3.2 (as amended and based on based on LR Rules (January 2013), Pt 4, Ch 9, 2.3.1). Aluminium may, under certain circumstances give rise to incendiary sparking on impact with oxidised steel. A particular risk is where an aluminium component is dragged or rubbed against the uncoated steel structure creating a thin smear of aluminium on the surface. Subsequent high energy impact by a rusted component on that smear could generate an incendiary spark capable of igniting any surrounding inflammable gas.

5 OTHER MATERIALS AND PRODUCTS

5.1 General

5.1.1

This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 5.1.1 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 5.1.1).

5.1.2

This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 5.1.2 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 5.1.2).

5.2 Iron cast parts

5.2.1

This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 5.2.1 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 5.2.1).

5.2.2

This requirement is from CSR BC (July 2010), Ch 3, Sec 1, 5.2.2 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 1, 5.2.2).

1 GENERAL

1.1 Application

1.1.1 Net thickness approach

Technical background is not considered necessary.

1.1.2 Local and global corrosion

Technical background is not considered necessary.

1.1.3 Exceptions in gross scantling

The structural scantlings in the Rules are based on the net scantling approach, but for massive structures such as superstructure, deckhouse, rudder structure, and massive pieces of forgings and castings, the scantlings of which are decided by empirical formulae, one cannot distinguish clearly the scantlings according to strength and the scantlings according to corrosion and thickness diminution; therefore, the non-application of the net scantling approach has been noted here.

1.2 Gross and net scantling definitions

1.2.1 Gross required thickness

The formula provided in these paragraphs reiterates the most significant relationships which can be derived from Figure 1.

1.2.2 Gross offered thickness

Refer to TB [1.2.1].

1.2.3 Net offered thickness

Refer to TB [1.2.1].

1.3 Scantling Compliance

1.3.1

Technical background is not considered necessary.

1.3.2

Compliance with the Rules can be broadly divided into two types as follows:

(a) Required thickness determined from rule formulae.

(b) Scantling that determines the structural properties, such as section properties from rule formulae, or thickness assessed from direct strength calculations, longitudinal bending strength, or fatigue strength assessment.

Item (a) was defined as the required net thickness, while item (b) was defined as the offered scantling. In each case, the application method of the corrosion addition was clearly defined.

Table 1: Assessment for corrosion applied to the gross scantlings (Refer to Rules)

For assessment of overall strength by the direct strength calculation or assessment of hull girder strength, the assumption that the thickness of all structural members to be assessed reduces to the permissible wastage amount is an assumption on the side of excessive safety. Considering the variation in the corrosion phenomenon, reduction in thickness to the average wastage amount may be assumed, where half the corrosion addition may be considered as the average wastage amount. In assessing the buckling strength of stiffeners or panels, stresses acting on the stiffeners or panels are used assuming that complete structures are in a fully corroded state. Since critical buckling stresses in stiffeners or panels are for local structures, these structures are assumed to be in a fully corroded state of 100% of corrosion addition for assessment on the side of safety.

Repetitive loads encountered within the assumed service period were considered for the fatigue strength assessment. Assessment is difficult for the elapsed period from the time of a new ship when the members to be assessed are not corroded at all, until the members to be assessed are in the wasted condition with the corrosion amount assumed for the assumed service period. It was therefore decided to assume an average corrosion and reduced thickness condition during the assumed service period. In the application of average corrosion amount in the fatigue strength assessment, since corrosion is minimal during the period the painting is effective, the assessment is very much on the safe side.

For fatigue strength assessment of local structures, a net thickness deducting half the corrosion addition from gross thickness is applied. In keeping with this, hull girder stresses for fatigue check are to be based on deducting a quarter of the corrosion addition from gross scantlings. Hull girder stresses based on this approach corresponds approximately to stresses in a model deducting half of the corrosion additions from gross scantlings multiplied by a correction factor of 0.95. In order to maintain consistency with other corrosion models, therefore, a corrosion model deducting half of the corrosion addition from gross scantlings is applied for hull girder stress determination in fatigue assessment.

As a conclusion, two corrosion models are considered; that is 100% corrosion additions are taken for the local scantling formulae and buckling capacity assessment and 50% corrosion additions are taken for hull girder check, FEA and fatigue check.

1 GENERAL

1.1 Applicability

1.1.1

Regarding the application of stainless steel, stainless clad steel and aluminium materials, it is recognised that while these materials may experience little or no corrosion in service, structures comprising of these materials in the ship might be subjected to mechanical wear and abrasion in service. To allow for this a corrosion addition of 0.5mm (t_{res}) has been specified consistent with the practice in the existing rules of many societies.

Regarding other materials that are not shipbuilding quality carbon steels, since no specific corrosion data has been considered in the development of these Rules on steels other than carbon steel (general steel), separate considerations are required for setting the corrosion addition.

1.2 Corrosion addition determination

1.2.1

The corrosion addition for each structural member, particularly those that form the boundaries of compartments, is to be determined after considering the application to each side of the member. The corrosion amount for each factor of the corrosive environment is in 0.1mm units. However, considering the relationship of the corrosion amount with the renewal criteria and that the nominal thickness of steel is generally in 0.5mm units, the value obtained by adding the value of the corrosive environment on one side to that of the other side is rounded up to 0.5mm units, and to this value, the maximum value of corrosion amount estimated to progress during the survey interval (2.5 years) of 0.5mm is added to arrive at the value of corrosion addition.

1.2.2 Minimum value of corrosion addition

A 2mm minimum corrosion addition is to generally be applied to all structure, consistent with Table 1. The general minimum of 2mm is not necessary for internals of dry spaces and pump rooms as the corrosion data used to generate these requirements shows a much reduced corrosion in service for these items.

1.2.3 Stiffener

Technical background is not considered necessary.

1.2.4

This requirement avoids the complications which would arise from single structural elements having multiple corrosion additions except vertical corrugations with vertical seam arrangements.

The corrosion additions are set as the estimated value of corrosion in a 25 years period from progressive corrosion models based on the probabilistic theory and thickness measurement data of several hundred thousands of points. Reference is made to the TB Report "TB Rep_Pt1_Ch03_Sec03_Corrosion Additions" for additional details on the background to the corrosion additions presented in Table 1.

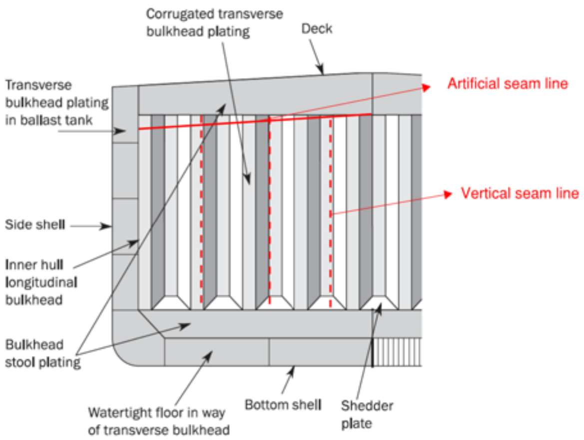
In current designs, the slop tank is usually designed as a cargo oil tank and in actual operation, the slop tank carries cargo oil in most of the time. The corrosion environment is also considered to be the same as for cargo oil tanks and the same corrosion addition should be applied, even though it is used as a storage tank for washing oil/water in limited part of the time.

The corrosion margin comparison for the inner bottom plating with two different approaches are shown below. It is noted that a slop tank is considered as a heated cargo tank and thus it requires a conservative corrosion margin.

Compartment 1	Compartment 2	Required corrosion margin
Slop tank considered as heated cargo tank	Double bottom ballast tank	2.1 + 1.2 + 0.5 + 0.5 = 4.5 mm
Slop tank considered as ballast tank	Double bottom ballast tank	1.2 + 1.2 + 0.5 = 3.0 mm

In order to have an appropriate application of corrosion additions for a vertical corrugation with vertical seams, an artificial seam line along 3m below the deck can be considered so that different corrosion additions can be applied above/below this artificial seam line. With this the realistic thickness requirement for corrugations can be obtained with correct corrosion addition.

The artificial seam line can be indicated on the plans to provide two separate renewal thicknesses defined by Ch 13, Sec 2, and, furthermore, may be marked by weld bead on the corrugation structure to make the different corrosion addition clearly visible for surveys during the ship-in-operation phase. (See Figures below)



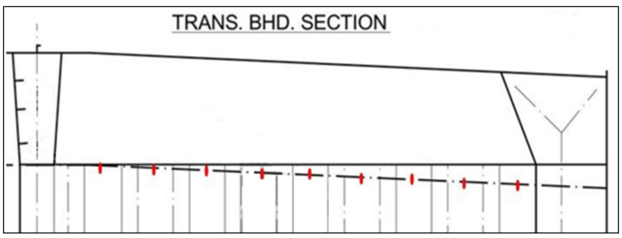


Table 1: Corrosion addition for one side of a structural member (Refer to Rules)

Additional notes to Table 1:

1) This 1.0mm increase in corrosion addition is to address the increased corrosion caused by the mechanical action of the chain cable.

2) This increase in the corrosion addition for structural members between water ballast tanks and heated cargo oil tanks/slop tanks, fuel oil or lube oil tanks is due to the increased corrosion in these areas which was highlighted by the collected data.
3) See Note 2.
4) This requirement for a higher corrosion addition in the upper part of the tank is because of the increased corrosion experienced due to heating from the sun and more aggressive environmental conditions, as also observed from collected data.
5) Technical background is not considered necessary.
6) Technical background is not considered necessary.
7) Transverse plane bulkheads at the forward end of the fore cargo hold and at the aft end of the aft cargo hold are to be treated in three zones in the same way that they are treated for corrugated bulkheads.
8) Corrosive substances (e.g. ballast water, water condensate, sludge etc.) may occur inside the duct keel space making the environment to which the inner surface of the outer shell plating is exposed to be more like that of a ballast tank causing increased corrosion.

1 GENERAL

1.1 Structures to be protected

1.1.1 Dedicated seawater ballast tanks

The designer's information is drawn to the statutory requirements stated in SOLAS, Ch II-1, Reg. 3-2 (as amended) requesting the structures of dedicated seawater ballast tanks to be protected against corrosion.

1.1.2 Cargo oil tanks

Only the locations where paint is to be applied are specified. Thus, compartments carrying fuel oil mentioned herein are subject to treatment similar to the CSR BC and CSR OT rules (July 2010).

1.1.3 Bulk carriers

Refer to TB [1.1.2].

1.1.4 Narrow spaces

Only the locations where paint is to be applied are specified. Thus, narrow compartments not mentioned herein are subject to treatment similar to the CSR BC and CSR OT rules. Narrow compartments can be filled generally with dry air.

2 SACRIFICIAL ANODES

2.1 Attachment of anodes to the hull

2.1.1

This regulation is in accordance with CSR OT (July 2010), Sec 6/2.1.2.4 (based on DNV Rules (January 2013), Pt 3, Ch 3, Sec 7, B300 and LR Rules (January 2013), Pt 3, Ch 2, 3.3 and 3.4).

2.1.2

This regulation is in accordance with CSR OT (July 2010), Sec 6/2.1.2.6 (based on DNV Rules (January 2013), Pt 3, Ch 3, Sec 7, B300 and LR Rules (January 2013), Pt 3, Ch 2, 3.3 and 3.4).

2.1.3

This regulation is in accordance with CSR OT (July 2010), Sec 6/2.1.2.7 (based on DNV Rules (January 2013), Pt 3, Ch 3, Sec 7, B300 and LR Rules (January 2013), Pt 3, Ch 2, 3.3 and 3.4).

2.1.4 Cargo oil tanks

Technical background is not considered necessary.

1 GENERAL

1.1 Limit states

1.1.1 Definition

This regulation defines the limit states such that the definitions coincide with those in ISO 2394 (as amended).

1.1.2 Serviceability limit state

Refer to TB [1.1.1].

1.1.3 Ultimate limit state

Refer to TB [1.1.1].

1.1.4 Fatigue limit state

Refer to TB [1.1.1].

1.1.5 Accidental limit state

This regulation defines the limit states such that the definitions coincide with those in ISO 2394. The flooded condition is considered as accidental limit states like IACS UR S17 (Rev 8, May 2010), S18 (Rev 8, May 2010) and S20 (Rev 5, May 2010).

1.2 Failure modes

1.2.1

Technical background is not considered necessary.

1.2.2 Yielding

Technical background is not considered necessary.

1.2.3 Plastic collapse

Technical background is not considered necessary.

1.2.4 Buckling

Technical background is not considered necessary.

1.2.5 Rupture

Technical background is not considered necessary.

1.2.6 Brittle fracture

Technical background is not considered necessary.

1.2.7 Fatigue cracking

Technical background is not considered necessary.

2 CRITERIA

2.1 General

2.1.1

The hull structure was classified into local structures considering local loads such as plates and stiffeners, primary supporting structures taking up loads on structural bodies such as girders, and the hull girder in which the entire hull structure is treated as a beam, for studying the strength characteristics to be assessed in CSR. The structural assessment items required for each structural category are shown in Table 2.

2.2 Serviceability limit states

2.2.1 Hull girder

This regulation gives the load level for the yielding check of the hull girder corresponding to the serviceability limit state. The strength criterion is based on the working stress design method for the stress obtained by the beam theory. This philosophy is the same of IACS UR S11 (Rev 7, November 2010).

2.2.2 Plating

This regulation gives the load level for the yielding and buckling strength check for platings constituting primary supporting members corresponding to the serviceability limit state. The stress of platings constituting primary supporting members are obtained by the Finite Element Analysis (FEA) based on the elastic theory. The strength criterion is based on the working stress design method.

2.2.3 Stiffeners

This regulation gives the load level for the strength check for ordinary stiffener corresponding to the serviceability limit state. The strength criterion is based on the working stress design method for the stress of ordinary stiffeners obtained by the beam theory.

2.3 Ultimate limit states

2.3.1 Hull girder

This regulation gives the load level for the ultimate strength check of the hull girder corresponding to the ultimate limit state. The strength criterion is based on the partial safety factor design method.

2.3.2 Plating

This regulation gives the load level for the ultimate strength check of the platings corresponding to the ultimate limit state. The strength criterion is based on the working stress design method.

2.3.3 Stiffeners

This regulation gives the load level for the ultimate strength check of the ordinary stiffener corresponding to the ultimate limit state. This strength check is included in the buckling check of stiffeners.

2.4 Fatigue limit state

2.4.1 Structural details

Fatigue strength of structural details such as connections of ordinary stiffeners and primary supporting members is assessed based on the linear cumulative fatigue damage procedure considering the cyclic loads during ship's life. This regulation gives the reference loads level for fatigue strength check.

For fatigue assessment, the expected load history needs to be defined. We assume that the load history can be approximated by a two-parameter Weibull distribution. The parameters are the scaling factor and the shape parameter. The probability level of 10^{-2} has been selected for the determination of scaling factor (loads) as it has been identified as the most contributing probability level to the fatigue damage. Refer to Ch 4, Sec 1.

2.5 Accidental limit state

2.5.1 Hull girder

Refer to TB [1.1.5].

2.5.2 Double bottom structure

Refer to TB [1.1.5].

2.5.3 Bulkhead structure

Refer to TB [1.1.5].

3 STRENGTH CHECK AGAINST IMPACT LOADS

3.1 General

3.1.1

Impact loads differ from general wave loads, and it is difficult to debate the load level of an impact load. This regulation has been specified for general items, while only the concepts of strength criteria used in the Rules have been given in [3.1.2].

3.1.2

This regulation has been specified for the concepts of strength criteria used in the Rules.

1 APPLICATION

1.1 General

1.1.1

Technical background is not considered necessary.

2 GENERAL PRINCIPLES

2.1 Structural continuity

2.1.1 General

Structural continuity is to be ensured and abrupt changes are to be avoided.

2.1.2 Longitudinal members

Technical background is not considered necessary.

2.1.3 Primary supporting members

Technical background is not considered necessary.

2.1.4 Stiffeners

Technical background is not considered necessary.

2.1.5 Plating

When connecting plates of different thicknesses in the same plane, the regulation of not permitting difference in thickness greater than 50% of the thickness of the thicker plate was specified as a practical measure. If the difference in thickness is greater than 50%, an intermediate plate has to be inserted, and the thicker plate is to be tapered to the thickness of the thinner plate to maintain continuity.

2.1.6 Weld joints

Technical background is not considered necessary.

2.2 Local reinforcements

2.2.1 Reinforcements at knuckles

The figure accompanying this text was selected, because it represents a typical knuckle found on tankers. General text has been included to clarify that some knuckles, such as main deck camber are, in general, exempted from the requirements of knuckle reinforcement because of their configuration and the manner in which they are loads.

2.2.2 Reinforcement in way of attachments for permanent means of access

This is a general requirement to note that structural elements which have access cut outs included in them are to be reinforced as necessary. Similarly attachment points for access walkways, hand grabs, etc., are to be kept clear of stress concentration points. Where the loads imposed on the structure are large then suitable reinforcement is to be provided.

2.2.3 Reinforcement of deck structure in way of concentrated loads

Technical background is not considered necessary.

2.2.4 Reinforcement by insert plates

Technical background is not considered necessary.

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

2.3.1

Where steels of different strengths are mixed in a hull structure, due consideration is to be given to the stress in the lower tensile steel adjacent to higher tensile steel.
Where stiffeners of lower tensile steel are supported by primary supporting members of higher tensile steel, due consideration is to be given to the stiffness of primary supporting members and scantlings to avoid excessive stress in the stiffeners due to the deformation of primary supporting members. 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.

Note: mild steel for the flat bar on the double bottom girder may be accepted provided that the stress level due to hull girder bending in such flat bar is within the permissible level of mild steel.

2.3.2

Precautions for treatment of connections of high tensile steel members to structural members of lower strength were established referring to the regulations of various classification societies. Members fitted to deck or bottom shell such as bilge keel and hatch-side coaming are not installed as longitudinal strength members. However, since they are subjected to longitudinal bending effects, they are required to be of materials with the same strength as the materials of the deck and bottom shell.

When stiffeners not continuous in the longitudinal direction are connected to girders installed as hatch coamings or longitudinal strength members such as stiffeners sniped at both ends and fitted to prevent buckling, the material of the stiffeners should have the same strength as the member to which they are fitted.

Note: mild steel for the flat bar on the double bottom girder may be accepted provided that the stress level due to hull girder bending in such flat bar is within the permissible level of mild steel.

3 STIFFENERS

3.1 General

3.1.1

Technical background is not considered necessary.

3.1.2

Technical background is not considered necessary.

3.2 Bracketed end connections

3.2.1

The requirements are in accordance CSR OT, July2010 (based on ABS Rules (January 2013), Pt 3, Ch 2, Sec 5, 1.5 and LR Rules (January 2013), Pt 3, Ch 10, 3.3.1 and 3.5.1). The scantlings formulas for the brackets are based on DNV Rules (January 2013), Pt 3, Ch 1, Sec 3, C200. The formulas are changed to net scantlings and to a ratio of yield stress instead of material factor in order to be in line with CSR philosophy.

3.2.2

Technical background is not considered necessary.

3.2.3

Technical background is not considered necessary.

3.2.4 Net web thickness

The scantlings formulas for the brackets are based on CSR OT, July 2010 (based on DNV Rules (January 2013), Pt 3, Ch 1, Sec 3, C200). The formulas are changed to net scantlings and to a ratio of yield stress instead of material factor in order to be in line with CSR OT philosophy.

3.2.5 Brackets at the ends of non-continuous stiffeners

The scantlings formulas for the brackets are based on CSR OT, July 2010 (based on DNV Rules (January 2013), Pt 3, Ch 1, Sec 3, C200). The formulas are changed to net scantlings and to a ratio of yield stress instead of material factor in order to be in line with CSR OT philosophy. Figure 3 of the Rules clarifies the application of the requirements, based on LR and DNV practices.

3.2.6 Brackets with different arm lengths

Refer to TB [3.2.4].

3.2.7 Edge stiffening of bracket

Refer to TB [3.2.4].

3.3 Bracketless connections

3.3.1

Technical background is not considered necessary.

3.4 Sniped ends

3.4.1

The requirements are in accordance CSR OT, July 2010 (based on DNV Rules (January 2013), Pt 3, Ch 1, Sec 3, C204 and ABS Rules (January 2013), Pt 3, Ch 1, Sec 2, 15). The equation is the same as the one presently used in the DNV Rules (January 2013), Pt 3, Ch 1, Sec 3, C204, with the DNV corrosion addition, "t_k", removed.

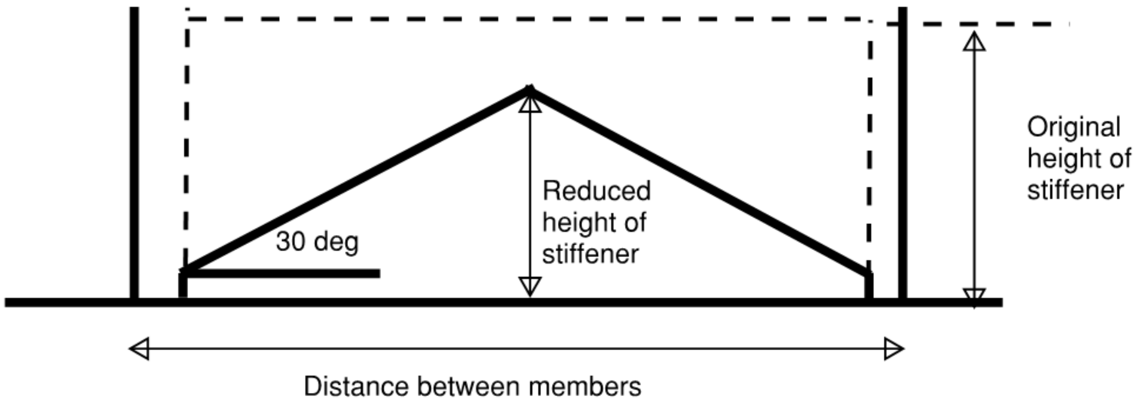
3.4.2

The requirements are in accordance CSR OT, July 2010 (based on DNV Rules (January 2013), Pt 3, Ch 1, Sec 3, C204 and ABS Rules (January 2013), Pt 3, Ch 1, Sec 2, 15).

For shorter span at the narrow space, the requirement that the tapering of sniped stiffeners is not to be more than 30° may lead to a triangle shape, as shown in Figure 1, so an alternative solution need to be considered in this case. This requirement is intended to be applied for the load bearing members with relatively longer span to mitigate hard spot due to plate bending.

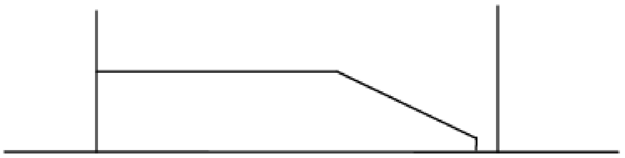
The height of snipped stiffeners is varying depends on the locations and design of the ship so one fixed distance between members cannot be proposed as a reference for the alternative solution.

Figure 1: Required sniped stiffener with 30° tapering at the narrow space

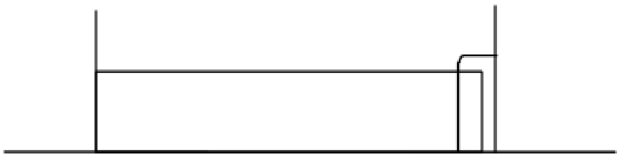


The following details may be considered as an alternative solution.

- One side taper



- Lap type connection



4 PRIMARY SUPPORTING MEMBERS (PSM)

4.1 General

4.1.1

This regulation is specified for the case where the requirement of arrangement of primary supporting members specified in the rules differs from the actual arrangement of primary supporting members.

4.2 Web stiffening arrangement

4.2.1

Technical background is not considered necessary.

4.3 Tripping bracket arrangement

4.3.1

Technical background is not considered necessary.

4.3.2

Technical background is not considered necessary.

4.3.3

Technical background is not considered necessary.

4.3.4 Arm length

The requirements are in accordance CSR BC, July 2010 (based on Pt B, Ch 4, Sec 3, 4.7.6 of the BV Rules, January 2013).
For superstructures and deckhouses where required scantlings are given in gross, only the part of the criteria which is not based on net scantlings is to be applied.

4.4 End connections

4.4.1 General

Technical background is not considered necessary.

4.4.2 Scantling of end brackets

The principles of the requirement are based on the fact that the connection with bracket cannot be weaker than the PSM itself. The formulae for the bracket arms are empirical formulae.

4.4.3 Arrangement of end brackets

The requirements are in accordance CSR BC, July 2010 (based on Pt B, Ch 4, Sec 3, 4.4 of the BV Rules (January 2013) and Pt C, 1.1.14 of NK Rules, January 2013).

5 INTERSECTION OF STIFFENERS AND PRIMARY SUPPORTING MEMBERS

5.1 Cut-outs

5.1.1

Technical background is not considered necessary.

5.1.2

Technical background is not considered necessary.

5.1.3

The requirements are in accordance CSR OT, July 2010 (based on LR Rules (January 2013), Pt 3, Ch 10, 5.2.1).

5.1.4

Technical background is not considered necessary.

5.1.5

The objective of the requirement on soft heels for PSM web stiffeners is to reduce the local stress at the connection of the longitudinal to the web stiffener and is an implicit means of fatigue control. Service records for ships in operation show problems with cracks in the coating and web stiffener itself at these connections. The problem is a combination of high and low cycle fatigue with the high cycle fatigue being the dominant factor for the side shell connections while the low cycle fatigue is also an important effect for the bottom and inner bottom longitudinals. The latter is a result of the loading and unloading of the vessel which gives high stress and strain at the heel of the web stiffener.

By providing a keyhole scallop at the heel of the web-stiffener the local stress and strain at this location is significantly reduced and hence the probability of encountering cracks in the web stiffener or coating is expected to be significantly reduced. The requirement to provide a keyhole scallop only applies to relatively highly stressed members, which have been defined here as 80% of the permissible stress under the design loads other than impact loads, i.e., bottom slamming and bow impact loads. Connections with a double side bracket and connections at watertight bulkheads and where the primary support member web is welded to the stiffener face plate are considered to relieve the local stresses at the heel of the web stiffener such that the keyhole scallop is not required.

5.1.6

The requirements are in accordance CSR OT, July 2010 (based on LR Rules (January 2013), Pt 3, Ch 10, 5.2.2).

5.2 Connection of stiffeners to PSM

5.2.1 General

The first sentence clarifies the application of requirements [5.2.2] to [5.2.3]. The requirements [5.2.2] and [5.2.3] are applicable to PSM in case of lateral pressure inclusive of the sloshing pressure, bottom slamming and bow impact loads.

The inclusions of angle together with the bottom slamming and bow impact loads are to solve the potential problem in the connection of stiffener and PSM in fore end, in which structural damage of a pre-CSR tanker has been reported.

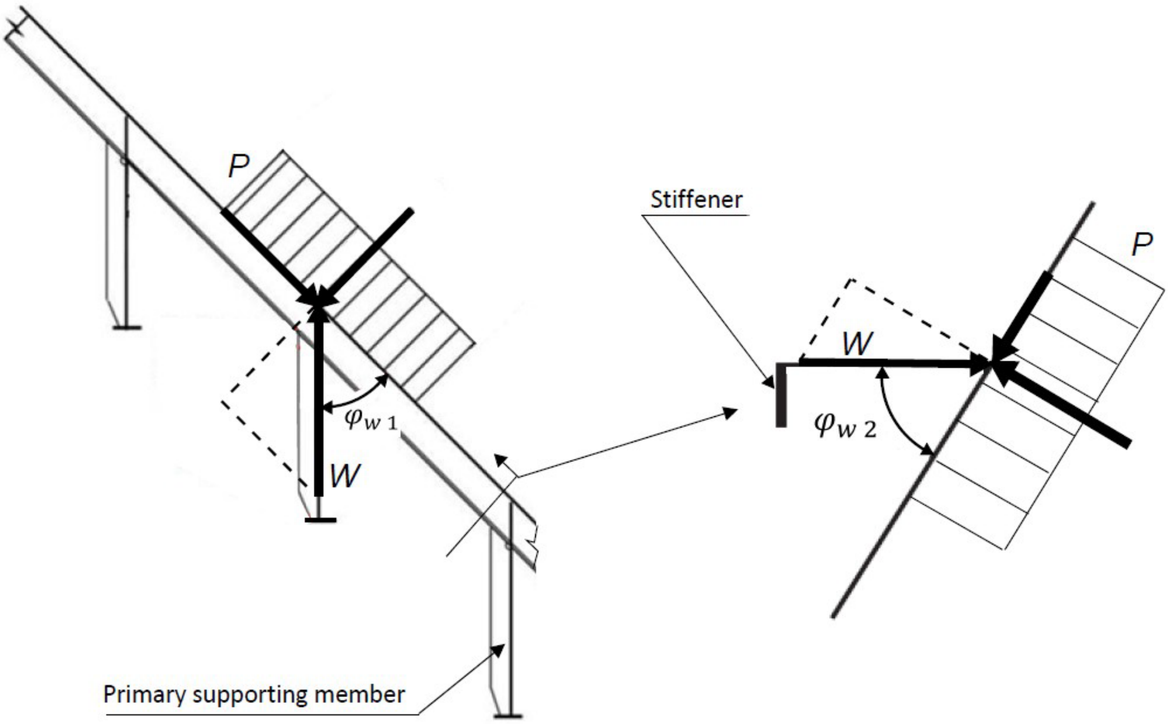
5.2.2

The requirements are derived from LR Rules (January 2013), Pt 3, Ch 10, 5.2.3 to 5.2.15. The details of these requirements have been modified to take account of the CSR Rule development philosophy, in terms of net thickness, loads and acceptance criteria.

The current formula for the lateral pressure including sloshing pressure and impact pressure, e.g. bottom slamming or bow impact loads, properly considers separately the load (W1) for longitudinal stiffener connection to the PSM and the load (W2) transmit through PSM web stiffeners. Therefore, this could avoid unbalanced connection design i.e. very slender PSM web stiffeners.

An acute angle between the side shell plating and the web frame/bulkhead/stiffener will produce a larger resultant force in the transverse plane. See Figure 2 below. The two angles, ϕ_{w1} and ϕ_{w2}, shown in Figure 2 below, are to be taken into account in calculation of total load (W).

Figure 2: Resultant force for primary supporting member and stiffener



5.2.3

Refer to TB [5.2.2].

5.2.4

Refer to TB [5.2.2].

5.2.5

Refer to TB [5.2.2].

5.2.6

Refer to TB [5.2.2].

5.2.7

Refer to TB [5.2.2].

5.2.8

Refer to TB [5.2.2].

6 OPENINGS

6.1 Openings and scallops in stiffeners

6.1.1

The figures are copied from a general ship building standard in order to show some example of common shapes of scallops. The range of 0.5 to 1.0 for the ratio of a/b is based on experience and generally accepted practice.

6.1.2

The basis of these requirements is LR Rules (January 2013), Pt 3, Ch 10, 5.3.3. Text has been added to limit the 200mm distance to a distance measured along the stiffener towards mid-span and to limit the distance to 50mm in the opposite direction. Also, the requirement has been modified to permit holes and scallops at locations of known low shear stress.

6.1.3

The special requirements are in accordance with LR Rules (January 2013), Pt 3, Ch 10, 5.3.3. Text has been added to clarify what is meant by closely spaced and to also make this requirement applicable to stiffeners that are not longitudinal strength members, consistent with present practice.

6.2 Openings in primary supporting members

6.2.1 General

Technical background is not considered necessary.

6.2.2 Manholes and lightening holes

The requirements are in accordance CSR OT, July 2010 (based on LR Rules (January 2013), Pt 3, Ch 10, 4.6.1 for single skin and LR Rules (January 2013), Pt 4, Ch 1, 8.2.8 and Pt 4, Ch 9, 9.3.7 for double skin).

6.2.3 Reinforcements around openings

The requirements are in accordance with DNV Rules (January 2013), Pt 3, Ch 1, Sec 3, C606. The criteria have been updated to suit the CSR acceptance criteria sets. Similar requirements are contained in the ABS Rules (January 2013), Pt 5, Ch 1, Sec 4, 11.17. When slots and lightening holes are cut in transverses, webs, floors, stringers and girders, they are to be kept well clear of other openings. The slots are to be neatly cut and well rounded.

Lightening holes are to be located midway between the slots and at about one-third of the depth of the web from the shell, deck or bulkhead. Their diameters are not to exceed one-third the depth of the web. In general, lightening holes are not to be cut in those areas of webs, floors, stringers, girders, and transverses where the shear stresses are high. The equivalent net shear sectional area approach is based on C15.2.3 of NK Guidance and Pt B, Ch 4, Sec 3, 4.6.5 of the BV Rules (January 2013).

6.3 Openings in the strength deck

6.3.1 General

Technical background is not considered necessary.

6.3.2 Small opening location

This article is based on CSR BC, July 2010 (based on BV Rules (January 2013), Pt B, Ch 4, Sec 6, 6.1).

7 DOUBLE BOTTOM STRUCTURE

7.1 General

7.1.1 Framing system

It is specified that the longitudinal framing system is mandatory for ships of length 120m and greater.

7.1.2 Variation in height of double bottom

Technical background is not considered necessary.

7.1.3 Breadth of inner bottom

Technical background is not considered necessary.

7.1.4 Drainage of tank top

Technical background is not considered necessary.

7.1.5 Striking plate

Technical background is not considered necessary.

7.1.6 Duct keel

The arrangement of girder plating was revised, when developing CSR BC, referring to the actual arrangements in existing ships.

7.2 Keel plate

7.2.1

The width of one strake of the keel plate has been specified referring to the regulations of shear strake and bilge strake in Pt C, 1.1.11 of NK Rules (January 2013).

7.3 Girders

7.3.1 Centre girder

Technical background is not considered necessary.

7.3.2 Side girders

Technical background is not considered necessary.

7.4 Floors

7.4.1 Web stiffeners

Technical background is not considered necessary.

7.5 Bilge keel

7.5.1 Material

Since a large number of comments from shipowners have been received about bilge keel and prevention of damage to its ends, it was decided that the material of the bilge keel should have the same strength as the bilge strake. Similar to long hatch side coamings of 0.15*L* specified in the IACS UR, S6 (Rev 6, May 2010), if the length of the bilge keel is greater than 0.15*L*, the grade material of the bilge keel and of the ground bar is required to be the same as that of the bilge strake.

7.5.2 Design

The purpose of these requirements is to ensure that failure of the bilge keel system does not induce damage to the hull structure itself.

7.5.3 Ground bars

The butt weld of the ground bar is to be made with removable backing strip for avoiding cracking inside the side shell due to root failure. The ground bar and the bilge keel butt welds are not to be in the same transverse plan for avoiding stress concentration leading to cracks.

7.5.4 End details

The requirements are based on CSR OT, July 2010 (based on LR Rules (January 2013), Pt 3, Ch 10, 5.6).

7.6 Docking

7.6.1 General

Docking arrangement has never been a class item and should continue to be so, for the simple reason that many aspects are not beyond verification by the Surveyor. However, a docking plan is required for large vessels by each of the three societies. Since structural arrangement in some instances is dependent upon the docking arrangement, the builder is held responsible to furnish the vessel a docking plan appropriate to the particular vessel; but, the majority of its contents will be outside the scope of classification, its approval by the society is not required.

7.6.2 Docking brackets

Technical background is not considered necessary.

8 DOUBLE SIDE STRUCTURE

8.1 General

8.1.1

Technical background is not considered necessary.

8.1.2

If the double side skin part is to be used as a void space, and cargo of high density is to be carried in the cargo holds, then local loads are not presumed to act on the side structure of the cargo hold on the double skin side. Even in such cases, appropriate thickness exceeding the minimum thickness is considered necessary. As a conclusion, even if the double skin side part is a void space, it is treated as a ballast tank and assessment of local strength is specified. Corrosion addition for the actual service environment, that is, void space, is also specified.

8.2 Structural arrangement

8.2.1 Primary supporting members

Technical background is not considered necessary.

8.2.2 Transverse stiffeners

Technical background is not considered necessary.

8.2.3 Longitudinal stiffeners

Technical background is not considered necessary.

8.2.4 Sheer strake

Requirement on sheer strake width comes from IACS UR S6 (Rev 6, May 2010).

8.2.5 Plating connection

In principle, continuity of structure similar to that in double bottom structure has been specified. Without hopper plating, the stress concentration is to be minimised and detail needs to comply with yielding and fatigue criteria. In addition no scallop is allowed in way of the knuckle.

9 DECK STRUCTURE

9.1 Structural arrangement

9.1.1 Framing system

Technical background is not considered necessary.

9.1.2 Stringer plate

Requirement on sheer strake width comes from IACS UR S6 (Rev 6, May 2010).

9.1.3 Connection of deckhouses and superstructures

Technical background is not considered necessary.

9.2 Deck scantlings

9.2.1

The requirements are based on CSR OT (July 2010).

10 BULKHEAD STRUCTURE

10.1 Application

10.1.1

Technical background is not considered necessary.

10.2 General

10.2.1

This paragraph allows tapering of vertical primary supporting members on bulkhead to take into account the fact that generally the lateral loads considered in the lower part of the bulkhead are greater than the loads on the upper part of the bulkhead.

10.2.2
Reinforcement is to be provided for avoiding buckling in way of the girder and to have a smooth load transmission.

10.2.3
Requirement is provided for preventing buckling in way of the girder.

10.2.4
Technical background is not considered necessary.

10.2.5
Technical background is not considered necessary.

10.3 Plane bulkheads

10.3.1 General
Technical background is not considered necessary.

10.3.2 End connection of stiffeners
Technical background is not considered necessary.

10.3.3 Sniped end of stiffener
This paragraph aims to limit the use of sniped end stiffeners on bulkheads subjected to hydrostatic pressure.

10.4 Corrugated bulkheads

10.4.1 General
CSR requires that strength assessment of primary supporting members to be performed based on the direct strength calculation, and also requires hull girder ultimate strength and fatigue strength assessment to be performed for ships of length 150m and greater. This regulation also covers strength requirements during flooding of IACS UR S17 (Rev 8, May 2010), S18 (Rev 8, May 2010), S20 (Rev 5, May 2010), and also IACS UR S25 (which is no more in force) specified for ships of 150m and greater. These applications are considered for consistent treatment. The treatment of stools in corrugated bulkheads considering construction that is more robust than used currently, has been made more stringent by application of the regulations for ships of length 190m and greater in IACS UR S18 (Rev 8, May 2010) to ships of length 150m and greater.

10.4.2 Construction
In principle, this regulation is based on IACS UR S18 (Rev 8, May 2010).

10.4.3 Corrugated bulkhead depth
This requirements is based on the ABS Rules (January 2013), Pt 5, Ch 1, Sec 4, 17.5.1 (for the oil tanker part) and provide a minimum stiffness requirement.

10.4.4 Actual section modulus of corrugations
Refer to TB [10.4.2].

10.4.5 Span of corrugations
Refer to TB [10.4.2].

10.4.6 Structural arrangements

Refer to TB [10.4.2].

10.4.7 Bulkhead end supports

Refer to TB [10.4.2].

10.4.8 Bulkhead stools

Refer to TB [10.4.2].

10.4.9 Lower stool

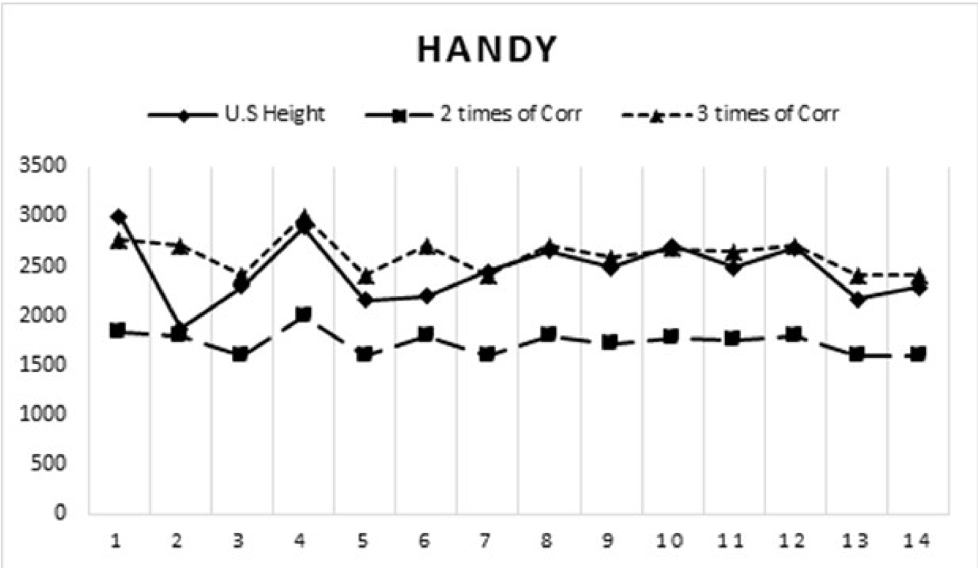
Refer to TB [10.4.2].

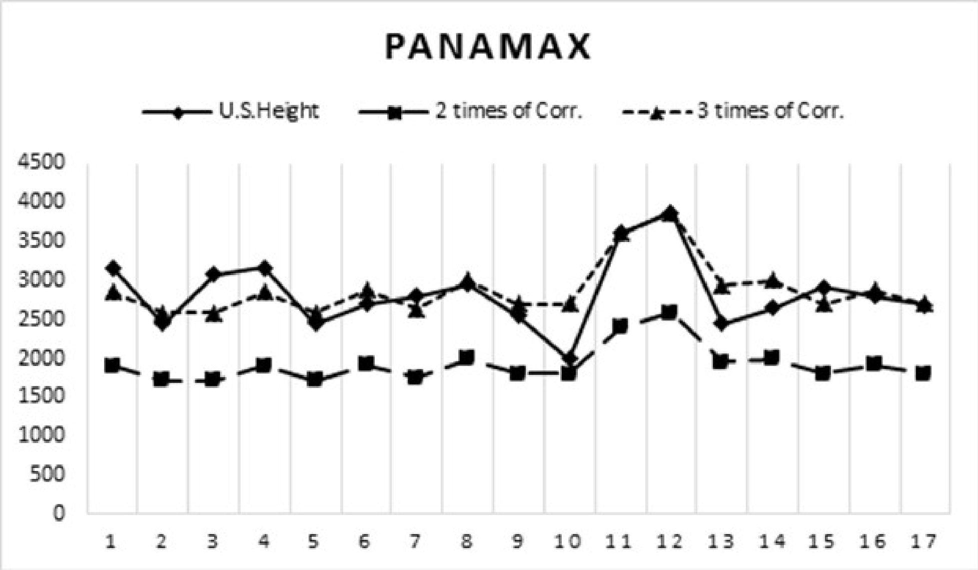
10.4.10 Upper stool

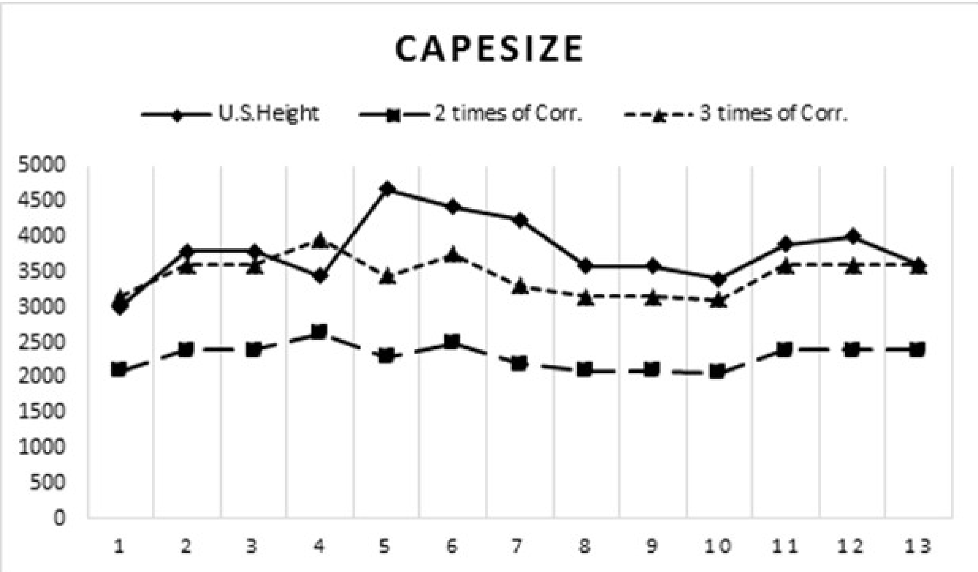
UR S18 states "The upper stool, where fitted, is to have a height generally between 2 and 3 times the depth of corrugations." Many existing bulk carriers were designed according to this requirement, as the phrase "generally" has been a part of this requirement since the introduction of UR S18, which has been applicable to all new construction bulk carriers since 1 July 1998. In many existing bulk carriers, the height of the upper stool is higher than three times the corrugation depth because of considerations related to a vessel's structural arrangement and not lower than twice the corrugation depth (see figures below). In addition, the direct strength analysis is mandatory, and provides sufficient verification of structural geometry of the upper stool.

According to the above background, this requirement is updated in the Rules issued on 1 Jan 2018 from UR S18 accordingly as prescriptive requirement for the height of upper stool of bulk carriers.

In addition, the Rules are to clarify the height of upper stool for rectangular stools.







10.5 Non-tight bulkheads

10.5.1 General

Technical background is not considered necessary.

10.5.2 Non-tight bulkheads not acting as pillars

This requirement is based on CSR BC (July 2010), Ch 3, Sec 6, 10.5.1 (based on 4.1.1, Sec 7, Ch 4, Pt B of the BV Rules, January 2013).

10.5.3 Non-tight bulkheads acting as pillars

This requirement is based on CSR BC (July 2010), Ch 3, Sec 6, 10.5.2 (based on 4.2, Sec 7, Ch 4, Pt B of the BV Rules, January 2013).

10.6 Watertight bulkheads of trunks and tunnels

10.6.1

This regulation is based on the Ch II-1, Reg. 16-1.1 of the SOLAS (as amended). The re-stated partial text is considered as Classification requirement.

11 PILLARS

11.1 General

11.1.1

Technical background is not considered necessary.

11.1.2

Technical background is not considered necessary.

11.1.3

Pillars in tanks are to be of solid or open type section to avoid problems that could occur in case of hollow type sections, such as explosive gas being trapped inside the pillar, or internal corrosion not detectable from visual inspections, etc.

11.2 Connections

11.2.1

This article is based on BV Rules (January 2013), Pt B, Ch 4, Sec 6, 4.2.

1 STRUCTURAL IDEALISATION OF STIFFENERS AND PRIMARY SUPPORTING MEMBERS

1.1 Effective spans

1.1.1 General

Technical background is not considered necessary.

1.1.2 Effective bending span of stiffeners

The reason why the span is reduced in way of brackets is that they provide a significant increase of section modulus/inertia compared to the cross section of the stiffener itself which results in a different load transfer than for a stiffener without brackets. The pressure applied to the stiffener in way of the stiffer ends (when bracket are fitted) will be, to a larger degree, transferred straight the support and not to be distributed to the two ends of the stiffener. This in effect results in smaller bending moment in the stiffener outside the bracket area than is found for the configuration without brackets and equal distance between supports.

When the brackets are fitted to the attached plating on the side opposite to that of the stiffener the change in section modulus/inertia is not significant as the added area is close to neutral axis and hence the stiffness effect is not pronounced and no reduction is given in the span length. In case of very large brackets on the attached plate side, typically seen for primary support members, the size of such brackets are taken into account in the definition of the effective bending span.

The span definition in case of brackets is based on ABS Rules (January 2013), Pt 5, Ch 1, Sec 4, Figure 5. No reduction in bending span is given in case of web stiffeners without a backing bracket as mentioned in the Rules as this will provide little or no rotational support for the passing longitudinal. As the connection will not be symmetric at the primary supporting member the passing stiffener will experience a slight rotation at the support. This rotation effectively gives an increase to the bending moment at the heel of the web stiffener. Based on this no reduction to the span length is given. If a backing bracket is fitted the end connection will be more symmetric and will not rotate and hence the web stiffener may be assumed effective even though it is sniped at the end not attached to the stiffener in question.

For single skin structures, FE analysis has shown that the tripping bracket without backing has very little effect on the effective bending span. The reason is that that the tripping bracket will rotate as the structure is non-symmetric and there is no adjoining structure to restrict the rotation. The effect of the rotation is that the bending moment is slightly reduced at the toe of the tripping bracket but increased at the heel of the tripping bracket. As an alternative to using a reduced span with a correction for the rotation the rules require that the full span be used for the calculations.

It is noted that soft toe bracket gives significantly lower stresses compared to a straight type bracket. This is however not due to the effect on the span but on the stress concentration around at the termination of the bracket.

1.1.3 Effective shear span of stiffeners

The reason why the shear and bending span are different is because for the shear loads, the bracket has an immediate and significant effect on the shear area which more than compensates for the increase in shear load towards the end support. Hence verification of the shear load at the end of the bracket is normally acceptable (provided the bracket is not too long and flat, hence the 1:1.5 bracket angle requirement). For the bending moments, over the first portion of the bracket, the bending moment is increasing more than the increase in section modulus of the beam including the bracket. At about the bracket half depth position, then the section modulus including the bracket has increased to such an extent that it is able to nullify the increase in bending moment and hence able to provide sufficient end rotation support.

The bracket has an immediate effect due to increase in shear area versus increase in shear force. The increase in shear area is independent of which side of the stiffener (face plate or attached plate) the bracket is fitted and hence reduction is given also for brackets fitted on the side of the attached plating.

The minimum reduction in effective shear span is given to account for the pressure that is not transferred to the support through shear in the stiffener but that is transferred directly to the short edge of the panel. For a plate subject to pressure the load is transferred to the closest support. This effectively gives constant shear force along the last $s/2$ of the stiffener as the pressure applied to the plating at the last $s/2$ is transferred directly to the short edge which typically is the primary support member.

For single skin structures FE analysis has shown that the tripping bracket has very little effect on the effective shear span. The reason is that that the tripping bracket will rotate as the structure is non-symmetric and there is no adjoining structure to restrict the rotation. The effect of the rotation is that the shear force will be slightly reduced at the stiffener end in way of toe of the tripping bracket but increased at the stiffener end in way of heel of the tripping bracket. As an alternative to using a reduced span with a correction for the rotation the rules require that the full span be used for the calculations. The span definition in case of brackets is based on ABS Rules (January 2013), Pt 5, Ch 1, Sec 4, Figure 7.

1.1.4 Effect of hull form shape on span of stiffeners

The definition of the length of the stiffener is in accordance with DNV Rules (January 2013), Pt 3, Ch 1, Sec 6, A201 and ABS Rules (January 2013), Pt 5, Ch 1, Sec 4, 7.5. For a stiffener in bending the smallest section modulus is typically at the face plate (free edge for flat bar) of the stiffener. Consequently, the length is measured along the flange/free edge of the stiffener.

Plates and stiffeners in ship structures are typically subject to pressures acting normal to the plate. When assessing curved plates and stiffeners the pressure is not corrected for the curvature effect but the length of the stiffener is corrected. It can be demonstrated that the integration of the pressure along the curved plate gives the same total force as the application of the pressure along the chord. The member is in other words assessed based on the projected length.

1.1.5 Effective span of stiffeners supported by struts

For the treatment of struts between primary supporting members (floors) in a double bottom structure, the regulation of Pt B, Ch 4, Sec 3, 3.2.2 of the BV Rules (January 2013) has been incorporated. For installing a strut, the demands of ship owners has been considered, and provision of struts is not approved in ships of length 120m and greater mainly due to the risk of puncture of the hull/double hull by the struts in case of damage.

1.1.6 Effective bending span of primary supporting members

The definition of bending span of primary support members is based on ABS Rules (January 2013), Pt 5, Ch 1, Sec 4, Figure 8. The definition of the span is also related to how the member is assessed. For a primary supporting member subject to pressure loads the bending moment will increase towards the ends of the member. Where brackets are fitted the section modulus of a cross section will also increase when inside of the toe of the bracket.

The objective of the Rule is to ensure that for any cross section along the length of the PSM that the capacity is greater than the acting load response, e.g. section modulus versus bending moment. In order to simplify the calculations, the CSR Rules require that the section modulus clear of the bracket is assessed against the bending moment at the end of the effective span. In case of a continuous face plate the section modulus increases more quickly than for brackets without continuous face plate and this is reflected in the definition of the span.

1.1.7 Effective shear span of primary supporting members

The definition of shear span of primary support members is based on ABS Rules (January 2013), Pt 5, Ch 1, Sec 4, Figure 7.

1.1.8 Effective brackets definition

The reason why the shear and bending span are different is because for the shear loads, the bracket has an immediate and significant effect on the shear area which more than compensates for the increase in shear load towards the end support. Hence verification of the shear load at the end of the bracket is normally acceptable (provided the bracket is not too long and flat, hence the 1:1.5 bracket angle requirement). The 1:1.5 limits for the effective bracket defines the applicability of the assumption related to increase of section modulus versus increase of bending moment.

1.2 Spacing and load supporting breadth

1.2.1 Stiffeners

Technical background is not considered necessary.

1.2.2 Primary supporting members

Technical background is not considered necessary.

1.2.3 Spacing of curved plating

Technical background is not considered necessary.

1.3 Effective breadth

1.3.1 Stiffeners

To assess the bending strength of stiffeners, the sectional characteristics of stiffeners should be assessed. In this case, the effective width of the plating attached to the stiffener needs to be considered. The regulation of Pt C, 1.1.13-3 of NK Rules (January 2013), which gives a simple index based on Shade's theory, is adopted for the effective width of plating.

The 600mm limit for the attached plating for thickness' less than 8mm is based on LR Rules (January 2013), Pt 3, Ch 3, Sec 3. The associated limit thickness of 8mm has been adjusted compared to the limit given in the source Rules to account for the net thickness concept of the CSR Rules.

1.3.2 Primary supporting members

The definition of effective breadth of attached plate flanges of primary supporting members for strength evaluation is based on the theoretical background published by Henry Schade "The effective breadth of stiffened plating under bending loads", SNAME Transactions, Vol.

59, 1951, and by G. Vedeler, DNV Rules (January 2013), Pt 3, Ch 1, Sec 3, C402. The theoretical formulation has been verified by FE analysis.

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 obtained from the following formula:

$$b_{eff} = S \cdot min\left[\frac{1.04}{1+2/\left(\frac{l_{bdg}}{S\sqrt{s}}\right)^2} ; 1.0\right]$$

1.3.3 **Effective area of curved face plate and attached plating of primary supporting members**

The definition of effective area of curved face plates/attached plating of primary support members is based on DNV Rules (January 2013), Pt 3, Ch 1, Sec 3, C406-7.The theoretical background is based on a paper by R.W. Westrup and P. Silver: Some Effects of Curvature on Frames, Aero/Space Sciences, September 1958.

The formula represents the efficiency of a curved faceplate in terms of bending moment. The efficiency is given as a fraction of the area of the face plate. The reason for the correction is that a curvature gives a change of force direction. The moment capacity of a member with curved face plate is given by its possibility to transfer the change in shear to the face plate. The wider a curved face plate is the less efficient the section becomes. Similarly a small radius will given a larger change in force and hence less efficiency.

The formula has been adjusted based on the comparison with the results from FE analysis. See Ch 3, Sec 7, [1.3.3] of TB for RCN 1 to CSR 01 Jan 2019.

1.4 Geometrical properties of stiffeners and primary supporting members

1.4.1 **Stiffener profile with a bulb section**

Stiffeners with bulb section are treated as equivalent sections, the simplified formulae that give the equivalent section modulus, section area, and so on were incorporated from Pt B, Ch 4, Sec 3, 3.1.2 of the BV Rules (January 2013).

1.4.2 **Net elastic shear area of stiffeners**

The net elastic shear area definition is based on CSR OT (July 2010), Sec 4/2.4.2.1.

1.4.3 **Effective shear depth of stiffeners**

The effective shear depth is based on CSR OT (July 2010), Sec 4/2.4.2.2 as well as the relevant requirement in CSR-BC (July 2012).

1.4.4 **Elastic net section modulus and net moment of inertia of stiffeners**

The calculation method for the elastic net section modulus of stiffeners with an inclined angle is a simplified method, which is based on CSR OT (July 2010), Sec 4/2.4.2.3 as well as the relevant requirement in CSR-BC (July 2012). The same calculation method has been extended to the determination of the net moment of inertia of stiffeners attached to plating at an inclined angle. Justification of the formula is shown below.

Stiffener Properties		T profile			Flat bar			I.Angle		
hw	mm	400	400	400	300	300	300	450	450	450
tw	mm	11.5	11.5	11.5	28.5	28.5	28.5	11.5	11.5	11.5
bf	mm	150	150	150	0	0	0	125	125	125
tf	mm	14.5	14.5	14.5	0	0	0	18	18	18
tp	mm	22.5	22.5	22.5	33	33	33	24	24	24
bp	mm	370	370	370	865	865	865	630	630	630
phi-w	deg	45	60	75	45	60	75	45	60	75
SM(cm3)	Exact value(a)	2729	3224	3538	11385	11125	11297	5464	6415	7019
	w/phi=90	3646	3646	3646	11387	11387	11387	7226	7226	7226
	sin phi-w (b)	2578	3157	3522	8082	9861	10999	5110	6258	6980
	Ratio (b/a)	0.94	0.98	1.00	0.71	0.89	0.97	0.94	0.98	0.99
I (cm4)	Exact value(a)	21380	31387	38676	13378	19185	23383	33258	48978	60427
	w/phi=90	41338	41338	41338	24911	24911	24911	64609	64609	64609
	sin2 phi-w(b)	20669	31003	38569	12455	18683	23242	32305	48457	60281
	Ratio (b/a)	0.97	0.99	1.00	0.93	0.97	0.99	0.97	0.99	1.00

Ratio (b/a): The ratio of the calculated value/exact value.

1.4.5 Effective net plastic shear area of stiffeners

The elastic net shear area is equal to the plastic net shear area for a stiffener.

1.4.6 Effective net plastic section modulus of stiffeners

The property of bulb profile sections is to be determined by either direct calculation or equivalent built-up section for both elastic and plastic section modulus in accordance with Pt.1Ch.3 Sec.7 [1.4.1].

1.4.7 Primary supporting member web not perpendicular to attached plating

Same as [1.4.4] for stiffeners, except that the section modulus is to be directly calculated for any angle less than 75°.

1.4.8 Shear area of primary supporting members with web openings

This requirement is based on CSR-OT and explains how to consider the web height effective for member shear strength in case of opening in web near the location of the shear strength assessment.

1.4.9 Stiffener flange width

Refer to TB of Pt 1, Ch 8, Sec 2, [3.1.1].

2 PLATES

2.1 Idealisation of EPP

2.1.1 EPP

Technical background is not considered necessary.

2.1.2 Strake required thickness

Technical background is not considered necessary.

2.1.3

Technical background is not considered necessary.

2.2 Load calculation point

2.2.1 Yielding

Technical background is not considered necessary.

2.2.2 Buckling

Technical background is not considered necessary.

3 STIFFENERS

3.1 Reference point

3.1.1

Technical background is not considered necessary.

3.2 Load calculation point

3.2.1 LCP for Pressure

Technical background is not considered necessary.

3.2.2 LCP for hull girder bending stress

Technical background is not considered necessary.

3.2.3 Non-horizontal stiffeners

Technical background is not considered necessary.

4 PRIMARY SUPPORTING MEMBERS

4.1 Load calculation point

4.1.1

Technical background is not considered necessary.

PART 1 CHAPTER 4

LOADS

Table of Contents

1 GENERAL

1.1 Application

1.1.1 Scope

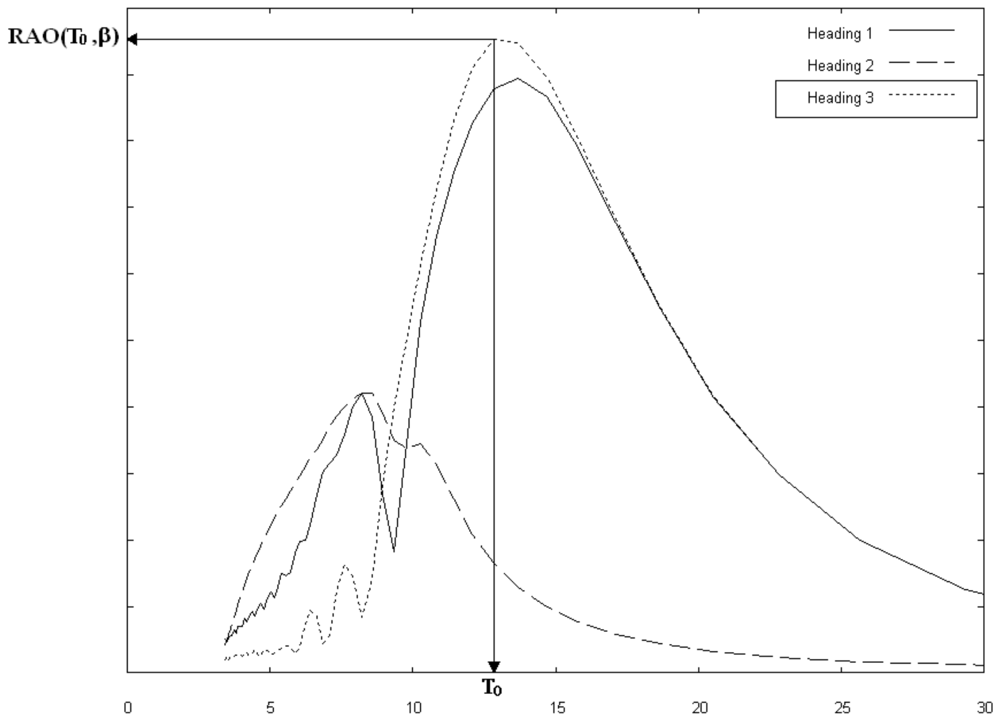
Technical background is not considered necessary.

1.1.2 Equivalent Design Wave EDW

An EDW is defined as a regular wave that reproduces the same response value as the reference design value, hence the envelope value at a certain probability level of a maximised response.

The EDW is defined by its period, amplitude and heading. The wave period (T_0) and heading (β_0) are defined based on the peak value of the Response Amplitude Operator (RAO) of the maximised response.

Figure 1: Definition of EDW heading and period



The amplitude (A_{EDW}) is defined by the ratio between the long term value of the response at a certain probability level and the peak of the RAO given at the period T_0 and for the heading β_0.

$$A_{EDW} = \frac{Longterm\ value}{RAO(T_0, \beta_0)}$$

By applying the method above described, an EDW is derived for each maximised response, that we call dominant load. The way the other responses, or subjected loads, are combined with the maximised load under the EDW is obtained by the load combination factors (LCFs). The load combination factor $C_{j,i}$ (also called superimposition ratio) for a given subjected load can be determined for each equivalent design using the response functions and long term predictions of the dominant load component by the following equation.

$$C_{j,i} = \frac{A_{EDW\,i}}{A_{EDW\,j}} \frac{RAO_j(T_i, \beta_i)}{RAO_{j\,max}} \times cos\{\varepsilon_j(T_i, \beta_i) - \varepsilon_i(T_i, \beta_i)\}$$

where,

i	Index used for the dominant load.
j	Index used for the subjected load.
$A_{EDW\,i}$	Amplitude of EDW of the *i*-th dominant load component.
$A_{EDW\,j}$	Amplitude of EDW of the *j*-th subject load component.
$\varepsilon_i(T_i,\beta_i)$	RAO phase angle of the dominant load component under the *i*-th EDW.
$\varepsilon_j(T_i,\beta_i)$	RAO phase angle of the subjected load component under the *i*-th EDW.
$RAO_j(T_i, \beta_i)$	Amplitude value of the RAO of the subjected load component under the *i*-th EDW.
$RAO_{j\,max}$	Maximum amplitude of the RAO of the subjected load component.

The LCFs are defined for the hull girder loads and acceleration components. For the external pressure, the distribution obtained directly for the EDW is defined. Therefore, the LCFs are not necessary for the external pressure or implicitly taken into account on the formulations.

1.1.3 Probability level for strength and fatigue assessments

The wording "strength assessment" is used for all strength criteria excluding fatigue. The strength assessments to be carried out are:

- Extreme operational at sea: associated to the sea loads encountered by the ship once in her lifetime (25 years). It corresponds to a probability of exceedance of the loads of approximately 10^{-8}.
- Ballast water exchange: associated sea loads encountered by the ship once in a year (probability factor of 0.8). This probability factor accounts for the fact that the ship will not exchange ballast water in very severe (extreme) weather conditions.
- Flooding conditions: associated to a joint probability factor of 0.8.
- Harbour conditions: associated to a joint probability factor of 0.4 that accounts for the probability of the vessel of being in harbour and for the reduction on wave properties comparing to the North Atlantic scatter diagram used for the seagoing conditions.

The wording "fatigue assessment" is used for the fatigue criteria. The sea loads used for fatigue assessment are defined at the representative level of probability at 10^{-2}. In fact, the loads at 10^{-2} are used as the scaling factor of the two-parameter Weibull distribution that together with the shape parameter and the mean period will be used to define the expected load history.

1.1.4 Dynamic load components

Technical Background is not considered necessary.

1.1.5 Loads for strength assessment

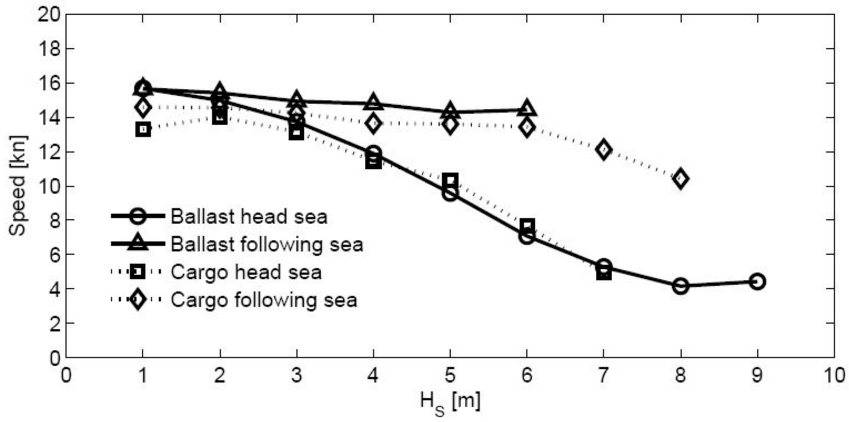
The sea loads for strength assessment have been derived based on the following assumptions:

- A representation of the North Atlantic wave environment. The North Atlantic scatter diagram is given in IACS Rec 34 (Corr. 1, November 2001).
- Pierson-Moskowitz wave spectrum.
- Angular spreading of the wave energy given by the function $\cos^2$.
- Equal heading probability.
- 3D linear with 30 degrees step of ship/wave heading.

- Design life of 25 years.
- Speed of 5 knots.

The 5 knots speed has been considered, as tankers and bulk carriers are full-form ships with very low manoeuvring speed in heavy weather. The following graph shows an example of the speed reduction with respect to wave height.

Figure 2: Speed reduction with respect to wave height



For scantling requirements and strength assessment, correction factors to account for non-linear wave effects are applied to the linear loads.

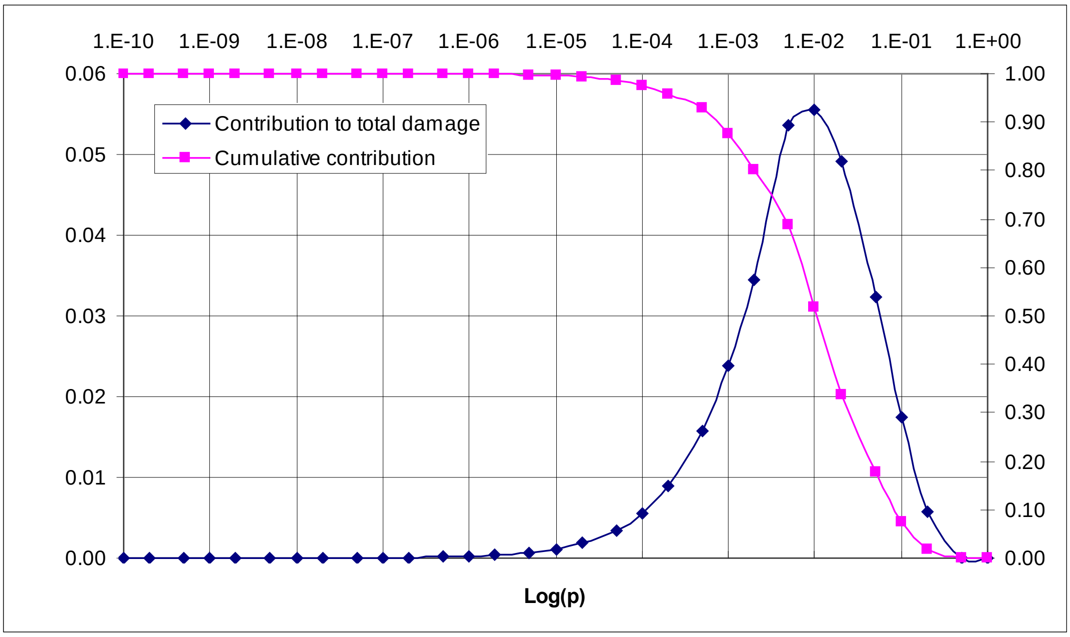
Each design load scenario is composed of the static loads and the dynamic loads when applicable. The EDW approach has been used for the setting of the dynamic loads including hull girder loads, motions, accelerations and external dynamic pressures.

1.1.6 Loads for fatigue assessment

For fatigue assessment, the expected load history needs to be defined. We assume that the load history can be approximated by a two-parameter Weibull distribution. The parameters are the scaling factor and the shape parameter. The probability level of 10^{-2} has been selected for the determination of scaling factor (loads) as it has been identified as the most contributing probability level to the fatigue damage.

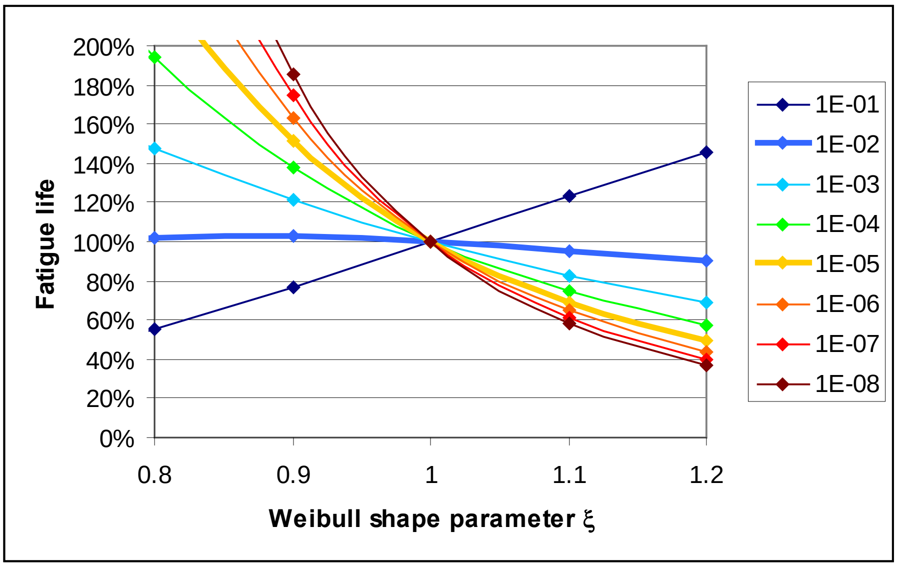
The definition of the loads at 10^{-2} probability level is also based on the EDW approach. The graph below provides an example of the contribution to the fatigue damage of a certain structural element. Calculations performed for different structural elements and SN curves have confirmed the results. It can be observed that almost the total damage is obtained up to the probability level of 10^{-5}. However, the most contributing probability level is around 10^{-2}.

Figure 3: Contribution of fatigue damage with respect to probability level



In theory, any probability could be chosen if the shape parameter is precise enough. However, if the value that contributes the most to the fatigue damage is better approached, the errors made in the assumption of the shape parameter have less impact on the total fatigue damage, and more than that, it is demonstrated that the impact is minor. Therefore, the shape parameter can be kept constant (e.g. equal to 1.0) irrespectively to the dynamic load case. The graph below shows the influence of the shape parameter on the fatigue life for different choices of scaling factor. It can be observed that the variation of fatigue life is minor for shape parameter varying from 0.8 to 1.2 if the scaling factor is chosen at 10^{-2} probability level.

Figure 4: Influence of shape parameter on fatigue life



A probability factor is used to bring down the loads defined at the probability level at 10^{-8} to the 10^{-2} probability level. This probability factor accounts for the speed changing from 5knots for 10^{-8} to 75% of service speed at 10^{-2}, which is considered as a mean speed during the ship life. Mathematically, the probability factor corresponds to the ratio between the long term value at 10^{-2} and the long term value at 10^{-8}.

$$f_p = \frac{Longterm\,value\left(10^{-8}\right)}{Longterm\,value\left(10^{-2}\right)}$$

1.2 Definitions

1.2.1 Coordinate system

Technical background is not considered necessary.

1.2.2 Sign convention for ship motions

Technical background is not considered necessary.

1.2.3 Sign convention for hull girder loads

Technical background is not considered necessary.

Symbols

f_{lp} : Factor applied to change the sign of the LCFs of vertical wave shear force from the aft to the fore part of the ship.

1 GENERAL

1.1 Definition of dynamic load cases

1.1.1

Structural analyses of double hull oil tankers and bulk carriers have been carried out in order to identify which EDWs were critical for the structure. Therefore, only the following EDWs have been selected.

Table 1: Definition of dynamic load cases

EDW	χ (Design wave encountering angles)
HSM	180 deg (head sea, the wave comes from bow)
HSA	180 deg (head sea, the wave comes from bow)
FSM	0 deg (following sea, the wave comes from stern)
BSR	90/270 deg (beam sea, the wave comes from portside/starboard
BSP	90/270 deg (beam sea, the wave comes from portside/starboard
OST	60/300 deg (Oblique sea, the wave comes from stern of portside/starboard)
OSA	120/240 deg (Oblique sea, the wave comes from bow of portside/starboard)

1.2 Application

1.2.1

Technical Background is not considered necessary.

2 DYNAMIC LOAD CASES FOR STRENGTH ASSESSMENT

2.1 Description of dynamic load cases

2.1.1

Table 1 to Table 3 provide a description of the simultaneous response of the ship under each EDW.

2.2 Load combination factors

2.2.1

The way the other responses, or subjected loads, are combined with the maximised load under the EDW is obtained by the load combination factors (LCFs). For further information, refer to Sec 1, [1.1.2].

The load combination factors have been derived through direct analysis for a significant number of oil tankers and bulk carriers covering ballast, full load and intermediate loading conditions.

3 DYNAMIC LOAD CASES FOR FATIGUE ASSESSMENT

3.1 Description of dynamic load cases

3.1.1

The load components that are maximised for the strength analyse are exactly the same load components that are maximised for fatigue analyse. However, due to speed effects, the EDW that maximises the vertical acceleration is the same EDW that maximises the vertical wave bending moment. Therefore, the load cases HSA and OSA were eliminated as they were redundant with load case HSM.

The EDWs for fatigue lead to long term value corresponding to 10^{-2} probability level. Table 7 to Table 9 provide a description of the simultaneous response of the ship under each EDW.

3.2 Load combination factors

3.2.1

Refer to TB [2.2.1].

Symbols

a_0 : The common acceleration parameter is a basic vertical acceleration parameter representing surge, sway and heave motions.

R : The vertical rotational centre is assumed to be the smaller of $D/2$ and $(D/4 + T_{LC}/2)$, which is an approximation of the vertical centre of gravity of the ship.

1 GENERAL

1.1 Definition

1.1.1

Ship motions and accelerations are assumed to vary periodically. The amplitude of ship motions and accelerations calculated from the formulae in this section is assumed as half the value from the peak to the trough.

2 SHIP MOTIONS AND ACCELERATIONS

2.1 Ship motions

2.1.1 Roll motion

The roll period T_θ is the natural period of roll estimated as follows:

$$T_\theta = 2\pi\sqrt{\frac{\left(k_r{}^2\Delta + A_r\right)}{g\,GM\,\Delta}}$$

where,

k_r Roll gyration radius.
Δ Displacement of the vessel.
A_r Added mass due to roll.
GM Transverse metacentric height.

By assuming that the roll added mass is approximately 30% of the roll inertia, and replacing A_r by $(0.3\, k_r{}^2\Delta)$ in the above equation, the Rules equation can be easily derived.

The values of gyration radius of roll k_r and transverse metacentric height GM are basically the values from the Loading Manual corresponding to the considered loading condition. If these values have been derived during the initial design stage, then the values shown in Table 1 for oil tankers or Table 2 for bulk carriers are be used.

The values of k_r, GM in the intact condition are different from those in flooded condition. However, it is difficult to develop the simplified formulae of GM for flooded conditions. Considering that the effect to the roll value due the difference between GM in intact and flooded conditions will be very small, GM in the intact condition is used for the corresponding flooded condition.

An adjustment factor f_p is used to change the probability level of the response taking account of the appropriate design load scenario. For fatigue assessment, this factor also accounts for speed effects.

2.1.2 Pitch motion

The pitch period T_φ corresponds to the period for which the pitch response function RAO is maximised due to the maximisation of the pitch excitation moment. The speed effect on pitch period is considered negligible.

The regular wave length λ at which the pitch motion response function becomes maximum is practically the same as the regular wave length at which the vertical wave bending moment amidships becomes maximum.

The pitch angle depends on the speed of the vessel, or, more consistently, with the Froude number. For strength evaluation, V is taken equal to 5 knots (2.57 m/s).

$F_n = \frac{V}{\sqrt{gL}} = \frac{2.57}{\sqrt{gL}}$ for strength evaluation.

V is fixed in the pitch angle formulation as the probability factor f_p already includes the speed effects.

An adjustment factor f_p is used to change the probability level of the response taking account of the appropriate design load scenario. For fatigue assessment, this factor also accounts for speed effects.

2.2 Ship accelerations at the centre of gravity

2.2.1 Surge acceleration

Technical Background is not considered necessary.

2.2.2 Sway acceleration

Technical Background is not considered necessary.

2.2.3 Heave acceleration

Technical Background is not considered necessary.

2.2.4 Roll acceleration

Technical Background is not considered necessary.

2.2.5 Pitch acceleration

The speed effects on pitch acceleration are not the same as for pitch motion. The pitch acceleration is considered to increase proportionally to a factor equal to $(1.2F_n + 1.0)$. In the same way as for pitch motion, the vessel speed was set to 2.57 m/s (5knots) in the Rules formula as the speed effects are already taken into account in the f_p value.

3 ACCELERATIONS AT ANY POSITION

3.1 General

3.1.1

Expressions for accelerations along body-fixed x-axis (longitudinal), y-axis (transverse) and z-axis (vertical) are given. The accelerations are combinations of the basic rigid body motion accelerations in all six degrees of freedom expressed at the centre of gravity of the ship. The accelerations are defined with respect to the ship fixed coordinate system; hence they include the roll and pitch static components.

3.1.2

Technical Background is not considered necessary.

3.1.3

Technical Background is not considered necessary.

3.2 Accelerations for dynamic load cases

3.2.1 General

The expressions correspond to a snapshot of the accelerations under the selected EDW load cases. The load combination factors should be applied to the basic acceleration components which are combined considering the rigid body motions.

3.2.2 Longitudinal acceleration

Technical Background is not considered necessary.

3.2.3 Transverse acceleration

Technical Background is not considered necessary.

3.2.4 Vertical acceleration

Technical Background is not considered necessary.

3.3 Envelope accelerations

The envelope accelerations expressions predict the longitudinal, transverse and vertical accelerations at the probability level corresponding to each design load scenario. The probability factors are included in the calculation of the basic acceleration components.

3.3.1 Longitudinal acceleration

The envelope of longitudinal acceleration is contributed by the surge, pitch and yaw acceleration. The longitudinal acceleration is constant along the ships length, assuming that the yaw acceleration is negligible. The yaw term is therefore not included in the expression. The static component due to pitch motion is included.

The pitch and surge accelerations are assumed to be statistically independent for larger ships. However for shorter ships, the accelerations start cancelling each other. A factor of $L/325$ to account for this is included.

3.3.2 Transverse acceleration

The envelope of transverse acceleration is contributed by the sway, roll and yaw accelerations. The transverse acceleration is constant along the ships breadth, assuming that the yaw acceleration is negligible. The yaw term is therefore not included in the expression. The static component due to roll motion is included.

The roll and sway transverse accelerations are assumed to be statistically independent.

3.3.3 Vertical acceleration

The envelope of vertical acceleration is contributed by heave, roll and pitch accelerations. The motion reference point is assumed to be at centreline and $0.45L$ from the aft end of L.

The vertical acceleration due to roll motion is multiplied by a factor of 1.2 to account for the phase difference between roll acceleration and the combined heave and pitch acceleration. The vertical acceleration due to pitch motion is multiplied by a factor of $(0.3+L/325)$ to account for the different phase relation between the acceleration components. This phasing is dependent on the ship length.

Symbols

C_w The wave coefficient given as a function of ship length and used in the expressions for wave pressures and global hull girder wave loads. The C_w values are valid for world wide service and are representative for the North Atlantic wave statistics.

f_β For dynamic load cases where the load is maximised in beam sea, a correction factor of 0.8 is applied to the dynamic load components. The factor of 0.8 corresponds to a reduction of the probability of occurrence of the EDW from 10^{-8} to $10^{-6.5}$ (1 year return period). Reducing the return period from 25 years to 1 year takes into account the joint probability of loss of propulsion or similar events in which case the ship is unable to maintain steerage in severe weather in beam sea.

Based on a study of how different assumptions affect the development of the non-uniform ship heading distributions, a sensitivity analysis was performed as presented in Technical Background report "CSR URCP1 TB Report(1) for NC01: The impact of non-uniform ship heading probability distributions, used in the sensitivity analysis of assumptions of the long-term wave loads, on CSRH", and as the result of the study, the heading correction factor $f_\beta = 1.05$ for HSM and FSM is to be applied for load cases in the extreme sea load design scenario. It is to be applied to the following requirements:

- Pt 1, Ch 4, Sec 4 [3.5.2] and [3.5.3];
- Pt 1, Ch 4, Sec 5 [1.3.2], [1.3.4], [2.3.1] and [2.3.2];
- Pt 1, Ch 4, Sec 6 [1.3.1], [1.5.1], [2.4.3], [2.5.3], [2.5.4], [5.2.1] and [5.3.1];
- Pt 1, Ch 5, Sec 1 [2.2.2], [2.4.1], and [3.3.1];
- Pt 1, Ch 5, Sec 2 [2.2.1];
- Pt 1, Ch 7, Sec 2 [4.3.3].

1 APPLICATION

1.1 General

1.1.1

Technical Background is not considered necessary.

1.1.2

Technical Background is not considered necessary.

2 VERTICAL STILL WATER HULL GIRDER LOADS

2.1 General

2.1.1 Seagoing and harbour/sheltered water conditions

Technical Background is not considered necessary.

2.1.2 Flooded condition

Technical Background is not considered necessary.

2.1.3 Still water loads for the fatigue assessments

Technical Background is not considered necessary.

2.2 Vertical still water bending moment

2.2.1 Minimum still water bending moment

The minimum rule hull girder still water bending moment is included in order to ensure that all ships have a certain operational flexibility regardless of conditions in the loading manual.

The formulation for the minimum hull girder still water bending moment was developed based on IACS UR, S7 (Rev 4, May 2010) and UR, S11 (Rev 7, November 2010). The UR, S7 (Rev 4, May 2010) defines a minimum hull girder section modulus, while the UR, S11 (Rev 7, November 2010) defines an allowable hull girder stress and hull girder wave bending moment. By combining the two requirements, an expression for the still water bending moment which satisfies the two criteria can be derived.

The rule minimum still water bending moment for sagging was calibrated against the permissible still water bending moments found in loading manuals for oil tankers by multiplication factor of 0.85.

The minimum still water bending moments were also compared to permissible still water bending moments for bulk carriers in order to ensure that these values would not drive the scantlings for this type of vessel. The minimum values have been found lower than the permissible values in the loading manual in all the cases evaluated.

2.2.2 Permissible vertical still water bending moment in seagoing condition

The permissible vertical still water bending moment is to be provided by the designer. It is to envelop:

- The most severe value in the loading manual for hogging and sagging condition.
- The most severe value for the loading conditions defined in the Rules.
- The minimum value.

2.2.3 Permissible vertical still water bending moment in harbour/sheltered water and tank testing condition

The permissible vertical still water bending moment in harbour/sheltered water and tank testing condition is to be defined by the user and is to envelop:

- The most severe value in the loading manual for hogging and sagging condition.
- The most severe value for the loading conditions defined in the Rules.
- The minimum value increased by 25%. The Rule minimum hull girder still water bending moment for harbour operations is taken as 25% higher than the Rule minimum allowable still water bending moment for the seagoing operations to allow for reasonable flexibility during loading and unloading operations. The 25% value was determined based on review of actual at-sea and in-port conditions and discussions with operators.

For preliminary design stage, a default value is provided which correspond to the total permissible bending moment, given by the sum of the permissible still water bending moment and the vertical wave bending moment in seagoing condition, minus the vertical wave bending moment in harbour condition, which is considered to be 0.4 the vertical wave bending moment in seagoing condition. Therefore, an increase of the permissible still water bending moment by the value of 0.6 the vertical wave bending moment in seagoing condition is derived ($1.0M_{wv} - 0.4M_{wv}$).

2.2.4 Permissible vertical still water bending moment in flooded condition at sea

The permissible still water bending moment in flooding condition is to be provided by the designer and is to envelop:

- The most severe value calculated for the flooding loading conditions defined in the Rules.
- The most severe still water bending moments for the flooding loading conditions defined in the loading manual.

Ballast water exchange conditions are excluded from flooding conditions, as they are very transient conditions, and normally occur in normal environmental conditions instead of extreme environmental conditions.

2.3 Vertical still water shear force

A minimum still water shear force is defined for oil tankers while there is no minimum value defined for bulk carriers. It has been considered that the bulk carrier's cargoes have very different densities and therefore it is harder to derive a simplified shear force formulation based on the hold volume. In addition, the loading manual of bulk carriers contain enough number of loading conditions to derive a permissible still water shear force that already allows for operational flexibility of the ship.

2.3.1 Minimum still water shear force in seagoing conditions for oil tankers

The minimum Rule hull girder still water shear force is included to ensure that all oil tankers have a certain operational flexibility regardless of the conditions included in the loading manual.

The formulae represent the local shear force that is generated by the difference of cargo weight, steel weight and buoyancy between adjacent holds. The hull girder still weight, in kN, between transverse bulkheads is expressed as:

$$W_{steel-weight} = 0.1 \rho g B_{local} l_{tk} T_{SC}$$

where,

ρ Density of cargo/seawater, not to be taken less than 1.025 t/m^3.

B_{local} Local breadth at T_{SC} at the mid-length of the tank under consideration, in m.

l_{tk} Length of cargo tank under consideration, taken at the forward or aft side of the transverse bulkhead under consideration, in m.

T_{SC} Scantling draught.

This simplification has through verification on typical tankers ranging from product carriers to VLCC's shown to be representative for the actual steel weight. For the bulk carriers, due to the different ship types and cargo densities, it has been found difficult to derive a single formula for the minimum still water shear force.

2.3.2 Minimum still water shear force in harbour conditions for oil tankers

Refer to TB [2.3.1].

2.3.3 Permissible still water shear force in seagoing condition

Refer to TB [2.2.2].

2.3.4 Permissible still water shear force in harbour/sheltered water and tank testing condition

Refer to TB [2.2.3].

2.3.5 Permissible still water shear force in flooded condition at sea

Refer to TB [2.2.4].

3 DYNAMIC HULL GIRDER LOADS

3.1 Vertical wave bending moment

3.1.1

The vertical wave bending moment values are in accordance with IACS UR, S11 (Rev 7, November 2010). The formulae specified in UR, S11 have been rewritten in order to explicitly give the non-linear factors used.

The hogging condition is assumed to be linear. Therefore, the non-linear factor applied to the sagging condition is equal to the ratio between sagging and hogging bending moments:

$$f_{nl-s} = \frac{110}{190}\frac{C_B + 0.7}{C_B} = 0.58\frac{C_B + 0.7}{C_B}$$

For fatigue assessments the non-linear factors are set to 1.0, meaning that the non-linearity is considered negligible at the response levels that contribute to the fatigue. An adjustment factor f_p is used to change the probability level of the response taking account of the appropriate design load scenario. For fatigue assessment, this factor also accounts for speed effects. The influence of whipping is not included in the non-linear effects.

3.2 Vertical wave shear force

3.2.1

The vertical wave shear force values are in accordance with IACS UR, S11 (Rev 7, November 2010). The formulae specified in UR, S11 (Rev 7, November 2010) have been rewritten in order to explicitly give the non-linear factors used.

The formulae in UR, S11 (Rev 7, November 2010) specify the shear force obtained at ¾ L when the vessel is in sagging condition. In order to derive the linear wave shear force (hogging condition), the formulae has been divided by the sagging non-linear factor specified in [3.1.1].

$$Q_{WV} = 0.30 f_q f_p C_w LB(C_B + 0.7) \times \frac{1}{0.58}\frac{C_B}{C_B + 0.7} = 0.52 f_q f_p C_w LBC_B$$

Differently from the vertical wave bending moment formulae, the non-linear factors for the vertical wave shear force have been included in the f_q definition. Therefore the shape distribution factors f_q are not limited to 1.0 due to the inclusion of the non-linear factors.

Same as the vertical wave bending moment, an adjustment factor f_p is used to change the probability level of the response taking account of the appropriate design load scenario. For fatigue assessment, this factor also accounts for speed effects.

3.3 Horizontal wave bending moment

3.3.1

The horizontal wave bending moment accounts for different loading conditions by using the draught as input to the formulae. Same as the vertical wave bending moment, an adjustment factor f_p is used to change the probability level of the response taking account of the appropriate design load scenario. For fatigue assessment, this factor also accounts for speed effects.

3.4 Wave torsional moment

3.4.1

The wave torsional moment formulae correspond to formulation in CSR BC (July 2010) and are associated to the moment obtained at baseline with a probability of exceedance of 10^{-8}. Same as the vertical wave bending moment, an adjustment factor f_p is used to change the probability level of the response taking account of the appropriate design load scenario. For fatigue assessment, this factor also accounts for speed effects.

3.5 Hull girder loads for dynamic load cases

3.5.1 General

The hull girder loads for the load cases correspond to the values defined for the appropriate design load scenario and multiplied by the LCFs defined in Ch 4, Sec 2 for each EDW load case. As the LCFs already contain the sign of the responses, the absolute values of the envelopes defined are to be used.

3.5.2 Vertical wave bending moment

Refer to TB [3.5.1].

3.5.3 Vertical wave shear force

Refer to TB [3.5.1].

3.5.4 Horizontal wave bending moment

Refer to TB [3.5.1].

3.5.5 Wave torsional moment

Refer to TB [3.5.1].

SYMBOLS

In the CSR RCN 1 (2017), the definition of Z_{SD} was introduced as “the Z coordinate, in m, of the midpoint of stiffener span, or of the middle of the plate field” to clarify the load point and the draught to be used for design external pressure calculations for superstructure and deckhouses.

The definition of “plate field” is not the usual term used in the rules and not defined in the rules, where the Z_{SD} is referred to.

IACS reviewed and agreed that the term “plate field” should be replaced by the term usually used in the rule, "elementary plate panel".

The proposed amendment is based on the Improvement Action Plan for addressing GBS audit Observation No. IACS/2018/MAINT/OBS/01.

In RCN 1 to CSR 01 Jan 2020, f_{yB} has been amended to consider the correct external pressure at Fore End (FE). For detailed technical background as well as the consequence assessment result, refer to TB for RCN 1 to CSR 01 Jan 2020.

1 SEA PRESSURES

1.1 Total pressure

1.1.1

Technical background is not considered necessary.

1.2 Hydrostatic pressure

1.2.1

Technical background is not considered necessary.

1.3 External dynamic pressures for strength assessment

1.3.1 General

The hydrodynamic pressure in the Rules results from a series of direct computations for oil tankers and bulk carriers in different loading conditions under the selected EDW. The hydrodynamic pressure distribution associated to each load case is obtained by multiplying the response function (RAO) of hydrodynamic pressure in each EDW (frequency and heading) by the regular wave amplitude of the corresponding EDW. The wave height associated to each EDW is presented below:

Table 1: Wave height associated to each EDW

EDW	*H* (Regular wave height, in m)
HSM	$1.31 \times C_w \sqrt{\frac{L+\lambda-125}{L}}$
HSA	$1.09 \times C_w \sqrt{\frac{L+\lambda-125}{L}}$
FSM	$1.31 \times C_w \sqrt{\frac{L+\lambda-125}{L}}$

BSR	$0.88C_w\sqrt{\frac{L+\lambda-125}{L}}$
BSP	$1.5C_w\sqrt{\frac{L+\lambda-125}{L}}$
OST	$1.38C_w\sqrt{\frac{L+\lambda-125}{L}}$
OSA	$1.38C_w\sqrt{\frac{L+\lambda-125}{L}}$

λ : Regular design wave length for each EDW, im m.
C_w : Wave coefficient in m, to be taken as:
$C_w = 10.75-\{(300-L)/100\}^{1.5}$ $90 \le L \le 300$m
$C_w = 10.75$ $300 < L \le 350$m
$C_w = 10.75-\{(L-350)/150\}^{1.5}$ $350 < L \le 500$m

1.3.2 Hydrodynamic pressures for HSM load cases

The distributions of wave pressure for HSM-1 and HSM-2 are the distributions in equivalent design wave HSM at which the vertical wave bending moment becomes minimum (sagging) and maximum (hogging), respectively.

The amplitude coefficient k_a represents the variation of the pressure amplitude along the length of the vessel with respect to the amplitude amidships. Therefore, k_a is always equal to 1.0 at midship section. The phase coefficient k_p represents the phasing of the pressure with respect to the EDW, which varies between -1.0 to 1.0.

The non-linear coefficient f_{nl} of 0.9 is considered based on the results of model tests for wave pressure for load cases HSM, HSA and FSM at the exceedance probability level of 10^{-8} (extreme sea loads). For lower probability levels the non-linearity is decreased. An adjustment factor for strength assessment f_{ps} is used to change the probability level of the response taking account of the appropriate design load scenario.

A minimum deck pressure has been considered in accordance with requirements of ICLL 1966 (as amended) for hatchways. This minimum pressure is only applicable to head sea and following sea EDWs.

The heading correction factor f_β represents the non-uniform ship heading distribution for HSM load case for the extreme sea load design scenario. See Pt 1, Ch 4, Sec 4, Symbols.

1.3.3 Hydrodynamic pressures for HSA load cases

The distributions of wave pressure for HSA-1 and HSA-2 are the distributions in equivalent design wave HSA at which the vertical acceleration at FP becomes maximum and minimum, respectively. The hydrodynamic pressure amidships for HSA load cases corresponds to 80% of the pressure amidships for HSM load cases. For further explanation refer to TB [1.3.2].

1.3.4 Hydrodynamic pressures for FSM load cases

The distributions of wave pressure for FSM-1 and FSM-2 are the distributions in equivalent design wave HSM at which the vertical wave bending moment becomes minimum (sagging) and maximum (hogging), respectively. No significant variation of the pressure at midship section with respect to the draft has been found for the FSM load cases. For further explanation refer to TB [1.3.2].

The heading correction factor f_β represents the non-uniform ship heading distribution for FSM load cases for the extreme sea load design scenario. See Pt 1, Ch 4, Sec 4, Symbols.

1.3.5 Hydrodynamic pressures for BSR load cases

The distributions BSR-1 and BSR-2 are the distributions in equivalent design wave BSR at which the roll angle becomes maximum and minimum, respectively. The distribution of wave pressure comprises the fluctuating part of the hydrostatic pressure from the roll angle (first term of the formula) and the fluctuating part due to heave (second term of the formula).

The non-linear coefficient f_{nl} of 0.8 is considered for wave pressure for load cases BSR at the exceedance probability level of 10^{-8} (extreme sea loads). For lower probability levels the non-linearity is decreased.

1.3.6 Hydrodynamic pressures for BSP load cases

The distributions BSP-1 and BSP-2 are the distributions in equivalent design wave BSP at which the hydrodynamic pressure at waterline becomes maximum and minimum at weather side, respectively. The non-linear coefficient 0.65 consists of a non-linear coefficient 0.8 at the exceedance probability level of $10^{-6.5}$ multiplied by the heading correction factor f_β of 0.8.

1.3.7 Hydrodynamic pressures for OST load cases

The distributions OST-1 and OST-2 are the distributions in equivalent design wave OST at which the torsion moment at $1/4L$ becomes maximum and minimum at weather side, respectively. The non-linear coefficient f_{nl} of 0.8 is considered for wave pressure for load cases OST at the exceedance probability level of 10^{-8} (extreme sea loads).

1.3.8 Hydrodynamic pressures for OSA load cases

The distributions OSA-1 and OSA-2 are the distributions in equivalent design wave OSA at which the vertical acceleration at FP becomes maximum and minimum at weather side, respectively. The non-linear coefficient f_{nl} of 0.8 is considered for wave pressure for load cases OST at the probability level of 10^{-8} (extreme sea loads).

1.3.9 Envelope of dynamic pressure

Technical background is not considered necessary.

1.4 External dynamic pressures for fatigue assessments

1.4.1 General

The hydrodynamic pressure distributions in the EDWs for fatigue assessment are defined for exceedance probability of 10^{-2}. The hydrodynamic pressure distributions have been completely reformulated for fatigue assessment due to difference on the ship speed.

Due to speed effects, the equivalent design waves HSA, OSA and HSM were confounded. Therefore, only the EDW HSM is necessary to maximise the vertical wave bending moment and vertical acceleration at FP.

The stretching of pressure above the waterline has been done for a probability level of 10^{-4} (assuming Weibull shape parameter of 1.0), which is equivalent to CSR BC and CSR OT stretching (July 2010). This is to avoid the underestimation of the fatigue damage on elements that are wetted at probability level lower than 10^{-2}. There is not any non-linear correction considered at the probability level of 10^{-2}.

1.4.2 Hydrodynamic pressures for HSM load cases

Refer to TB [1.3.2].

1.4.3 Hydrodynamic pressures for FSM load cases

Refer to TB [1.3.4].

1.4.4 Hydrodynamic pressures for BSR load cases

Refer to TB [1.3.5].

1.4.5 Hydrodynamic pressures for BSP load cases

Refer to TB [1.3.6].

1.4.6 Hydrodynamic pressures for OST load cases

Refer to TB [1.3.7].

2 EXTERNAL PRESSURES ON EXPOSED DECKS

2.1 Application

2.1.1

The external pressures on deck are not to be considered for fatigue assessment.

2.1.2

The simultaneous consideration of the green sea loads and deck cargo loads is not to be envisaged.

2.2 Green sea loads

2.2.1 Pressure at an exposed deck

External pressures on exposed deck specified in [2] also apply to the exposed decks of superstructure and deckhouses.

2.2.2

The green sea pressures are to be considered regardless of the existence of water breakers on the exposed deck.

2.2.3 HSM, HSA and FSM load cases

The green sea pressure in HSM, HSA, FSM load cases is function of the side-shell wave pressure at the deck corner defined in [1.3.2] to [1.3.4], but is not to be taken less than the value specified in ICLL, Annex I, Ch II Reg.16 considering the appropriate coefficient χ for the exposed deck position (χ, coefficient depending on the height of deck which becomes smaller as the height of deck increases). The minimum loads from ICLL reference are considered as Classification requirement.

2.2.4 BSR, BSP, OST and OSA load cases

The green sea pressure in BSR, BSP, OST and OSA load cases is function of the side-shell wave pressure at the deck corner defined in [1.3.5] to [1.3.8]. The variation of the pressure across the deck is obtained by a linear interpolation between the green sea pressure value obtained at deck corner on starboard and on portside.

2.2.5 Envelope of dynamic pressures on exposed deck

The green sea pressure in BSR, BSP, OST and OSA load cases is function of the side shell.

2.3 Load carried on exposed deck

2.3.1 Pressure due to distributed load

When the exposed deck is loaded with distributed cargo load (such as lumber, etc), the static and dynamic loads due to such cargo should be considered.

2.3.2 Concentrated force due to unit load

When unit load is carried on the exposed deck (such as outfitting items), the static and dynamic forces due to this unit load must be considered.

3 EXTERNAL IMPACT PRESSURES FOR THE BOW AREA

3.1 Application

3.1.1

The impact pressures are not to be envisaged for fatigue assessment.

3.2 Bottom slamming pressure

3.2.1

The bottom slamming pressure formula based on LR Rules (January 2013), Pt 3, Ch 5, 1.5.8. The reduction of the bottom slamming pressure to account for the counter-acting head of ballast water is allowed and is based on LR Rules (January 2013), Pt 3, Ch 5, 1.5.8.

The LR Rules slamming pressure formula is an empirical formulation based on the results of a study into the bottom slamming pressures for a range of general cargo and full form ships using the Ochi-Motter approach. In this study, the slamming velocities and relative vertical motions were derived using ship motion analysis and based on short term statistical analysis of motions in North Atlantic sea states. Bow shapes of typical ships were used to derive the impact shape coefficients. The study included forward speed.

The LR rule application has been revised with respect to the forward draughts to be used for the bottom slamming assessment in order to match the Rule design basis. Hence, two sets of minimum draughts forward are to be specified:

- One set specifies the minimum draught forward with each double bottom ballast tank (or fore peak/forward deep tank) empty.
- The other set specifies the minimum draught forward applicable with each ballast tank is filled, hence reducing the effective slamming pressure due to the counter-acting ballast water.

The minimum draughts forward are to be specified by the designer and are not to be taken less then the minimum draughts obtained in the loading manual. If only one draught is provided, it will be considered as being the minimum draught with ballast tank empty, and no counter-pressure will be considered.

3.2.2 Loading manual information

Technical background is not considered necessary.

3.3 Bow impact pressure

3.3.1 Design pressures

The bow impact pressure formula is based on the CSR OT (July 2010), Sec 7/4.4. The bow impact pressure is due to frontal impact force in the longitudinal direction, which is converted to the pressure to the bow area.

The bow impact pressure is approximately proportional to the square of relative impact velocity based on experimental and theoretical studies by Hagiwara and Yuhara:

$$P_{im} \propto \rho V_{im}^2$$

where:

ρ Density of seawater, in kg/m^3.

V_{im} Relative impact velocity, in m/s^2.

The impact velocity represents the relative velocity between the ship and the fluid. The ship speed is estimated to be 75% of the ship service speed, taking into account voluntary and involuntary speed reduction due to slamming, bow sub-mergence and added wave resistance. The velocity of the critical encountering waves is assumed to be associated to a wave length of 65% of the ship length. These two components are estimated based on the study by Ochi and Tasai. The formulation does not include any contribution from bow flare slamming pressure.

In RCN 1 to CSR 01 Jan 2021 further Rule clarity is provided towards bow impact pressure with extreme bow impact angle between 0 and 50 degrees which is to be as per individual society. However, the resulting scantling is to be not less than that determined according to [3.3.1] with bow impact angle equal to 50 degrees.

4 EXTERNAL PRESSURES ON SUPERSTRUCTURE AND DECKHOUSES

4.1 Application

4.1.1

Technical background is not considered necessary.

4.1.2

Technical background is not considered necessary.

4.2 Exposed wheel house tops

4.2.1

Technical background is not considered necessary.

4.3 Sides of superstructures

4.3.1

Technical background is not considered necessary.

4.4 End bulkheads of superstructures and deckhouse walls

4.4.1

The pressure acting on the superstructure bulkheads and deckhouse walls is estimated according to the longitudinal position and height on the bulkhead (wall).

5 EXTERNAL PRESSURES ON HATCH COVERS

5.1 Application

5.1.1

Technical background is not considered necessary.

5.2 Green sea loads

5.2.1

The green sea loads are obtained according to [2.2]. The minimum deck pressure defined in ICLL, Annex I, Ch II, Reg. 16, is applied with χ coefficient equal to 1.0. The minimum loads from ICLL reference are considered as Classification requirement.

5.3 Load carried on hatch covers

5.3.1

When cargo is loaded on hatch covers, the static and dynamic loads due to the loaded cargo are specified in [2.3] according to the type of cargo.

1 PRESSURES DUE TO LIQUID

1.1 Application

1.1.1 Pressures for the strength and fatigue assessments of intact conditions

Technical background is not considered necessary.

1.1.2 Pressures for the strength assessments of flooded conditions

Technical background is not considered necessary.

1.2 Static liquid pressure

1.2.1 Normal operations at sea

Technical background is not considered necessary.

1.2.2 Harbour/sheltered water operations

Technical background is not considered necessary.

1.2.3 Sequential ballast water exchange

Technical background is not considered necessary.

1.2.4 Flow through ballast water exchange

Technical background is not considered necessary.

1.2.5 Ballasting using ballast water treatment system

Technical background is not considered necessary.

1.2.6 Static liquid pressure for the fatigue assessment

Technical background is not considered necessary.

1.3 Dynamic liquid pressure

1.3.1

Under the assumptions that the tank or compartment of any type is fully filled with the homogeneous liquid of unique density ρ_L, and the tank wall is rigid, the dynamic liquid pressure, P_{ld}, in kN/m² is defined by the formula:

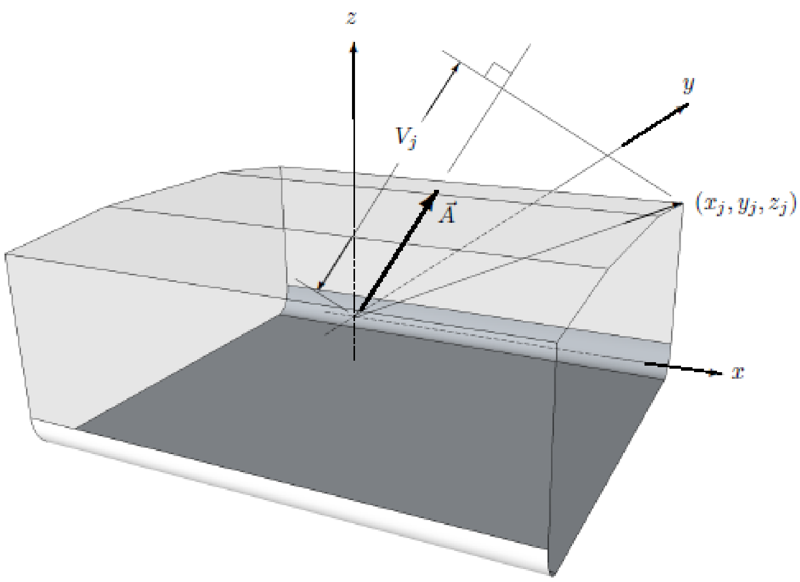
$$P_{ld} = f_\beta \, f_{cd} \rho_L \, [a_Z \, (z_0 - z) + f_{ull-l} \, a_X \, (x_0 - x) + f_{ull-t} \, a_Y \, (y_0 - y)]$$

The ullage factors f_{ull-l} and f_{ull-t} have been taken in accordance with CSR OT (July 2010). It considers that the Rules are developed for the tank completely full, whether in reality cargo tanks will normally not be more than 98% full. Therefore, the ullage factors represent the difference between the tank pressure at 98% tank filling and 100% tank filling at the tank sides.

The acceleration components (a_X, a_Y, a_Z) are measured at the centre of the tank G (x_G, y_G, z_G) and the reference point O (x_o, y_o, z_o) is defined as the point with the highest value of V_j. The value of V_j is computed for all points that define the upper boundary of the tank or ballast hold by the formulae:

$$V_j = a_x \, (x_j - x_G) + a_Y \, (y_j - y_G) + (a_Z + g) \, (z_j - z_G)$$

Figure 1: Definition of reference point coordinate x_0



In fact, V_j is the projection of the position vector (originated at COG) to the total acceleration vector:
$A = A\ (a_X, a_Y, a_Z + g)$

That is, the reference point O (x_o, y_o, z_o) should be defined by a mathematical formulation like $O = P_j$, for max (V_j, j = 1, 2, 3, …) where P_j is the j-th point along the tank boundary with coordinates P_j (x_j, y_j, z_j). In principle, all particular points like vertex/summits of tank boundary should be considered in the choice of P_j. Some possible (not exhausted) examples are as follows:

Figure 2: Cargo hold of Bulk Carriers

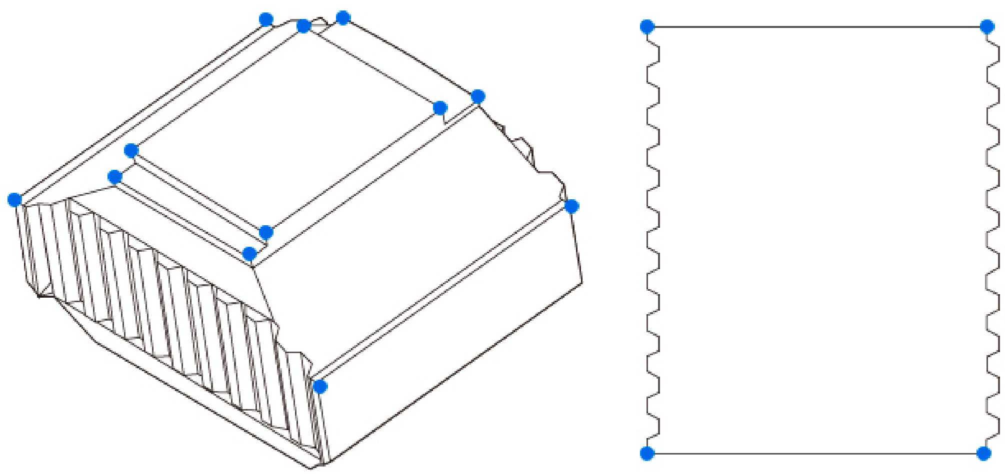


Figure 3: Cargo tank of Tankers (considering camber)

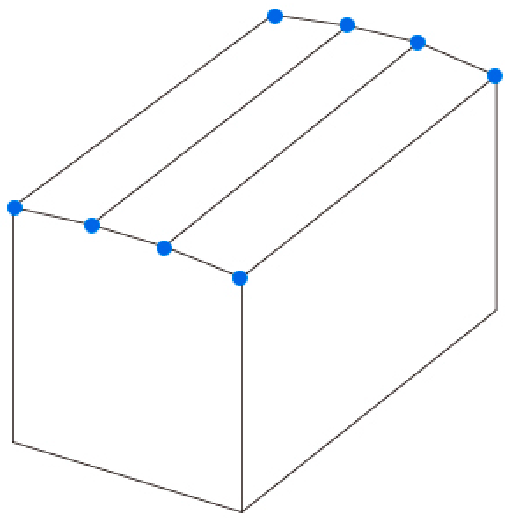


Figure 4: Ballast tank

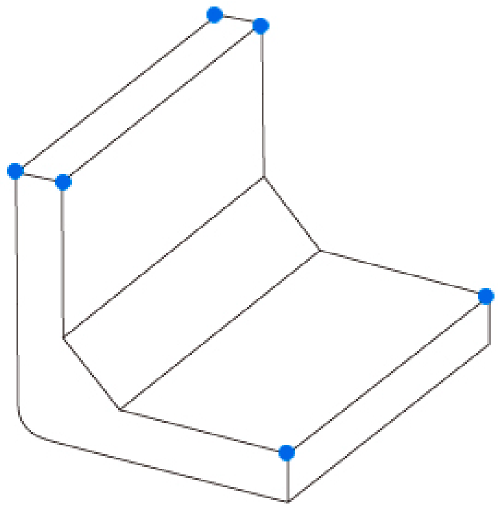
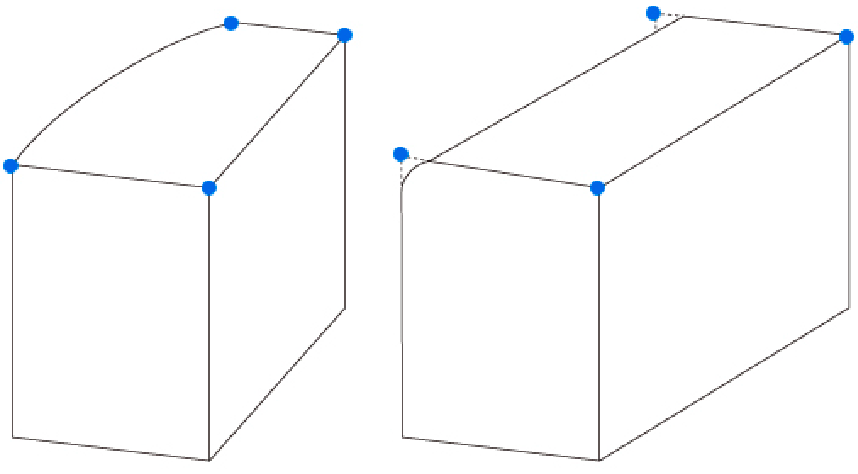


Figure 5: Curved plans and sides



1.4 Static pressure in flooded conditions

1.4.1 Static pressure in flooded compartments

Technical background is not considered necessary.

1.5 Dynamic pressure in flooded conditions

1.5.1 Dynamic pressure in flooded compartments

Refer to TB [1.3.1].

2 PRESSURES AND FORCES DUE TO DRY BULK CARGO

2.1 Application

2.1.1

Technical background is not considered necessary.

2.2 Hold definitions

2.2.1 Geometrical characteristics

Technical background is not considered necessary.

2.2.2 Fully and partially filled cargo holds

For the computation of the dry bulk cargo pressure it is important to define the filling ratio of the hold which is dependent on the loading patterns envisaged for the structural assessment of the holds. These loading patterns are defined in details in Sec 8. However, the relevant parameters for the pressure computation are defined in this section. Two filling conditions are considered:

- Cargo hold filled up to the hatch coaming;
- Cargo hold not completely filled

2.3 Dry cargo characteristics

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

When the hold is filled up to the top of hatch coaming, the upper surface of the bulk cargo should be taken ignoring the topside tanks, based on practicality and safety and taking into account the friction effects between the cargo and the wall surfaces.

The height of surface contour of loaded cargo (h_C, vertical distance from the inner bottom plating to the assumed bulk cargo upper surface) is determined assuming loaded condition with width equal to the width between side shell plating or longitudinal bulkheads surrounding the cargo in the cargo hold considering an equivalent volume of cargo.

2.3.2 Upper surface of dry bulk cargo for partially filled cargo holds

When the cargo hold is loaded with heavy cargo, the upper surface of the cargo may not reach the position of the upper deck. To set the cargo pressure applied on the inner bottom plating on the safe side, the height of the shape of the surface of cargo (h_C) should be set assuming that the volume and mass (M) of the cargo remain unchanged, the upper surface of the cargo is considered as having a plane surface of width $B_H/2$ on the centreline (B_H is the mean width of the cargo hold), and the shape of the cargo has inclined parts with an angle equal to half the angle of repose ($\Psi/2$) at sides.

2.3.3 Mass and density

Further to examination of CSR BC (July 2010) requirements of Ch 4, Sec 7 based on IACS UR, S25 (which is no more in force), it appears that the consideration of the maximum cargo density only, may not lead to the most severe cases against yielding, flooded (IACS UR, S18, Rev 8, May 2010) and fatigue criteria. This is particularly true for the upper parts of the cargo holds or transverse bulkheads.

Therefore, the lowest cargo density corresponding to the complete filling of the cargo hold should be considered in the structure assessment in agreement with CSR BC (July 2010), Ch 4, Sec 7, [2.1.2] in homogeneous loading and [3.4.2] in alternate loading.

For yielding and flooding, this leads to the fact that for BC-A and BC-B two loading conditions are to be considered in each cargo hold for homogeneous conditions and for BC-A two other for alternate conditions, as follows:

For BC-A & BC-B ships loaded in homogeneous conditions:

- One loading condition with highest cargo density.
- One loading condition with the lowest cargo density corresponding to the complete filling of the cargo hold.

For BC-A ships loaded in alternate conditions:

- One loading condition with highest cargo density.
- One loading condition with the lowest cargo density corresponding to the complete filling of the cargo hold.

The loading patterns used for pressure calculation for fatigue assessment were considered the same as the ones defined in CSR BC for FEM calculations (CSR BC (July 2010), Ch 4, App 3, Table 1 and Table 2).

2.3.4 FE application

Technical background is not considered necessary.

2.4 Dry bulk cargo pressures

2.4.1 Total pressure

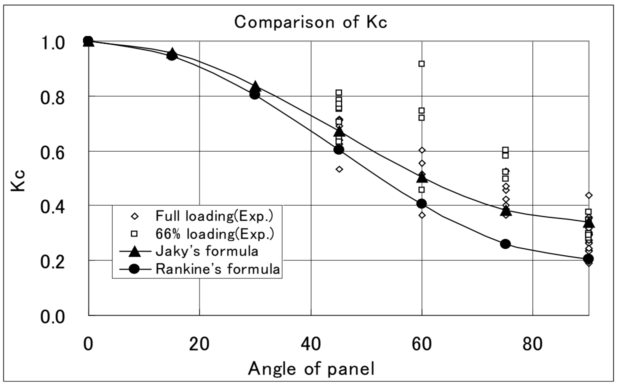
The total (static + dynamic) pressure should be zero for any load point of cargo boundary above the level of cargo surface given by h_c.

2.4.2 Static pressure

The static pressure depends on the height of the cargo upper surface and the coefficient K_C ($K_C = \cos^2 \alpha + K_0 \sin^2 \alpha$) which takes the coefficient of the earth pressure at rest K_0, and the angle of the slant plate as parameters.

The coefficient of earth pressure at rest applicable to the inclined wall for the estimation of static pressure is examined referring to the experimental results. The comparisons of earth pressure at rest using Jaky’s formula and Rankine’s formula are shown in the figure below together with the experimental results. It can be noticed that the Jaky's formula is found to be in good agreement with the experimental results and on the safer side of the estimation compared with Rankine’s formula. Therefore, Jaky's formula was adopted as the coefficient of earth pressure at rest. Furthermore, the correction method of the surface shape of bulk cargo has been developed considering the effect of mutual friction between bulk cargoes to estimate bulk cargo pressure accurately.

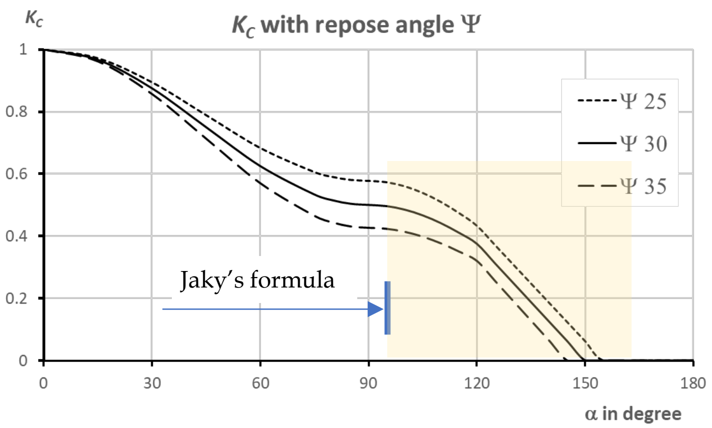
Figure 6: Comparison of K_C with respect to angle of panel



However, this formula is valid only for α angles between 0 and 90 degrees and it has been adapted for angles above 90 degrees so that *Kc* is gradually reduced and reaches zero when the angle of the panel α combined with the angle of repose ψ reaches 180 degrees, as shown in figure 7.

For topside tank and main deck, K_C would consequently be equal to zero in conventional designs while for the sloped upper stools from the upper surface of the cargo(z_C), K_C is not zero but very small lateral pressure will be applied on them.

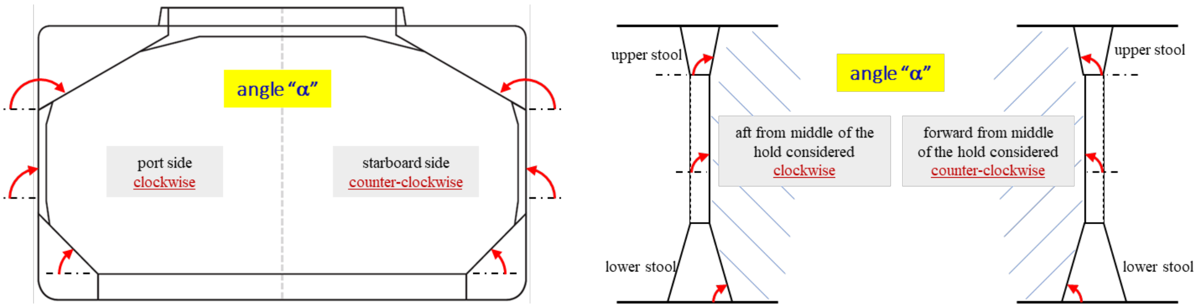
Figure 7: K_C with respect to angle of panel with repose angle



Guide notes for the measurement direction of the angle between panel considered and the horizontal plane has been added in α definition (Section 6 Symbols), to clarify that it is to be measured inward and upward loaded cargo and expanded from 90 degree to 180 degree in result. Figure 8 shows how the angle (α) shall be measured;

- Clockwise for portside and counter-clockwise for starboard side in a section view of longitudinal members (hopper tank, topside tank, main deck, longitudinal bulkhead, inner side and side shell).
- In an elevation view of transverse members (lower stool, upper stool, transverse bulkhead), clockwise for aft panel and counter-clockwise for forward one from middle of the hold considered.

Figure 8: Measurement of angle α



2.4.3 Dynamic pressure

The dynamic pressure due to inertial force of the grain cargo depends on the height of the cargo upper surface, the coefficient K_C, and the longitudinal, transverse and vertical accelerations obtained at the volumetric centre of gravity the dry bulk cargo for the considered fully or partially filled cargo hold as defined in Ch 4, Sec 3, [3.2] and for each load case defined in Ch 4, Sec 2.

Based on the experimental results, the dynamic pressure induced by dry bulk cargo due to static inclination of pitch or roll can be approximately obtained by multiplying $\rho g \theta$ (or, $\rho g \phi$) by the distance from the centre of gravity of the cargo hold or from the centre of gravity of the dry bulk cargo depending on cargo filling condition to the load point considered and a correction factor $C_{\theta\phi}$. Here, θ and ϕ are the single roll amplitude and single pitch amplitude respectively. The correction factor $C_{\theta\phi}$ is to be taken 0.25 based on the experimental results.

2.5 Shear Load

2.5.1 Application

The shear load is considered to guarantee the balance between the overall internal pressure or force of the FE model in direct structural analysis. The shear load is considered for FE strength assessment and FE fatigue assessment.

2.5.2 Static shear load on the hopper tank and lower stool plating

To consider a balance between the overall internal pressure or force (gravity and inertial force due to vertical acceleration) in the vertical direction of the FE structural model in direct structural analysis, shear load according to the calculation formula in Ch 4, Sec 6, [2.5.2] should be considered in addition to the static internal pressure according to the calculation formula in Ch 4, Sec 6, [2.4.2].

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

To consider a balance between the overall internal pressure or force (gravity and inertial force due to vertical acceleration) in the vertical direction of the FE structural model in direct structural analysis, shear load according to the calculation formula in Ch 4, Sec 6, [2.5.3] should be considered in addition to the dynamic internal pressure according to the calculation formula Ch 4, Sec 6, [2.4.3].

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

Only inertial forces due to longitudinal and transverse accelerations exist in the longitudinal and transverse directions of the ship because of basically the same reasons as in [2.5.2] and [2.5.3], and therefore, shear load is applied on the inner bottom plating to consider the balance of overall forces (inertial force due to acceleration) in the longitudinal and transverse directions of the FE structural model.

3 PRESSURES AND FORCES DUE TO DRY BULK CARGOES IN FLOODED CONDITION

3.1 Vertically corrugated transverse watertight bulkheads

3.1.1 Application

The requirements are in accordance with the regulation of IACS UR, S18 (Rev 8, May 2010). For each cargo hold, the flooded condition is considered independently.

3.1.2 General

The requirements are in accordance with IACS UR, S18 (Rev 8, May 2010).

3.1.3 Flooded level

Refer to TB [3.1.2].

3.1.4 Flooded patterns

Refer to TB [3.1.2].

3.1.5 Pressures and forces on vertically corrugated transverse bulkheads of flooded cargo holds

Refer to TB [3.1.2].

3.1.6 Pressures and forces on vertically corrugated transverse bulkheads of non-flooded cargo holds

Refer to TB [3.1.2].

3.1.7 Resultant pressures and forces on vertically corrugated transverse bulkheads of flooded holds

Refer to TB [3.1.2].

3.2 Double bottom in cargo region of bulk carrier in the flooded condition

3.2.1 Application

The regulation is based on the regulation of IACS UR, S20 (Rev 5, May 2010). For each cargo hold, the flooded condition is considered independently.

3.2.2 General

The regulation is based on the regulation of IACS UR S20 (Rev 5, May 2010).

3.2.3 Flooded level

Refer to TB [3.2.2].

4 STEEL COIL LOADS IN CARGO HOLDS OF BULK CARRIERS

4.1 General

4.1.1 Application

The steel coil loads are defined in accordance with CSR BC (July 2010). CSR BC formulas have been modified in order to include physical details but with the same results. Additional information concerning the steel coil loads is given in the TB Report, “TB Rep_Pt1_Ch04_Sec06_Steel Coil Loads”.

4.1.2 Arrangement of steel coils on inner bottom

As steel coils are loaded on a wooden support (dunnage) provided on the inner bottom plating and bilge hopper plating, the concentrated loads due to steel coils act on the plating through the dunnage.

However, as the location of concentrated loads and the distance between concentrated loads depend on the loading pattern and size of dunnage, it is assumed that the concentrated load is transformed to a line load with a small breadth (hereinafter referred to as "rectangular load") which acts on the most severe conditions (load point and distance between load points).

Based on this assumption, the specific formulae for dimensioning the plating and ordinary stiffeners under steel coil loading are introduced in the Rules separately from those based on uniformly distributed loads. Steel coils are usually secured to each other by means of steel wires. Heavier steel coils are loaded with one or two tiers, and lighter ones are loaded with two or more tiers. Examples of steel coil loading are shown in Figure 7 and Figure 8 below.

Figure 9: Loading conditions of one tier

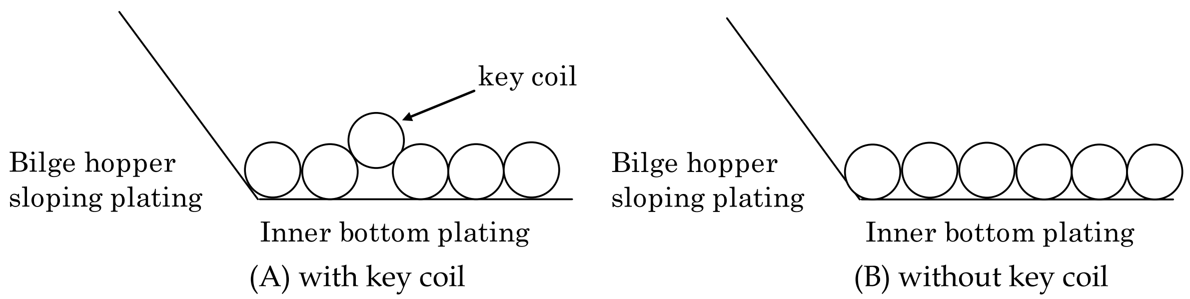
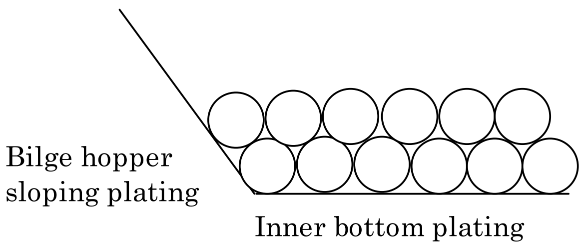


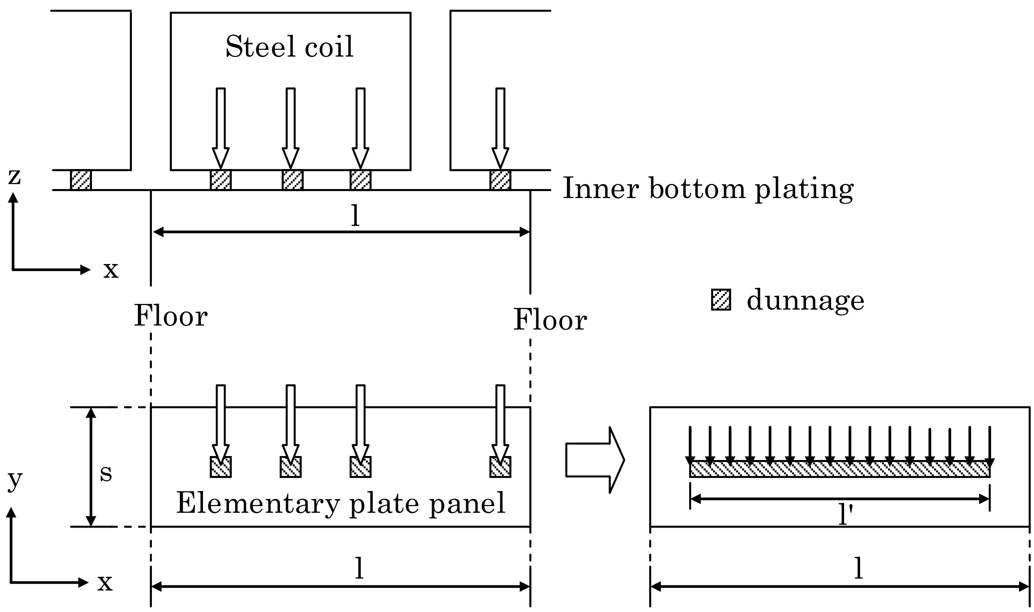
Figure 10: Loading conditions of two tiers



The load due to steel coils acts on an elementary plate panel as a concentrated load through dunnages. However, it is difficult to treat concentrated loads directly because the location of concentrated loads and the distance between concentrated loads depend on the loading pattern and size of dunnage. Then, the following assumptions regarding the loads due to steel coils are considered.

1. Loads due to steel coils act along a centreline of a plate panel.
2. A rectangular load instead of concentrated loads is used in order to be on the safer side considering the interaction between concentrated loads.

Figure 11: Convert concentrated loads to rectangular loads



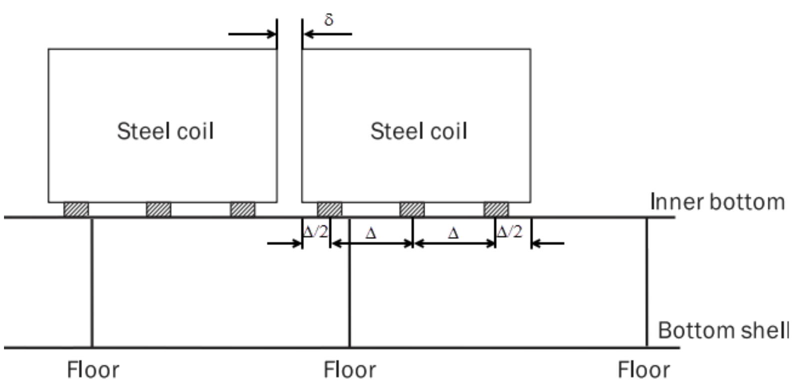
As it is the most severe when loads act on the inner bottom vertically, the vertical acceleration is considered for the scantling formula of inner bottom structures.

4.1.3 Arrangement of steel coils independently of the floor locations

The number of load points per EPP, n_2, is derived based on the length of both EPP and steel coil, as well as the number of dunnages supporting one row of steel coils, n_3.

The calculation of n_2 is based on the following assumption:
(1) The dunnages per steel coil are arranged uniformly along the length of a row of steel coils, l_{st}, with an interval $\Delta = l_{st}/n_3$, and the distance between the end of steel coil and the outmost dunnage is $\Delta/2$, see Figure 12.
(2) The gap between two rows of steel coils, δ, is assumed as $0.2 l_{st}$, see also Figure 12.

Figure 12: The arrangement of dunnages



Based on the above assumption, n_2 is determined according to the following formula:

$$(n_2 - 1) \cdot \Delta + int\left(\frac{n_2 - 1}{n_3}\right) \cdot \delta < l \leq n_2 \cdot \Delta + int\left(\frac{n_2}{n_3}\right) \cdot \delta \qquad (1)$$

Where:

n_2 : positive integer, taken as 2, 3, …

$int(\,)$: the integer function.

Introducing $\Delta = l_{st}/n_3$ and $\delta = 0.2 l_{st}$ into the Formula (1) to get the relational expression among the n_2, n_3 and l/l_{st} as following:

$$\frac{n_2-1}{n_3} + 0.2int\left(\frac{n_2-1}{n_3}\right) < \frac{l}{l_{st}} \le \frac{n_2}{n_3} + 0.2int\left(\frac{n_2}{n_3}\right) \quad (2)$$

The distance between outermost load point dunnages per EPP, l_{lp}, can be obtained from the following formula:

$$l_{lp} = (n_2 - 1)\cdot\Delta + int\left(\frac{n_2-1}{n_3}\right)\cdot\delta \quad (3)$$

Introducing $\Delta = l_{st}/n_3$ and $\delta = 0.2 l_{st}$ into the Formula (3), it is derived as Formula (4):

$$l_{lp} = \left[\frac{n_2-1}{n_3} + 0.2int\left(\frac{n_2-1}{n_3}\right)\right] l_{st} \quad (4)$$

4.1.4 Arrangement of steel coils between floors

The number of load points per elementary plate panels and the distance between outermost load points are defined in accordance with CSR BC (July 2010).

4.1.5 Centre of gravity of steel coil cargo

If the actual centre of gravity in steel coil loaded condition is known, it is better to use the actual one in calculating the acceleration. If the actual centre of gravity is not known, the default position of the centre of gravity is given by the following:

x : $0.5\,\ell_H$

y : $\varepsilon B_h/4$, measured from the centreline

z : $h_{DB} + \left(1 + (n-1)\sqrt{3}/2\right) d_{SC}/2$

where,

ℓ_H : the cargo hold length, in m

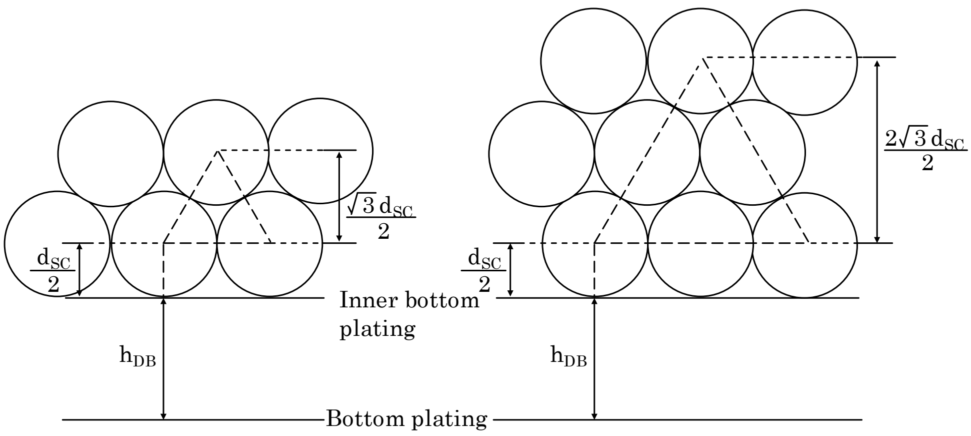
d_{sc} : The diameter, in m, of steel coil

h_{DB} : The height, in m, of double bottom

B_h : breadth, in m, at the mid of the hold

ε : 1.0 when a port side structural member is considered,
-1.0 when a starboard side structural member is considered.

Figure 13: The height of steel coils



4.2 Total loads

4.2.1 Total load on the inner bottom

The total load acting on the inner bottom due to steel coils is decomposed into static and dynamic loads weighted by their respective load combination factors.

4.2.2 Total load on the hopper side

The total load acting on the hopper side due to steel coils is decomposed into static and dynamic loads weighted by their respective load combination factors.

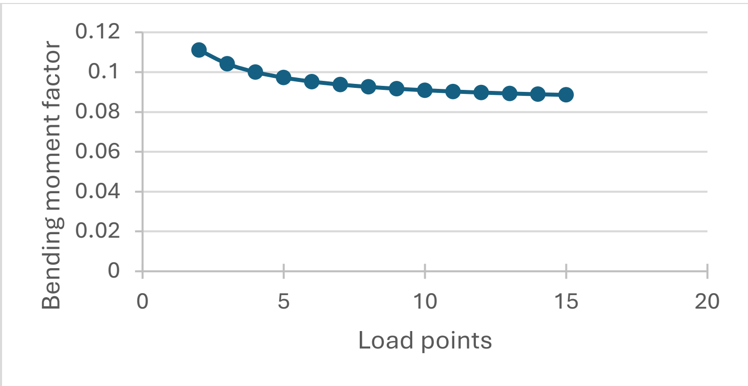
4.3 Static loads

4.3.1 Static loads on the inner bottom

The static load acting on the inner bottom is due to gravitational acceleration applied on an equivalent mass of steel coils which is determined in accordance with CSR BC (July 2010).

Considering the mechanical model, when the number of load points increases, the steel coil load acts more closely to distributed loads. Figure 14 gives the curve of bending moment factor, which is the ratio between the bending moment at ends and the total loads applied on the span, with the increasing of load points, n2. When n2 is equal to or greater than 10, the factor tends to be constant. Therefore, n2 =10 is selected as the criteria for distributed loads.

Figure 14: Bending moment factor



4.3.2 Static loads on the hopper side

The static load acting on the hopper side is due to gravitational acceleration applied on an equivalent mass of steel coils which is determined in accordance with CSR BC (July 2010). Refer to TB of [4.3.1].

4.4 Dynamic loads

4.4.1 Tangential roll acceleration

The tangential roll acceleration is determined in accordance with CSR BC (July 2010).

4.4.2 Dynamic load on the inner bottom

The dynamic load acting on the inner bottom is due ship's acceleration applied on an equivalent mass of steel coils which is determined in accordance with CSR BC (July 2010).

4.4.3 Dynamic loads on the hopper side

The dynamic load acting on the hopper side is due to ship's acceleration applied on an equivalent mass of steel coils which is determined in accordance with CSR BC (July 2010).

5 LOADS ON NON-EXPOSED DECKS AND PLATFORMS

5.1 Application

5.1.1 General

Technical background is not considered necessary.

5.2 Pressure due to distributed load

5.2.1

Technical background is not considered necessary.

5.3 Concentrated force due to unit load

5.3.1

Technical background is not considered necessary.

6 SLOSHING PRESSURES IN TANKS

6.1 General

The sloshing pressures were defined in accordance with CSR OT (July 2010) which is based on DNV Rules (January 2010), Pt 3, Ch 1, Sec 4.

6.1.1 Application

Sloshing pressures are pressure induced by the movement of liquid in tanks due to ship motions and only applied to the tanks of large volume.

6.1.2

The sloshing pressure is applicable for tanks with effective breadth and length within $b_{slh} \leqslant 0.56B$ and $l_{slh} \leqslant 0.13L$ respectively. As a result of MARPOL requirements (as amended), it is rare to see an oil tanker that has an effective tank length greater than $0.13L$. Likewise the stability requirements do not allow larger ships to have full breadth cargo tanks. A full breadth forepeak ballast tank will generally have a significant amount of internal stiffeners and webs that reduce the effective sloshing breadth. Based on this no effort was put on unifying the sloshing loads for such tanks in the present version of the common Rules.

6.1.3 Sloshing pressure on tank boundaries and internal divisions

Technical background is not considered necessary.

6.2 Minimum sloshing pressure

6.2.1

The minimum sloshing pressure, $P_{slh\text{-}min}$, is included in order to ensure that all internal structures are able to withstand the pressures due to fluid motion in the tank.

6.3 Sloshing pressure due to longitudinal liquid motion

6.3.1 Application

Technical background is not considered necessary.

6.3.2 Effective sloshing length

The sloshing pressure acting on the transverse bulkhead and transverse wash bulkhead are different since the effective sloshing length is different. The sloshing pressure formulation takes into account the internal web-frames and transverse swash-bulkheads that reduce the fluid motion in the tanks, by reducing the effective sloshing length of the tank.

6.3.3 Sloshing pressure in way of transverse bulkheads

The coefficient f_{slh} is based on the fact that the maximum calculated sloshing pressure is found at a filling level of $0.7h_{max}$. This will be the case for all tank configurations without wash bulkheads or transverse struts, i.e. with only vertical webs in the tank. For tanks with a strut/cross tie the maximum sloshing pressure will typically be found at a filling level between $0.7h_{max}$ and $0.8h_{max}$. Sloshing pressure on internal web frames or transverse stringers adjacent to a transverse bulkhead.

6.3.4 Sloshing pressure on internal web frames or transverse stringers adjacent to a transverse bulkhead

The sloshing pressure due to longitudinal fluid motion is also assumed to act on the 1st internal web-frame away from the transverse tight/wash-bulkhead. This pressure arises due to the reflection of the liquid from the transverse bulkhead under consideration and is consequently lower than pressure acting directly on the transverse bulkhead. The closer the web-frame is to the bulkhead in question the higher the pressure will be. The distribution of sloshing pressure on web-frames and stringers gives a reduction towards the free edge to account for limited possibility of pressure build up.

6.4 Sloshing pressure due to transverse liquid motion

6.4.1 Application

Technical background is not considered necessary.

6.4.2 Effective sloshing breadth

The sloshing pressure formulation takes into account the internal longitudinal girders and longitudinal wash-bulkheads that reduce the fluid motion in the tanks. The sloshing breadth in cargo tanks will normally be equal to the tank breadth. The reduced sloshing breadth will mainly be applicable for sloshing assessment of aft- and fore peak ballast tanks.

6.4.3 Sloshing pressure in way of longitudinal bulkheads

The sloshing pressure acting on the tank-sides/longitudinal bulkheads and longitudinal wash-bulkhead are different due to different sloshing breadths. This gives lower sloshing pressure in way of wash bulkheads compared to tight bulkheads.

6.4.4 Sloshing pressure on internal girder or longitudinal stringers adjacent to longitudinal bulkheads

The sloshing pressure due to transverse fluid motion is also assumed to act on the 1st internal girder away from the longitudinal tight/wash bulkhead. The pressure is however reduced somewhat from that calculated for the longitudinal bulkhead, as the sloshing pressure on the frame arises as a reflection of the liquid motion acting on the longitudinal bulkhead. The greater distance the girder is away from the bulkhead in question the lower the pressure is. The distribution of sloshing pressure on girders and stringers gives a reduction towards the free edge to account for limited possibility of pressure build up.

7 DESIGN PRESSURE FOR TANK TESTING

7.1 Definition

7.1.1

During local strength assessment of plate members and stiffeners for which hydrostatic testing is required, the still water pressure due to the hydrostatic test is estimated from the water head of the hydrostatic test, and compartments and positions of structural members.

1 GENERAL

1.1 Application

1.1.1

Technical background is not considered necessary.

1.1.2

For the strength assessment, the design load combination consists of either S (Static) loads or S+D (Static+Dynamic) loads. For the accidental flooding design load scenarios, the design load combinations are preceded by the letter "A", which stands for Accidental. There are some additional design load combinations to be considered which relate to impact (I) loads and sloshing (Sl) loads.

For fatigue assessment, the design load combination S+D is considered preceded by the letter F, which stands for Fatigue. For fatigue assessment, the dynamic loads are used to obtain the stresses range while the static loads are used to obtain the mean stresses for the fatigue damage correction. Both types of loads do not need to be considered simultaneously.

2 DESIGN LOAD SCENARIOS FOR STRENGTH ASSESSMENT

2.1 Principal design load scenarios

2.1.1

For strength assessment in harbour and sheltered water design load scenario, the S and S+D design load combination are considered because different acceptance criteria are applied. Also, the accidental flooding is checked for S and S+D loads.

2.2 Additional design load scenarios

2.2.1

Technical background is not considered necessary.

3 DESIGN LOAD SCENARIOS FOR FATIGUE ASSESSMENT

3.1 Design load scenarios

3.1.1

Technical background is not considered necessary.

1 APPLICATION

1.1 Ships having a length *L* of 150m and above

1.1.1
Technical background is not considered necessary.

1.1.2 Design loading conditions for strength assessment
Technical background is not considered necessary.

1.1.3
Technical background is not considered necessary.

1.1.4
Technical background is not considered necessary.

1.1.5 Standard design load conditions for fatigue assessment
Technical background is not considered necessary.

1.2 Bulk carriers having a length *L* less than 150m

1.2.1
This regulation was adopted from the CSR BC (July 2010).

1.3 Dynamic load cases

1.3.1 Seagoing conditions
Technical background is not considered necessary.

1.3.1 Beam and oblique sea dynamic load cases
This requirement does not mean that there are two possible methods because the expected final results should be exactly the same for ships with structure symmetrical about the centreline and loaded with a pattern symmetrical to centreline In other words, it is expected to provide exactly the same yielding and buckling results:

a) If beam and oblique sea load cases calculated for both port and starboard side are directly applied to the model.
b) If beam and oblique sea load cases calculated only for port side (those designated with a P in their name) are applied and then the results from each of these load cases are mirrored across the centreline.

For ships with structure symmetrical about the centreline but loaded with a pattern not symmetrical to centreline, refer to TB of [3.2.5].

2 COMMON DESIGN LOADING CONDITIONS

2.1 Definitions

2.1.1
Technical background is not considered necessary.

2.1.2 Departure conditions

The filling level of fuel oil bunker tanks for departure conditions is taken not less than 95% full. In case of liquefied gas fuel, the filling limit is to be taken as defined in IGF code 6.8, taking into account the temperature factor and resulting in filling levels lower than 95%.

2.1.3 Arrival conditions

Technical background is not considered necessary.

2.2 Partially filled ballast tanks

2.2.1 Partially filled ballast tanks in ballast loading conditions

Technical background is not considered necessary.

2.2.2 Partially filled ballast tanks in cargo loading conditions

Technical background is not considered necessary.

2.3 Seagoing conditions

2.3.1

Technical background is not considered necessary.

2.4 Harbour and sheltered water conditions

2.4.1

During harbour and sheltered water conditions observance of the permissible shear forces and bending moments must be ensured. Consequently following conditions must be included in the loading manual:

a) Conditions representing typical complete loading and unloading operations.
b) Docking condition afloat.
c) Propellers inspection afloat condition.

2.5 Loading conditions

2.5.1 Alternative design

Technical background is not considered necessary.

3 OIL TANKERS

3.1 Specific design loading conditions

3.1.1 Seagoing conditions

Technical background is not considered necessary.

3.1.2 Additional loading conditions

Technical background is not considered necessary.

3.2 Design load combinations for direct strength analysis

3.2.1

Design FE load combinations for direct strength analysis are adopted from CSR OT based on the following:

(a) A finite element load combination is the combination of a loading pattern defined in Table 2 to Table 9 of the Rules and a dynamic load case defined in Pt 1, Ch 4, Sec 2 of the Rules. The corresponding dynamic load cases for each loading pattern are indicated under the column 'Dynamic Load Cases' in Table 2 to Table 9 of the Rules.

(b) The standard FE analysis considers loading patterns, ship draughts, hull girder still water bending moments and shear forces that are intended to provide an envelope of the typical loading conditions anticipated in operations. The operation envelope stipulates:

- A maximum ship draught equal to 90% of the ship's scantlings draught and a minimum ship draught equal to 60% of the ship's scantlings draught for seagoing partial load conditions.
- For tankers with two longitudinal bulkheads, a maximum ship draught equal to the ship's scantling draught and a minimum ship draught equal to 25% of the ship's scantlings draught for harbour and tank testing conditions.
- For tankers with one centreline longitudinal bulkheads, a maximum ship draught equal to the ship's scantling draught and a minimum ship draught equal to 33.3% of the ship's scantlings draught for harbour and tank testing conditions.
- Seagoing and harbour hull girder still water bending moments and shear forces specified by the designer as included in the ship's loading manual.

(c) The seagoing ship draughts considered are to provide adequate flexibility for partial load conditions in normal operations. Full scantling draught is normally not achieved when one or more cargo holds are empty unless the master intentionally increases the draught by filling a number of ballast holds. Hence, it is considered that partial loading conditions with full scantling draught, and one or more cargo holds empty, are not necessary as a mandatory requirement for all designs. Instead, a maximum ship draught equal to 90% of the ship's scantlings draught is used. The minimum ship draught considered for seagoing partial load conditions is 60% of the ship's scantling draught.

(d) For harbour and tank testing load cases, shallow draught conditions could be critical for the double bottom structure. The minimum draught chosen for the analysis is based on the smallest draught that can be achieved with the loading pattern considered for a given tank arrangement, see item (b). Note that the minimum ship draught used in harbour/tank testing conditions is less than that for the seagoing conditions to allow additional flexibility during these operations. The strength of the hull structure under harbour permissible still water bending moment and still water shear force is also assessed for shallow and full scantling draught conditions.

(e) A deep draught condition with an empty cargo tank is critical for the bottom structure due to high upward acting static and wave pressure on the bottom shell and no counteracting tank pressure. When a wing cargo tank is empty in a deep draught condition, the side and transverse structures are also under critical condition in beam seas due to lack of counteracting tank pressure against the static and wave dynamic pressure on the ship side. Likewise, shallow draught with a full tank is also a critical loading condition for the bottom structure due to high downward acting static and dynamic tank pressure and little counteracting external sea pressure. When a wing tank is full with a shallow draught, the side and transverse structures are also under considerable load due to small counteracting pressure on the ship side. It is therefore extremely important to note that if the required operational draughts for partial load conditions are greater than the maximum draught and/or lesser than the minimum draught used in the standard FE analysis, the required draughts must be specified and included in the FE analysis.

(f) Refer to TB [3.2.6].

(g) Fully loaded condition and normal ballast condition are not included in the FE loading patterns, as these conditions do not impose the most onerous loads on the main supporting structural members as the net load on the double hull structure is small in both cases, i.e. full cargo tank with deep draught and empty cargo tank with shallow draught. Fully loaded and normal ballast conditions are important for determination of hull girder bending strength, which is adequately checked by the longitudinal strength calculation described in Pt 1, Ch 5 of the Rules.

(h) Where the designer requests an operation envelope that is not covered by the standard FE load combinations, the additional loading conditions must be specified and included in the FE analysis.

(i) The loading patterns used in the finite element analysis were chosen such that the most severe static pressure loads, localised shear forces and bending moments are imposed on the primary supporting structure of the hull (i.e. frame and girder system). The loading patterns chosen consist of possible alternative tank partial load conditions, where adjacent holds are in various configurations of fully loaded and empty condition in both longitudinal and transverse directions, to maximise the loads acting on the structure using an optimized number of loading patterns.

(j) For each of the loading pattern analysed, the distribution of cargo and ballast is only defined within the three-tank length FE model. The use of actual still water bending moment from the loads applied to the three tank FE model may be non-conservative as this does not take into account the loads applied along the whole ship length outside the extent of the model. For this reason, the permissible seagoing and harbour still water hull girder bending moments are used in the seagoing and harbour FE load combinations respectively.

(k) The hull girder still water shear force is most critical for loading conditions with either all cargo holds abreast empty (and all adjacent cargo holds abreast full) or all cargo holds abreast full (and all adjacent cargo holds abreast empty), whilst the hull girder still water shear force resulting from other 'checker board' loading patterns is less critical. This “full or empty across” loading condition is analysed using FE loading patterns A3, A5, A11, A13, B3, B6, B8 and B11 in combination with the dynamic load cases with maximum wave shear force to assess the hull strength against hull girder shear loads. For these load case combinations, shear force correction procedure is to be applied, where necessary, to ensure that the required combined seagoing permissible still water and maximum wave shear force is achieved in the sea going FE load combinations and harbour permissible still water shear force is achieved in the harbour/tank testing FE load combinations. By carefully matching of the FE loading pattern with ship draught, only minor adjustment of shear forces are needed to obtain the required hull girder shear forces. Shear force correction procedure is not required to be applied to other “checker board” FE loading patterns where the hull girder shear force is less critical, unless this hull girder shear force exceeds the permissible value.

(l) Refer to TB [3.2.7].

(m) The finite element load combination (i.e. combination of static and dynamic loads for seagoing conditions and static loads only for harbour conditions) are to generate the most severe combination of global and local loads on the structure for the loading patterns considered.

(n) The following general considerations are given in combining a loading pattern with dynamic load cases:

- The hull girder loads are maximised by combining a static loading pattern with dynamic load cases that have hull girder bending moments/shear forces of the same sign.
- The net local load on primary supporting structural members is maximised by combining each static loading pattern with appropriate dynamic load cases, taking into account the net pressure load acting on the structural member and influence of loads acting on an adjacent structure. The general principle of maximising the net local pressure loads is explained in Table 1.

Table 1: Principle of maximising the net local pressure loads

	Loading pattern	Ship draught	Dynamic loads
Internal tight-bulkheads	Full tank/adjacent tank empty	NA	Maximise load due to accelerations in fully loaded holds
Double bottom or double side	Empty tank	Deep still water draught	Maximise external sea pressure (head sea wave crest condition or weather side beam/oblique sea condition)
Double bottom or double side	Full tank	Shallow still water draught	Maximise internal pressure due to accelerations. Minimise external sea pressure (head sea wave trough condition or lee side beam sea condition)

(o) The global hull girder loads and local loads are to be combined in such a way that the stresses due to net local pressure loads acting on the primary support members and hull girder loads are additive to maximise the stress in certain parts of the structure. For example, hull girder maximum sagging condition (i.e. dynamic load case HSM-1, defined in Pt 1, Ch 4, Sec 2 of the Rules, with maximum wave sagging bending moment in a wave trough, and maximum sagging still water bending moment) is combined with a loading pattern with fully loaded holds (middle hold of FE model) and shallow draught to generate maximised tensile stress at the outer bottom.

(p) Similarly, hull girder maximum hogging condition (i.e. dynamic load HSM-2, defined in Pt 1, Ch 4, Sec 2 of the Rules, with maximum wave hogging bending moment in a wave crest, and maximum hogging still water bending moment) is combined with a loading pattern with empty holds (middle holds of FE model) and deep draught to maximise compressive stress at the outer bottom.

(q) For seagoing finite element load combinations, several different dynamic load cases may require to be combined with one loading pattern in order that critical conditions for different structural members can be examined.

(r) For the harbour FE load combinations, only static loads are to be applied. The required still water bending moment and shear force for these FE load combinations are based on harbour permissible still water bending moments and shear forces.

(s) A study was carried out for a number of designs of various configurations and sizes to further minimise the required number of combinations of loading pattern and dynamic load cases.

From the loading principles enumerated from (a) to (s) it is possible to make an educated guess about which primary supporting members are more likely to be challenged by each FE

Load combination: most cases have been explicitly cited (e.g. double bottom, double side, bottom plating).
However, linking the FE Load combination to a limited set of primary supporting members for which it is bound to be critical is not a priori certain because the outcome may depend from different design options. The development of FE load combinations for aftmost and foremost cargo hold models is in progress.

3.2.2

The still water draughts given in Table 2 to Table 9 of the Rules for Tankers type A and type B are required for typical tankers of a typical arrangement i.e. VLCC, suezmax, aframax and product carriers. For other designs with cargo tanks of shorter lengths, e.g. tankers for chemicals and oil products, more severe draughts can be archived than the required draughts for standard designs: a deeper draught for loading condition with all cargo tanks abreast empty (and all adjacent cargo tanks abreast full) and a more shallow draught for loading condition with all cargo tanks abreast empty (and all adjacent cargo tanks abreast full). The separate draught requirements apply for ships where the ration between the ship rule length and the length of cargo tank is lesser than 0.15 for Tankers Type A and 0.11 for tankers Type B.

3.2.3

Refer to TB [3.2.2].

3.2.4

Refer to TB [3.2.1].

3.2.5 Ships with structure symmetrical about centerline

In case a ship has structure symmetrical to centreline and is loaded with an unsymmetrical loading pattern (e.g. A7a and A12a in Pt 1, Ch 4, Sec 8, Table 2), then the loading pattern that is symmetrical across the centreline (A7b and A12b in our example) may be omitted provided that the results (either for each FEM load combination or the worst one and for each element) is mirrored across the centreline.

3.2.6 Tankers with two oil-tight longitudinal bulkheads and a cross tie arrangement in the centre cargo tanks

For tankers with two oil-tight longitudinal bulkheads and a cross tie arrangement in the centre cargo holds, special asymmetrical loading patterns with one wing tank abreast full (i.e. seagoing condition A7 and harbour condition A12) are analysed to verify the strength of the longitudinal bulkhead and support structure (in way of the empty wing tank) under the 'punching' load exerted by the cross tie in the middle tank as a result of the fluid pressure in the full wing tank. In the seagoing condition, this loading pattern is combined with the beam sea dynamic load case to obtain the maximum combined static and dynamic tank pressure acting on the longitudinal bulkhead in way of the full wing tank.

Loading pattern A12 is mandatory and is to be analysed for the possibility of unequal filling level in paired wing cargo holds in harbour or tank testing operation operations and to account for accidental non-symmetric filling of holds. Loading pattern A7 is optional and is only required to be analysed if such loading pattern is included in the ship loading manual as a condition for seagoing operation, therefore *GM* and k_r values contained in the loading manual for this loading condition are to be used: only in case these values are not given in the loading manual, then the values in Pt 1, Ch 4, Sec 3, Table 1 and Table 2 are to be used. These asymmetrical loading patterns are not critical for the longitudinal bulkhead and supporting structure for ships with no cross-tie structure in the middle tank, and therefore these loading patterns do not need to be analysed for ships with no centre tank cross-tie structure.

3.2.7

For tankers with two oil-tight longitudinal bulkheads (typical for VLCC designs), loading condition with all cargo holds abreast empty (and all adjacent cargo holds abreast full) is not typically adopted for all designs. This loading condition in combination with a deep draught will result in still water shear forces much higher than that of other loading conditions; and will require additional strengthening of side shell, inner hull, bottom girders, hopper plate and longitudinal bulkheads. For this design configuration, the inclusion of deep draughts for the FE loading patterns A3 and A13, and shallow draughts for the FE loading patterns A5 and A11 as a mandatory requirement is not necessary. Instead, less demanding draught conditions are used in the FE loading patterns A3, A5, A11 and A13 to assess the hull strength against the required hull girder shear loads.

However, if all cargo holds abreast empty (with all adjacent cargo holds abreast full) loading conditions are required in operation for a particular vessel, where the maximum seagoing/harbour draughts specified in the ship's loading manual for these conditions are greater than the default draughts used in the FE loading patterns A3 and A13, then the specified maximum draughts should be used in the FE loading patterns to assess the hull strength against the required maximum negative hull girder shear forces at sea and in harbour.

Similarly, the minimum seagoing/harbour draughts specified for the condition with all cargo holds abreast full (and all adjacent cargo holds abreast empty) in the ship's loading manual are to be used in the FE loading patterns A5 and A11 to assess the hull strength against the required maximum positive hull girder shear forces, should the minimum seagoing/harbour draughts specified for a particular vessel be smaller than the standard default draughts used in FE loading patterns A5 and A11.

The design draughts for FE loading patterns A3, A5, A11 and A13 required in CSR OT (July 2010), are adjusted in the Rules, as follows:

- The maximum realistic draught in the loading condition with all cargo tanks abreast empty (A3, A11).
- The minimum realistic draught in the loading condition with all cargo tanks abreast full (A5, A13).

The design draughts are considered to provide adequate flexibility for partial load conditions in normal seagoing and harbour operations.

3.2.8

Refer to TB [3.2.7].

3.2.9

Refer to TB item (c) of [3.2.1].

3.2.10 Ballast Conditions

Gale/emergency ballast condition is only required to be analysed if the condition is specified in the ship’s loading manual. If the actual loading pattern as specified in the loading manual is different from load pattern B7, e.g. ballast tanks adjacent to ballasted cargo tanks are empty or unsymmetrical filling the ballast in cargo tanks, then the actual is to be used in the

FE analysis. Additional strength assessment needed for unsymmetrical filling will be evaluated by the individual class societies.

4 BULK CARRIERS

4.1 Specific design loading conditions

These requirements is providing improved transparency with regard to the cargo carrying capabilities of bulk carriers by assigning harmonised notations and applying corresponding unified design loading conditions among the societies. A bulk carrier may in actual operation be loaded differently from the design loading conditions specified in the loading manual, provided limitations for longitudinal and local strength as defined in the loading manual and loading instrument onboard and applicable stability requirements are not exceeded.

4.1.1 Seagoing conditions

This regulation was adopted from the CSR BC (July 2010) and IACS UR, S25 (which is no more in force).

4.1.2 Cargo loading conditions for BC-C

Refer to TB [4.1.1].

4.1.3 Cargo loading condition for BC-B

To reflect the most onerous condition, the homogeneous cargo loaded condition with maximum density of the cargo that the ship is allowed to carry is to be considered for cases where the cargo density applied for this loading condition is different from 3.0 t/m^3.

4.1.4 Cargo loading condition for BC-A

To reflect the most onerous condition, the alternate loaded condition with maximum density of the cargo that the ship is allowed to carry is to be considered for cases where the cargo density applied for this loading condition is different from 3.0 t/m^3.

4.1.5 Additional ballast conditions

Refer to TB [4.1.1].

4.1.6 Steel coils or heavy cargoes

Refer to TB [4.1.1].

4.2 Design load combinations for direct strength analysis

4.2.1 Applicable general loading patterns

This regulation was adopted from the CSR BC (July 2010) and IACS UR, S25 (which is no more in force).

4.2.2 Multiport conditions

Refer to TB [4.2.1].

4.2.3 Alternate conditions

Refer to TB [4.2.1].

4.2.4 Heavy ballast condition

Refer to TB [4.2.1].

4.2.5 Additional harbour conditions for all bulk carriers

Refer to TB [4.2.1].

4.2.6 Additional harbour conditions for bulk carrier with {No MP}

Refer to TB [4.2.1].

4.2.7 Design load combination for direct strength analysis

Loading patterns to be considered in direct strength analysis are categorised by type of ship (by notation) summarised in Table 10 of the Rules.

4.2.8

Design FE load combinations for direct strength analysis are adopted from CSR BC based on the following:

(a) A finite element load combination is the combination of a loading pattern defined in Table 12 to Table 21 of the Rules and a dynamic load case defined in Pt 1, Ch 4, Sec 2 of the Rules. The corresponding dynamic load cases for each loading pattern are indicated under the column 'Dynamic Load Cases' in Table 12 to Table 21 of the Rules.

(b) The standard FE analysis considers loading patterns, ship draughts, hull girder still water bending moments and shear forces that are intended to provide an envelope of the typical loading conditions anticipated in operations. The operation envelope stipulates:

- Seagoing and harbour hull girder still water bending moments and shear forces specified by the designer as included in the ship's loading manual and fulfilling the minimum requirements in Pt 1, Ch 4, Sec 4. However, still water vertical bending moments that do not normally occur are exempted. Moreover, still water vertical bending moment in the homogenous loading condition is taken as 50% of the permissible value.
- A maximum ship draught equal to 100% of the ship's scantlings draught and a minimum ship draught equal to of the deepest ballast draught of the ship.

(c) The seagoing ship draughts considered are to provide adequate flexibility for multi-port and alternate block load conditions. Full scantling draught in these partial load conditions is not necessary as a mandatory requirement for all designs.

(d) An alternate condition with an empty cargo tank is critical for the bottom structure due to high upward acting static and wave pressure on the bottom shell and no counteracting cargo pressure. The side and transverse structures are also under critical condition due to lack of counteracting cargo pressure against the static and wave dynamic pressure on the ship side. Likewise, in the loaded hold of an alternate condition a critical condition for the bottom structure exist, due to high downward acting static and dynamic tank pressure and little counteracting external sea pressure. The side and transverse structures are also under considerable load due to small counteracting pressure on the ship side.

(e) In heavy ballast condition the shallow draught with the full heavy ballast hold is also a critical loading condition for the bottom structure due to high downward acting static and dynamic tank pressure and little counteracting external sea pressure.

(f) For harbour load cases, shallow draught conditions could be critical for the double bottom structure. The minimum draught chosen for the analysis is based on the smallest draught that can be achieved with the loading pattern. The strength of the hull structure under harbour permissible still water bending moment and still water shear force is also assessed for shallow draught conditions only.

(g) Normal ballast condition are not included in the FE loading patterns, as this condition do not impose the most onerous loads on the main supporting structural members as the net load on the double hull structure is small with empty cargo tank and low shallow draught. Normal ballast conditions are important for determination of hull girder bending strength, which is adequately checked by the longitudinal strength calculation described in Pt 1, Ch 5 of the Rules.

(h) Where the designer requests an operation envelope that is not covered by the standard FE load combinations, the additional loading conditions must be specified and included in the FE analysis.

(i) The loading patterns used in the finite element analysis were chosen such that the most severe static pressure loads, localised shear forces and bending moments are imposed on the primary supporting structure of the hull (i.e. frame and girder system).

(j) For each of the loading pattern analysed, the distribution of cargo and ballast is only defined within the three tank length FE model. The use of actual still water bending moment from the loads applied to the three-tank FE model may be non-conservative as this does not take into account the loads applied along the whole ship length outside the extent of the model. For this reason, the permissible seagoing and harbour still water hull girder bending moments are used in the seagoing and harbour FE load combinations respectively.

(k) The hull girder still water shear force is most critical for alternate and heavy ballast conditions. These loading patterns in combination with the dynamic load cases with maximum wave shear force in head or following sea assess the hull strength against hull girder shear loads. For these load case combinations, shear force correction procedure is to be applied, where necessary, to ensure that the required combined seagoing permissible still water and maximum wave shear force is achieved in the sea going FE load combinations. By carefully matching of the FE loading pattern with ship draught, only minor adjustment of shear forces are needed to obtain the required hull girder shear forces. For all other load combinations the actual shear forces that results from the application of static and dynamic local loads to the FE model are to be used. Where this shear force exceeds the required value, corrections of vertical loads are to be applied to adjust the shear force down to the required value.

(l) The finite element load combination (i.e. combination of static and dynamic loads for seagoing conditions and static loads only for harbour conditions) are to generate the most severe combination of global and local loads on the structure for the loading patterns considered.

(m) The following general considerations are given in combining a loading pattern with dynamic load cases:

- The hull girder loads are maximised by combining a static loading pattern with dynamic load cases that have hull girder bending moments/shear forces of the same sign.
- The net local load on primary supporting structural members is maximised by combining each static loading pattern with appropriate dynamic load cases, taking into account the net pressure load acting on the structural member and influence of loads acting on an adjacent structure. The general principle of maximising the net local pressure loads is explained in Table 1.

(n) The global hull girder loads and local loads are to be combined in such a way that the stresses due to net local pressure loads acting on the primary support members and hull girder loads are additive to maximise the stress in certain parts of the structure. For example, hull girder maximum sagging condition (i.e. dynamic load case HSM-1, defined in Pt 1, Ch 4, Sec 2 of the Rules, with maximum wave sagging bending moment in a wave trough, and maximum sagging still water bending moment) is combined with a loading pattern with fully loaded holds (middle hold of FE model) and shallow draught to generate maximised tensile stress at the outer bottom.

(o) Similarly, hull girder maximum hogging condition (i.e. dynamic load HSM-2, defined in Pt 1, Ch 4, Sec 2 of the Rules, with maximum wave hogging bending moment in a wave crest, and maximum hogging still water bending moment) is combined with a loading pattern with empty holds (middle holds of FE model) and deep draught to maximise compressive stress at the outer bottom.

(p) For seagoing finite element load combinations, several different dynamic load cases may require to be combined with one loading pattern in order that critical conditions for different structural members can be examined.

(q) For the harbour FE load combinations, only static loads are to be applied. The required still water bending moment and shear force for these FE load combinations are based on harbour permissible still water bending moments and shear forces.

A study was carried out for a number of designs of various configurations and sizes to further minimise the required number of combinations of loading pattern and dynamic load cases.
From the loading principles enumerated from (a) to (q) it is possible to make an educated guess about which primary supporting members are more likely to be challenged by each FE Load combination: most cases have been explicitly cited (e.g. double bottom , side, bottom plating).
However, linking the FE Load combination to a limited set of primary supporting members for which it is bound to be critical is not a priori certain because the outcome may depend from different design options.

The development of FE load combinations for aftmost and foremost cargo hold models specified in Table 18 to Table 21 is in progress.

4.3 Hold mass curves

4.3.1

This regulation was adopted from the CSR BC (July 2010) and IACS UR, S25 (which is no more in force).

4.3.2

Refer to TB [4.3.1].

5 STANDARD LOADING CONDITIONS FOR FATIGUE ASSESSMENT

5.1 Oil tankers

5.1.1

For normal and heavy ballast conditions, the filling level of fuel oil tanks, other oil tanks or fresh water tanks for simplified fatigue stress analysis and direct strength analysis is to be taken as full for keeping consistent approach between both analyses.

5.2 Bulk carriers

5.2.1

The loading patters and dynamic load cases must be combined as specified in Table 23 to Table 25 of the Rules. The required still water vertical bending moments are listed in these tables. The actual shear forces that results from the application of static and dynamic local loads to the FE model are to be used. Where this shear force exceeds the target value, the corrections of vertical loads are to be applied to adjust the shear force down to the target value. The still water shear force was decided to be taken as 100% of permissible SWSF for alternate and heavy ballast condition, based on the collected database of actual and permissible SWSF from nine societies.

For normal and heavy ballast conditions, the filling level of fuel oil tanks, other oil tanks or fresh water tanks for simplified fatigue stress analysis and direct strength analysis is to be taken as full for keeping consistent approach between both analyses.

PART 1 CHAPTER 5

HULL GIRDER STRENGTH

Table of Contents

1 STRENGTH CHARACTERISTICS OF HULL GIRDER TRANSVERSE SECTIONS

SYMBOLS

f_β The heading correction factor representing the effect of the non-uniform ship heading distribution on the hull girder wave load for seagoing conditions. Technical Background report “CSR URCP1 TB Report(1) for NC01: The impact of non-uniform ship heading probability distributions, used in the sensitivity analysis for assumptions of the long-term wave loads, on CSRH” can be referred to.

1.1 General

1.1.1

Technical background is not considered necessary.

1.2 Hull girder transverse sections

1.2.1 General

Technical background is not considered necessary.

1.2.2 Net scantling

Since the Rules is based on the net scantling approach, the assessment of hull transverse section characteristics are required to be performed taking scantlings equal to the offered scantling minus $0.5t_c$. See the Technical background of Ch 3, Sec 3.

1.2.3 Structural members not contributing to hull girder sectional area

Structural members not contributing to hull girder sectional area are specified taking into account the hull girder stress transmissions.

1.2.4 Continuous trunks and longitudinal hatch coamings

Considering that usual structural proportions of continuous trunk and longitudinal hatch coamings, they may be included in the hull girder transverse sections. This requirement is in accordance with IACS UR S5 (Rev 1, May 2010).

1.2.5 Longitudinal stiffeners or girders welded above the strength deck

When the section modulus at deck is calculated, longitudinal stiffeners and girders welded above the strength deck are to be considered as defined in [1.4.3]. This requirement is based on IACS UR S5 (Rev 1, May 2010).

1.2.6 Longitudinal girders between hatchways, supported by longitudinal bulkhead

Considering hull girder stress transmission, longitudinal girders between hatchways are considered to be effective if they are supported by longitudinal bulkheads. This requirement is based on IACS UR S5 (Rev 1, May 2010).

1.2.7 Longitudinal bulkheads with vertical corrugations

Longitudinal bulkheads with vertical corrugations are not effective for hull girder loads bending because their longitudinal stiffness is small due to out-plane displacements of corrugations. For hull girder shear the out-plane displacement is smaller, and corrugation may be considered effective.

1.2.8 Members in materials other than steel

In this requirement, equivalent areas of members having Young's modulus not equal to 2.06×10^5 N/mm^2 are calculated. This requirement is in accordance with CSR BC (July 2010), Ch 5, Sec 1, [1.2.6] (based on 2.1.6, Sec 1, Ch 6, Pt B of the BV Rules, January 2013).

1.2.9 Definitions of openings

This requirement is based on IACS UR S5 (Rev 1, May 2010). However, "lightening holes" are of unspecified size and may be large openings which should be deducted from the sectional areas. Drain holes are small openings.

1.2.10 Large openings

Refer to TB [1.2.9].

1.2.11 Isolated small openings

Refer to TB [1.2.9].

1.2.12 Lightening holes, draining holes and single scallops

Refer to TB [1.2.9].

1.2.13 Non-continuous decks and longitudinal bulkheads

This requirement is in accordance with CSR OT (July 2010), Sec 4/2.6.3.10.

1.3 Strength deck

1.3.1

This requirement is in accordance with CSR BC (July 2010), Ch 5, Sec 1, [1.3.1] (based on 2.2.1 of Sec 1, Ch 6, Pt B of the BV Rules, January 2013).

1.4 Section modulus

1.4.1 Section modulus at any point

The equation in this requirement can be obtained from the linear beam theory.

1.4.2 Section modulus at bottom

The requirement is based on IACS UR S5 (Rev 1, May 2010) and the equation in this requirement can be obtained from the linear beam theory.

1.4.3 Section modulus at deck

The requirement is based on IACS UR S5 (Rev 1, May 2010) and the equation considers the shear lag of deck members.

1.5 Moments of inertia

1.5.1

Technical background is not considered necessary.

2 HULL GIRDER BENDING ASSESSMENT

2.1 General

2.1.1

This requirement is based on IACS UR S7 (Rev 4, May 2010).

2.1.2

This requirement is in accordance with CSR BC (July 2010), Ch 5, Sec 1, [4.1.2] (based on 4.2.3 of Sec 2, Ch 6, Pt B of BV Rules, January 2013). See Technical background of Ch 3, Sec 1 for factor *k*.

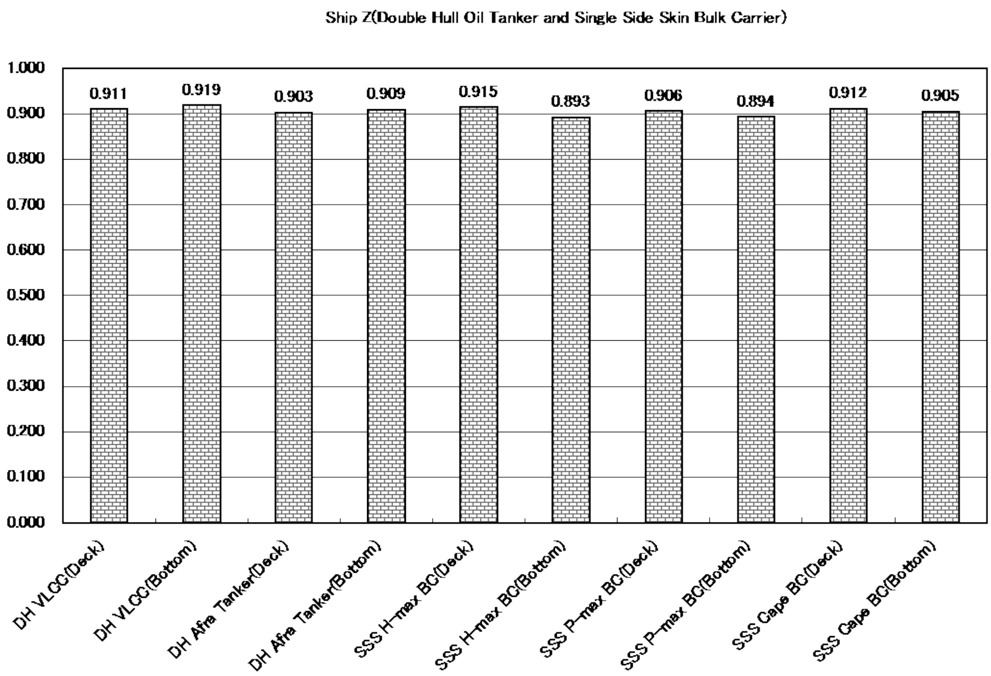
2.2 Normal stresses

2.2.1

IACS UR S11 (Rev 7, November 2010) takes the permissible stress in the 0.4*L* region amidships based on the gross scantling approach as 175 N/mm^2 (based on mild steel). In CSR which uses the net scantling approach, since the figure is 0.9 times the original section modulus, which becomes the renewal criterion of various classification societies for hull transverse section, the permissible stress in the gross scantling approach is divided by 0.9 to arrive at the value of 190 N/mm^2 as the permissible stress (17.5 kgf/mm^2/0.9 × 9.81 = 190).

The corrosion amount specified in Ch 3, Sec 3 is applicable to existing ships (5 types of ships namely VLCC, Aframax, Capesize BC, Panamax BC and Handymax BC). The figure here after shows the ratio of the section modulus of deck and bottom to the original section modulus for each type of ship. From this figure, since the section modulus is about 0.9 times the original section modulus for all ship types, evaluation with the net scantling approach using the permissible value is equivalent to the method used in the existing rules.

Figure 1: Section modulus considering corrosion of BC and Tankers



Generally, scantling of members contributing to the hull girder longitudinal strength may be gradually reduced, outside 0.4*L* amidships. In CSR, the gradual reduction of scantlings of structural members contributing to hull girder strength are unified by setting the allowable stress outside 0.4*L* amidships.

2.2.2

The calculation formula for normal stress arising from vertical bending moment in the intact condition (non-flooded condition) is shown, and it is the same as in the existing rules.
In harbour conditions, only the (S) design load is considered as specified in Table 1 of Ch 4, Sec 7.

The requirement of longitudinal strength of hull girder in flooded condition is to be complied with in respect of the flooding of any cargo hold of bulk carriers having a length L of 150 m or above and the calculation formula for normal stress due to vertical bending moment in flooded condition is given in the rules.

The heading correction factor f_β is introduced to represent the effect of the non-uniform ship heading distribution on hull girder wave loading for seagoing conditions in Table 2. Technical Background report “CSR URCP1 TB Report(1) for NC01: The impact of non-uniform ship heading probability distributions, used in the sensitivity analysis of assumptions of the long-term wave loads, on CSRH” can be referred to.

2.2.3

Normal stress when a material other than steel is used is to be calculated by simplified formula using the ratio of Young's modulus.

2.3 Minimum net moment of inertia and net section modulus at midship section

2.3.1

This regulation is based on IACS UR, S4 (Rev 3, May 2010).

2.3.2

This requirement is based on IACS UR, S7 (Rev 4, May 2010) taking into account the coefficient 0.9 based on the corrosion deduction, $0.5t_c$.

2.4 Extent of high tensile steel

2.4.1 Vertical extent

The vertical extent of higher strength steel considers hull girder bending stresses only and takes into account the actual hull girder bending stress in deck or bottom. Similar to the longitudinal extent of higher strength steel the requirement of vertical extent of higher strength steel is included to ensure that the stress level in the structural members outside the high strength steel area are not above the allowable in relation to the material in this area.

The heading correction factor f_β is introduced to represent the effect of the non-uniform ship heading distribution on hull girder wave loading for seagoing conditions in Table 3. Technical Background report “CSR URCP1 TB Report(1) for NC01: The impact of non-uniform ship heading probability distributions, used in the sensitivity analysis of assumptions of the long-term wave loads, on CSRH” can be referred to.

2.4.2 Longitudinal extent

The longitudinal extent of material with higher strength steel is to be carried through to a position where the hull girder stress is below the permissible for mild steel or high tensile steel of lower yield stress if this is used.

3 HULL GIRDER SHEAR STRENGTH ASSESSMENT

3.1 General

3.1.1

Technical background is not considered necessary.

3.2 Hull girder shear capacity

3.2.1

Permissible shear stress for seagoing operations (S+D condition) is increased from 110/k N/mm^2 for gross scantlings (IACS UR, S11, Rev 7, November 2010) to 120/k N/mm^2 to reflect the net thickness approach. The acceptance criteria for harbour/tank testing operations is 87.5% of that for the seagoing conditions. The corresponding ratio for the allowable bending stress is 75%. The reason for the difference is that the ratio between dynamic and the static component is different for the two responses.

Whereas the wave bending moment is typically 1.5-2 times the static bending moment the situation is opposite for shear where the design static shear forces is about 2 times the wave shear. The 87.5% for the harbour is set such that 100% is achieved by adding half the dynamic component which is the hull girder wave shear force.

3.3 Acceptance criteria

3.3.1 Permissible vertical shear force

The required vertical shear forcer can be obtained from summation of permissible still water shear force and wave induced shear force. This required vertical shear force is to be smaller than the total vertical hull girder shear capacity Q_R. For bulk carriers, the shear force correction which is caused by shear force transmission in longitudinal girders may be taken into account. In harbour conditions, only the (S) design load is considered as specified in Table 1 of Ch 4, Sec 7.

The heading correction factor $f_\beta$is introduced to represent effect of the non-uniform ship heading distribution on hull girder wave loading for seagoing conditions. Technical Background report "CSR URCP1 TB Report(1) for NC01: The impact of non-uniform ship heading probability distributions, used in the sensitivity analysis of assumptions of the long-term wave loads, on CSRH" can be referred to.

3.3.2 Vertical still water shear force

The corrected vertical still water shear force, whatever the considered loading condition is, is to be smaller than the permissible still water shear force.

3.4 Effective net thickness for longitudinal bulkheads between cargo tanks of oil tankers

3.4.1

Towards each end of the cargo tanks, the shear force carried by longitudinal bulkheads, inner hull and side shell departs from closed cell shear flow theory, due to “local shear force distribution” effects.

3.4.2

“Local shear force distribution” is due to the shear load being transferred into the longitudinal structure via the transverse structure such as floors to the longitudinal bulkheads and girders into the transverse bulkheads. The “local shear force distribution” is accounted for by applying a thickness deduction, t_{Δ}, to the longitudinal bulkhead thickness used in the calculation of shear capacity. This thickness deduction represents the proportion of the longitudinal bulkhead shear capacity that is required to resist the local shear force distribution effects and hence can not be utilised as part of the longitudinal shear capacity.

$$t_{sfi-n50} = t_{i-grs} - 0.5t_c - t_{\Delta i}$$

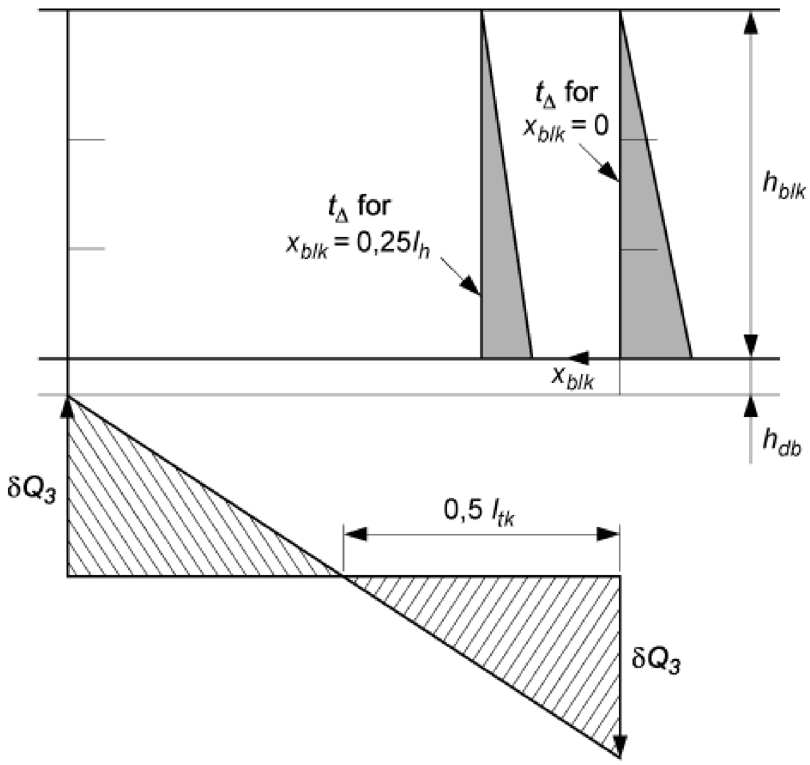
$$t_{\Delta i} = \frac{\delta Q_3}{h_{blk}\tau_{i-perm}}\left(1 - \frac{x_{blk}}{0.5l_{tk}}\right)\left(2 - \frac{2(z_p - h_{db})}{h_{blk}}\right)$$

The additional shear stress caused by the local shear force distribution is assumed to be a triangularly distributed with the maximum value at the inner bottom level decreasing to zero at upper deck, hence the vertical distribution of the thickness deduction also linearly decreases. This distribution is consistent with that seen in 3D FEM analysis results.

It is assumed that the maximum thickness reduction, $t_{\Delta max}$, due to the shear force correction will be close to transverse bulkhead just above inner bottom, hence where $x_{blk} = 0$ and $z_p = h_{db}$, see Figure 2, and that the reduction is linearly tapered from this maximum value to zero in middle of the tank ($x_{blk} = 0.5\ell_{tk}$).

$$t\frac{2\cdot\delta Q_3}{h_{blk}\cdot\tau_{i-perm}}_{\Delta max}$$

Figure 2: Shear force correction for longitudinal bulkheads



3.4.3 Shear force correction for a ship with a centreline longitudinal bulkhead

The term δQ_3 represents the mean value of local shear force that is transferred to the longitudinal bulkhead via the floors. This value is dependent on the cargo tank configuration as well as the bottom structure arrangement and stiffness. In all cases, the magnitude of δQ_3 is based on the worst case differential net load on the double bottom structure.

$$\delta Q_3 = 0.5 K_3 F_{db}$$

For tankers with a centre line bulkhead the local load distribution factor, K_3, is calculated depending on the structural arrangement. The formulation for K_3 assumes there are no partial girders fitted to the design. It is known that maximum δQ_3 occurs in the loading condition with the greatest downwards net load in the cargo tanks.

3.4.4 Shear force correction for a ship with two longitudinal bulkheads between the cargo tanks

For tankers with two longitudinal bulkheads the local load distribution factor, K_3, is calculated depending on the structural arrangement. Based on previous studies, it is known maximum δQ_3 occurs in the loading condition with the greatest downwards net load in the centre cargo tank.

3.4.5 Vertical force on double bottom

For consistency of calculation of maximum resulting (or net load) force (or net load) on the double bottom, F_{db}, the loading patterns used in the design verification by finite element analysis are also used to derive the maximum net load on the double bottom. For standard tankers and simplicity F_{db} can be expressed as a function of the principal dimensions of the cargo tank and the ship's draught.

3.4.6 Equivalent net thickness of corrugated bulkhead

This statement is taken from CSR OT (July 2010), Sec 4/2.6.4.4 and 2.6.4.5. The equivalent net thickness for corrugated plate is reduced by the ratio between projected length of the corrugation and expanded length of the corrugation. This equivalent net thickness represents the shear stiffness of the corrugation.

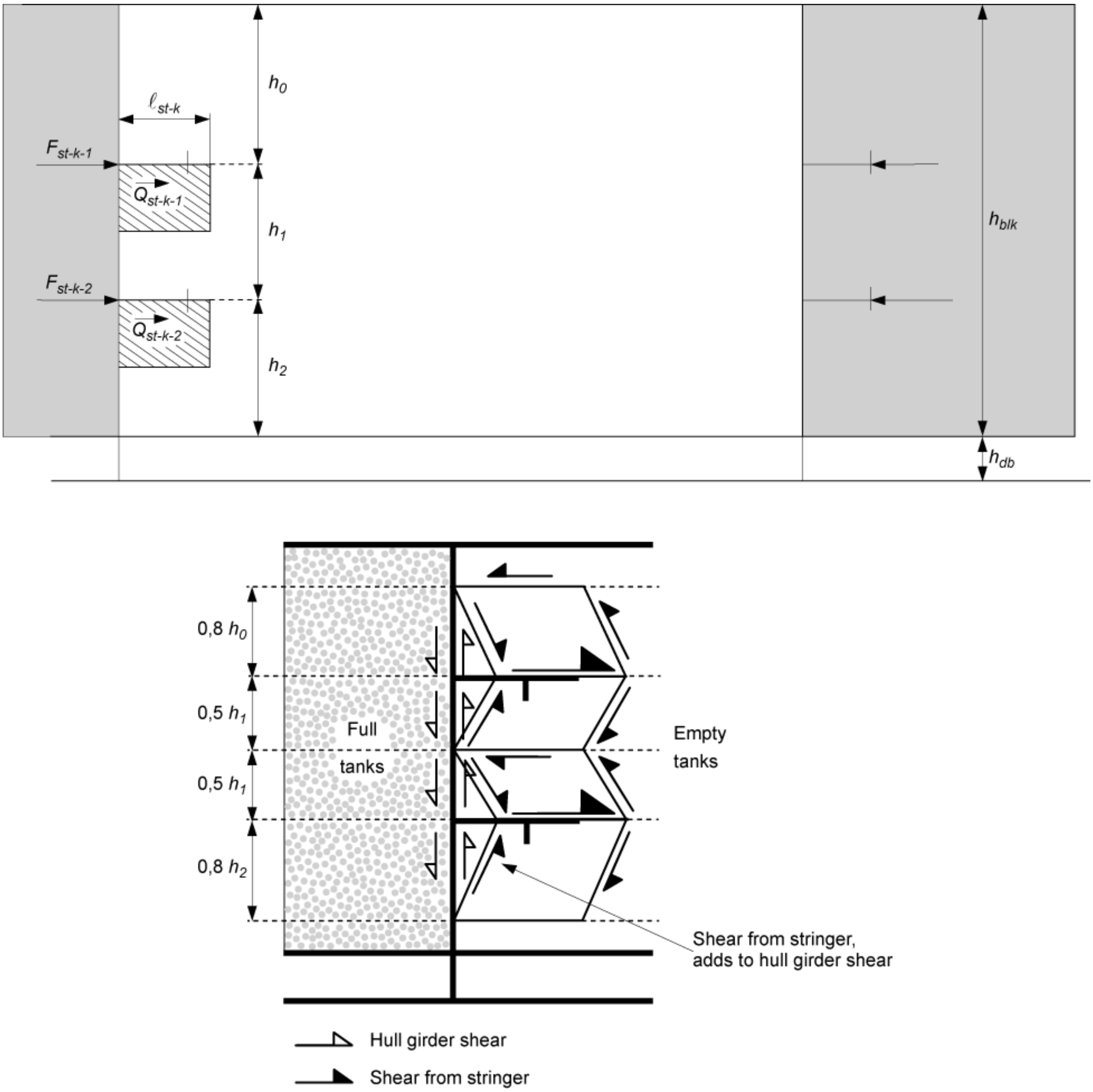
3.5 Effective net thickness for longitudinal bulkheads between cargo tanks of oil tankers - Correction due to loads from transverse bulkhead stringers

3.5.1

It is known from the results of 3D FEM analysis that loading conditions which feature wing and centre tanks abreast filled with adjacent cargo tanks fore/aft empty result in very high shear stress at longitudinal bulkhead in the vicinity of transverse bulkhead below the horizontal stringers. This is due to the local shear force transferred from the transverse bulkhead stringers into the longitudinal bulkheads. This phenomenon can be address using finite element analysis. However, in the Rules, it was therefore decided that the assigned shear forces should account for this additional local shear stress in an explicit and transparent way.

Accordingly the rule formulation for permissible hull girder shear force accounts for the additional shear stress components acting in this loading condition by reducing the effective longitudinal bulkhead thickness used in the hull girder shear capacity calculation. The main areas affected are the longitudinal bulkhead plating in way of the ends of the transverse bulkhead stringers. The maximum local shear stresses are experienced when the transverse bulkhead is only loaded from one side. For example, with a combination of all cargo tanks across being empty on one side of the bulkhead and all full on the other side, see Figure 3, this induces the maximum net load across the bulkhead and hence the maximum reaction/support forces in the ends of the bulkhead stringers.

Figure 3: Region for stringer correction for a Tanker with two stringers



3.5.2

The total stringer supporting force ($F_{st\text{-}k}$) in way of a longitudinal bulkhead may be divided into three parts:

(a) Below the stringer, complimentary shear acting downwards ($Q_{st\text{-}k}$) which adds to the hull girder longitudinal shear stress.

(b) Above the stringer, complimentary shear acting upwards ($Q_{u\text{-}k}$) which will subtract from the hull girder shear stress.

(c) Direct stresses in way of toe and heel of stringer connection to longitudinal bulkhead (axial stress in longitudinal or platform in way of termination of stinger).

Note: *k* denotes the *k*-th bulkhead stringer from the deck.

Correspondingly, the shear force above the stringer ($Q_{u\text{-}k}$) will produce a shear stress ($\tau_{u\text{-}k}$) with opposite sign to the hull girder shear stress. The total shear stress below a stringer must satisfy the following:

$$\tau_{HG} + \tau_k \le C_t \cdot \tau_{yd}$$

The actual hull girder shear stress in way of a stringer is given by:

$$\tau_{HG} = \frac{t_r \cdot \tau_{i-perm}}{t_k} \text{ hence } \frac{t_r \cdot \tau_{i-perm}}{t_k} + \frac{Q_{st-k}}{\ell_{st-k} \cdot t_k} \le C_t \cdot \tau_{yd}$$

and consequently,

$$t_r = \frac{t_k}{\tau_{i-perm}} \cdot \left(C_t \cdot \tau_{yd} - \frac{Q_{st-k}}{\ell_{st-k} \cdot t_k} \right)$$

where,

C_t : 0.90 permissible shear stress coefficient.
τ_{yd} : Specified minimum shear yield stress of the material, in N/mm^2.
t_r : The available or equivalent thickness in way of the k-th stringer based on the hull girder shear stress assessment taking into account the shear load from stringers.
$\tau_{i\text{-}perm}$: Permissible hull girder shear stress.

In the Rules, the thickness, t_r, has been redefined as the equivalent net thickness, $t_{sti\text{-}k\text{-}n50}$. This thickness is the thickness that is available to be used in the hull girder shear capacity assessment after deducting a proportion of that thickness which is used to resist the local shear stresses arising from the bulkhead stringers. Hence $t_{sti\text{-}k\text{-}n50}$ is given by:

$$t_{sti-k-n50} = \frac{t_{sfi-n50}}{\tau_{i-perm}} \left(C_t \tau_{yd} - \frac{Q_{st-k}}{\ell_{st} t_{sfi-k-n50}} \right)$$

where,

$t_{sfi\text{-}n50}$: Effective net plating thickness after local shear correction for longitudinal bulkheads between cargo tanks, calculated at the lower edge of plate i connecting to the stringer.
$t_{sfi\text{-}k\text{-}n50}$: Effective net plating thickness after local shear correction for longitudinal bulkheads between cargo tanks, calculated at the transverse bulkhead for the height corresponding to the level of the stringer.

This stringer correction is to be carried out in the full length of the stringer connection (buttress) and from the level of the considered stringer to a level $0.5h_k$ below, see Figure 1. For the lowermost stringer, the stringer correction to be applied down to the level of the inner bottom, see also Figure 2.

Based on FEM analyses the total shear force in the longitudinal bulkhead was found to be 75-80% of the total stringer supporting force ($F_{str\text{-}k}$) and with the remaining force carried by direct stresses in way of toe and heel of the stringer connection. The distribution between the stringer shear force above and below the stringer connection was found to be dependent on the relative distance to the inner bottom and upper deck. From this the following expressions for the stringer shear forces $Q_{str\text{-}k}$ and $Q_{u\text{-}k}$ were developed:

$$Q_{\text{st-k}} = 0.8 \cdot F_{\text{st-k}} \cdot \left(1 - \frac{z_{\text{st-k}} - h_{\text{db}}}{h_{\text{blk}}}\right) \text{ and } Q_{\text{u-k}} = 0.8 \cdot F_{\text{st-k}} \cdot \frac{z_{\text{st-k}} - h_{\text{db}}}{h_{\text{blk}}}$$

where,

$h_{db} \leq z_{st\text{-}k} \leq h_{blk} + h_{db}$

3.6 Shear force correction for bulk carriers

3.6.1

The formula of shear force correction is obtained by supposing that the girders are simply supported by transverse bulkheads. Moreover, the ratio of the total stress transmitted to the girders in the cases of the following hypothesis is determined.

(a) The frames are supposed by be simply supported.
(b) A ratio takes into account the fact that the frames have a certain degree of fixity.

The loads transmitted by the double bottom longitudinal girders to the transverse bulkheads are estimated by the function of the aspect ratio of the double bottom structure, ℓ_0/b_0.

1 APPLICATION

1.1 General

1.1.1

The hull girder strength is the most critical failure mode for hull structure. As the ships length becomes longer, this strength is more important. Hence, the hull girder ultimate strength check is required to ships with length (*L*) not less than 150m.

1.1.2

Since the bending moment is quite small in fore and aft, it is not relevant to do the ultimate strength check.

1.1.3

The conditions for which the hull girder ultimate bending capacity is to be checked are listed for bulk carriers and oil tankers.

2 CHECKING CRITERIA

2.1 General

2.1.1

The conditions that need to be checked are different for Bulkers and Tankers, due to the difference in operation pattern, loading distribution, and structural configurations.
The condition B is to be checked especially for tankers, with consideration of the operational full load condition rather than the limit values of the bending moment. The partial safety factors have been calibrated with direct reliability analysis.

Failure in sagging is identified as the most critical failure mode for double hull tankers in the full load condition due to the way they are loaded and due to the conventional structural arrangement with a double bottom and single skin deck. Hence only sagging is included for condition B.

2.1.2

The hull girder ultimate capacity is an explicit control of one of the most critical failure modes of a double hull tanker. Therefore, the criterion for the ultimate strength of the hull girder is given in a partial safety factor format. The partial safety factor for the vertical hull girder ultimate bending capacity is to be taken equal to:
$\gamma_R = \gamma_M \, \gamma_{DB}$

where γ_M is the partial safety factor for the vertical hull girder ultimate bending capacity, covering material, geometric and strength prediction uncertainties; in general, to be taken equal to 1.1 and γ_{DB} is the partial safety factor for the vertical hull girder ultimate bending capacity, covering the effect of double bottom bending, to be taken equal to 1.25 for BC-A bulk carriers in in hogging condition, 1.1 for oil tankers in hogging condition and BC-B/BC-C bulk carriers in hogging condition and 1.0 for oil tankers and bulk carriers in sagging condition.

Refer to TB Report, “TB Rep_Pt2_Ch01_Sec02_BC Double Bottom Arrangement” and TB Report, “TB Rep_Pt1_Ch05_HG Longitudinal Strength”.

2.2 Hull girder ultimate bending loads

2.2.1

Refer to TB Report, “TB Rep_Pt1_Ch05_HG Longitudinal Strength”.

The heading correction factor f_β is introduced to represent the effect of the non-uniform ship heading distribution on hull girder wave loading for seagoing conditions. Technical Background report “CSR URCP1 TB Report(1) for NC01: The impact of non-uniform ship heading probability distributions, used in the sensitivity analysis of assumptions of the long-term wave loads, on CSRH” can be referred to.

2.3 Hull girder ultimate bending capacity

2.3.1

Refer to TB Report, “TB Rep_Pt1_Ch05_Sec02_Iterative Method for HGULS”.

2.3.2

Refer to TB [2.3.1].

1 APPLICATION

1.1 General

1.1.1

As the ships length becomes longer, this strength is more important. Hence, the hull girder residual strength check is required to ships with length (*L*) not less than 150m.

1.1.2

Technical background is not considered necessary.

1.1.3

It has been decided that the hull girder residual strength is to be checked within the cargo area and the machinery space since damages in the fore and aft peaks have limited influence on the hull girder strength.

2 CHECKING CRITERIA

2.1 General

2.1.1

The residual strength is to be checked for both hogging and sagging conditions.

2.1.2

The criterion for the residual strength of the hull girder is given in a partial safety factor format.

2.2 Damage conditions

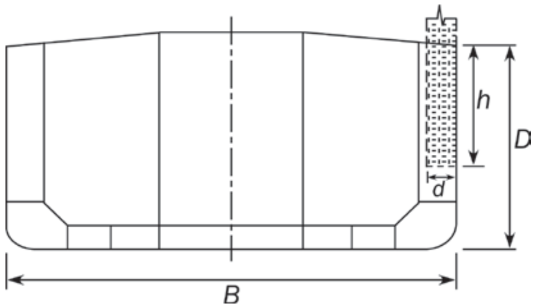
2.2.1 General

The two damage conditions taken into account are collision and grounding.

2.2.2 Collision

The damage extent for collision is described. The capacity of the damaged transverse cross section is calculated with the damage extent on one side, the ship kept in upright position. In addition, a figure illustrates how *h* and *d* is measured for ship with camber is attached in Figure 1.

Figure 1: Damage extent for ship with chamber



2.2.3 Grounding

The damage extent for grounding is described. The damage is to be considered on the bottom in the most unfavourable transversal position as regard to the structure considered by the damage, i.e. the damage extent is to be shifted on the bottom line to find the most unfavourable position based on actual design.

2.3 Hull girder ultimate bending loads in the damaged condition

2.3.1

For the residual strength case, which is a major incident with a high uncertainty as to the magnitude and location of the damage, it is reasonable to accept a more all-round evaluation, and a factor of 1.1 on M_{sw} is intended to cover the potential increase in still water loads at the location of the damage. This factor also ties in with the minimum $M_{sw\text{-}f}$ which is to be at least 1.1 times the M_{sw}.

The residual strength criterion is likely to be a different scenario than a flooding scenario because:

(a) Collision and grounding are more likely to take place closer to the coast, and in milder environmental conditions than e.g. flooding due to hatch cover problems that may occur in severe weather, open sea.

(b) The residual strength is an issue after a rather unlikely event leading to major damage and a significant reduction in the structural strength which calls for an immediate repair. Flooding may occur under a number of other circumstances that have a less significant effect on the residual strength. Flooding then is a more frequent even than the residual strength situation.

For these reasons it is rationale to argue for a lower factor (i.e. 0.67) in the residual strength case. γ_{SD} is the partial safety factor for the still water bending moment in the damaged condition, to account for increased still water bending moment due to accidental flooding and γ_{WD} is the partial safety factor for the vertical wave bending moment in the damaged condition, accounting for 3 months exposure in the worldwide condition. Refer to TB Report, "TB Rep_Pt1_Ch05_Sec03_HG Residual Strength".

2.4 Hull girder ultimate bending capacity in the damaged condition

2.4.1

Refer to TB Report, "TB Rep_Pt1_Ch05_Sec03_HG Residual Strength" and "TB Rep_Pt1_Ch05_Sec02_Iterative Method for HGULS".

2.4.2

Refer to TB [2.4.1].

1 CALCULATION FORMULA

1.1 General

1.1.1

The shear flow q, working along a ship cross section due to hull girder shear force, at each location in the cross section, can be obtained by summing the determinate shear flow, q_D, calculated according to the method given in TB [1.2] and the indeterminate shear flow, q_I calculated according to the method given in TB [1.3].

$$q = q_D + q_I \tag{1}$$

1.2 Determinate shear flow

1.2.1

Let's consider that the thin-walled beam is bending under lateral loads and the equilibrium of force into a small piece element as shown in Figure 1, we can obtain the following equations.

$$\int_0^s \sigma_x t ds = \tau t dx + \int_0^s \left(\sigma_x + \frac{\partial \sigma_x}{\partial x}\right) t ds \tag{2}$$

Axial stress, σ_x can be calculated from bending moment, M working in the thin-walled beam as:

$$\sigma_x = \frac{M}{I_y}(z - z_G) \tag{3}$$

where,

M : Bending moment.

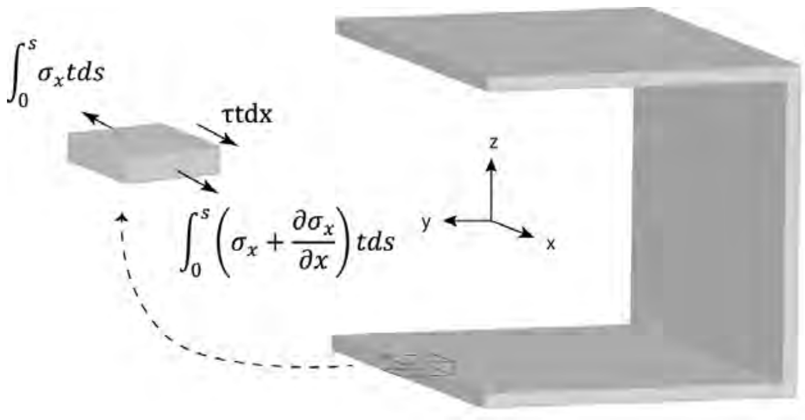
I_y : Moment inertia about y-axis.

z_G : Z coordinate of horizontal neutral axis.

Substituting Equation (3) into Equation (2), we can obtain the formula of determinate shear flow as follows:

$$q_D = \tau t = -\frac{\partial M}{\partial x}\frac{1}{I_y}\int_0^s (z - z_G) t ds \tag{4}$$

Figure 1: Small elements in thin-walled beam



1.2.2

The formula defined in TB [1.2.1] can be obtained if you assume that the thin-walled beam is composed of line segments and discretise Equation (4).

1.2.3

The requirement is just an explanation of the way to calculate determinate shear flow.

1.2.4

The requirement is just an explanation of the way to calculate determinate shear flow.

1.3 Indeterminate shear flow

1.3.1

The Strain energy, *I* of the thin-walled beam can be written as:

$$\mathrm{I} = \frac{1}{2}\int_A \left(\frac{{\sigma_x}^2}{E} + \frac{\tau^2}{G}\right) t\,ds \qquad (5)$$

Since indeterminate shear flow, q_I around each closed cell, arise so as to minimise the strain energy of the beam, the following equation holds:

$$\frac{\partial I}{\partial q_{Ik}} = 0 \qquad (6)$$

q_{Ik} : Indeterminate shear flow of closed cell *k*.

Substituting Equation (5) into Equation (6), we can obtain the following equation as q_{Ik} is included only in the terms of the walls constituting closed cell *k*.

$$\oint_k \frac{q}{t} ds = 0 \qquad (7)$$

Total shear flow along closed cell *k* can be written as:

$$\mathrm{q(s)} = \mathrm{q}_D(s) + \mathrm{q}_{Dk} - \mathrm{q}_{Di} \qquad (8)$$

If closed cell *k* and closed cell *i* have a common wall. Substituting Equation (8) into Equation (7), the following equation can be obtained.

$$\mathrm{q}_{Ik} \oint_k \frac{1}{t} ds - \sum_i q_{Ii} \oint_{k,i} \frac{1}{t} ds = -\oint_k \frac{q_D}{t} ds \qquad (9)$$

1.3.2

The formula defined in TB [1.3.1] of the rule can be obtained if you assume that the thin-walled beam is composed of line segments and discretise Equation (9).

1.4 Computation of several properties of the cross section

1.4.1

Technical background is not considered necessary.

1.4.2
Technical background is not considered necessary.

1.4.3
Technical background is not considered necessary.

2 EXAMPLE OF CALCULATIONS FOR A SINGLE SIDE HULL CROSS SECTION

2.1 Cross section data

2.1.1
The coordinates of the node points (filled black circles on Figure 4) are given in Table 1.

2.1.2
The Z coordinate of neutral axis and the inertia moment about the neutral axis are calculated according to the methods given in TB [1.4].

2.2 Calculations of the determinate shear flow

2.2.1
The determinate shear flow, q_D, is calculated according to the method given in TB [1.2].

2.3 Calculations of the indeterminate shear flow

2.3.1
The indeterminate shear flow, q_I, is calculated according to the method given in TB [1.3].

2.3.2
Refer to TB [2.3.1].

2.4 Summation

2.4.1
The shear flows, q, is obtained by summing the determinate shear flow, q_D, and the indeterminate shear flow, q_I.

1 GENERAL

1.1 Application

1.1.1
Technical background is not considered necessary.

1.1.2
The definition of the hull girder ultimate longitudinal bending moment capacity is given.

1.2 Methods

1.2.1 Incremental-iterative method
There is a method of deriving the hull girder ultimate bending capacity in sagging included in the Rules. This method is the incremental-iterative method for calculation of the progressive failure of the hull girder.

1.2.2 Alternative method
There are many methods for deriving hull girder ultimate strength capacity. They can be grouped as simplified formula, progressive failure analysis approach or non-linear FEM approach. Comparison studies performed indicate that the results of the methods are similar.

1.3 Assumptions

1.3.1
Technical background is not considered necessary.

1.3.2
Technical background is not considered necessary.

1.3.3
Technical background is not considered necessary.

1.3.4
Technical background is not considered necessary.

2 INCREMENTAL-ITERATIVE METHOD

2.1 Assumptions

2.1.1
The incremental-iterative method is based on the following simplifying assumptions:

- Each cross section is made of an assembly of independent elements or "components": plate panels, stiffened plate panels and hard corners, thus enabling to determine the structural behaviour for each "component".
- Transverse cross-sections of the ship hull remain plane after deformation and perpendicular to the neutral surface, enabling to calculate the strain ε_E for any curvature χ, according to the following formula: $\varepsilon_E = z\chi$ (z being the distance from the element under consideration to the neutral axis).

- Collapse occurs for panels located between two adjacent transverse primary members.
- Elasto-plastic behaviour of each "component" is determined both in tension and in compression.
- Influence of shear stresses is neglected.
- Calculations are made considering the net scantlings of the section.

The method takes advantage of the possibility to determine for each "component" the relevant load-end curves "σ-ε", as indicated hereafter. The load-end curves "σ-ε" are based on the elasto-plastic collapse for lengthened components and on the buckling collapse for shortened components. The method adopted for determination of the load-end shortening curves "σ-ε" is based on the following two assumptions:

- Variation of the "effective width of attached plating" with the strain ε_E, as originally proposed by Gordo and Soares.
- Generalisation of the Johnson-Ostenfeld correction to any strain level.

2.2 Procedure

2.2.1 General

Refer to TB Report, "TB Rep_Pt1_Ch05_Sec02_Iterative Method for HGULS".

2.2.2 Modelling of the hull girder cross section

Refer to TB [2.2.1].

2.3 Load-end shortening curves

2.3.1 Stiffened plate element and stiffener element

Refer to TB [2.2.1].

2.3.2 Hard corner element

Refer to TB [2.2.1].

2.3.3 Elasto-plastic collapse of structural elements

Refer to TB [2.2.1].

2.3.4 Beam column buckling

Refer to TB [2.2.1].

2.3.5 Torsional buckling

Refer to TB [2.2.1].

2.3.6 Web local buckling of stiffeners made of flanged profiles

Refer to TB [2.2.1].

2.3.7 Web local buckling of stiffeners made of flat bars

Refer to TB [2.2.1].

2.3.8 Plate buckling

Refer to TB [2.2.1].

3 ALTERNATIVE METHODS

3.1 General

3.1.1

Technical background is not considered necessary.

3.2 Non-linear finite element analysis

3.2.1

Technical background is not considered necessary.

3.2.2

Technical background is not considered necessary.

PART 1 CHAPTER 6

HULL LOCAL SCANTLING

Table of Contents

1 APPLICATION

1.1 Application

1.1.1

Technical background is not considered necessary.

1.1.2

Technical background is not considered necessary.

1.1.3 Required scantlings

Technical background is not considered necessary.

1.1.4 Additional local strength requirements

Technical background is not considered necessary.

1.2 Acceptance criteria

1.2.1

Technical background is not considered necessary.

1 LOAD COMBINATION

1.1 Hull girder bending

1.1.1 Normal stresses

This requirement specifies the normal stress to be considered for the strength check of plating and stiffeners contributing to the hull girder longitudinal strength.

1.2 Lateral pressures

1.2.1 Static and dynamic pressures in intact conditions

The basic concept considered related to loads are static loads and dynamic loads corresponding to static and dynamic load cases, induced by the sea, cargoes, other liquids and various type of loads.

1.2.2 Lateral pressure in flooded conditions

Flooding pressures on boundaries of compartments carrying liquids are generally less than pressures in intact conditions and/or tank testing pressures because air pipes of such compartments are fitted above the freeboard deck. On external shell such as bottom and side shell, flooding pressures are reduced due to the consideration of counter pressures from the external sea. Therefore, lateral pressure in flooded conditions is considerable only to the compartments not intended to carry liquids excluding external shell.

1.3 Pressure combination

1.3.1 Elements of the outer shell

Technical background is not considered necessary.

1.3.2 Elements other than those of the outer shell

Technical background is not considered necessary.

2 DESIGN LOAD SETS

2.1 Application of load components

2.1.1 Application

Design load sets applicable to both ship types are defined in this section. Design load sets for primary supporting members in cargo area are ship type-specific and defined in each chapter of Pt 2.

2.1.2 Load components

Load components, P_{in}, P_{ex}, P_{dl}, etc are defined in Ch 4, Sec 7, Table 1 for the various combination of compartments and design load scenarios being considered.

2.1.3 Design load sets for plating, stiffeners and PSM

In general, maximum pressure of two sides of the boundary at the corresponding draft is to be used except bottom and side shell for which “net” pressure difference between tank pressure and sea pressure is to be used. Table 1 is introduced for common understandings on this principle.

For bottom and side shell in static condition – tank testing – (Design Load Set WB-3, WB-6, TK-2), $0.25T_{SC}$ is to be used for the net pressure difference of internal ballast pressure and external sea pressure irrespective of vessel configuration.

Tank testing is assumed carried out filling half of ballast tanks fully for zig-zag loading. Then, testing draught may be assumed as the average of lightship draft and normal ballast draft. Following table shows that $0.25T_{SC}$ as testing draft from CSR OT (July 2010) is less than the average of two drafts, therefore $0.25T_{SC}$ is taken as a reasonable and conservative-side approximation of testing draft.

Table 1: Testing draft, $0.25T_{SC}$ for different vessels

	T_{sc} [m]	Lightship draft [m]	N. Ballast draft [m]	Average [m]	$0.25T_{sc}$ [m]
BC-1	11.50	2.26	4.88	3.57	2.28
BC-2	13.00	2.33	5.92	4.13	3.25
BC-3	14.55	2.23	5.78	4.01	3.64
BC-4	18.20	2.68	8.10	5.39	4.55
OT-1	12.30	2.56	6.69	4.63	3.08
OT-2	22.60	3.40	9.60	6.50	5.65

In case of tank testing in dry dock, the pressure on bottom shell will typically increase about 20% if counter pressure $0.25T_{SC}$ is disregarded. The static case shall also address frequent loads and the dry dock testing can be handled as an extreme load AC-SD which has 20% higher allowable stress. Longitudinal stresses can also be ignored, so this case will not be relevant for design verification.

1 PLATING

1.1 Minimum thickness requirements

1.1.1

These requirements are applicable to the entire hull structure. The requirements are derived from a combination of the existing rule requirements of CSR for tankers and bulk carriers (July 2010). It is emphasised that the existing minimum requirement formulas were developed based on sound service history over many years and also served to add a degree of robustness to implicitly take care of issues not explicitly handled in the rules such as; vibrations, vibration-induced fatigue, impact loads, contact loads, local buckling in way of large curved panels, etc, which are prevalent in the area near the propeller.

In order for an effort to maintain the minimum scantlings as much as those required in the current CSR (July 2010), conservative approach that takes whichever greater requirements between CSR for tankers and CSR for bulk carriers has been made. However, unlike its CSR requirement for tankers (July 2010), CSR requirements for bottom and side shell plating of bulk carriers are different. Such discrepancy used to be a source of ambiguity during scantling application especially for non-parallel body of vessels where the boundaries of bottom and side shell or bilge are not clear. Therefore, it has been decided to adopt CSR requirement of bottom plating for bulk carriers applicable to both of the bottom and side shell/bilge plating since it closely simulates a derived formula from linearisation of two requirements.

The parameter ship length has been limited to 300m. This limitation has been adopted from CSR for tankers (July 2010). This limitation is feasible because tanker designs with length over 300m confirm the validity of this limit within the tanker rules, while no bulk carriers which comply with CSR for bulk carriers (July 2010) and which are larger than 300m exists. The detailed comparison study between CSR for tankers and CSR for bulk carriers has been carried out and the results are shown in Table 1.

Table 1: Comparison of minimum thickness for plating (net)

Description	*L* (m)	150	200	250	300	350
Keel	CSR OT (mm)	11.0	12.5	14.0	15.5	15.5
	CSR BC (mm)	12.0	13.5	15.0	16.5	-
	CSR-H (mm)	12.0	13.5	15.0	16.5	16.5
Bottom shell	CSR OT (mm)	9.0	10.5	12.0	13.5	13.5
	CSR BC (mm)	10.0	11.5	13.0	14.5	-
	CSR-H (mm)	10.0	11.5	13.0	14.5	14.5
Side shell (Aft end)	CSR OT (mm)	11.0	12.5	14.5	16.0	16.0
	CSR BC (mm)	10.5	12.0	13.5	14.5	-
	CSR-H (mm)	11.0	12.5	14.5	16.0	16.0
Side shell & Bilge	CSR OT (mm)	9.0	10.5	12.0	13.5	13.5
	CSR BC (mm)	10.5	12.0	13.5	14.5	-
	CSR-H (mm)	10.0	11.5	13.5	14.5	14.5
Weather deck & Strength deck	CSR OT (mm)	7.5	8.5	9.5	10.5	10.5
	CSR BC (mm)	7.5	8.5	9.5	10.5	-
	CSR-H (mm)	7.5	8.5	9.5	10.5	10.5
Platform deck (Machinery)	CSR OT (mm)	8.5	8.5	8.5	8.5	8.5
	CSR BC (mm)	6.5	6.5	6.5	6.5	6.5
	CSR-H (mm)	8.5	8.5	8.5	8.5	8.5

Inner bottom	CSR OT (mm)	-	-	-	-	-
	CSR BC (mm)	10.0	11.5	13.0	14.5	-
	CSR-H (mm)	10.0	11.5	13.0	14.5	14.5
Inner bottom (Machinery)	CSR OT (mm)	9.5	10.5	11.5	12.5	12.5
	CSR BC (mm)	10.0	11.5	12.5	14.0	-
	CSR-H (mm)	10.0	11.5	12.5	14.0	14.0
Hopper, Top side (BC only)	CSR OT (mm)	-	-	-	-	-
	CSR BC (mm)	8.5	10.0	11.0	12.0	-
	CSR-H (mm)	8.5	10.0	11.0	12.0	12.0
Hull internal tank	CSR OT (mm)	7.5	8.5	9.5	10.5	10.5
	CSR BC (mm)	-	-	-	-	-
	CSR-H (mm)	7.5	8.5	9.5	10.5	10.5
Trans/Longi WT BHD	CSR OT (mm)	7.5	8.5	9.5	10.5	10.5
	CSR BC (mm)	7.5	8.5	9.5	10.5	-
	CSR-H (mm)	7.5	8.5	9.5	10.5	10.5
Non-tight/ Wash BHD	CSR OT (mm)	6.0	6.5	7.0	7.5	7.5
	CSR BC (mm)	6.5	6.5	6.5	6.5	6.5
	CSR-H (mm)	6.0	6.5	7.0	7.5	7.5
Pillar BHD	CSR OT (mm)	7.5	7.5	7.5	7.5	7.5
	CSR BC (mm)	-	-	-	-	-
	CSR-H (mm)	7.5	7.5	7.5	7.5	7.5

2 STIFFENERS AND TRIPPING BRACKETS

2.1 Minimum thickness requirements

2.1.1

This requirement specifies minimum net thickness of web and tripping bracket, based on the one indicated in the existing rule requirements of CSR for tankers (July 2010), see Table 2 below. The requirement for web thickness of side hold frames is based on requirement of IACS UR S12.3 (Rev 5, May 2010) of which length L has been limited to 200m. In addition, some ratio between web thickness of stiffener and thickness of attached plating is specified to allow a suitable weldability.

Table 2: Comparison of minimum thickness for stiffener web/tripping bracket (net)

Description	L (m)	150	200	250	300	350
Tight boundary	CSR OT (mm)	6.0	6.5	7.5	8.0	8.0
	CSR BC (mm)	6.0	6.5	7.5	8.0	-
	CSR-H (mm)	6.0	6.5	7.5	8.0	8.0
Elsewhere	CSR OT (mm)	5.0	5.5	6.5	7.0	7.0
	CSR BC (mm)	-	-	-	-	-
	CSR-H (mm)	5.0	5.5	6.5	7.0	7.0
Ordinary side hold frame (BC only)	CSR OT (mm)	-	-	-	-	-
	CSR BC (mm)	8.5	10.0	11.0	12.0	-
	CSR-H (mm)	8.5	10.0	10.0	10.0	10.0
Tripping BKT	CSR OT (mm)	7.5	8.0	9.0	9.5	9.5
	CSR BC (mm)	-	-	-	-	-
	CSR-H (mm)	7.5	8.0	9.0	9.5	9.5

3 PRIMARY SUPPORTING MEMBERS

3.1 Minimum thickness requirements

3.1.1

The requirements are derived from combination of the existing rule requirements of CSR for tankers and bulk carriers. In order for an effort to maintain the minimum scantlings as much as those required in the current CSR (July 2010), conservative approach that takes whichever greater requirements between CSR for tankers and CSR for bulk carriers has been made.

The minimum web plating thickness of primary supporting members in cargo compartments $0.6\sqrt{L_2}$, was increased to $0.7\sqrt{L_2}$ in aft and forward part regions considering actual as built thicknesses. These requirements are based on CSR for bulk carriers (July 2010) and RINA Rules (January 2013). The required minimum thickness for floors and web plating of primary supporting structures derived from the criteria were compared with the scantling requirements for CSR vessels. Comparisons for primary supporting members are shown in Table 3.

Table 3: Comparison of minimum thickness for PSM (net)

Description	*L* (m)	150	200	250	300	350
DB CL girder Machinery space	CSR OT (mm)	9.5	10.5	12.0	13.0	13.0
	CSR BC (mm)	11.5	12.5	13.5	14.0	-
	CSR-H (mm)	11.5	12.5	13.5	14.0	14.0
DB CL girder Elsewhere	CSR OT (mm)	9.5	10.5	12.0	13.0	13.0
	CSR BC (mm)	7.5	8.5	9.5	10.5	10.5
	CSR-H (mm)	9.5	10.5	12.0	13.0	13.0
Bottom girder Machinery space	CSR OT (mm)	8.5	9.5	10.5	11.5	11.5
	CSR BC (mm)	10.0	11.0	11.5	12.5	-
	CSR-H (mm)	10.0	11.0	11.5	12.5	12.5
Bottom girder Fore part	CSR OT (mm)	8.5	9.5	10.5	11.0	11.0
	CSR BC (mm)	8.5	10.0	11.0	12.0	12.0
	CSR-H (mm)	8.5	10.0	11.0	12.0	12.0
Bottom girder Elsewhere	CSR OT (mm)	8.5	9.5	10.5	11.5	11.5
	CSR BC (mm)	7.5	8.5	9.5	10.5	10.5
	CSR-H (mm)	8.5	9.5	10.5	11.5	11.5
Duct keel Machinery space	CSR OT (mm)	-	-	-	-	-
	CSR BC (mm)	12.5	14.0	15.0	16.5	16.5
	CSR-H (mm)	12.5	14.0	15.0	16.5	16.5
Bottom floor Machinery space	CSR OT (mm)	8.5	9.5	10.5	11.5	11.5
	CSR BC (mm)	10.0	11.0	11.5	12.5	-
	CSR-H (mm)	10.0	11.0	11.5	12.5	12.5
Bottom floor Fore part	CSR OT (mm)	8.5	9.5	10.5	11.0	11.0
	CSR BC (mm)	8.5	10.0	11.0	12.0	12.0
	CSR-H (mm)	8.5	10.0	11.0	12.0	12.0
Bottom floor Elsewhere	CSR OT (mm)	7.5	8.0	8.5	9.5	9.5
	CSR BC (mm)	7.5	8.5	9.5	10.5	10.5
	CSR-H (mm)	7.5	8.5	9.5	10.5	10.5
Aft peak floor	CSR OT (mm)	8.5	9.5	10.5	11.5	11.5
	CSR BC (mm)	8.5	10.0	11.0	12.0	12.0
	CSR-H (mm)	8.5	10.0	11.0	12.0	12.0
Web Aft/Fore	CSR OT (mm)	8.5	9.5	10.5	11.5	11.5
	CSR BC (mm)	8.5	10.0	11.0	12.0	12.0
	CSR-H (mm)	8.5	10.0	11.0	12.0	12.0
Web Elsewhere	CSR OT (mm)	7.5	8.5	9.5	10.0	10.0
	CSR BC (mm)	7.5	8.5	9.5	10.5	10.5
	CSR-H (mm)	7.5	8.5	9.5	10.5	10.5

SYMBOLS

α_p : Aspect Ratio Correction

This correction is based on non-linear analysis carried out during development of CSR OT (July 2010) for evaluation of aspect ratio. The results are in good agreement with the existing DNV formulation. Since the curve in the existing DNV formulation is nearly straight for s/l ratio between 0.4 and 1.0, the format of the equation is changed similar to that in the existing LR Rules (January 2013).

ABS Rules:

$$k(ABS) = \frac{3.075\sqrt{\frac{\ell}{s}} - 2.077}{\frac{\ell}{s} + 0.272}, (max\,1.0)$$

DNV Rules:

$$k(DNV) = \left(1.1 - 0.25\frac{s}{\ell}\right)^2, (max\,1.0)$$

This curve used

LR Rules:

$$k(LR) = 1.1 - 0.4\frac{s}{\ell}, (max\,1.0)$$

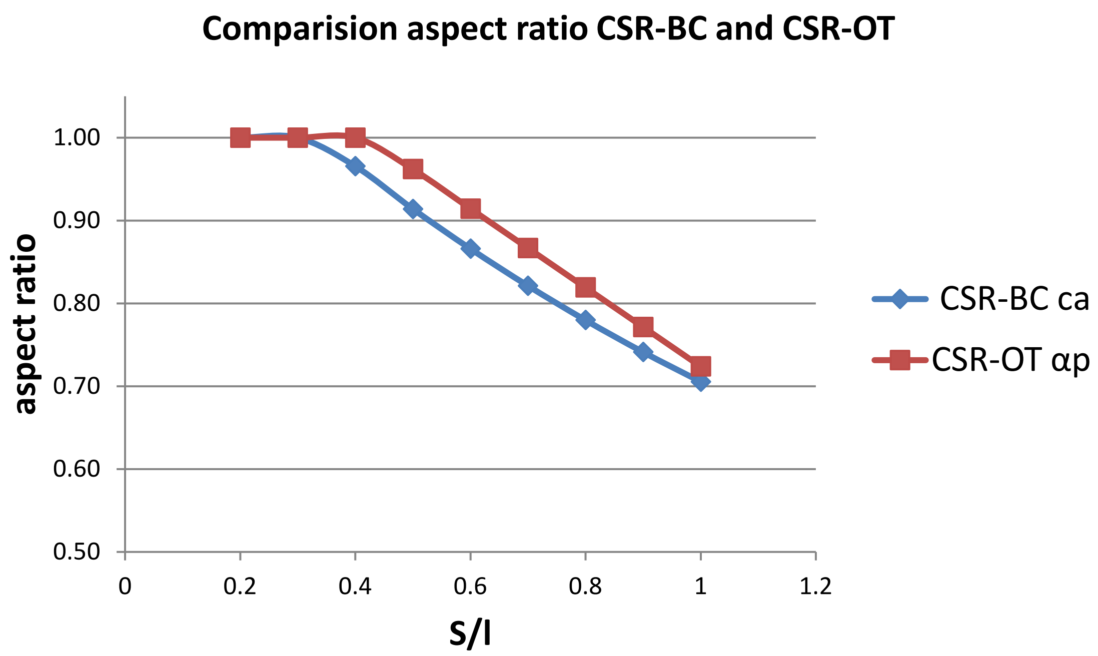
This format used

CSR-H:

$$k(CSR) = 1.2 - \frac{s}{2100\,\ell}$$

$$max.1.0, s(mm), \ell(m)$$

Figure 1: Plate aspect ratio for BC and OT



χ **: Coefficient**

The coefficient, χ, is applicable for boundaries of flooded compartments, which are not intended to carry liquids (i.e. dry and void spaces or cargo holds carrying dry cargo in bulk), except bulkhead structure covered by Pt 2, Ch 1, Sec 3, [3]. The standard acceptance criteria is adjusted for the collision bulkhead and other watertight boundaries by the coefficient χ

which represents the ratio of permissible stress in flooded condition to that in intact condition. The coefficient is calibrated in order to maintain similar severity in flooded condition with CSR for bulk carriers (July 2010).

The coefficient, χ, also reduces allowable stress on inner bottom and hopper in cargo holds of bulk carriers:

- *χ = 0.7 for plates*
- *χ= 0.9 for stiffeners and primary supporting members*

The purpose is to adjust scantling requirement for plate and stiffeners in this Rules to be similar to required scantlings in CSR BC (July 2010) and to reflect the expected variation in local load level for bulk cargos. For simplicity the same value is also applied for liquid pressures on inner bottom and hopper of bulk carriers.

1 PLATING SUBJECTED TO LATERAL PRESSURE

1.1 Yielding check

1.1.1 Plating

Technical background is provided for:

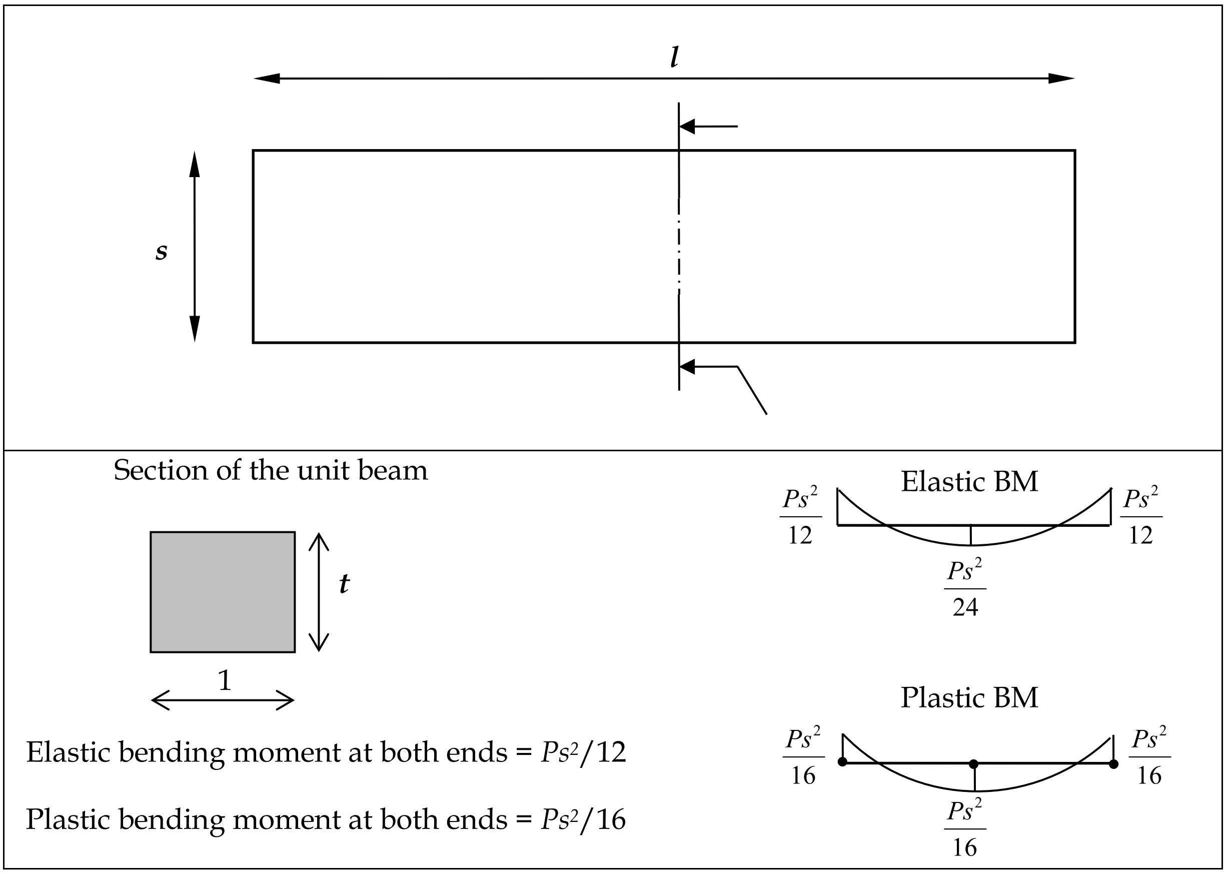
- Capacity formula.
- Allowable stress for C_a.
- Coefficient χ.
- Plate aspect ratio correction α_p.

The capacity formula:
The requirement to net thickness, in mm, of plate subject to lateral pressure is given by the following formula:

$$t = 0.0158\,\alpha_p\, s\sqrt{\frac{|P|}{\chi C_a R_{eH}}}$$

The formula is derived considering a beam having section with a unit width (1) and depth of plate thickness; the bending moment distribution when both ends are fixed is as follows:

Figure 2: Plate panel surrounded by local/primary support members



If the above model is loaded until plastic hinges are created at the mid-span and at the ends then:

Moment at both ends and mid-span	$= Ps^2/16$	
Plastic section modulus	$= t^2/4$	
Assuming allowable stress	$= C_a\,R_{eH}$	$= M/SM = Ps^2/(4t^2)$

Therefore,

$$t = \frac{s}{2}\sqrt{\frac{P}{C_a\,R_{eH}}}$$

where,

s is in mm.

P is in N/mm².

R_{eH} is in N/mm.

Converting the unit of P from N/mm² to kN/m²:

$$t = \frac{s}{2\sqrt{1000}}\sqrt{\frac{P}{C_a\,R_{eH}}} = 0.0158\,s\sqrt{\frac{P}{C_a\,R_{eH}}}$$

Allowable stress factor, C_a:

The permissible bending stress factor (C_a) was determined during development of CSR OT (July 2010) and based on non-linear finite element analysis as outlined below.

The study investigated plastic strain and permanent deformation of a long plate with characteristic as given in Table 1. All edges were fixed against rotation and kept straight. The material curve has a linear strain hardening of E_T =1000 N/mm² for stresses exceeding yield stress, R_{eH}. Young's modulus was E = 206,000 N/mm², and Poisson ratio was set to ν = 0.3.

The plate was subject to incremental lateral pressure until C_a = 1.0 and different combinations of transverse and longitudinal membrane stresses. The plate was loaded with due consideration to loading sequence in order to apply the load history which give the lowest possible plate bending capacity.

Table 1: Characteristics of finite element models used

Plate thickness t (mm)	Length of plate, l (mm)	
	800	4800
10	-	HT32
13	-	MS, HT32, HT36
16	HT32	HT32

Summary analysis results:

1. The results show that the bending strength of plates is particularly sensitive to transverse compression.
2. Also longitudinal compression reduces the plate bending strength, but primarily when acting in combination with transverse compression.
3. The evaluation of the results has mainly focused on the permanent plastic strain.

Benchmark giving permanent plastic surface strain based on the following upper limitations:

1. Load combination a (static loads, functional loads or loads with short return period) 2 times yield.
2. Load combination b (static loads and dynamic loads at 10^{-8} probability level) 4 times yield strain.
3. The maximum strain value for load combination b corresponds to a maximum permanent deformation of 0,004*s*. This is significantly lower than the standard imperfection level used in buckling strength assessment (0.05*s*) as well as production standard given in IACS Rec 47 (Rev 5, October 2010).

Based on the above analysis, the formula for permissible bending stress factors, C_a was determined with factors given in Table 2.

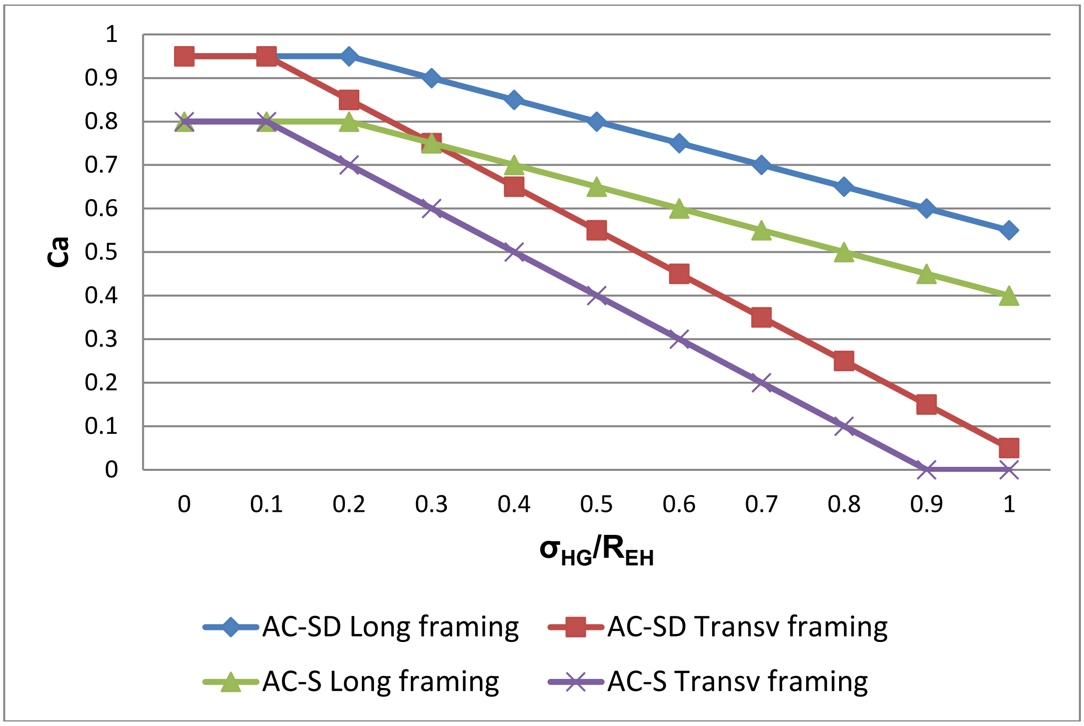
$$C_a = \beta - \alpha \frac{|\sigma_{hg}|}{R_{eH}}$$

Table 2: Permissible bending stress factors

Acceptance Criteria Set	Structural Member		β	α	$C_{a\text{-}max}$
AC-S	Longitudinal Strength Members	Longitudinally stiffened plating	0.9	0.5	0.8
		Transversely or vertically stiffened plating	0.9	1.0	0.8
	Other members		0.8	0	0.8
AC-SD	Longitudinal Strength Members	Longitudinally stiffened plating	1.05	0.5	0.95
		Transversely or vertically stiffened plating	1.05	1.0	0.95
	Other members, including watertight boundary plating		1.0	0	1.0

For plating subjected to hull girder stresses, acceptance range for various combinations of hull girder stresses and local pressure based stresses are as follows:

Figure 3: Permissible bending stress coefficient for plate



1.2 Plating of corrugated bulkheads

1.2.1 Cold and hot formed corrugations

Corrugated bulkhead may have significant in plane stresses (uni-axial in the direction of the corrugation). In addition, corrugated bulkhead has less redundancy than plane bulkhead where loads may be redistributed by membrane stresses in case of local failure. A local failure at lower end or corrugation mid-span will in most cases result in a total collapse of the bulkhead. Hence permissible bending stress coefficients for corrugated bulkhead (*Ca* factor) are set at slightly lower values than that for plane bulkhead.

1.2.2 Built up corrugations

The formula is based on DNV Rules (January 2013), Pt 3, Ch 1, Sec 9, C101.

This formula considered different plate thickness for web and flange of a corrugation in relation to the scantling requirement of corrugation, built with uniform thickness. The thickness of the thicker plate is increased in relation to the uniform thickness by the same portion, as the thickness of the thinner plate is smaller than the required one for uniform thick corrugation.

2 SPECIAL REQUIREMENTS

2.1 Minimum thickness of keel plating

2.1.1

This requirement specifies the thickness of the keel in respect to the thickness of the adjacent bottom plating.

2.2 Bilge plating

2.2.1 Definition of bilge area

Technical background is not considered necessary.

2.2.2 Bilge plating thickness

This paragraph contains scantling requirements for bilge plating.

(a) The consideration of adjacent plate thickness ensures a sufficient continuity of strength based on the required thickness against the applicable pressures, e.g., EDWs. Slamming pressure is relevant only for the forward bottom plate up to 500 mm from base line so this requirement is not part of general minimum requirement for bilge plating.

(b) The formula of the bilge minimum thickness is based on buckling requirements for transverse stiffened rounded plates under lateral pressure and axial hull girder bending stress.

(c) Longitudinally stiffened bilge plating has to be considered as stiffened flat plates taking into account yield check according to Ch 6, Sec 4 and buckling in Ch 8. The plate thickness is not to be less than the minimum resulting from the application of the formula in (b) and the capacity formula given in [1.1.1].

2.2.3 Transverse extension of bilge minimum plate thickness

The extent of application of this requirement is limited in side shell and bottom direction based on the distance of the next welding seams to the endpoints of curvature.

2.2.4 Hull envelope framing in bilge area

This paragraph restricts the distance between the first longitudinal stiffeners and the end of the bilge curvature. If the distance exceeds the Δs_1 or Δs_2, the assumptions made for the derivation of the scantling requirement, given in Ch 6, Sec 4, [2.2.2] are no longer valid.

2.3 Side shell plating

2.3.1 Fender contact zone

The requirements are based on fender contact requirements in accordance with CSR OT (July 2010) and DNV Rules (January 2013). The coefficient in the formula has been adjusted for the net scantlings.

2.3.2 Application of fender contact zone requirement

The whole length of the cargo area is to be checked between minimum ballast draught and a horizontal line $0.25T_{SC}$ (minimum 2.2m) above the scantling draught. Trim is not considered.

2.4 Sheer strake

2.4.1 General

Technical background is not considered necessary.

2.4.2 Welded sheer strake

This requirement specifies the thickness of the sheer strake in respect to the thickness of the adjacent side plating. Additional requirements to ensure that no stress concentrations can occur at the bottom edge of the sheer strake in the area of high hull girder bending stresses.

2.4.3 Rounded sheer strake

This requirement specifies the thickness of the sheer strake in respect to the thickness of the adjacent deck plating. This is an additional requirement to ensure that no stress concentrations can occur at the top edge of the rounded sheer strake.

2.5 Deck stringer plating

2.5.1

Technical background is not considered necessary.

2.5.2

This requirement specifies the thickness of the deck stringer plate in respect to the thickness of the adjacent deck plating and is inline with common practice for ship design.

2.6 Supporting structure in way of corrugated bulkheads

2.6.1 General

Technical background is not considered necessary.

2.6.2 Lower stool

This requirement is generally based on IACS UR, S18 (Rev 8, May 2010), which considers flooded conditions only. It is extended for all loading conditions and design checks equal to CSR OT (July 2010).

2.6.3 Upper stool

This requirement is based on IACS UR, S18 (Rev 8, May 2010) and CSR OT (July 2010).

2.6.4 Local supporting structure in way of corrugated bulkheads without lower stool

This requirement is based on IACS UR, S18 (Rev 8, May 2010) and CSR OT (July 2010).

1 STIFFENERS SUBJECT TO LATERAL PRESSURE

1.1 Yielding check

1.1.1 Web plating

The formula given in the Rules for stiffener web thickness is based on general elastic beam theory with the both ends fixed in general. "f_{shr}" for horizontal stiffeners of 0.5 is for the uniform pressure distribution. "f_{shr}" for vertical stiffeners of 0.7 is for the lower end of the stiffener with linearly varying pressure distribution. The factor of 0.5 has been considered for upper end of vertical stiffeners taking the conservative approach.

The values of permissible shear stress factor (C_t) of 0.75 for AC-S and 0.9 for AC-SD are consistent with the values of permissible bending stress factors (C_s) not subjected to hull girder stresses.

This formula is applicable for boundaries of flooded compartments, which are not intended to carry liquids (i.e. dry and void spaces or cargo holds carrying dry cargo in bulk). The standard acceptance criteria is adjusted for the collision bulkhead and other watertight boundaries by the factor χ which represents the ratio of permissible stress in flooded condition to that in intact condition. The factor is calibrated in order to maintain similar severity in flooded condition with CSR for bulk carriers (July 2010).

1.1.2 Section modulus

Stiffener bending:
The stiffener section modulus formula given in the Rules is based on general elastic beam theory with the both ends fixed in general. "f_{bdg}" for horizontal stiffeners of 12 is based on the bending moment at ends of $|P| s \ell_{bdg}^2 / 12$ assuming uniform loading.

"f_{bdg}" for vertical stiffeners of 10 is based on the bending moment at lower end of $|P| s \ell_{bdg}^2 / 10$ for linearly varying pressure distribution (higher loads at lower end of the stiffener) and also assuming certain degree of carry over bending moment transmitted from the adjacent lower stiffener. The factor of 12 has been considered for upper end of vertical stiffeners taking the conservative approach.

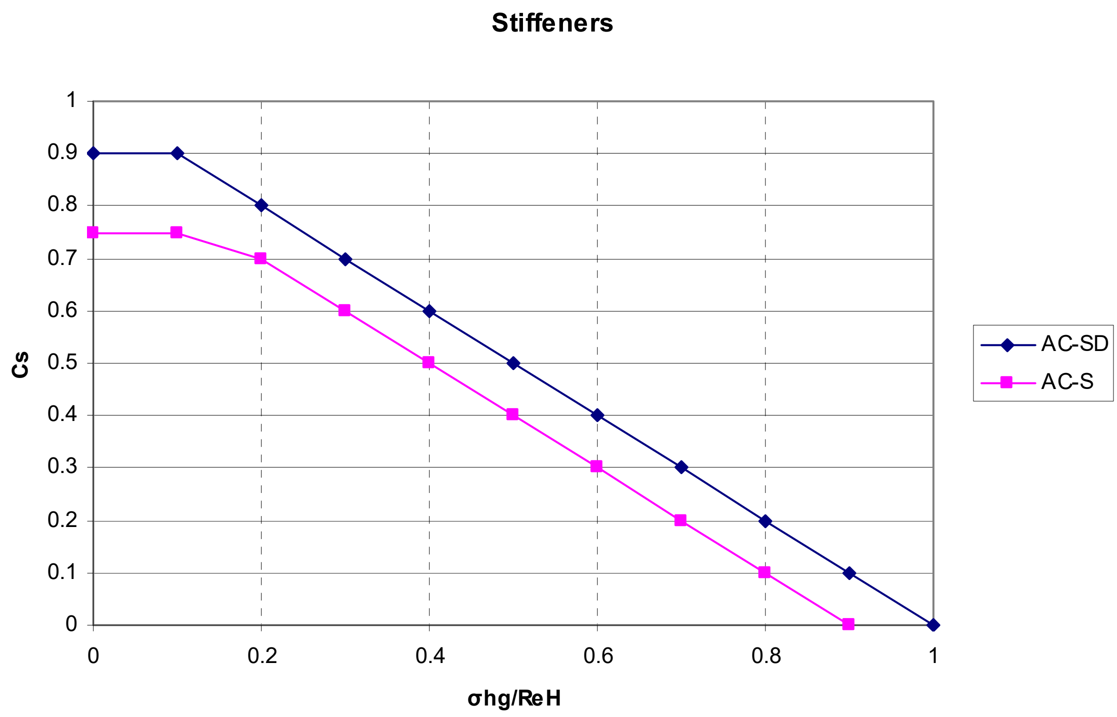
The same formula is applicable for boundaries of flooded compartments, which are not intended to carry liquids (i.e. dry and void spaces or cargo holds carrying dry cargo in bulk). The standard acceptance criteria is adjusted for the collision bulkhead and other watertight boundaries by the factor χ.

Permissible bending stress factor (C_s):
Permissible bending stress factor (C_s) for stiffener is to be considered in elastic range (unlike plate). The total permissible bending stress factor based on combined local pressure based stress and hull girder stress are basically set to be 1.0 for "Static+Dynamic" condition and 0.85 for "Static" condition respectively (with maximum limit of 0.9 and 0.75 respectively for local pressure only).

C_s factor for the member subjected to hull girder stresses:
For stiffeners subjected to hull girder stresses, acceptance criteria for various combinations of hull girder stresses and local pressure based stresses are as follows:

Refer to Table 1 and Table 2 in the Rules.

Table 1: Coefficient of C_S for stiffeners



Where the member is subjected to hull girder stresses, the local pressure based stress is simply added on the hull girder stress. Where the directions of hull girder stress and local pressure based stress are different, the "net" total stress is to comply with the permissible limit with the exception that the local pressure based stress ratio itself should not exceed the maximum limit ($C_{s\text{-}max}$). Also, hull girder stress itself should not exceed the hull girder stress limit.

1.1.3 Group of stiffeners

This requirement indicates practical criteria to check scantlings of stiffeners gathered in group having the same actual scantlings. The concept of grouping can be applied to stiffeners on a single stiffened panel which is surrounded by primary supporting members and/or bulkheads.

1.1.4 Plate and stiffener of different materials

This requirement is taken from CSR OT (July 2010), Sec 3/5.2.6. When the section modulus requirement of stiffener has been determined based on the higher strength material, this requirement is to make sure the plate of the lower yield stress material does not yield before the stiffener side reaches the minimum yield stress.

The formula has been derived as follows:

Assuming $\alpha_s/\beta_s = 1.0$, the minimum yield stresses of the plate side and stiffener side at an equilibrium state are expressed as follows respectively in conjunction with a given critical bending moment;

$$R_{eH-P} = \frac{M_p}{Z_p} + \left|\sigma_{hg}\right| \quad R_{eH-S} = \frac{M_s}{Z} + \left|\sigma_{hg}\right|$$

Hence;

$M_p = Z_P\left(R_{eH-P} - \left|\sigma_{hg}\right|\right)$ and $M_s = Z\left(R_{eH-S} - \left|\sigma_{hg}\right|\right)$

Since the plate side should not yields before the stiffener side yields, M_p should not be less than M_s;

$Z_P\left(R_{eH-P} - \left|\sigma_{hg}\right|\right) \geq Z\left(R_{eH-S} - \left|\sigma_{hg}\right|\right)$, then it becomes;

$$\frac{Z_P}{Z}\left(R_{eH-P} - \left|\sigma_{hg}\right|\right) + \left|\sigma_{hg}\right| \geq R_{eH-S}$$

where,

M_p : Critical bending moment at the attached plate kNm.
M_s : Critical bending moment at the stiffener kNm.
R_{eH-S} : Minimum specified yield stress of the material of the stiffener, in N/mm^2.
R_{eH-P} : Minimum specified yield stress of the material of the attached plate, in N/mm^2.
σ_{hg} : Maximum hull girder stress in sagging and hogging conditions for S and S+D, in N/mm^2, $|\sigma_{hg}|$ is not to be taken less than $0.4R_{eH-P}$.
Z : Net section modulus, in way of face plate/free edge of the stiffener, in cm^3.
Z_P : Net section modulus, in way of the attached plate of stiffener, in cm^3.
α_s, β_s : Coefficients defined in Table 2.

The 1.35 criterion of the material ratio as well as the lower bound of 0.4 ratio of σ_{hg} indicate the criteria from practical experience in the past.

1.2 Beam analysis

1.2.1 Direct analysis

This requirement specifies the parameters to take into account for the determination of normal and shear stresses in a stiffener with reduced end fixity and variable load or stiffeners being part of grillage such as multi-span stiffeners.

1.2.2 Stress criteria

This requirement indicates the admissible normal and shear stresses to consider for the check of stresses based on a direct analysis.

1 GENERAL

1.1 Application

1.1.1

Technical background is not considered necessary.

2 PRIMARY SUPPORTING MEMBERS WITHIN CARGO AREA

2.1 Flooded condition

2.1.1

Technical background is not considered necessary.

2.1.2

Technical background is not considered necessary.

2.2 Bulk carriers

2.2.1 Bulk carriers having a length *L* of 150m and above

Double bottom structures of bulk carriers are constructed in a complex grillage of floors and girders. Typically, floors and girders have comparable spacing to vessel's intended loads. Deck girders in way of the cross deck are cantilever beams in which stress distribution is more dependent on global deformation of the vessel than local pressures. Hence, direct analysis, (e.g. finite element analysis) is used for the evaluation of yielding and buckling of primary supporting members.

2.2.2 Bulk carriers having a length *L* less than 150m

Technical background is not considered necessary.

2.3 Oil tankers

2.3.1

Technical background is not considered necessary.

3 PRIMARY SUPPORTING MEMBERS OUTSIDE CARGO AREA

3.1 Application

3.1.1

Technical background is not considered necessary.

3.2 Scantling requirements

3.2.1 Net section modulus

The criteria for primary support members incorporates flexibility and judgment with respect to analysis of the required bending and shear strength by way of the selection of bending moment and shear force distribution factors (as per Table 2 of the Rules). The applied bending moment and shear force distribution factors are based on selected formulas for simple beam analysis. This analysis approach is consistent with criteria in portions of Rule requirements.

3.2.2 Net shear area

Refer to TB [3.2.1].

3.3 Advanced calculation methods

3.3.1 Direct analysis

Direct analysis shall be applied for complex structure when simple modelling with bending moment and shear force distribution factors given in Table 2, are considered not satisfactory to verify that stress level is in compliance with [3.2].

3.3.2 Analysis criteria

The permissible stress criteria given in [3.3] apply for more advanced beam analysis.

4 PILLARS

4.1 Pillars subjected to compressive axial load

4.1.1 Criteria

Buckling requirements are given for pillar type structures subject to axial loading only. Compressive load acting in pillars is required to be less than the permissible load derived from the critical buckling stress.

4.2 Pillars subject to tensile axial load

4.2.1 Criteria

Pillars subject to tensile axial load are to be evaluated with yield criteria. Buckling criteria given in [4.1.1] of the Rules is not applicable.

PART 1 CHAPTER 7

DIRECT STRENGTH ANALYSIS

Table of Contents

1 GENERAL

1.1 Application

1.1.1

This chapter describes the calculation methods for direct strength assessment of bulk carriers and oil tankers for with the Rules are applicable.

Cargo hold structural strength FE analysis is applicable to:

a) Double hull oil tankers greater or equal to 150m in length.

b) Bulk carriers greater or equal to 150m in length.

1.1.2

The analysis required in Sec 2 will give the scantling of primary supporting members and the Sec 3 is for the local reinforcement of stress concentration area.

1.1.3

For the fatigue analysis, please refer to TB for Ch 9.

1.1.4

Stress used for FE analysis considered the following:

- For yield strength assessment: primary and secondary stress
- For fatigue assessment: primary, secondary and tertiary stress

1.1.5

Technical background is not considered necessary.

1.1.6

Technical background is not considered necessary.

2 NET SCANTLING

2.1 Net scantling application

2.1.1

The corrosion amount given in Ch 3 is the maximum expected value by which the thickness is considered to decrease during the design life of a ship. Deducting the required wastage amount from all the members of the hold model used was considered excessive; it was considered more appropriate to deduct the average wastage amount. The average wastage amount was set as half the required amount, and it was decided as the deduction amount for the model.

However, 100% corrosion in each panel is fairly appropriate when determining the critical buckling stress, and therefore, the corrosion deduction is taken as 100% in this case.

3 FINITE ELEMENT TYPES

3.1 Used finite element types

3.1.1

Technical background is not considered necessary.

3.1.2

Technical background is not considered necessary.

4 SUBMISSION OF RESULTS

4.1 Detailed report

4.1.1

A detailed report is required in order to allow the Society to assess the correctness of the model, of the boundary conditions, of the loads and of the loading conditions and to check the values of stresses in the entire model.

It is recommended that section modulus and neutral axis in FEM is checked and compared to actual value in order to check for a correct modelling.

5 COMPUTER PROGRAMS

5.1 Use of computer programs

5.1.1

Technical background is not considered necessary.

1 OBJECTIVE AND SCOPE

1.1 General

1.1.1

The assessment procedure is applicable to with the following configurations:

- For double hull oil tankers as defined in Ch 1, Sec 1, [1.2] of the Rules.
- For bulk carriers as defined in Ch 1, Sec 1, [1.3] of the Rules.

The assessment procedure is applicable to with the following configurations:

- For double hull oil tankers as defined in Ch 1, Sec 1, [1.32] of the Rules.
- For bulk carriers as defined in Ch 1, Sec 1, [1.23] of the Rules.

1.1.2

The FE structural assessment is mandatory for all longitudinal hull girder structural members, primary supporting members and bulkheads within the cargo area. This also applies to structural members forward, the collision bulkhead and structural members in engine room with extent given in Ch 7, Sec 2, [5.1.2].

1.1.3

For the purpose of defining which holds are to be considered for the midship region strength assessment, holds in the midship cargo region are defined as holds with their longitudinal centre of gravity position at or forward of $0.3L$ from AP and at or aft of $0.7L$ from AP. This follows the logic that if a hold with over 50% of its length is within the traditional definition of the midship region (i.e. $0.3L < \times < 0.7L$), then this hold should be considered for the midship region strength assessment.

In practise, for design with 5 cargo holds along its length, this would normally mean that no. 3 and 4 holds (no. 1 hold is the foremost hold) will be considered as midship cargo hold region. For design with 6 cargo holds along its length, it would normally mean that no. 3, 4 and 5 holds (no. 1 hold is the foremost hold) will be considered as midship cargo hold region. For design with 7 cargo holds along its length, it would normally mean that no. 3, 4, 5 and 6 holds (no. 1 hold is the foremost hold) will be considered as midship cargo hold region. For design with 9 cargo holds along its length, it would normally mean that no. 4, 5, 6 and 7 holds (no. 1 hold is the foremost hold) will be considered as midship cargo hold region.

Consequently, forward and after cargo hold regions are defined as holds located forward and after the midship cargo hold region. The foremost cargo hold(s) and the aft most cargo hold(s) are defined as separate regions. This result with 5 cargo hold regions:

- Aftermost cargo hold(s).
- After cargo hold region.
- Midship cargo hold region.
- Forward cargo hold region.
- Foremost cargo hold(s).

For each cargo hold region applies separate design FE load combinations which are defined in Ch 4, Sec 8 of the Rules.

1.2 Cargo hold structural strength analysis procedure

1.2.1 Procedure description

Technical Background is not considered necessary.

1.2.2 Mid-hold definition

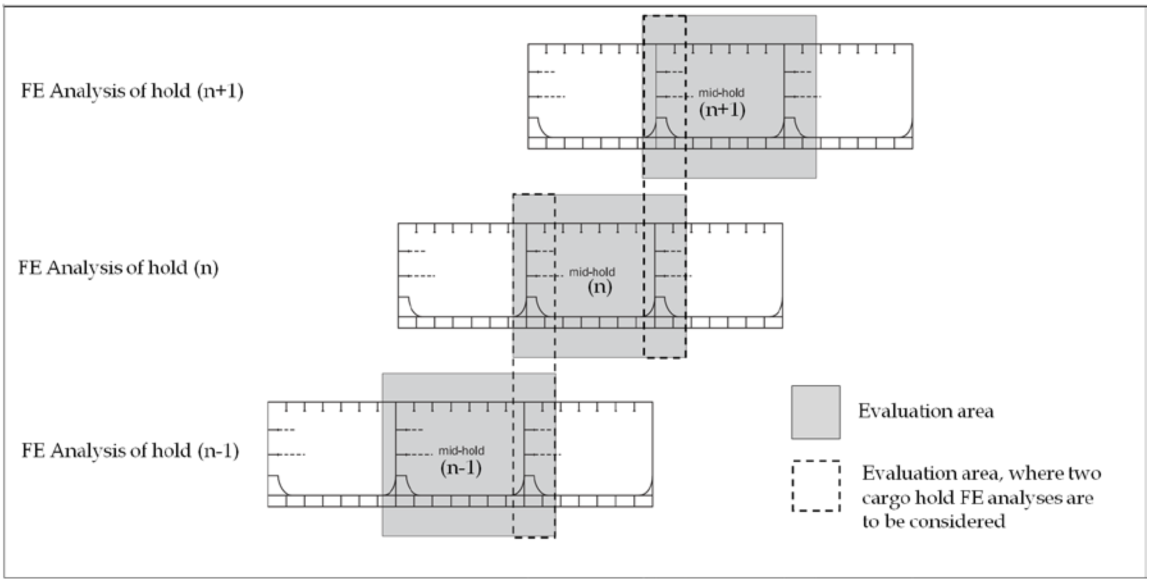
In case of the FE model in the aftmost cargo hold region of oil tankers, the forward holds of the three-hold length FE model is to be cargo holds no. N-1 (i.e. No. 5 cargo holds in case of 6 cargo holds along its length within cargo area), and the after holds is to be engine room.

In this particular case, the mid-hold of the three hold model represents the cargo holds no. N and slop tanks located from the engine room bulkhead to the forward bulkhead of cargo holds no. N.

1.2.3 Scantling assessment with individual cargo hold method (IM)

The evaluation area for FE analysis, as defined in Ch 7, Sec 2, [5.1.1], includes forward and aft transverse bulkhead of the mid-hold of the FE model. All transverse bulkheads except collision bulkhead and the aft bulkhead of the aftmost hold, are included in the results from two FE analyses, as shown in Figure 1. The scantlings in way of these bulkheads are to be evaluated based on two corresponding FE analyses.

Figure 1: Scantling assessment with individual cargo hold method (IM)



2 STRUCTURAL MODEL

2.1 Members to be modelled

2.1.1

The choice of modelling thickness is in accordance with the Rule net thickness philosophy described in Ch 3, Sec 2.

The cargo tank FE model is to represent the overall corroded state of the hull. It is not realistic to assume that the whole hull structure is corroded by the maximum corrosion addition thickness for each individual member. In the assessment of the overall strength of the hull, it is assumed that all plates of the structure are corroded by 50% of the corrosion addition thickness. This is consistent with the assessment of global hull girder properties as well as consistent with the in-service global hull girder gauging requirements to be followed throughout the life of the vessel.

The examples of other structural members which contribute to hull girder strength are listed and are not limited to as below;

- Longitudinally continuous trunks as defined in Ch 5, Sec1, [1.2.4].
- Longitudinal girders welded above the strength deck as defined in Ch 5, Sec 1, [1.2.5].
- Longitudinal girders between hatchways, supported by longitudinal bulkhead as defined in Ch 5, Sec 1, [1.2.6].

2.2 Extent of model

2.2.1 Longitudinal extent

Boundary conditions applied at the ends of the cargo hold model in general will introduce abnormal stress responses in way of the constrained areas due to the constraint of model displacements. The area in the model where the stress responses are to be assessed must be adequately remote from the model boundary so that the constraint applied will not have significant effect on the stress responses.

A three-hold length finite element (FE) model is used for the following reasons:

(a) A three-hold length FE model is used to ascertain that the area in the model where the stress responses are assessed are adequately remote from the model boundary so that the constraint applied will not affect the stress result. It is to be noted that the area in the model for assessing against the acceptance criteria covers structure within the longitudinal extent from the termination of the transverse bulkhead stringer/buttress aft of middle hold to the termination of the bulkhead stringer/buttress forward of the middle hold. A three-hold length FE model is considered more appropriate than a ½ +1 + ½ hold length model in this case, especially with correction bending moment applied to the model ends, otherwise, the effect of the end constraints may be significant as the ends of the model could be only two web frame spaces from the areas that are required to be assessed.

(b) With the presence of the transverse bulkheads at both ends of the three-hold length model, the three hold model ascertains that the middle hold of the model has similar deformation as the one for the whole vessel.

(c) A three-hold length model is used in conjunction with the procedure of applying adjustment forces, bending and torsional moments to obtain the required shear force, bending and torsional moment distributions along the model length. The required distributions are difficult to achieve with a ½ + 1 + ½ model.

2.2.2 Hull form modelling

In the FE models of the foremost and aftmost cargo hold regions, the hull forms in the model should be represent the actual shell curvature to get correct FE stresses and pressure loads. To avoid any complication in the FE modelling of foremost and aftmost cargo hold regions, simplified procedures without influencing the results of the mid-hold of the three hold model can be used as follows;

- Foremost cargo hold model

  The hull form is to be modelled up to the first forward transverse web frame from the middle of the fore parts. The middle of the fore part is located at the mid position of the longitudinal distance between the collision bulkhead and the model end where the reinforced ring or web frame remains continuous from the base line to the strength deck.

- Aftmost cargo hold model

  The hull form is to be modelled up to the first aft transverse web frame from the middle of the machinery space.

The properties of the transverse web frames in the extrusion parts are to be same to those of the transverse web frame at the starting point of the extrusion. The transverse web frame spacing is also considered as one of the properties of the transverse web frame.

2.2.3 Transverse extent

Where asymmetrical loads are applied, if the structure is symmetrical about the ship's centreline, the analysis could theoretically be carried out using a half breadth FE model by combining the stress responses obtained from the analysis of a number of symmetrical and anti-symmetrical load cases with appropriate boundary conditions imposed at the centreline plane. The procedure is complicated and increases risk in introducing user errors in the analysis. The requirement of a full breadth FE model is to simplify the analysis of asymmetrical loading conditions and hence reduce the probability of introducing errors in the analysis process.

2.2.4 Vertical extent

It is important to include all structural members above the upper deck which contribute in hull girder strength, such as longitudinal trunk structure when fitted.

2.3 Finite element types

The stresses and strains to be used in this finite element analysis are in linear functions one of the other. Using linear theory also displacements are controlled by stresses.

2.3.1

Two node beam elements and three or four node shell elements are sufficient for the representation of the hull structure and are most commonly used by Societies, shipbuilders and designers for carrying out the finite element analysis. These elements are recommended to be used for the construction of the FE models. Additional information can be found in TB of Ch 7, Sec 1.

2.3.2

The eccentricity of the neutral axis of the ship's stiffener systems allows determining the representation of the actual structural response as closely as possible. It is considered to be factual for stiffened panels under lateral pressure load as well as for stiffened panels where no lateral pressure is applied. In addition, a common way of modelling of all stiffeners minimises the discrepancy in the result which helps to achieve common scantlings in the application of the Rules.

2.3.3

Modelling of face plates of primary supporting members with plate elements normally will require using elements with aspect ratio more than 3, as limited in Ch 7, Sec 2, [2.3.2]. It is sufficient to represent face plates with rod or beam elements to obtain main stress component in the flange which is axial stress.

2.4 Structural modelling

2.4.1 Aspect ratio

The elements used in the Finite Element Method have limitations with respect to the mesh used. Elements with high aspect ratio as well as distorted elements will give inaccurate results and should be avoided. It is considered that element with aspect ratio not more than 3 are sufficient to obtain correct results for the FE analyses required by the Rules.

2.4.2 Mesh

Modelling the ship's plating and stiffener systems as closely as possible to the actual structure allows a more accurate structural response to be determined, and minimises the discrepancy in the result which helps to achieve common scantlings in the application of the Rules. In addition, modelling plate mesh that follows the stiffening system eliminates the need of approximating the property of group of stiffeners by a single line element at the edges of a plate element. This modelling procedure also makes the process of extracting stresses for buckling assessment of panels easier and more accurate.

It should be noted that the aim of the cargo hold finite element analysis is to assess the overall strength of the structure and is not intended to determine the stresses at structural details and discontinuities, as the mesh size employed is too coarse to correctly represent their geometry. Instead, fine mesh finite element analysis is used to determine such stresses.

2.4.3 Finer mesh

In the case where the geometry of a structural detail cannot be adequately represented by the 'coarse mesh' in the cargo hold finite element model, then a finer mesh analysis can be used to obtain the stress for comparison with the criteria. It is to be noted that this analysis option is only applicable to area of stress concentration. Average stress calculated over an area equivalent to the mesh size of the cargo hold finite element model is not to exceed the allowable stress required by the cargo hold finite element analysis (i.e. below yield) to retain the consistency between finer mesh analysis and cargo hold analysis. The average stress is calculated based on weighted average of Von Mises stress and area of elements within the equivalent area.

2.4.4 Corrugated bulkhead

For corrugated bulkheads, it is important to retain the correct geometrical shape of the corrugation. A difference in geometry alters the sectional inertia and cross sectional area of the corrugation which will result in incorrect stress response. Inaccurate modelling of corrugation shape is better to be avoided.

The dummy rods are to be modelled along the entire length of the corrugation knuckle as shown in the following examples.

Figure 2: Example of dummy rod elements at the corrugation knuckle for a tanker

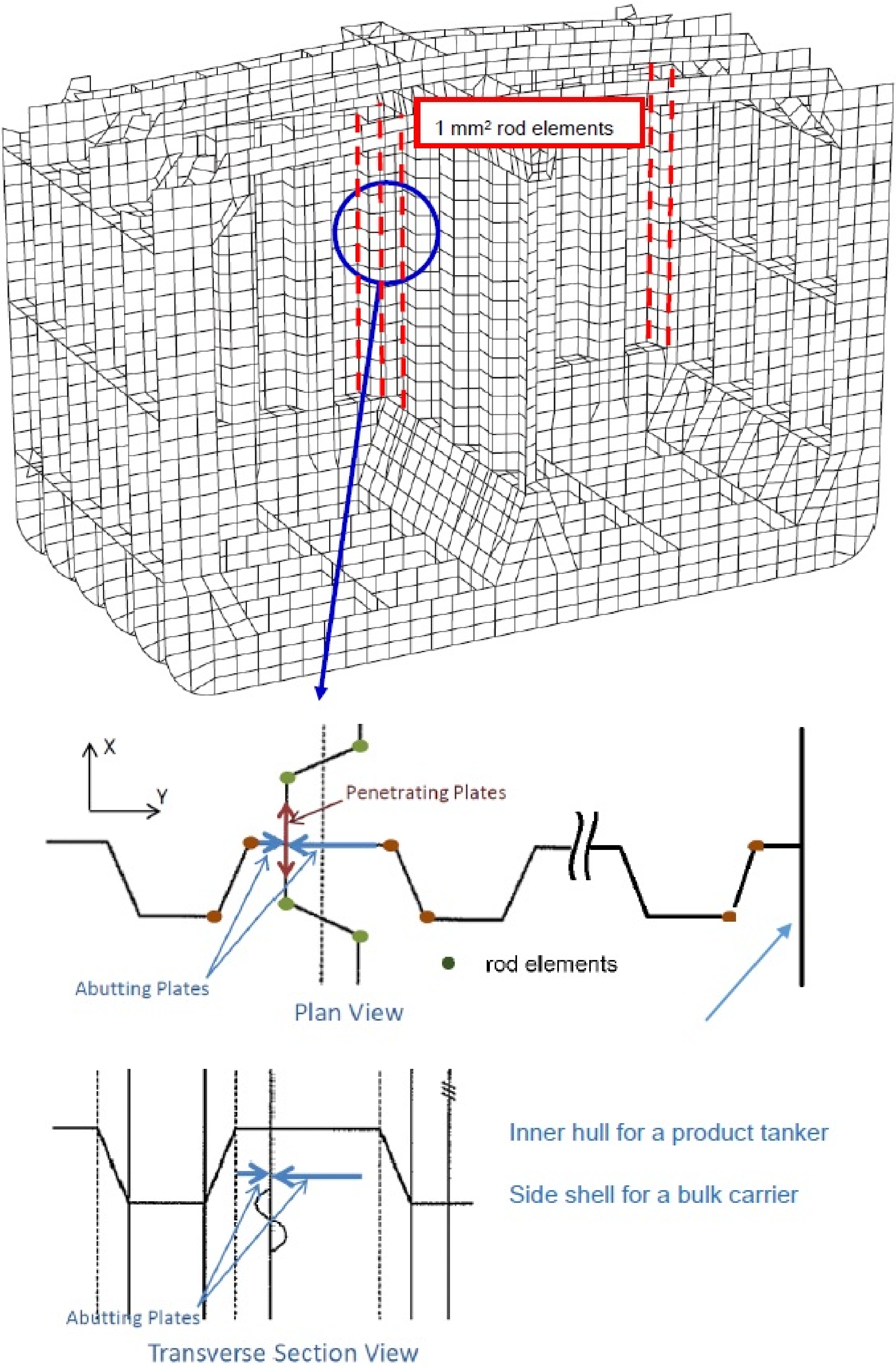
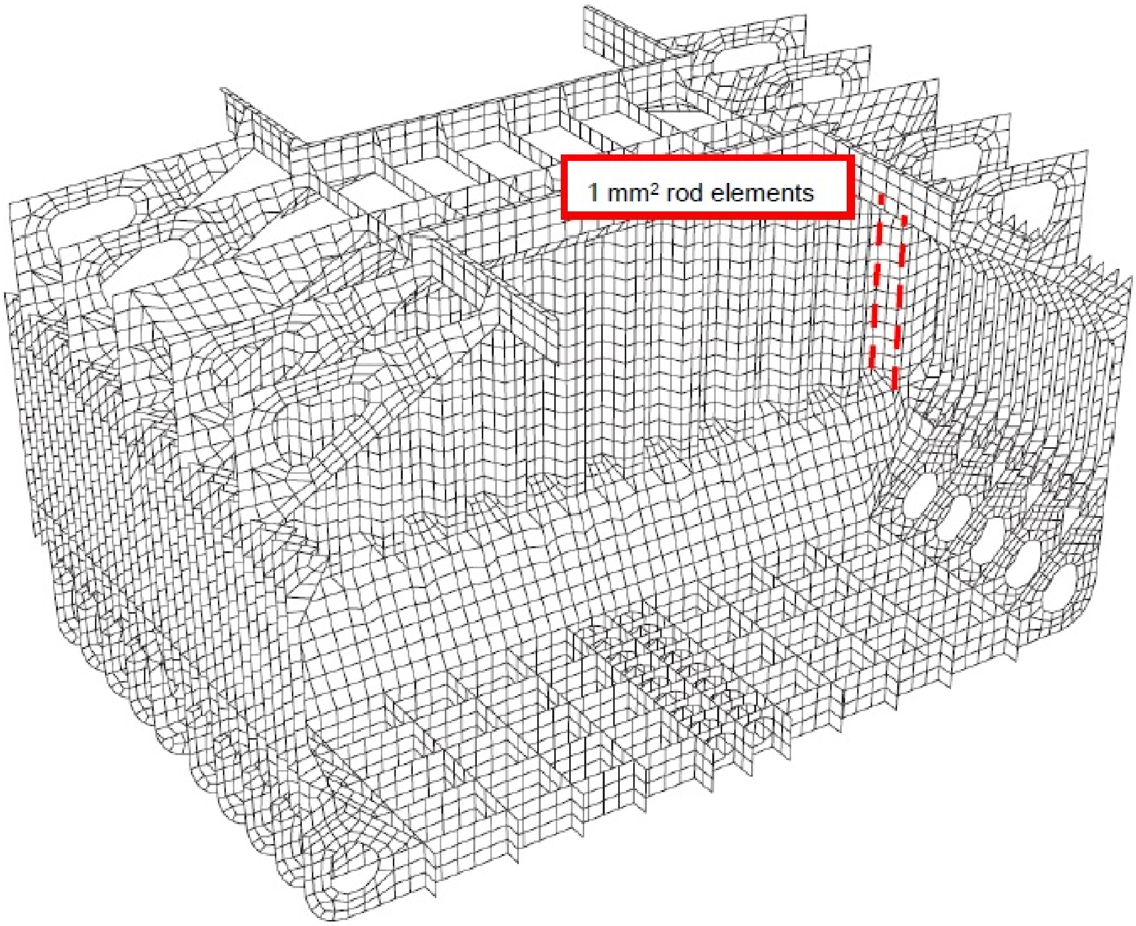


Figure 3: Example of dummy rod elements at the corrugation knuckle for a BC



2.4.5

Technical background is not considered necessary.

2.4.6 Sniped stiffener

Technical background is not considered necessary.

2.4.7

On transverse web frames and bulkhead stringers, the arrangement of web stiffeners can become irregular. In order to avoid undesirable element mesh (such as introduction of triangular or highly skewed elements) in way, consideration may be given to slightly adjusting the end points of the web stiffener in line with the primary element mesh. In general, it is considered acceptable if the adjusted distance does not exceed 0.2 times the stiffener spacing. Provided that this tolerance is met the stresses and buckling capacity models may be taken from the FE model and do not need to be adjusted. The use of rod elements representing the web stiffeners on primary supporting members are to be limitedly used to the unstiffened panels only as defined in Ch 8, Sec 4, Table 1.

2.4.8 Face plate on primary supporting member

The technical background is based on a paper by R.W. Westrup and P. Silver, "Some effects of curvature on frames", Aerospace Sciences, September 1958.

The formula represents the efficiency of a curved faceplate in terms of bending moment. The efficiency is given as a fraction of the area of the face plate. The reason for the correction is that a curvature gives a change of force direction. The moment capacity of a member with curved face plate is given by its possibility to transfer the change in shear to the face plate. The wider a curved face plate is the less efficient the section becomes. Similarly a small radius will given a larger change in force and hence less efficiency.

2.4.9 Openings

The cargo hold analysis is only intended for assessing the overall strength of the structure. Local stresses in way of an opening is in addition assessed using fine mesh finite element analysis, as required by Ch 7, Sec 3 of the Rules, with accurate modelling of the opening geometry.

For large openings, i.e. with $h_o/h \geq 0.5$ or $g_o \geq 2.0$, it is considered necessary to include the geometry of the opening in the cargo hold model in order to obtain an acceptable result, see Ch 7, Sec 2, Table 1 of the Rules for definitions of l_o, h_o and g_o. In this case, fine mesh finite element analysis is mandatory in order to determine the local stress in way of the opening. See in the TB of Ch 7, Sec 3.

For other openings, i.e. with $h_o/h < 0.5$ and $g_o < 2.0$, it is considered not necessary to include such openings in the cargo hold model. Instead, shear stresses in way of cut-outs in webs need to be corrected for the loss in shear area according to Ch 7, Sec 2, [5.2.6]. In all cases the geometry of an opening can be included in the cargo hold finite element model.

However, it should be noted that the screening formula, given in Ch 7, Sec 3 of the Rules for determining whether it is necessary to perform a fine mesh analysis of the opening, is only applicable for the cases where the geometry of an opening has not been included in the cargo hold model. If the geometry of an opening is included in the cargo hold model, fine mesh analysis is to be carried out to determine the local stress in way of the opening.

2.5 Boundary conditions

2.5.1 General

Technical background is not considered necessary.

2.5.2 Application

The boundary conditions are applicable for three cargo hold length FE model analysed with the design load application given by the Rules.

2.5.3 Boundary conditions

Rigid links in y and z are applied at both ends of the cargo hold model so that the constraints of the model can be applied to the independent points. Rigid links in x-rotation are applied at both ends of the cargo hold model so that the constraint at fore end and required torsion moment at aft end can be applied to the independent point.

The x-constraint is applied to the intersection between centreline and inner bottom at fore end to ensure the structure has enough support. The reasons for selecting this point for x-constraint are (1) the physical FE node exits at this point and (2) it is close to the independent point so the resultant vertical bending moment due to this constraint, if any, will be minimum.

2.5.4 End constraint beams

The end beams are applied at both ends of the cargo hold model to simulate the warping constraints from the cut-out structures. For three-hold model, the stiffness from the cut-off part of the hull girder shall be represented. Under torsional load, this out of plan stiffness acts as warping constraint. The influence of the cut-off parts on the hull girder bending is simulated by adding out-of-plane bending stiffness to the end sections of the model. It is accomplished by adding a series of 'end constraint beams' at the both end sections along all longitudinally continuously structural members, including cross deck plate for bulk carrier.

3 FE LOAD COMBINATIONS

3.1 Design load combinations

3.1.1 FE load combination definition

Refer to TB in Ch 4, Sec 8.

3.1.2 Mandatory load combinations

Refer to TB in Ch 4, Sec 8.

3.1.3 Additional loading conditions

Refer to TB in Ch 4, Sec 8.

4 LOAD APPLICATION

4.1 General

One important aspect of FE analysis is to determine the response of the structure as accurately as possible for a given set of applied loads. For this reason, the Rules require that all simultaneously acting hull girder and local loads are to be applied directly to the FE model. This ensures that the effect of the interaction of all structural parts is included in the solution.

The method of superimposition of stresses derived from FE analysis for local loads and simplified beam theory model for hull girder loads is not adapted as important structural interaction cannot be preserved. Refer to TB in Ch 4, Sec 8.

4.1.1 Structural weight

It is important to include the static effect of structural steel weight of the ship in the analysis as this weight represents a significant proportion of total weight carried by the ship. For example, for a typical VLCC, the lightship weight is equal to 12% to 16% of the total weight of the cargo carried for a typical full load condition (cargo density of 0.85 t/m^3) and 40% to 50% of the total weight of the ballast carried based on typical normal ballast condition.

4.1.2 Sign convention

Technical background is not considered necessary.

4.2 External and internal loads

4.2.1 External pressure

External sea pressures are to be applied to the FE model explicitly according with Ch 4, Sec 6.

The green sea loads are to be applied along the top of hatch coaming in such way that sum of distributed forces along the hatch coamings is equal to sum of loads from green sea pressure acting on the corresponding hatch cover.

4.2.2 Internal pressure

Internal pressures are to be applied to the FE model explicitly according with Ch 4, Sec 6.

4.2.3 Pressure application on FE element

It is considered that the application of a constant pressure or a linear pressure distribution on a plate element results with insignificant difference in stress results for the strength assessment required by the Rules.

4.3 Hull girder loads

4.3.1 General

As the three-holds FE model is only representing part of the ship simply supported at both ends, when the required local loads (i.e. static and dynamic hold pressure, static sea and dynamic wave pressure and structural weight) are applied to the model, the global hull girder loads generated may not necessarily reach the required target values specified in [4.3]. The hull girder loads need to adjusted by applying additional forces and moments to the model. The adjustments are calculated and applied to each hull girder component separately, as follows:

a) Hull girder vertical shear force.

b) Hull girder vertical bending moment.

c) Hull girder horizontal bending moment.

d) Hull girder torsional moment.

All hull girder components can be controlled independently, however some adjustments need to be calculated in correct order, see more in [4.4].

4.3.2 Target hull girder vertical bending moment

The hull girder vertical bending targets represent the maximum nominal design hull girder vertical bending moments for a given FE load combination. For FE strength assessment, the vertical bending moment target consists of the following basic components:

(a) Still water bending moment, M_{sw}, for Static load scenarios (S).

(b) Still water bending moment, M_{sw}, and vertical wave bending moment, $M_{wv\text{-}LC}$, for Static plus Dynamic load scenarios (S+D).

Still water bending moment, M_{sw}, is a permissible still water bending moment at the considered longitudinal position for seagoing and harbour conditions as defined in Ch 4, Sec 4, [2.2.2] and Ch 4, Sec 4, [2.2.3] respectively. The still water bending moment is reduced by $C_{BM\text{-}LC}$ factor for loading patterns where the maximum permissible value cannot be reached. Vertical wave bending moment, $M_{wv\text{-}LC}$, is a bending moment for the dynamic load case under consideration, calculated in accordance with Ch 4, Sec 4, [3.5.2].

In the midship cargo region, the vertical bending moment target is given by one value, which is the maximum combination of M_{sw} and $M_{wv\text{-}LC}$ within considered mid-hold of the FE-model, since the still water permissible bending moments may not be necessary constant as well wave vertical bending moment within $0.3L$ to $0.7L$. Outside midship the combination of M_{sw} and $M_{wv\text{-}LC}$ gradually sloping toward the ships fore and aft ends. Hence the targets outside midship region are defined at each web frame/transverse bulkhead position along the considered FE model.

4.3.3 Target hull girder shear force

The hull girder shear stress is considered to give the most onerous combination with stress due to local loads close to transverse bulkheads. The hull girder shear force is adjusted to reach the required maximum value defined by the hull girder shear force targets, as described in [4.4.5].

The targets are defined for the forward and aft transverse bulkheads of the mid –hold of the FE model. The hull girder shear force targets represent the maximum nominal design hull girder shear forces. For FE strength assessment, the shear force target consists of the following basic components:

(a) Still water shear force, Q_{sw}, for Static load scenarios (S).

(b) Still water shear force, Q_{sw}, and wave shear force, $Q_{wv\text{-}LC}$, for Static plus Dynamic load scenarios (S+D).

Still water shear force, Q_{sw}, is a permissible still water shear force given at considered forward and aft transverse bulkheads of the mid–hold of the FE model. The still water shear force is reduced by $C_{SF\text{-}LC}$ factor for loading patterns which the maximum permissible value cannot be reached, e.g. chess loading pattern. The sign of the permissible still water shear force is determined by the sign of the shear force due to local loads applied to the FE model.

For bulk carriers, the permissible still water shear force, Q_{sw}, is based on the shear force envelope after shear force correction, as defined in Ch 4, Sec 4, [2.3.3] and [2.3.4]. In order to account the nominal value of the shear force, the shear force correction is to be added to Q_{sw}. The basis for the shear force corrections are followed according to Ch 5, Sec 1 [3.6.1].

Vertical wave shear force, $Q_{wv\text{-}LC}$, is included for the dynamic load case under consideration, where the value and the sign of the shear force is defined at the considered transverse bulkhead position in accordance with Ch 4, Sec 4, [3.5.3].

4.3.4 Target hull girder horizontal bending moment

The global hull girder horizontal bending moment needs to be considered for the beam sea and oblique sea dynamic load cases. Horizontal wave bending moment target, $M_{wh\text{-}LC}$, for the dynamic load case under consideration is to be calculated in accordance with Ch 4, Sec 4, [3.5.4].

Following the same argument given in [4.3.2], in the midship cargo hold region the horizontal bending moment target is given by one target value. Outside midship region the targets are defined at all web frame and transverse bulkhead positions of the FE model under consideration.

4.3.5 Target hull girder torsional moment

The global hull girder torsional moment needs to be considered for the beam sea and oblique sea dynamic load cases. For designs with a closed cross section, such as oil tankers, the influence from the hull girder torsional moment is considered to be negligible. Hence targets are defined only for bulk carriers. Wave torsional moment target, $M_{wt\text{-}LC}$, for the dynamic load cases OST and OSA, is to be calculated in accordance with Ch 4, Sec 4, [3.5.5].

In order to apply the maximum M_{wt-LC} to the FE model, the target is defined at forward bulkhead or aft bulkheads of mid-hold, depending on the longitudinal location of the considered mid-hold. The reference position of 0.531*L* represents a zero crossing location of the rule torsional moment. For irrelevant cases with respect to the hull girder torsion moment, the target, M_{wt-LC}, is zero at the middle of the mid-hold. This requires the balancing of the model which is comparable to a fixation of rotations (Θ_x) at both ends of the FE model.

4.4 Procedure to adjust hull girder shear forces and bending moments

4.4.1 General

The final hull girder shear needs not to exceed the target hull girder shear force at the target bulkhead locations. The final hull girder bending moment needs not to exceed the target hull girder bending moment at any location within the middle cargo. In order to reach all desired targets, it is important that all adjustments related to shear forces are to be calculated before the adjustments of the corresponding bending moments.

4.4.2 Local loads distribution

The longitudinal station close to the transverse bulkhead should be defined such that the accurate hull girder shear forces right before and after target bulkhead can be obtained so that the maximum absolute hull girder shear at target bulkhead location can be used for the hull girder shear adjustment.

4.4.3 Hull girder forces and bending moment due to local loads

The method used to calculate the hull girder bending moment and shear force along the length of the cargo hold finite element model should be consistent with that used in the longitudinal strength calculation and ship's loading computer, which is used for calculating the still water bending moment and shear force of the ship in operation. The hull girder bending moment and shear force due to local loads is to be calculated based on a simple beam model, where the applied loads are aggregated from the FE model.

It should be noted that a ship's loading computer calculates the bending moments and shear forces based on a simple beam and does not take into account abreast distribution of cargo/ballast in tanks. When a ship is loaded unevenly abreast, due to the effect of local loads, the longitudinal stress and shear stress will be increased in some parts of the hull girder more than that of an evenly loaded condition for the same amount of hull girder bending moment and shear force. The stress increase due to local loads resulting from uneven abreast tank loading distribution is checked by the finite element analysis to ensure adequate hull strength when the ship is subjected to the maximum permissible still water bending moment and shear force in uneven abreast tank loaded conditions.

4.4.4 Longitudinal unbalanced force

The unbalanced longitudinal force is applied by the distributed longitudinal forces at fore end so that correction force, if any, will not create significant high stress spot and spurious bending moment.

If total net longitudinal force of the model is not equal to zero, the unbalanced longitudinal force, Fl, exists in the model and need to be balanced to avoid additional vertical bending moment generated by the longitudinal reaction force. It is to be done by applying the counter longitudinal distributed forces to all end section elements, which are effective for hull girder bending, at the end of the model where the translation on x-direction is constrained, so that any effect on the model of the reaction force is avoided.

4.4.5 Hull girder shear force adjustment procedure

The vertical hull girder shear force adjustment procedure in principle can be applied also to FE load combinations other than those enumerated in Ch 4, Sec 8 provided that the relevant FE load combinations parameters are taken based on the principles stated in Ch 4, Sec 8 for similar loading conditions.

These parameters are:

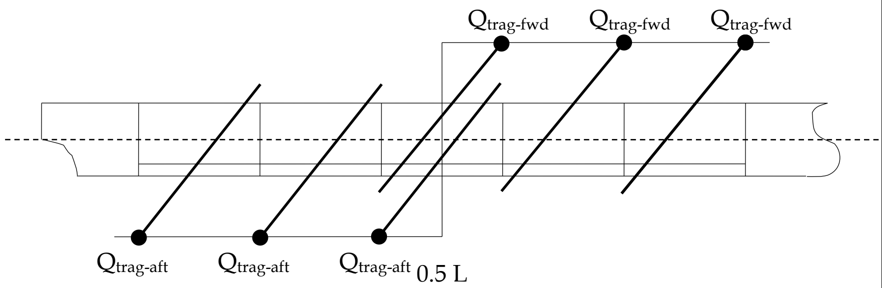
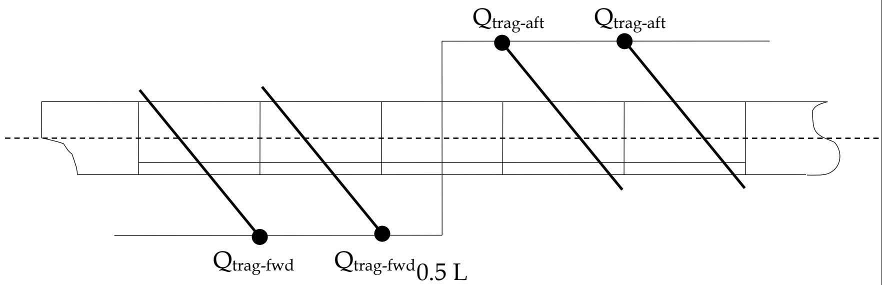
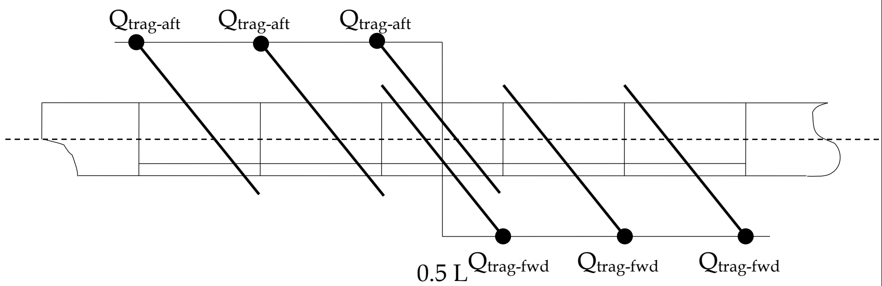
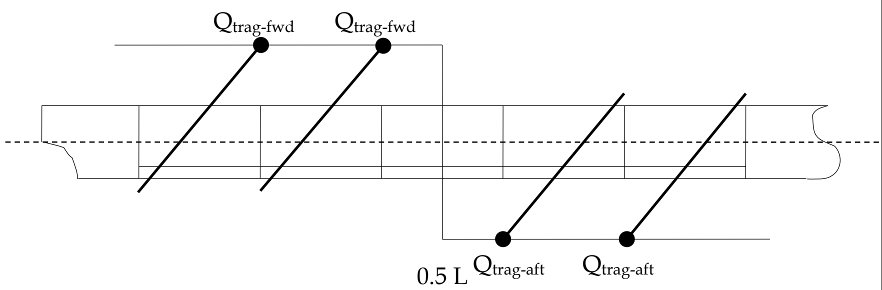
1) Loading Pattern
2) Draught
3) C_{BM-LC}: % of perm. SWBM
4) C_{SF-LC}: % of perm. SWSF
5) Weather it is to be considered as a "Max SFLC" or not
6) For (S+D) LC the dynamic load cases

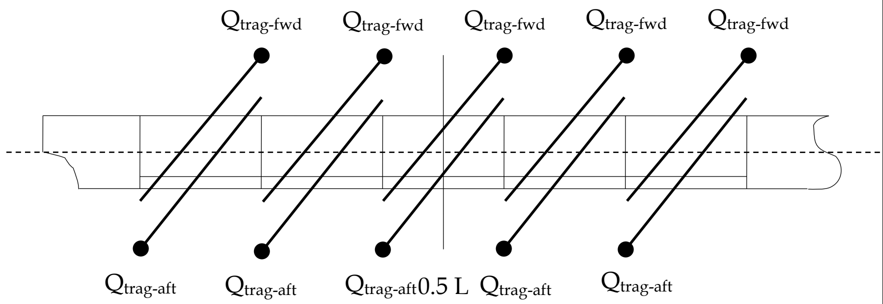
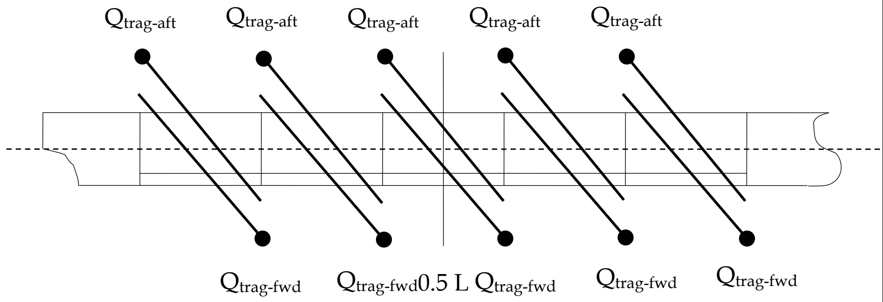
It is important to remember that both bulkheads of the mid-hold are to be checked, therefore for "Max SFLC" not enumerated in Ch 4, Sec 8, dynamic load cases are to be chosen so that each dynamic load case targets the shear force at only one bulkhead.

For "Max SFLC" the mid-hold bulkhead location for shear force adjustment is chosen according to Ch 7, Sec 2, Table 6.

Table 1 contains a graphical depiction of the families of "Max SFLC" necessary to check both mid-hold bulkheads along the length of the cargo area. Each shear force diagram in Table 1 corresponds to a family of "Max SFLC" (e.g. for A3 outside midship cargo hold region HSM-2 and FSM-2 dynamic load cases are one family).

Table 1: SF adjustments to target in the mid-hold of FE models considered in cargo area

Load scenario	Local SF at fwd blhd mid-hold	Wave condition	
(S+D)	$Q_{fwd}>0$	Sagging	
(S+D)	$Q_{fwd}\le 0$	Sagging	
(S+D)	$Q_{fwd}\le 0$	Hogging	
(S+D)	$Q_{fwd}>0$	Hogging	

(S)	$Q_{fwd}>0$	-	
(S)	$Q_{fwd}\leq 0$	-	

The 2 Methods introduced here (Method 1 and Method 2) are not two possible alternative ways of achieving the same results; their nature is different and each has to be applied when specified in this article.

If shear force is to be adjusted, the procedure of Method 1 is considered better (or preferable compared to the one of Method 2) because it does not introduce along the FE model any adjustment force: the effect is that the slope of shear force due to local loads is kept (with a more "physical" outcome).

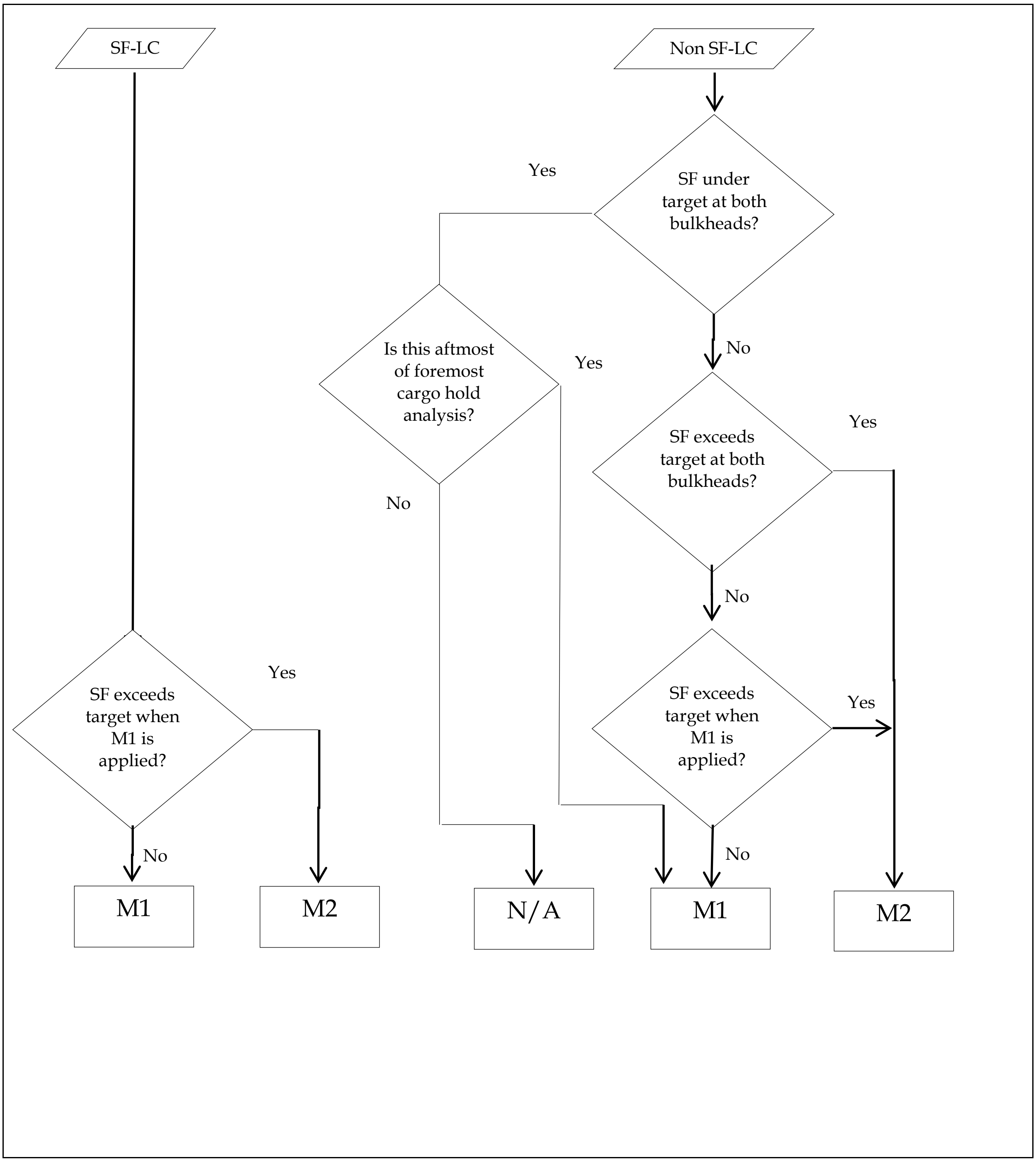
In practice Method 2 is used only if with Method 1 the resulting shear force exceeds the target (permissible) value at the other mid-hold bulkhead. In other words the procedure of Method 2 is to be used only because otherwise in some cases it would be possible that permissible shear force value is exceeded within the results evaluation area, complicating a lot the task of checking the FE results.

The logic process of choosing between Method 1 (M1) and Method 2 (M2) is shown in Figure 4 for both SF-LC and Non SF-LC. The N/A box means that no vertical shear force adjustment is needed for that FE Load combination.

Standard shear force adjustments (method 1 and method 2) apply to all models. For aft most and foremost cargo hold models, additional vertical forces, $\delta w'_1$ or $\delta w'_3$, are to be applied. Those forces change shear force distributions and together with all other shear force adjustments give zero shear forces at the model's aft end (in aftmost cargo hold model) and forward end (in foremost cargo hold model).

Refer to Ch 7, Sec 2, [4.4.5], [4.4.6] and [4.4.7] of TB for RCN 1 to CSR 01 Jan 2019.

Figure 4: Application of shear force adjustment methods.



4.4.6 Method 1 for vertical shear force adjustment at one bulkhead

With Method 1, except for foremost and aftmost cargo hold FE model, only loads at the boundary of the FE model are used to adjust the vertical hull girder shear force, i.e. no vertical and horizontal internal forces are added to the local loads (calculated for each independent loading scenario). For foremost and aftmost cargo hold FE model, in addition to the above loads at the boundary of the FE model, vertical internal forces are added to keep vertical shear force consistent with the actual vertical shear force in the region of the foremost of aftmost cargo hold.

4.4.7 Method 2 for vertical shear force adjustment at both bulkheads

The procedure described in Method 2 consists in two logical steps:

First a shift of SF curve due to local loads parallel to itself by means of end bending moments (similarly to Method 1). Secondly a (subsequent) correction of SF curve slope to meet the targets (actually one target and one permissible value) at mid-hold bulkheads

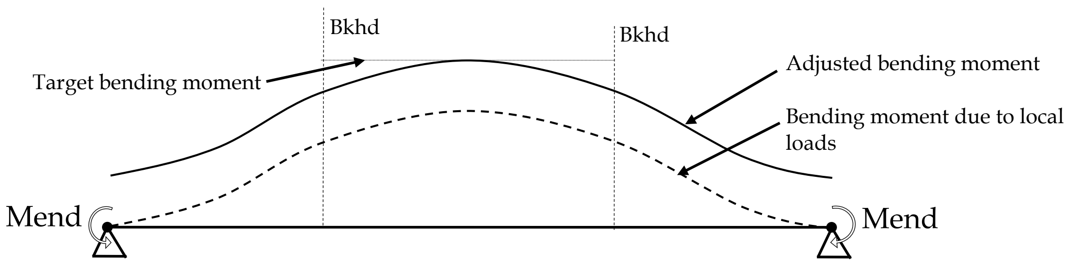
The first step is performed to minimise the amount of vertical internal forces that will have to be introduced with the second step, thus practically obtaining the minimum change in shear force curve slope compared to the one due to local loads. Method 2 can be also seen as a continuation of Method 1 that however has to come into play only when necessary: the result is that for borderline situations the transition from Method 1 to Method 2 is absolutely smooth.

The proportion of vertical force to be distributed to longitudinal continuous member of each cross section is determined by a shear flow calculation. Both vertical and horizontal force components calculated with the shear flow method are to be applied because it was found that applying only the vertical component (as could have been possible) gave too much spurious distortion when applied to sloped and horizontal structures (i.e. out of structure plane).

4.4.8 Procedure to adjust vertical and horizontal bending moments for midship cargo hold region

In midship cargo hold region, the hull girder vertical and horizontal bending moment is adjusted by applying a vertical and a horizontal bending moment to the model ends to obtain the specified value within of the middle hold, as shown in Figure 5.

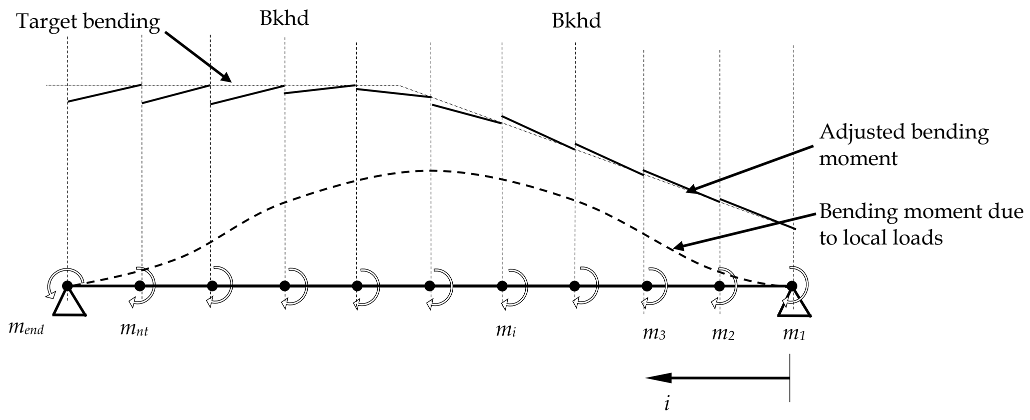
Figure 5: BM adjustments to required target for the midship cargo hold region



4.4.9 Procedure to adjust vertical and horizontal bending moments outside midship cargo region

Outside midship cargo hold region, the hull girder vertical and horizontal bending moment is adjusted by applying a vertical and a horizontal bending moments, m_i, to all web frame and transverse bulkhead positions of the FE model under consideration to obtain the specified target values, as shown in Figure 6. Similarly as the bending moment adjustment in midship cargo hold region, shear forces are not induced by this adjustment.

Figure 6: BM adjustments to required target for outside midship cargo hold region



4.4.10 Application of bending moment adjustments on the FE model

The required vertical and horizontal bending moment adjustments including shear force adjustments by end bending moments, as given in [4.4.6] are to be applied by nodal forces in longitudinal direction. Their distribution based on the stress distribution at the considered section according to simple beam theory. Since there is no rigid link in x-translation, y-rotation and z-rotation at the model ends, bending moments at the end cross sections must be also applied by the equivalent longitudinal forces.

4.5 Procedure to adjust hull girder torsional moments

4.5.1 General

The arguments given in [4.5] apply to the adjustment of hull girder torsional moments.

4.5.2 Torsional moment due to local loads

It is very important to refer the correct torsion moment reference point for sectional torsional moment calculation. The horizontal reaction force needs to be included at the model end with free rotation (Θ_x).

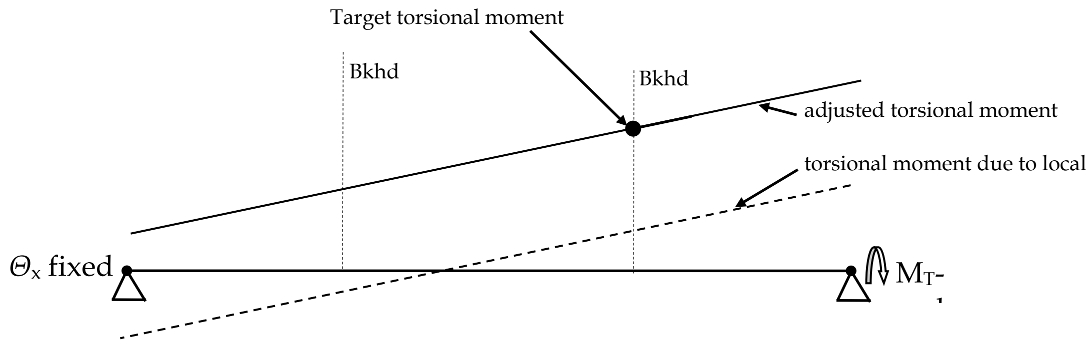
4.5.3 Hull girder torsional moment

The torsional moments are accumulated starting from the model end with free rotations (Θ_x) applied in boundary constrains.

4.5.4 Procedure to adjust hull girder torsional moment to target value

The adjustment, $M_{T\text{-}end}$, is to be applied only to independent point at the model end with free rotation (Θ_x). The torsional moment due to local loads will be lift up or down to the target, as shown in Figure 7.

Figure 7: Torsional moment adjustment to required target



4.6 Summary of hull girder load adjustments

4.6.1

Technical background is not considered necessary.

5 ANALYSIS CRITERIA

5.1 General

5.1.1 Evaluation areas

Verification of results against the acceptance criteria is carried out within the longitudinal extent of the middle hold of the three-hold FE model, and the regions forward and aft of the middle holds up to the extent of the transverse bulkhead stringer and buttress structure. The FE result in this region is considered to be valid for assessment against the acceptance criteria, as:

- The analysis procedure ascertains that the required hull girder bending moments and shear force are correctly applied within middle-hold region of the model. Also see Ch 7, Sec 2, [4.3] to [4.5] of the Rules for a detailed explanation of the procedure for adjusting hull girder bending moments and shear forces.
- The boundary of the model is sufficiently remote from the area under assessment so that the constraint applied at the model ends will not affect the stress responses. Also see Ch 7, Sec 2, [2.4] for further information.

5.1.2 Structural members

Technical background is not considered necessary.

5.2 Yield strength assessment

Yield and buckling are two main failure modes of structure under static and dynamic loads related to Serviceability Limit State. The structural strength capability against these two modes of failure is verified by the cargo hold strength assessment. The structural analysis is to demonstrate that the permissible von Mises stress criteria and utilisation factor against buckling for plate and stiffened panels are not exceeded. The permissible were considered for the severest conditions of operation in a 25 year period in the North Atlantic route.

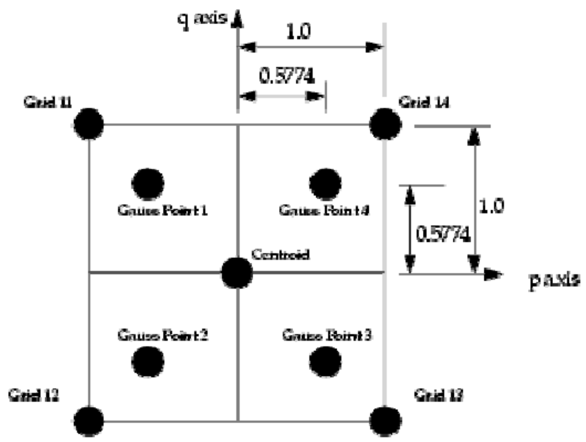
5.2.1 Von Mises stress

The stresses are to be taken at the mid-plane of the shell elements to eliminate the bending effect due to local pressure load. Most finite element analysis programs will have output for stress evaluated at the element centroid. Where element centroid stress is not available, it can be calculated using the stresses at the Gauss points based on the shape function of the element.

The calculation method is described in most finite element text books and software manuals. Figure 8 shows an example for a simple four node element with four interior Gauss points. It is important to note that the shape functions vary by element type and element order.

Figure 8: Coordinates of Gauss points and element centroid

Coordinates of Gauss points and element centroid



The Gauss points are located in the p/q parametric space at +/- $(3)^{-1/2}$. The element centroid is at coordinate (0,0)

Note: For simple 4-node element, the centroid stress is equal to the average of the stresses at the four Gauss points.

5.2.2 Axial stress in beams and rod elements

The axial stress in the flange (of the primary supporting member), modelled with beam or rod elements, represents normal stress in the girder. Similarly, the axial stresses in the intersections between the flange and web of the corrugations, modelled with beam and rod elements, represent normal stresses in the corrugation. Evaluation of other beam and rod elements included in the FE model is not required, see [5.2.4].

5.2.3 Coarse mesh permissible yield utilisation factors

The stress criteria are based on Von-Mises stress and an explicit criterion on pure shear stress is not used. A von-Mises stress criteria will normally be more stringent than a pure shear criteria (i.e. based on shear yield stress with the same factor of utilisation) as the calculation of von-Mises stress includes shear stress and other additional axial stress components. Note that shear and biaxial direct stresses are used in the calculation of the buckling utilisation factor of panels.

The stress criteria are based on membrane stress of elements, which represents the stress due to hull girder effect, deflection of primary support members and stiffener bending stress but does not include plate bending stress.

The harbour/tank testing load cases (S design combination) are assessed based on static loads only. The acceptance criteria on yield and buckling utilisation factors for harbour/tank testing load cases (S design combination) is set at 80% of the corresponding criteria for seagoing load cases (S+D design combination) which effectively allow a margin equal to 20%

of the criteria for dynamic loads. This margin allows for some dynamic wave loads in harbour and tank testing operations which may be carried out at sea in sheltered waters, and also gives a safety margin to ensure that temporary accidental overloading will not cause permanent deformations. These acceptance criteria are adopted from CSR OT (July 2010).

5.2.4 Yield criteria

For shell elements representing the corrugation of corrugated bulkheads under lateral pressure from liquid load an additional factor of safety (equivalent to 10% reduction in the stress and buckling acceptance utilisation factors) is applied to achieve the same level of confidence for these members. These acceptance criteria are adopted from CSR OT (July 2010).

Corrugations of vertically corrugated bulkheads under bulk cargo pressure do not require this additional factor of safety, similarly to CSR BC (July 2010), also because these critical members are checked also by prescriptive requirements with more severe accidentally flooded holds scenarios (even if checking for ultimate strength and not first yielding).

The stress acceptance criteria are set against a particular mesh size. These criteria should not be used in conjunction with stress obtained from a model with mesh size larger than that intended as this will lead to a non-conservative scantling requirement.

Where a lower bulkhead stool is not fitted to a vertically corrugated bulkhead, an additional factor of safety (equivalent to 10% reduction in the stress and buckling acceptance utilisation factors) is applied in the assessment of corrugated bulkhead and its supporting structure when a lower bulkhead stool is not fitted to achieve the same level of confidence as in designs fitted with a lower bulkhead stool.

Service experience indicates that vertically corrugated bulkhead designs without a lower stool are more critical (e.g. prone to local fracture) than those fitted with a lower bulkhead stool due to higher stress level and alignment problems with the supporting structure in the double bottom. The reduction in acceptance utilisation factors is introduced also as a measure to account for lack of prescriptive requirements for vertically corrugated bulkheads without lower stool. These acceptance criteria are adopted from CSR OT (July 2010).

5.2.5 Corrugation of corrugated bulkhead

The stresses in the corrugation of corrugated bulkheads have a gradient over the flange breath and web height therefore the evaluation is based:

(a) For the von Mises stress in the shell elements on a 10% reduced acceptance criteria. (only under lateral pressure from liquid loads).

(b) On the axial stress, σ_{rod}, in dummy rod elements, modelled with unit cross sectional properties at the intersection between the flange and web of the corrugation. This is due to the fact that in the dummy rod elements no stress gradient is present (as they are 1d elements) therefore full permissible yield utilisation factor is adequate.

5.2.6 Shear stress correction for cut-outs

The element shear stress in way of openings in webs is to be corrected for loss in shear area and is be calculated based on normal shear area in accordance with Ch 3, Sec 7, [1.4.8].

5.2.7 Exceptions for shear stress corrections for openings

The exception conditions for some standard configuration of girders webs are given in order to limit the application of the shear force stress correction for cut-outs, as required in [5.2.6].

For these standard configurations no correction of the shear stress (and thus of the von Mises stress) is necessary. The correction is given in terms of a more convenient reduction factor of the permissible yield criteria.

5.3 Buckling strength assessment

5.3.1

Technical background for buckling is given in Ch 8.

References:

1. IACS, “Common Structure Rules for Double Hull Oil Tankers”, July 2010.
2. IACS, “Common Structure Rules for Bulk Carriers”, July 2010.

1 OBJECTIVE AND SCOPE

1.1 General

1.1.1

Technical background is not considered necessary.

1.1.2

The selection of locations for investigation is based on service experience and previous finite element studies carried out on tanker and bulk carrier designs. Detailed description of the locations is given in [2.1]and [3.2]. The locations identified cover the most critically stressed areas in the midship region for conventional designs. As the number of locations that are required to be investigated is extensive, a screening procedure has been developed, which is based on a correlation study of the stresses obtained from the 'coarse mesh' cargo tank FE analysis and fine mesh FE analysis, to identify the critical locations that need to be assessed using fine mesh analysis, and avoid unnecessary and repetitive analysis being carried out. The screening criteria for fine mesh analysis are given in [3.3].

In view of the large number of locations that need to be investigated, a mathematical formula based screening procedure, based on the stresses obtained from the 'coarse mesh' cargo tank FE analysis, has been developed to identify the critical locations that need to be assessed using finite element fine mesh analysis to avoid unnecessary and repetitive analysis. The screening procedure applies to common structural details including openings, bracket toes and heels of primary support members. Fine mesh analysis is not required for structural details that comply with the screening criteria.

1.1.3 Fine mesh analysis procedure

Evaluation of detailed stresses requires the use of refined finite element mesh in way of areas of high stress. This localised stress cannot be obtained from the cargo tank FE model due to the limited accuracy in representation of a structural detail and modelling simplifications owing to the coarser mesh size used. The objective of the local fine mesh analysis is to verify that detailed stress at critical locations, including the effects due to local structural geometry, is within the acceptable limit.

1.1.4 Scope of fine mesh verification

Technical Background is not considered necessary.

2 LOCAL AREAS TO BE ASSESSED BY FINE MESH ANALYSIS

2.1 List of mandatory structural details

2.1.1 List of structural details

Technical Background is not considered necessary.

2.1.2 Hopper knuckle for ship with double side

Hopper knuckles for ship with double side are defined as the joints of below structural members and not limited to:

(a) Lower Hopper Knuckle
- Inner bottom
- Transverse scarping bracket

- Hopper plate
- Double bottom side girder
- Transverse double bottom floor
- Transverse web frame in way of hopper tank

(b) Upper Hopper Knuckle
- Inner hull longitudinal bulkhead
- Hopper plate
- Horizontal girder in double side space
- Transverse web frame in way of double side
- Transverse web frame in way of hopper tank

The critical areas of hopper knuckle that require finite element fine mesh analysis are selected based on service experience and previous finite element studies where are always the high stress connections.

2.1.3 Side frame end brackets and lower hopper knuckle for single side bulk carrier

Lower hopper knuckle for single side bulk carrier is defined as the joint of below structural members and not limited to:
- Inner bottom
- Transverse scarping bracket
- Hopper plate
- Double bottom side girder
- Transverse double bottom floor
- Transverse web frame in way of hopper tank

By experience of service and previous FE studies, the lower knuckle, lower and upper end bracket of side frame are always the high stress connections, furthermore the geometry of the end bracket detail cannot be thoroughly represented by the 'coarse mesh' in the cargo tank finite element model, then a fine mesh analysis can be used to obtain the stress for comparison with the criteria.

2.1.4 Large openings

If the geometry of an opening is roughly modelled in the cargo tank model, the stress concentration usually occurs at the edge or corners. Fine mesh analysis is an effective method to determine the exact local stress around the opening.

Among the same type of primary support members, those with the highest von Mises stresses at the location of the same large openings from the cargo hold model analysis are to be selected for the fine mesh analysis. Since large openings can be located at different type of primary support members and even for the same type of primary support member large openings may exist at different locations, in general, above selection may involve multiple fine mesh analyses.

2.1.5 Connections between deck and double bottom longitudinal stiffeners and adjoining structures of transverse bulkhead

The objective of the fine mesh analysis of end connections of longitudinal stiffeners at deck and double bottom is to investigate the increased stresses caused by the relative deflection between the stiffener supports, which may cause localised structural and/or paint cracks. Selection of the stiffeners for analysis is based on maximum relative deflection between primary supports and transverse bulkheads.

Longitudinally, maximum relative defection of deck, inner and outer bottom longitudinal stiffeners usually occurs in way of transverse watertight bulkheads and transverse swash bulkhead. Transversely, maximum deflection usually occurs in way of the mid-tank position between longitudinal bulkheads.

Originally, the Rules imposed a relative deflection criterion, which was derived based on a simple beam under deflection and calibration with existing designs, to control the stress level at the end connection of the stiffeners caused by the relative deflection between primary support members. If the deflection criteria was not satisfied, a mandatory fine mesh analysis was required to assess the total stress in way of the end brackets and attached web stiffeners of longitudinal stiffeners of double bottom and deck, and adjoining vertical stiffener of transverse bulkhead, where maximum relative deflection between primary supports exists. It was later decided to delete the deflection criteria and require a local fine mesh analysis in all cases.

The advantage of using a fine mesh analysis over a simple relative deflection criterion is that the fine mesh analysis can provide a more accurate control of the stress level as the analysis takes into account the actual geometry of the connection detail, bracket arrangement and all load components. The intention of the fine mesh analysis is to verify that the structure has adequate strength when subjected to the increased stress caused by the relative deflection of the stiffener and all other applied loads.

2.1.6 Connections between corrugation and adjoining lower structure

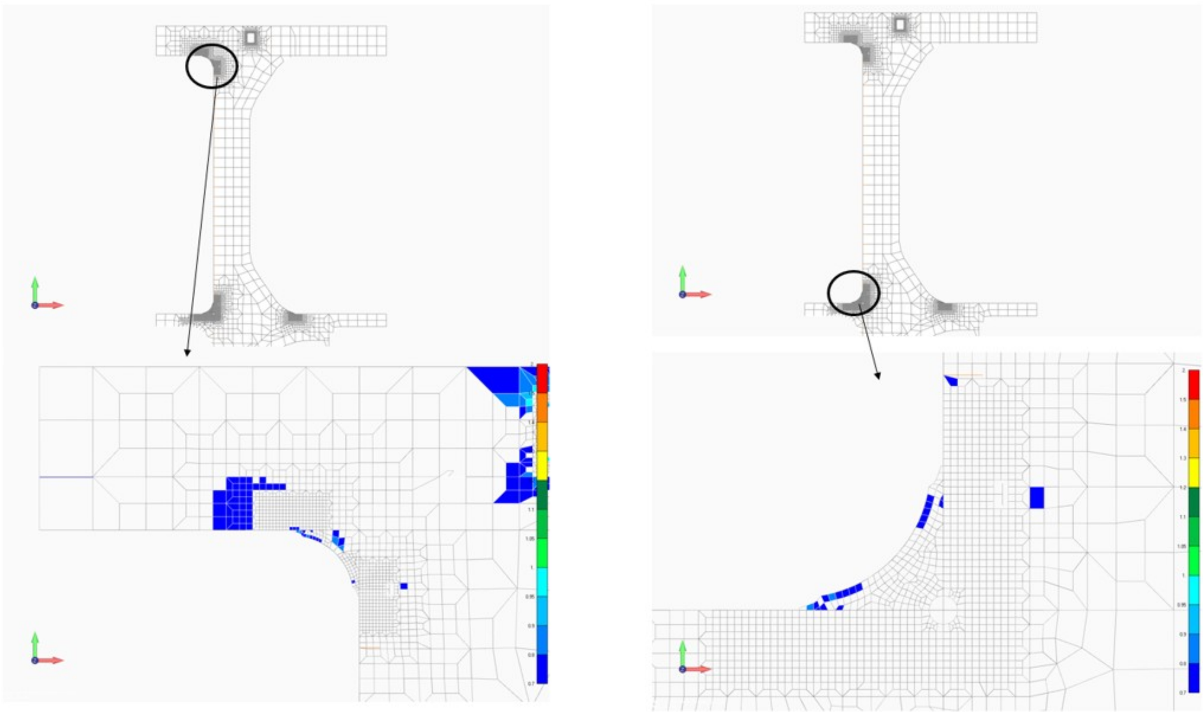
For the connections of corrugated bulkhead to adjoining structures, where the structural member connections are rather complex and their geometry of structural detail cannot be adequately represented by the 'coarse mesh' in the cargo tank finite element model. By experience of service and previous FE analysis in design where is stress concentration and structural discontinuity, then a fine mesh analysis can be used to obtain the stress for comparison with the criteria.

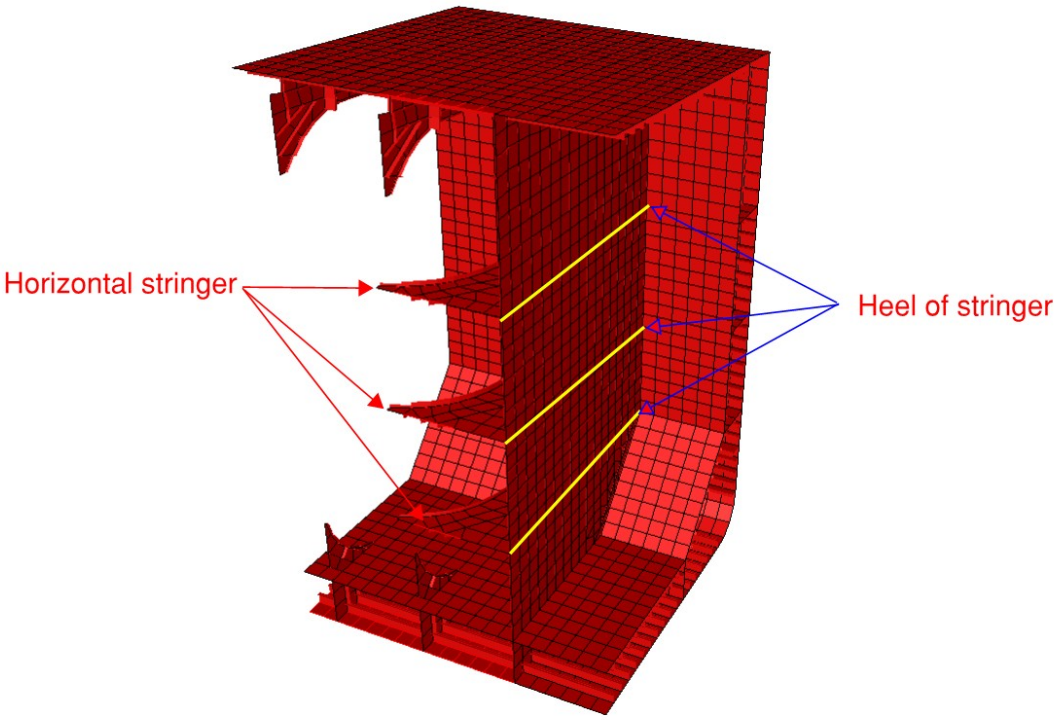
2.1.7 Bracket at the heel of horizontal stringer

The bracket at the heel of horizontal stringers in way of transverse bulkheads, if cannot be modelled properly in the cargo hold FE model due to the size of bracket, i.e. 600 mm - 800 mm, is to be assessed by direct fine mesh analysis as shown in Figure 1, to take into account the different shape and size of these brackets. If the size of bracket is able to be reflected in cargo hold FE model with suitable number of element along the edge of bracket then, the screening requirements in Pt 1, Ch 7, Sec 3, table 6 may be applied.

The recommended brackets are defined in Pt.1 Ch.9 Sec.6 Table 9 "Design standard I-transverse bulkhead horizontal stringer heel".

Figure 1





3 SCREENING PROCEDURE

3.1 Screening areas

3.1.1

Technical background is not considered necessary.

3.2 List of structural details

3.2.1 Cargo hold region

Screening criteria apply to the areas where the stress grads is higher but not to areas under uniform stresses where no stress concentration exists. The screening procedure applies to structural details including openings, bracket toes and heels of primary support members. The screening criteria is used to predict whether the stress may exceed the permissible stress. Fine mesh analysis is not required for structural details that comply with the screening criteria.

Fine mesh finite element analysis is to be carried out if the structural details under assessment do not comply with the screening criteria. The compliance with these criteria is to be verified for all finite element load cases.

It is to be noted that the screening formulae given are intended to provide a conservative estimation of the localised stress in way of the structural details, based on the stresses obtained from the cargo tank FE analysis, for the purpose of identifying the necessity for carrying out a further fine mesh analysis. These formulae will not necessarily give accurate prediction of the stress level.

The screening criteria were developed based on correlation studies of the stresses obtained from the 'coarse mesh' cargo tank FE analysis and the fine mesh FE analysis. Unless the requirements specified in [3.2.2] of the Rules for the construction of the cargo hold finite element model are followed, any screening assessment carried out is not valid.

a) As there are many openings in the web of primary support members, except the large opennings which is mandatory as defined in [3.2], a further screening procedure is introduced to identify openings in non-critical areas that need not be checked (using the screening formula or fine mesh analysis). The deciding criterion is based on the size of the opening and its location.

The screening verification can be performed for the one represented detail of the group with the maximum yield utilisation factor and the results to this represented detail by the screening verification can be applied to all the details in the considered group. Each structural detail in the group inside the cargo region shall have same geometry and same relative locations to those of one represented detail.

In each group, structural details shall have same geometrical properties as listed below:

- The shape and the size of openings.
- The arrangement of the edge stiffeners in way of openings.
- The plate thickness and its geometrical shape.
- The arrangement of the stiffeners in way of the structural details' area to be evaluated by screening.

- The geometrical shape of the flange in way of bracket toes in deck transverses, vertical web frames on longitudinal bulkhead and horizontal stringers on transverse bulkhead.

If the geometry and the relative locations of a structural detail is different from the group in the consideration, this structural detail shall not be categorised as the same group of structural details. Therefore, the screening verification for this structural detail should be performed separately.

3.2.2 Outside midship cargo hold region

The screening procedure as described in Ch 7, Sec 3, [3.2.2] is applied to the structural detail which is located outside midship cargo hold region and corresponding to a similar detail in midship cargo hold region.

The fine mesh result for the 'similar detail' in midship cargo hold region can be a reference when verifying the connection of corrugation to adjoining structure and the bracket at the heel of horizontal stringers outside midship cargo hold region.

a) If for a specific structural detail outside midship cargo hold region, there is no similar corresponding detail in midship cargo hold region which has been verified by the fine mesh analysis, a separate fine mesh analysis can be performed for the one represented detail of the group with the maximum yield utilisation factor and the results to this represented detail by the separate fine mesh analysis can be applied to all the details in the considered group. Each structural detail in the group outside midship cargo hold region shall have same geometry and same relative locations to those of one represented detail.

b) If the geometry and the relative locations of a structural detail is different from the group in the consideration, this structural detail shall not be categorised as the same group of structural details. Therefore, a separate fine mesh analysis for this structural detail shall be performed.

3.3 Screening criteria

3.3.1 Screening factors and permissible screening factors

After coarse mesh analysis of ship structures, the presented results are the average stress on each of coarse element area. For those local positions where the stress gradient is changed sharply due to geometry complex, the real stress will much higher than the average stress on the area of coarse mesh. Then, the fine mesh analysis is necessary for those positions to investigate the real stress distribution.

By experience, some local structural positions where the stress is certainly high could be picked out. Therefore, the mandatory fine mesh analysis for these positions is necessary. The positions except mentioned in [2.1] is complex in geometry, should be screening by certain criteria to determine positions where the stress is most probable to exceed safety criteria and the fine mesh analysis should be carried for these positions only.

The numerical study of bulk carriers D1 and S1 by 50×50 fine mesh analysis indicates that stress of all elements at hatch corner of S1 ship and of most elements at hatch corner of D1 ship does not exceed permissible stress. That is because the stress at hatch corner is much released and reduced by corner’s parabola shape and locally strengthened deck plate,these detail of structural can't be presented in coarse mesh model. So that the CSR BC’s screening criteria for fine mesh analysis (95% of the coarse mesh allowable stress) is introduced for hatch corner screening, and the fatigue analysis should be carried out mandatory.

The object of screening is to predict such kind of joints or locations where the fine mesh stress exceeds the allowable stress:

$$\sigma_{fine\_mesh} \geq [\sigma_{fine\_mesh}] \qquad (1)$$

There must be a relationship between average stresses of coarse mesh element and of fine mesh element as:

$$\sigma_{fine\_mesh} = f_g \sigma_{coarse\_mesh} \qquad (2)$$

The ratio between allowable stresses for two kinds of mesh size has already been given by rules as:

$$f_s = \frac{\lfloor \sigma_{fine\_mesh} \rfloor}{\lfloor \sigma_{coarse\_mesh} \rfloor} = \begin{cases} 1.7 & element\_not\_adjacent\_to\_weld \\ 1.5 & element\_adjacent\_to\_weld \end{cases} \qquad (3)$$

Put Equation (2) and Equation (3) into Equation (1):

$$f_g . \sigma_{coarse\_mesh} \geq f_s . [\sigma_{coarse\_mesh}]$$

$$\sigma_{coarse\_mesh} \geq \frac{f_s}{f_g} [\sigma_{coarse\_mesh}]$$

That means factor $C = f_s / f_g$ is the screening criteria in the form of percentage of permissible stress as used in CSR BC (July 2010). While the f_s has been defined in rules, the key point is to define the coefficient of $f_g = \dfrac{\sigma_{fine\_mesh}}{\sigma_{coarse\_mesh}}$ for different interested joints.

For each typical joins, the average ratios of f_g is obtained for each structure plate, then the biggest ratio of f_g is obtained for the joint. This means every joint has one ratio for screening criteria analysis. We separated all joints to two kinds: mandatory area and screening area. Total average ratio of mandatory area and screening area is obtained. Considering the current coarse mesh criteria 1.0 λ_y, the Rules required fine mesh (50×50mm) criteria is 1.5 λ_y, the margin value of 75% is accepted for screening criteria. The results are presented as following table.

Table 1: Stress screening criteria analysis of D1 and S1

Ship type	D1		S1	
Area kind	Mandatory	Screening area	Mandatory	Screening area
f_g	2.77	1.96	2.43	2.04
f_s	1.5	1.5	1.5	1.5
screening criteria	54%	77%	62%	74%
Conclusion for screening areas	75%(average of 77% and 74%)			

Based on D1 and S1 ships, a correlation numerical analysis on a series of typical joints with $s \times s$ coarse mesh and 50mm×50mm fine mesh are carried out. For each joint the stress comparison is made and the factors f_g are gained for all loading cases. For each joints, only the f_g from the loading case which corresponding to maximum fine mesh stress is pick out. The final f_g is taken the average of maximum f_g for all joints and then the screening criteria is found as $C = 0.75[\sigma_{coarse\_mesh}]$.

It is reasonable to set the screening criteria $C = 0.75[\sigma_{coarse\_mesh}]$ tentative. The data of correlation analysis are not enough based on 2 ships only. The criteria may be modified when more data of correlation comes from more ships.

Table 5: The screening formula for openings in primary supporting structural members given in this table of the Rules is intended to predict the maximum stress at the corners of an opening in a web plate. The intention of each term in the formula is given below:

- The term $\left|\sigma_x + \sigma_y\right|$ in the formula is to account for the contribution from element axial stresses in both x direction and y direction.
- The term $\left(2 + \left(\frac{l_0}{2r}\right)^{0.74} + \left(\frac{h_0}{2r}\right)^{0.74}\right)\left|\tau_{xy}\right|$ in the formula is to account for the contribution from element shear stress.
- The term of C_h is to account for the effect of limited height of a web. For an opening in the web of main bracket or buttress, this effect is ignored and the value of C_h is set to 1.0.
- The coefficient of 0.85 is a factor derived from correlation of the stresses obtained from the 'coarse mesh' cargo tank FE analysis and fine mesh FE analysis.

Table 6: The screening formula for bracket toes of primary support members given in this table of the Rules is intended to predict the maximum stress at the bracket toe in way of the termination of the bracket flange. The intention of each term in the formula is given below:

- The term $\left(\frac{b_2}{b_1}\right)^{0.5}\left|\sigma_{vm}\right|$ in the formula is to account for the stress contribution from the plate element in way of bracket toe, where the ratio $\left(\frac{b_2}{b_1}\right)^{0.5}$ accounts for the effect of steepness (angle) of bracket toe.
- The term $\left(\frac{A_{bar-net50}}{b_1 t_{net50}}\right)^{0.5}\left|\sigma_{bar}\right|$ is to account for the stress contribution from the flange of the bracket, where the term $\left(\frac{A_{bar-net50}}{b_1 t_{net50}}\right)^{0.5}$ represents the effect of flange size.
- The term of C_a is a correction factor to account for the geometry of the bracket toe (i.e. toe angle and length), which is not included in the cargo tank FE model.
- The coefficients 0.75 and 0.55 to the above terms are derived from correlation of the stresses obtained from the 'coarse mesh' cargo tank FE analysis and fine mesh FE analysis.

Table 7: Localised stress at the heel of side horizontal girder and transverse bulkhead horizontal stringer was found to be proportional to the von Mises stress of the element in way of the heel in the cargo tank FE model (see screening formula given in [3.2.1], Table 3 of the Rules). A stress concentration factor of 3.0 was derived from correlation between stress result from cargo tank and fine mesh analysis.

Localised stress at the heel of longitudinal bulkhead horizontal stringer and transverse bulkhead horizontal stringer was found to be proportional to the longitudinal axial stress of the element in way of the heel in the cargo tank FE model (see screening formula given in this table of the Rules). A stress concentration factor of 5.2 was derived from correlation between result from cargo tank and fine mesh analysis.

3.3.2 Screening criteria

Technical Background is not considered necessary.

4 STRUCTURAL MODELLING

4.1 General

4.1.1

Technical background is not considered necessary.

4.2 Extend of model

4.2.1

To ensure the reliable boundary displacements from global model, the local fine mesh model should be cut along with main supporting members.

4.3 Mesh size

4.3.1

A maximum mesh size of 50×50mm is chosen on the basis that this mesh size is required for representing the actual geometry of structural details, such as toe of brackets and corner of openings. Local stress is sensitive to the localised geometry of the structure and actual modelling of the geometry is necessary to determine the stress level in different detailed design.

4.3.2

The extent of fine mesh zone shall be no less than 500mm, i.e. 10 elements in each direction. Smooth transition to coarse mesh zone is required to avoid abrupt change of stress distribution.

4.4 Elements

4.4.1

Edge stiffener of opening, i.e. flat bar stiffener welded directly to the edge of the opening, is to be modelled with plate elements. Web stiffener which is welded to the web plating but not directly to the edge of the opening can be modelled using line elements. If the web stiffener is located less than 50mm from the edge of the opening (i.e. less than the width of one element in the fine mesh zone of mesh size 50×50mm) then it can be represented by line elements along the nearest plate element’s boundary inboard of the opening edge. These line elements are not to be located on the edge of the opening.

4.4.2

Technical Background is not considered necessary.

4.4.3

For openings, the minimum extent of the fine mesh zone is to be taken at least 100mm (two layers of elements) from the opening edge. Area within the fine mesh zone is assumed to be corroded half of the minimum allowance thickness.

4.4.4

Technical background is not considered necessary.

4.5 Transverse web frames

4.5.1

Technical Background is not considered necessary.

4.5.2

Technical background is not considered necessary.

4.5.3

Technical background is not considered necessary.

4.6 Transverse bulkhead stringers, buttress and adjacent web frame

4.6.1

Technical background is not considered necessary.

4.6.2

Technical background is not considered necessary.

4.6.3

Technical background is not considered necessary.

4.6.4

Technical background is not considered necessary.

4.7 Deck, double bottom longitudinal and adjoining transverse bulkhead vertical stiffeners

4.7.1

Technical Background is not considered necessary.

4.7.2

Technical Background is not considered necessary.

4.7.3

Technical Background is not considered necessary.

4.7.4

Technical background is not considered necessary.

4.8 Corrugated bulkheads

4.8.1
Technical background is not considered necessary.

4.8.2
Technical Background is not considered necessary.

4.8.3
Technical Background is not considered necessary.

4.8.4
Technical Background is not considered necessary.

4.8.5
Technical Background is not considered necessary.

4.8.6
Technical Background is not considered necessary.

4.8.7
Technical Background is not considered necessary.

4.9 Hatch corner structures

4.9.1
Technical background is not considered necessary.

4.9.2
Technical background is not considered necessary.

5 FE LOAD COMBINATIONS

5.1 General

5.1.1
Technical background is not considered necessary.

5.2 Application of loads and boundary conditions

5.2.1 General
The most common method used is to apply the nodal displacements as prescribed boundary condition to the sub-model. Where the sub-model has additional grid points between the common nodal points, multi-point constraint equations can be used to define the displacements at the additional grid points. Linear multi-point constraint equation is considered to be sufficient.

It is to be noted that multi-point constraint equations can appear in different forms in different finite element software. However, as long as the displacements at the nodes on the primary support members (such as girders and floors) are defined, the exact choice of multi-point constraint equations should not have significant effect on the stresses at the area of interest, which should be located at adequate distance from the boundary of the model.

Where nodal forces are applied, it is common to hold the model at certain point(s) on its boundary to prevent rigid body motion. As the system is itself in equilibrium, the net force at the fixed point(s) should be negligibly small. In practice, prescribed nodal displacements will usually be applied, as most finite element software caters for this method.

6 ANALYSIS CRITERIA

6.1 Strength assessment

6.1.1 General

Steel is ductile. Through ductility, structural steel is able to absorb extensive local yielding without the danger of structural failure. Yielding commonly occurs in steel structures even before the intended service loads are applied. For hull structures which are complex in geometry as well as in connection details, local yielding is actually inevitable.

Yielding can occur during fabrication and erection. For instance, welding often produces over-yield residual stresses in the heated zone, especially in the joint connections. Yielding is also possible when structural members are fitted into positions and formed into desired shapes. In most cases, the yielding is highly localised, and that will be surrounded by lower stress regions causing load re-distributions, and as a result, constitutes no consequence to the integrity of the structure.

6.1.2 Reference stress

The reference stress is defined in Ch 7, Sec 2, [5.2.1] of TB.

6.1.3 Permissible stress

As the acceptance criteria are set against a given mesh size, these criteria should not be used in conjunction with stresses obtained from a model with mesh size larger than that is intended as this will lead to non-conservative scantling requirement. For models with a mesh size smaller than that intended, an average scheme can be used to calculate the equivalent stress over a patch size of 50×50mm.

Average stress calculated over an area equivalent to the mesh size of the cargo tank finite element model is not to exceed the allowable stress required by the cargo tank finite element analysis (i.e. below yield) to retain the consistency between fine mesh analysis and cargo tank analysis. The average stress is calculated based on weighted average of Von Mises stress and area of elements within the equivalent area.

6.2 Acceptance Criteria

6.2.1

It is noted that in order to account for the redistribution of localised stresses as mentioned in [6.1.1] above, ASME pressure vessel codes allow membrane stresses in the shell to go up to yield strength, and for membrane plus bending, the allowable is 1.5 times yield. If local bending is present due to a structural discontinuity, the allowable is two times yield. For ship structures, there is no reason why very localised yielding, which occurs commonly during construction, should then be prohibited during their service life.

It is well known that calculated stresses in linear finite element analysis can continue to increase beyond yield as the mesh size decreases, particularly in way of structural connections or discontinuities. It is important to note that all stresses that exceed the yield point are direct results of linear finite element analysis based on a linear stress-strain relationship. In reality, a stress in steel can only go slightly beyond the yield stress, and a stress of "1.5 or 2 times yield" does not exist physically. In other words, without resorting to non-linear analysis for more accurate structural behaviour beyond yield, an over-yield stress should really be evaluated in conjunction with the corresponding stress in the area in question, with a view of load actions and not solely based on the magnitude of the over-yield stress itself. Calibration of the load model, the structural model and the acceptance criteria against service experience is therefore essential in the setting of the acceptance criteria.

The Rules adopted an approach commonly used by shipbuilding industries in which the localised area acceptance stress criteria (For static and dynamic load cases; 1.7 times yield in general and 1.5 times yield for element adjacent to a weld. For static load cases; 1.36 times yield in general and 1.2 times yield for element adjacent to a weld.) are set against a standard mesh size (50×50mm) to obtain a standard of the scantling requirement. The acceptance stress criteria are calibrated against the applied load model using existing service experience of design details to ensure the set standard is not lower (and in many cases higher) than that currently required.

Furthermore, it is noted that the over-yield stresses by linear finite element analysis at the structural details where they are obvious that no fatigue problems exist will be surrounded by lower stress region causing load redistribution, and as a result, constitutes no consequences to the integrity of the structure. Therefore, from the yield strength point of view, 20% lift-up of the localised area acceptance criteria with calibration of load and structural models and with the consideration of service experiences can be limitedly given to the design details fully compliant with the requirements in very fine mesh analyses as specified in Ch 9, Sec 2.

The yield strength check with fine mesh analyses i.w.o base material at free edge of plating should not take into account fatigue factor "f_f =1.2" since the redistribution of over-yield localised stresses to the neighbouring structures cannot be the same as the one in the welded cruciform joints, e.g. hopper knuckle. It is therefore to be noted that this fatigue factor "f_f=1.2" is relevant only for fine mesh yielding analysis with 50x50 mm mesh size but typical openings, i.e., manholes in way of primary members are not included in mandatory locations for fine mesh analysis.

As the acceptance criteria are set against a given mesh size, these criteria should not be used in conjunction with stresses obtained from a model with mesh size larger than that is intended as this will lead to non-conservative scantling requirement. For models with a mesh size smaller than that intended, an average scheme can be used to calculate the equivalent stress over a patch size of 50×50mm.

6.2.2 Lower stool not fitted to a transverse or longitudinal corrugated bulkhead

Technical background is not considered necessary.

PART 1 CHAPTER 8

BUCKLING

Table of Contents

1 INTRODUCTION

1.1 Assumption

1.1.1

It gives the scope of failure modes and elements regarding buckling strength criteria in this chapter:

- The failure modes (elastic overall and local buckling, and ultimate limit state).
- The types of members (local supporting members, primary supporting members).
- Other structures (pillars, corrugated bulkheads and brackets).

And states the requirements/criteria in this chapter are to be applied for design verification of scantling requirements for Ch 6 and FE buckling check for Ch 7.

1.1.2

This criterion is basic principle for structural buckling design.

1.1.3

It states the net scantling approach is applied in bucking requirements and all requirements / parameters related to overall strength PSM, shear area, section modulus and moment of inertia are to be calculated based on the gross offered thickness minus 50% of the corrosion margin, t_c considering the average corrosion. See also Ch 3, Sec 2, [1.1.2]. For other few scantlings required n50 in the slenderness requirements, e.g. net cross sectional area of flange for tripping brackets, might be based on the past engineering practice for the rule scantling requirements.

1.1.4

It states the sign specification of compressive and tensile stresses applied for the buckling requirements in this chapter.

2 APPLICATION

2.1 Scope

2.1.1

It gives the applications of buckling checks for Sec 2 to Sec 5, e.g. which section can be applied to a certain type of the structural element.

2.1.2 Stiffener

For the stiffened panel, the stiffener buckling requirements in this chapter apply to the stiffener fitted along the longer edge of its buckling panel in order to check this configuration. For other stiffeners such as carling or secondary beam the buckling check, if needed, can be performed using the column-beam mode described in Sec 5 of this chapter but the applied loads and boundary condition etc. should be case by case considered.

2.1.3 Enlarged stiffener

Stiffeners that are not used for PMA and whose web heights are close to 700 mm in large vessels are assessed as ordinary stiffeners, hence, special consideration as enlarged stiffeners is given to PMA stiffeners whose net web height are above 700 mm and net offered section modulus are 3 times greater than the smaller one of adjacent surrounding stiffeners. Platform structure installed independently on transverse bulkheads only for PMA is not considered as primary structural members, and this structure is assessed in accordance with relevant requirements if applicable.

Buckling strength of enlarged stiffeners (with or without web stiffening) used for Permanent Means of Access (PMA) is controlled by,

(a) the slenderness requirements for Primary Supporting Members (PSM),
(b) the prescriptive buckling requirements, and
(c) FE buckling requirements specified in Sec 4 respectively with different requirements to enlarged stiffener web and enlarged stiffener/flange, i.e. plate or stiffener buckling.

Buckling strength of longitudinal PMA platforms without web stiffeners may also be ensured using the criteria for Local Supporting Member (LSM), provided shear buckling strength of web is verified in line with plate buckling.

3 DEFINITIONS

3.1 General

3.1.1 Buckling definition

It gives the explanation/definition of "buckling" generic term. Also the concept of ultimate strength is introduced to be applied for the buckling capacity by taking into account the load redistribution.

3.1.2 Buckling capacity

It gives the basic principle of buckling capacity and the basic principle of its calculation method, which utilises the positive elastic post-buckling effect for plates and accounts for load redistribution between the structural components.

3.1.3 Assessment methods

It gives the definition of two methods in this chapter depending on different types of boundary condition, i.e. Method A and Method B. The relationship among ultimate strength Method A (= M1), Method B (= M3) and elastic buckling (= M2) are shown in the Figure 1.

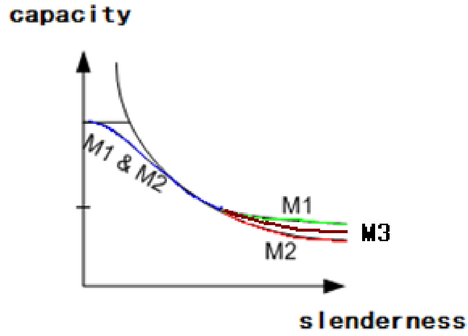
The boundary condition of Method A is that all the edges are forced to remain straight (but free to move in-plane) due to surrounding structure/neighbouring plates. Under this boundary condition, Method A can be regarded as taking the load redistribution and can considered as the ultimate strength.

The boundary condition of Method B is that of long edges of the plate panel (parallel to the stiffeners) is not forced to remain straight (or, called as "free to pull-in") since there is no surrounding structure to restrain the long edges in the in-plane direction. This is somewhat more conservative compare to Method A depending on plate slenderness.

The application of Method A and Method B are defined in Sec 4, while for prescriptive buckling requirements in Sec 3, only Method A is applied. The difference approach of Method A and Method B is by using different *c* value in Case 2 of Sec 5, Table 2.

More details can be seen in the "TB Rep_Pt1_Ch08_Sec04_In-plane Constraint Study".

Figure 1: The relationship concerning capacity among ultimate strength (Method A), Method B and elastic buckling



M1: Ultimate capacity, i.e. Method A
M2: Elastic buckling

M3: Method B, low in-plane stiffness at the edge

3.2 Buckling utilisation factor

3.2.1

It gives the definition of the utilisation factor, η.

3.2.2

It gives the calculation formulae/method for the utilisation factor. The Figure 1 in this Rules show the relationship between the applied loads and buckling strength/ultimate capacity.

The physical meaning of utilisation factor (the ratio of utilised factor) is different from the usage factor; the latter is calculated directly from the interactive equation although the two of them are similar when they close to 1.0.

The value of γ_c is obtained by iteration in the different formulae in Sec 5, not the simple linear relationship. The concept of the γ_c is mentioned here.

3.3 Allowable buckling utilisation factor

3.3.1 General structural elements

Table 1 gives the allowable buckling utilisation factor for each structural component corresponding to different utilisation factors for “S+D” and “S” load combinations as well as for corrugated bulkheads. The possibility of occurrence can be used for simple explanation for different utilization factors, i.e. for “S+D” load combinations, the utilisation factor can be taken as 1.00, while for “S”, just 0.80, this is reasonable for less occurrence, take the more relax requirements (higher utilisation factor).

The values are based on CSR OT (July 2010) and have been used for many years. Also, the allowable buckling utilisation factor is consistence with the yielding usage factors; see also TB of Ch 7, Sec 7 for reference.

3.4 Buckling acceptance criteria

3.4.1

It gives the definition of buckling acceptance criteria.

1 STRUCTURAL ELEMENTS

1.1 General

1.1.1

It states all structural elements, except for the items listed below, should comply with the slenderness and proportion requirements given in this section:

- Bilge plates within the cylindrical part of the ships and radius gunwale;
- Corrugation;
- Structure members in superstructures and deck houses, if the structural members do not contribute to the longitudinal strength.

The requirements for the minimum proportions of local and primary support members are based on elastic buckling capacity of plate panels, with an aspect ratio (long edge/short edge) not less than one, given by:

$$\sigma_E = 0.9 C_\sigma E \left(\frac{t_p}{1000 l_a}\right)^2 \qquad \text{N/mm}^2$$

$$\tau_E = 0.9 C_\tau E \left(\frac{t_p}{1000 l_a}\right)^2 \qquad \text{N/mm}^2$$

where,

$0.9 = \pi^2/[12(1-\nu^2)]$
$\nu = 0.3$

The buckling coefficient is calculated for the critical buckling mode for each structural member and is calibrated at the lower limit of slenderness area "A" and the upper limit of slenderness area "C". The Johnson-Ostenfeld correction is used to calculate the critical buckling capacity from the elastic buckling capacity making allowance for the plasticity effects.

The requirements are based on mild steel with a correction factor for higher material yield strength, an example showing the requirements for the breadth of flange outstands to flange thickness ratio is given below:

$$b_{f-out}/t_f = 12\sqrt{\frac{235}{R_{eH}}} \quad \Rightarrow \quad t_f = \frac{b_{f-out}}{12}\sqrt{\frac{R_{eH}}{235}} \qquad \text{mm}$$

The requirements for the minimum thickness of the plate, web and flange are derived from slenderness requirements of the corresponding structural parts. These slenderness requirements are measurements for the relative difference between the elastic buckling capacity and material yield strength. This is similar to the definition of the slenderness ratio $\lambda = (R_{eH}/\sigma_{EL})^{0.5}$. Then, the slenderness ratios increase if the material yield strength increases. Consequently, thicker plates are required if materials with a high tensile strength is used.

However, the rule allows using minimum yield stress of mild steel if the plates are checked with prescriptive and FE buckling formulae. The details are:

(a) For plates and web plates assessed in accordance with Ch 8, Sec 3 (prescriptive longitudinal material) and Ch 8, Sec 4 (FEM) using 235MPa also the slenderness criteria in Ch 8, Sec 2 can be calculated based on 235MPa. This will typically cover all plates and web plates in cargo area (both prescriptive and FEM) as well as longitudinal material (plates) outside cargo area (only prescriptive).

(b) For members not assessed in accordance with Ch 8, Sec 3 (prescriptive longitudinal material) and Ch 8, Sec 4 (FEM), this relaxation is not relevant, e.g. primary supporting members, transverse bulkheads and other plates not taking part in hull girder bending outside cargo area, where the only buckling scope is the slenderness criteria.

The slenderness requirements in this section including minimum thickness, proportion of thickness/width ratio limit, stiffness, structural flexural and/or rotational rigidity and minimum bending moment of inertia requirements can also be as the function that is to avoid excessive deformation of hull girder and structural members because based on the elastic buckling theory, the excessive deformation is not allowed.

In addition, densely stiffened panel structures with prescribed stiffener spacing generally ensure good vibration behaviour of a local plate panel, a stiffened panel or a grillage. Thus, it can be easily understood that the vibration which may damage or impair the ship structure, equipment or machinery can be limited or controlled based on the slenderness requirements.

The slenderness criteria is considered not applicable to corrugations for the following reasons:

- As specified in the table 1 of [2.1.1], the factor C=100 for plate panels is actually calibrated for general stiffened plate panels on hull structures and is not specifically applicable to corrugation usually with much bigger panel length and width.
- Due to the actual complex stress distribution within the big size face/web plate panel of a corrugation, a specific buckling check scheme is provided in the rule (Ch8, Sec4) to check all possible buckling modes including both local buckling due to dominant normal/shear stress or combined stresses and global column buckling of a corrugation unit. Therefore, buckling capacity of corrugations is well covered by FE analysis in the rule.

The structure members in superstructures and deckhouses are generally not located in midship cargo hold / tank region, hence don’t contribute to longitudinal strength. Accordingly, criticality is low comparing with cargo region and very low level of compressive loads are expected. However, if any structural members do contribute to the longitudinal strength then the slenderness requirement is still to be applied.

2 PLATES

2.1 Net thickness of plate panels

2.1.1

The requirement for the minimum proportions of plate panels between the stiffeners / longitudinals is a maximum slenderness ratio and is calibrated based on current practice with adjustments for the net thickness approach and using the upper limit of slenderness area “C”. The proportional requirements are developed based on the assumptions shown in Table 1. For consistency, $b_{f\text{-}out}$ is in net scantling.

Table 1: Proportions for plates and stiffeners, normal strength steel, R_{eH}=235N/mm²

Comparison based on the assumption of axial compressive stresses							
Requirement	F	σ_{EL}	K	λ	σ_{cr}	η	Required slenderness coefficient, C
s/t (1)	4.00	74	0.32	1.78	74	0.32	100
s/t (2)	4.00	48	0.20	2.22	48	0.20	125
d_w/t_w: L and T	4.00	132	0.56	1.33	131	0.56	75
d_w/t_w: Bulb (3)	1.25	115	0.49	1.43	115	0.49	45
d_w/t_w: FB	0.43	165	0.70	1.19	152	0.64	22
$b_{f\text{-}out}/t_f$	0.43	556	2.37	0.65	210	0.89	12

where,

F Buckling edge constraint factor

σ_{EL} Elastic buckling stress, in N/mm²

K Ratio between elastic buckling stress and yield stress, $K = \sigma_{EL}/R_{eH}$

λ Slenderness ratio $\lambda = (R_{eH}/\sigma_{EL})^{0.5}$

σ_{cr} Critical buckling stress (Johnson-Ostenfeld correction), in N/mm²

η Utilisation factor relative to yield, $\eta = \sigma_{cr}/ R_{eH}$

Notes:
1) Hull envelope and tank/hold boundaries.
2) Higher for slenderness for structures such as non-watertight bulkheads, platforms and internal decks in machinery area, accommodations, etc.
3) The values are based on and edge constraint factor of 1.25 according to CSR OT (Corr. 2).

The relationship between the coefficients in Table 1 for the face plate is shown in detail below:

$$\sigma_E = F \quad \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_f}{b_{f-out}}\right)^2 \ \mathrm{N/mm^2}$$

$$\sigma_E = \quad \geq K R_{eH}\,\mathrm{N/mm^2}$$

hence

$$\frac{b_{f-out}}{t_f} \leq \sqrt{\frac{F}{K}\frac{\pi^2}{12(1-\nu^2)}} \cdot \sqrt{\frac{E}{R_{eH}}}$$

$$\leq 0.4\sqrt{\frac{E}{R_{eH}}}$$

$$t_f = \frac{b_{f-out}}{12}\sqrt{\frac{R_{eH}}{235}}\mathrm{m\ \ m}$$

where,

F : 0.43, $F = 0.425+(s/l)2 \approx 0.43$ for plate that simply supported at 3 sides, and 1 edge free side without loads.

K : 2.36

In the Table 1, the required slenderness coefficients *C* is mainly based on experience both from the CSR rules and other explicit design codes such as DNV-RP-C202 (Buckling strength of shells, January 2013). The slenderness requirement for the plate, flatbars, T and L-bars, is the same coefficient as in CSR OT (July 2010). The slenderness coefficient *C* for bulbs is tuned using PULS in order to have the same safety level as for flatbar, i.e. the same strength relative to the yield strength. This value is increased from 41 to 45 as compared the CSR OT (July 2010).

In order to prevent buckling of the face plate, the same requirement as in DNV-RP-C202 (January 2013) is used:

$$t_f = 0.4\sqrt{\frac{E}{R_{eH}}} = \frac{b_{f-out}}{12}\sqrt{\frac{R_{eH}}{235}}$$

3 STIFFENERS

3.1 Proportions of stiffeners

3.1.1 Net thickness of all stiffener types

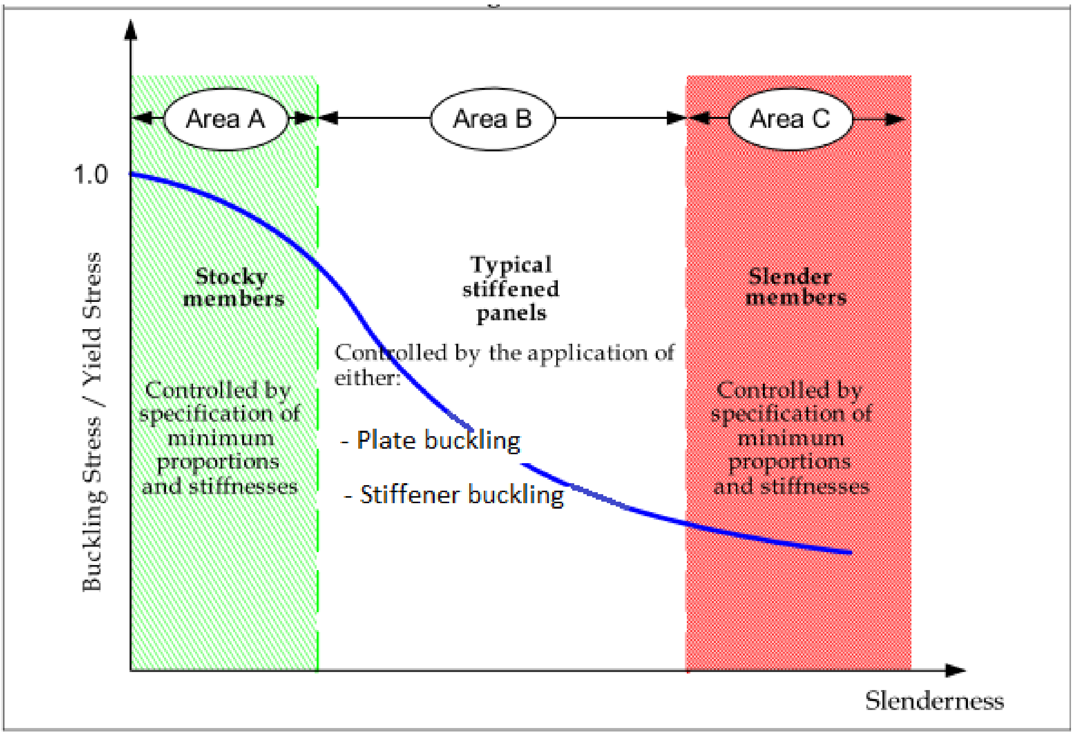
The requirement for the minimum proportions of web plate is a maximum slenderness ratio and is calibrated based on current practice with adjustments for the net thickness approach and using the upper limit of slenderness area “C” in the Figure 1 below.

The requirement for face plate and flanges is specified such that torsional buckling of the flange is inhibited; noting that torsional buckling of the flange is not covered by other buckling criteria. The requirement is calibrated to give stocky proportions of the face plates, based on existing practice with adjustments for the net thickness approach and using the lower limit of slenderness area “A” in the Figure 1 below. The proportional requirements are developed based on the assumptions shown in Table 1.

Rule has been further updated to allow the use of stiffeners not complying with the slenderness criteria for flange. In such case, the effective free flange outstand to be used for strength assessment is provided. For more details refer to Ch 8 of TB for RCN 1 to CSR 01 Jan 2022.

Rule has also been updated for the case of very short stiffeners complying with the yielding criteria without considering their flange (or edge flat bar). In such case, web and flange can be considered separately, and the flange can be assessed using $C_w = 22$ instead of $C_f = 12$.

Figure 1: Critical buckling stress and slenderness



3.1.2 Net dimensions of angle and T-bars

This regulation is taken from CSR OT (July 2010) and is included to prevent torsional instability of angle and T profiles.

3.1.3 Bending stiffness of stiffener

The purpose of the inertia stiffness requirement for stiffeners is to prevent lateral instability and is based on the Euler buckling formula for a simply supported stiffener. The required inertia stiffness is higher for longitudinals subject to hull girder stresses than for other stiffeners. The criteria will effectively limit the use of flat bars for the deck longitudinals.

$$\sigma_E = \frac{10^{-4}\pi^2 EI_{net}}{l^2 A_{eff}} \quad N/mm^2$$

$$\sigma_E \geq K R_{eH}$$

hence

$$I_{net} = C l^2 A_{eff} \frac{R_{eH}}{235} \ cm^4$$

The inertia stiffness requirement has been based calibrated based on current practice with adjustments for the net thickness approach to give a slenderness coefficient *C* of:

- 1.43. Based on *K*=1.24 for stiffeners subjected to hull girder stresses, which represents a slenderness ratio of λ=0.90. This factor should be used for all longitudinal stiffeners, both continuous and sniped stiffeners. The reason for using the same factor for sniped stiffeners is because stresses will be distributed from the plating to the stiffener due to shortening of the plate.
- 0.72. Based on *K*=0.61 for stiffeners not subject to hull girder stresses, which represents a slenderness ratio of λ=1.28.

In deriving the required inertia requirements, an effective breadth of attached plating not exceeding 80% of the total width for cross sectional area and moment of inertia is to be assumed for simplicity. Formulae for calculating the effective plate width are found in several buckling codes. However, adopting such approach was not considered necessary for this simplified approach.

The reference yield stress is to be taken for the attached plate. The purpose of the stiffener is to stabilise the plate, and the higher yield stress of the plate which allows higher compressive stresses in the panel should result in the higher moment of inertia to keep the panel in shape.

4 PRIMARY SUPPORTING MEMBERS

4.1 Proportions and stiffness

4.1.1 Proportions of web plate and flange

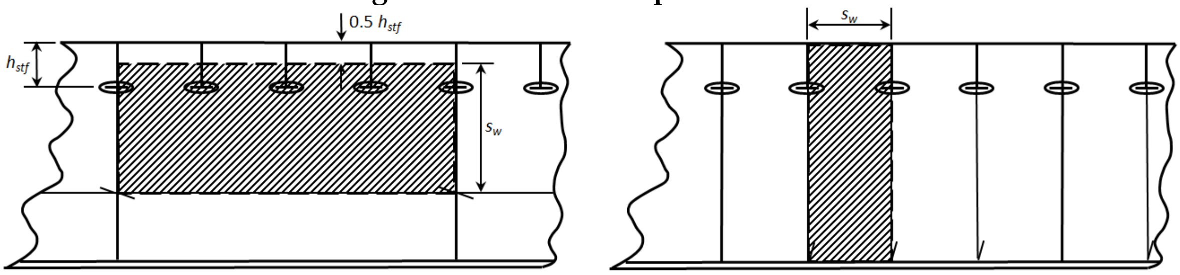
The requirements for the minimum proportions of PSM are based on the assumptions shown in Table 2. The web spacing to thickness ratio, s/t_w requirement is the same as for plate panels making up the hull envelope plating or tank/hold boundaries. The breadth of flange outstands to flange thickness ratio, $b_{f\text{-}out}/t_f$ for stiffeners is also used for the PSM face flat to ensure that the flange is stocky and hence supports the “free” edge of the PSM.

Table 2: Proportion to primary support members, mild steel, R_{eH}=235N/mm²

Requirement	F	σ_{EL}	K	λ	σ_{cr}	η	Required slenderness coefficient, C
web plate s/t_w	4.0	74	0.32	1.78	74	0.32	100
face flat $b_{f\text{-}out}/t_f$	0.43	554	2.36	0.65	210	0.89	12

The plate breadth, s_w, should be taken as shown in figure 2.

Figure 2: Definition of plate breadth



For web plate with stiffening parallel to the attached plate, the correction of plate breadth is applicable also for other slot configurations provided that the web or collar plate is attached to at least one side of the passing stiffener.

Rule has been further updated to allow the use of members not complying with the slenderness criteria for flange. In such case, the effective free flange outstand to be used for strength assessment is provided. For more details refer to Ch 8 of TB for RCN 1 to CSR 01 Jan 2022.

4.1.2 Deck transverse primary supporting members

This requirement applies to the deck transverse PSM. For other transverse PSM this criteria is not governing. The purpose of the overall stiffness criterion is to ensure that the transverse primary supporting members have sufficient stiffness to ensure that axially compressed longitudinals are effectively supported.

The criteria controls global lateral instability of the PSM and is based on S. P. Timonshenko and J. M. Gere "Theory of Elastic Stability" and calibrated with current practice. For bulk carriers, this requirement is applicable to deck transverse inside the top wing tank, but it is not applicable to the transverse hatch coaming.

4.2 Web stiffeners of primary supporting members

4.2.1 Proportions of web stiffeners

The purpose of these criteria is to prevent instability of web stiffeners. The criteria are based on Euler buckling equations and consider compressive stresses parallel and normal to the direction of the web stiffening. The criteria are calibrated such that the web stiffeners provide effective support for the web plate and hence the PSM.

4.2.2 Bending stiffness of web stiffeners

The criterion for web stiffeners parallel to compressive stresses as given in item (A) of Table 2 in the Rules is identical to local support members, see [3.1.3]. The buckling mode for web stiffeners normal to the compressive stress as given in item (B) in Table 2 in Rules is more complicated. The criterion is based on DNV, CN30.1 (Buckling strength analysis of bars and frames, and spherical shells, April 2004).

It is assumed that out of plane force in the web plate is related to the thickness of the web. Hence, the web stiffener inertia stiffness requirement to resist the out of plane forces increases proportionally to the web-thickness. This requirement has been calibrated to ensure that the web stiffener elastic buckling capability is higher that the elastic buckling capability of the web plate. In case of slender web plates, this criterion will also provide a higher elastic buckling capability in the web stiffener than the ultimate capacity of the web plate.

5 BRACKETS

5.1 Tripping brackets

5.1.1 Unsupported flange length

The purpose of this requirement is to prevent torsional buckling of primary support members. This is the only requirement covering the torsional buckling mode of PSM and hence the requirement is calibrated to ensure that the flanges are stocky.

The correction for web-area $A_{f\text{-}n50}/(A_{f\text{-}n50}+0.33A_{w\text{-}n50})$ will require a smaller distance between tripping brackets for primary support members with a large web depth to flange area ratio. The requirement is based on the torsional buckling strength criteria in Ch 8.5 of DNV-RP-C201 (Buckling strength of plated structures, October 2010). The slenderness coefficients provide a torsional buckling capacity σ_T as follows:

- For symmetrical flanges, C=0.022: $\sigma_T = 0{,}85R_{eH}$
- For one sided flanges, C=0.033: $\sigma_T = 0.96\ R_{eH}$

It has been the intention to keep one sided flanges more stocky than the symmetrical ones, due to the asymmetric bending behaviour of the members with one sided flanges. Tripping brackets need not be spaced closer than 3.0m on PSM supporting tank or external boundaries, i.e. subjected to tank pressures or sea pressures, based on ABS Rules and current practice.

Based on current experience, tripping brackets in other areas need not be spaced closer than 4.0m, e.g. in way of engine room and superstructure (excluding in way of tank boundaries and external boundaries). For such PSM, which usually have small flange area and moderate stress level, s_{bmin}= 4.0 has been considered to be sufficient. In addition the stiffening between tripping brackets will usually contribute with some tripping resistance for these primary support members.

5.1.2 Edge stiffening

Where the length of the edge of tripping brackets exceeds 75 times the net thickness, then the free edge is to be stiffened by a flange or edge stiffener. For a connection bracket this ratio is 50-55, however the stress level in the middle of a tripping brackets is lower than for end brackets, as end brackets will have maximum compression near the midpoint of the edge whereas tripping brackets act as a cantilever and hence the maximum compression is close to the support. Rules have a value of 60, based on gross scantlings. For a typical tripping bracket in a cargo tank, the gross thickness might be 12.5mm which corresponds to a net thickness of 12.5-2.5=10mm (20-25% corrosion allowance) and hence the coefficient for net scantlings becomes: 60×12.5/10 = 75.

5.2 End brackets

5.2.1 Proportions

The criteria are based on DNV Rules, Pt 3, Ch 1, Sec 3, C202 (January 2013). These Rules specify that the length of the free edge of brackets is not to exceed 50 times the thickness, calculated as gross thickness minus the corrosion addition specified in the Rules. In way of a ballast tanks, this corrosion addition is typically 1.5mm which is 50% of t_{corr} as defined in Ch 3, Sec 3.

Assuming 20% wastage allowance applied in the current Rules, this ratio to be 55 (10% increase from 50) for net scantlings as defined in CSR Rules (July 2010). Based on a standard end bracket having a base angle, α of 90 deg (see Figure 2) and with edge length/net thickness ratio of 55, a number of other bracket geometries with same buckling strength have been found, see [4.2.1].

The minimum thickness of end brackets satisfying the given buckling requirements is given. The buckling formulation is based on the following assumptions; see also TB of Table 3 and Figure 2:

- Limiting the depth to thickness ratio of end brackets without edge stiffening to ensure brackets are stocky i.e. in slenderness area "A".
- The triangular end bracket is idealised as a rectangular plate with short and long edge taken as 2/3 of the length of free edge and 2/3 of the depth of the bracket, respectively.
- The free edge of brackets without edge stiffening is allowed to move out of plane.
- The loading pattern is triangular.
- The thickness slenderness coefficient is applicable for a range off base angles ($50^{o}<\alpha<150^{o}$). Studies have confirmed this to be adequate.

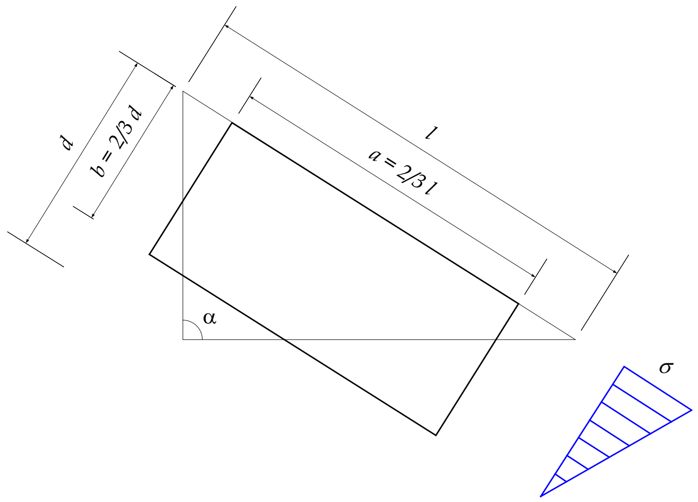
- End brackets with edge reinforcements are based on the same assumptions as for end brackets without edge reinforcement. The buckling coefficient for brackets with edge reinforcement assumes that the edge reinforcement is sufficiently stiff to prevent buckling of the bracket edge (simply supported edge).

Since this is a buckling requirement for brackets subjected to compression at edge, it is not relevant for brackets only subjected to tensile stresses, e.g. internal brackets in a tank surrounded by void spaces, and hence this buckling requirement is not applicable for these brackets. However, other requirements to bracketed connections will apply to such brackets, see Ch 3, Sec 6.

Table 3: Proportion to brackets, normal strength steel, R_{eH}=235N/mm²

Requirement	F	σ_{EL}	K	λ	σ_{cr}	η	Required slenderness coefficient, C
Without edge reinforcement	0.90	498	2.12	0.69	207	0.88	
With edge reinforcement	7.64	650	2.77	0.60	214	0.91	70
where, F : Buckling edge constraint factor based on the assumptions above (third bullet).							

Figure 2: Definition of brackets



5.3 Edge reinforcement

5.3.1 Edge reinforcements of bracket edges

The requirement for the minimum depth of end bracket edge stiffening is calibrated to give a stocky slenderness ratio, noting that the highest compressive stress occurring at the mid-span, and hence K is taken as 4, where K is the elastic buckling strength to yield strength ratio. This gives:

$$h_w \geq 2200\, l_{stf} \sqrt{\frac{R_{eH}}{E}} = 75\, l_{stf} \sqrt{\frac{R_{eH}}{235}}$$

The requirement for the minimum depth of edge stiffening of tripping brackets or openings takes into account the lower stress level at the mid-span of the edge stiffener and hence *K* is taken as 2, which gives:

$$h_w \geq 1560\, l_{stf} \sqrt{\frac{R_{eH}}{E}} = 50\, l_{stf} \sqrt{\frac{R_{eH}}{235}}$$

A minimum depth of 50mm for the edge stiffener is found reasonable and comparable with existing practice.

5.3.2 Proportions of edge stiffeners

Technical background is not considered necessary.

6 OTHER STRUCTURES

6.1 Pillars

6.1.1 Proportions of I-section pillars

For I-section pillars, the local buckling of the web and flanges of a pillar cross section are controlled by limiting the slenderness proportional requirements that of ordinary stiffeners as that defined in [3.1.1] and [3.1.2].

6.1.2 Proportions of box section pillars

For box-section pillars, the local buckling of the web and flanges of a pillar cross section are controlled by limiting the slenderness proportional requirements that of ordinary stiffeners as defined in item (a) of [3.1.1].

6.1.3 Proportions of circular section pillars

For circular-section pillars, the local buckling of the web and flanges of a pillar cross section are controlled by limiting the slenderness proportional requirements.

6.2 Edge reinforcements in way of openings

6.2.1 Depth of edge stiffener

The requirement for the moment of inertia of edge reinforcement stiffeners in way of openings or cut outs is based on the Euler buckling formula for a simply supported stiffener. It is assumed that only sectional properties of the edge reinforcement itself are used and that the edge reinforcement is a flat bar stiffener, excluding the effective web plate flange which is a conservative assumption.

$$\sigma_E = \frac{10^{-4} \pi^2 E}{l_{stf}^{\ 2}} i^2 \quad N/mm^2$$

$$\sigma_E \geq K R_{eH}$$

hence,

$$i \geq 100 \frac{\sqrt{K}}{\pi} l_{stf} \sqrt{\frac{R_{eH}}{E}} \qquad cm$$

the radius of gyration, *i* for an flatbar stiffener is:

$$i = \sqrt{\frac{I}{A}} = \frac{h_w}{20\sqrt{3}} \; cm$$

$$h_w \geq \frac{2000\sqrt{3K}}{\pi} l_{stf} \sqrt{\frac{R_{eH}}{E}} \quad mm$$

6.2.2 Proportion of edge stiffeners

It indicates that the proportional requirements of edge stiffeners are to comply with that of ordinary stiffeners specified in [3.1.1] and [3.1.2].

1 GENERAL

1.1 Scope

1.1.1

This section summarises the technical background of prescriptive buckling requirements for plates and stiffeners subjects to hull girder bending/compressive and shear stresses. In addition, the structural members such as corrugation mentioned in the rule, strut/pillar and cross tie subjected to compressive stresses are also being included.

1.1.2

It emphasises that hull girder buckling strength check should be preformed along the full length of the ship.

1.1.3 Design load sets

It introduces the design load sets for prescriptive buckling check. The load sets defined in Ch 6, Sec 2, both intact and in flooded should be considered. For all design dynamic load set, the lateral pressure should be considered according to the Ch 4 with the LCP defined in Ch 3, Sec 7. The above lateral pressure should be combined with the hull girder stresses given in [2.2].

It is to be noted that as required in [1.1.1], all plate panels and stiffeners are to be checked for the criteria given in [3] for the hull girder loads even if they are not loaded with lateral pressure. For example, the plate panels and stiffeners belonging to the longitudinal bulkhead of an oil tanker separating cargo tanks are to be checked with respect to buckling for the hull girder stresses corresponding to ballast conditions although those elements are not subject to lateral pressure in these loading conditions.

1.2 Equivalent plate panel

1.2.1

If the net thickness is not uniform within the width b, the equivalent width should be used. The study using non-linear finite element analysis has been performed to check the validity on the formula of equivalent plate panel. The results are shown based on the following plate with a change of net thickness over its width:

- b = 850 mm
- a = 2550 mm
- t_1 = 11.08 mm
- t_2 = 15.83 mm
- R_{eH} = 315 N/mm^2

Three figures attached are shown for axial, transverse and shear stresses. The blue data points show the plate reduction factors (i.e. C_x, C_y and C_{tau}) for a plate with a thickness change over the width (see the bottom x-axis for the ratio of thinner plate width to total plate width). The pink data points show the plate reduction factors (i.e. C_x, C_y and C_{tau}) for equivalent plate panels with a thickness of 11.08 mm (see the upper x-axis for the ratio of equivalent plate width to total plate width).

In the case of transverse and shear stresses, the plate reduction factors are always calculated using the stress in the thinner plate (the stress in the thicker plate is reduced out of necessity for force equilibrium). Furthermore, although a moment is introduced into the plating under transverse and shear stresses (i.e. since mid-plane thicknesses are not coplanar), this moment is not considered in the finite element analysis.

More analyses might be needed (e.g. other t_1/t_2, plate slenderness and aspect ratios).

Figure 1: Plate thickness change over width – Axial stress

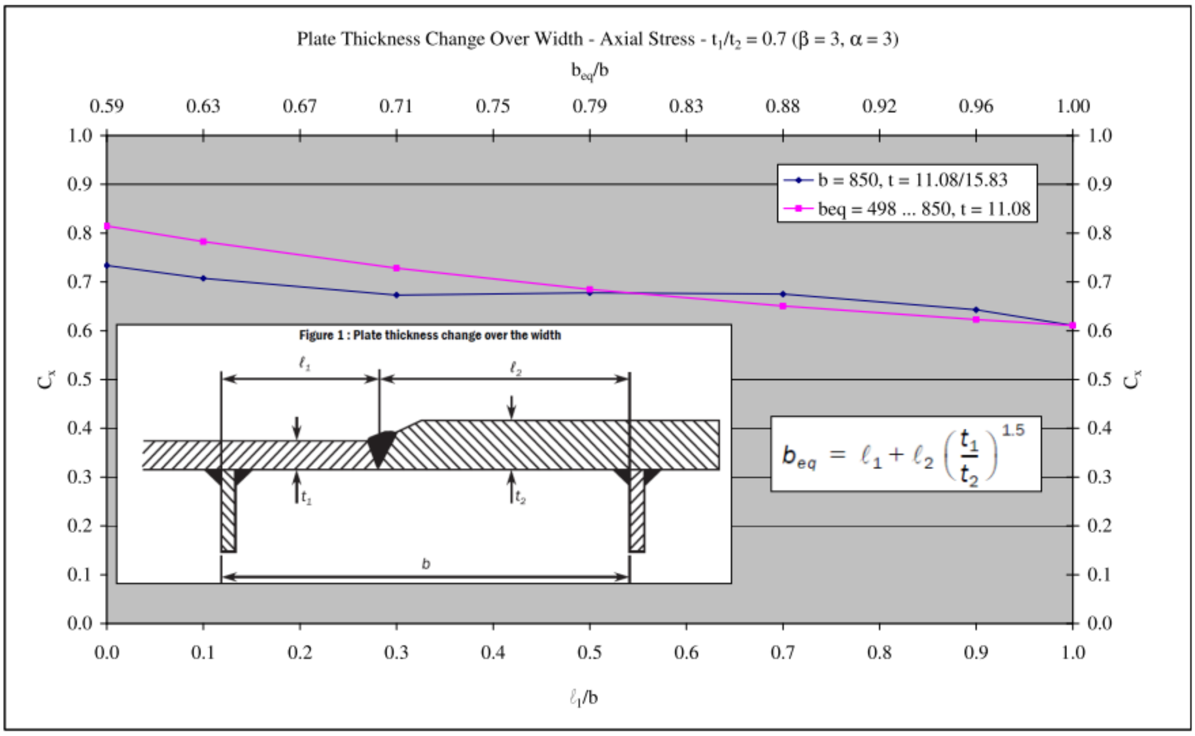


Figure 2: Plate thickness change over width – Transverse stress

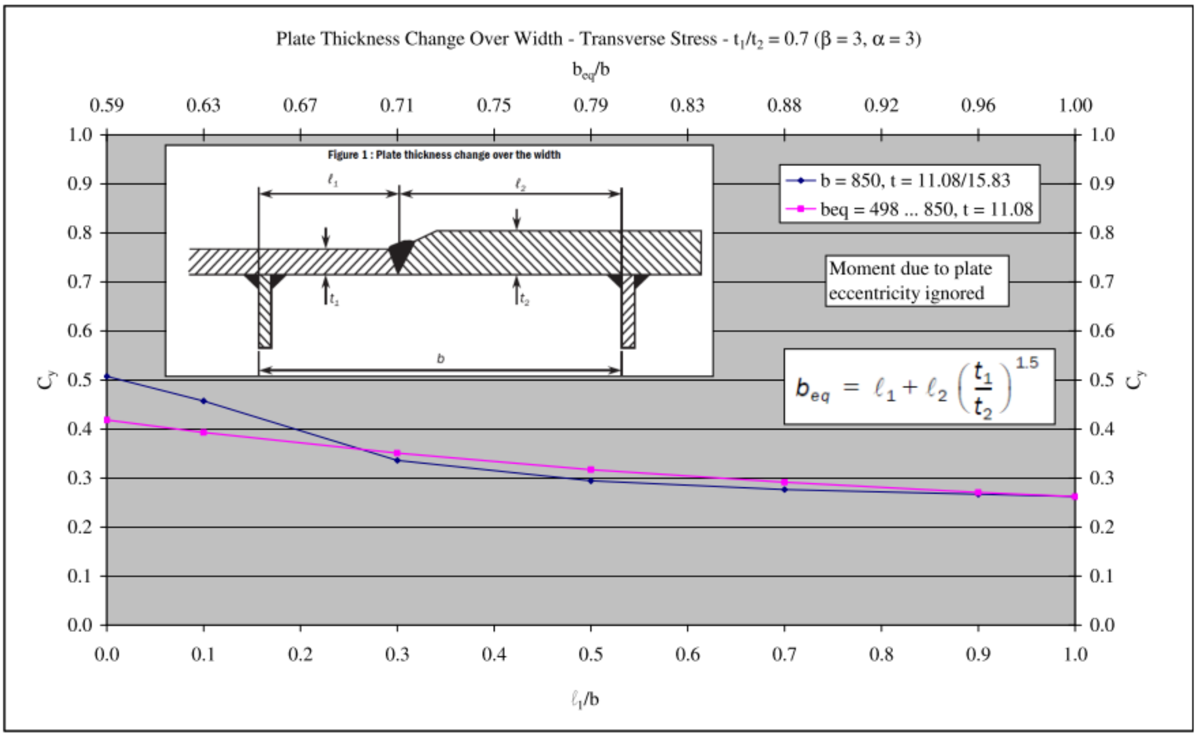
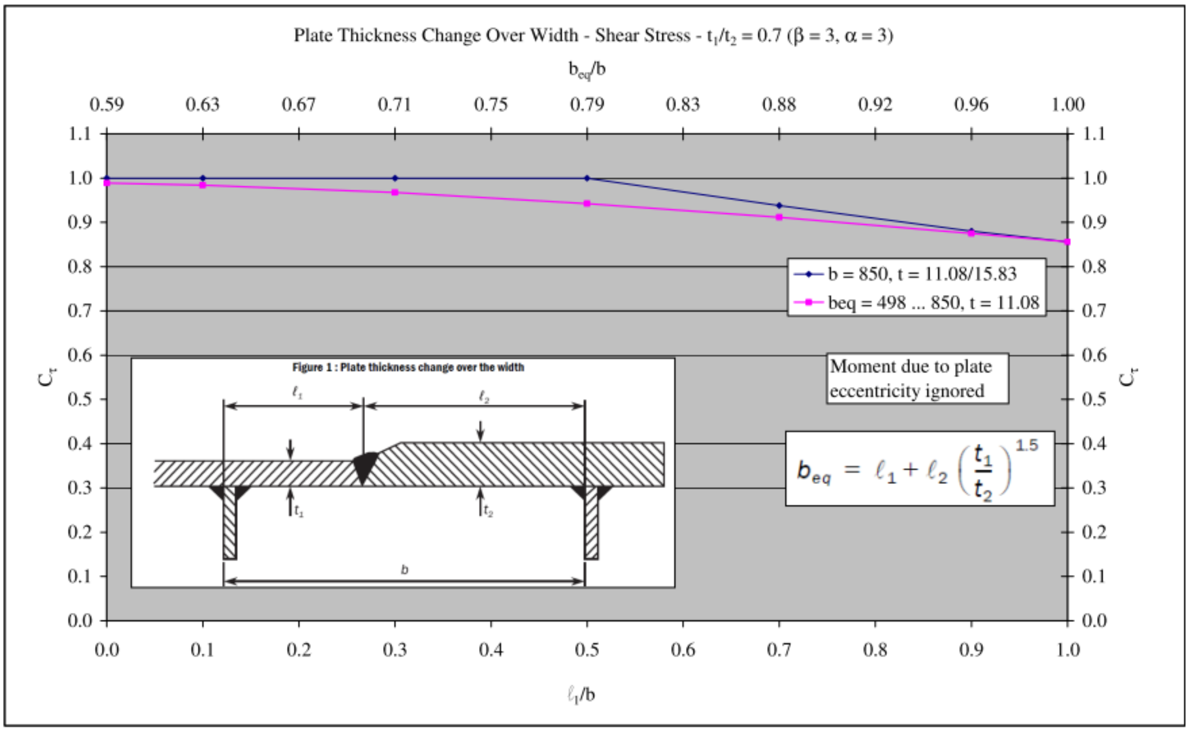


Figure 3: Plate thickness change over width – Shear stress



1.2.2

If the thickness is not uniform in transverse stiffening arrangement, each thickness should be used and this will be able to find out the minimum capacity of the EPP.

1.2.3 Material

This requirement clarifies how to consider the case of a buckling panel made of several materials. The minimum yield strength for different plate materials within the panel is to be used for carrying out the panel buckling check.

2 HULL GIRDER STRESS

2.1 General

2.1.1

The hull girder bending stresses used for buckling check are determined according to Ch 6, Sec 2 where shows the formula of σ_{hg}.

2.1.2

It gives the formula of hull girder stresses used for buckling check. For shear stress calculations, the corrected "n50" thickness as defined in Ch 5, Sec 1, [3.2.1] shall be used because the buckling capacity shall be based on the full net thickness (full t_c deduction) without applying any shear correction, as defined in Ch 5, Sec 1, [3.6].

2.2 Stress combinations

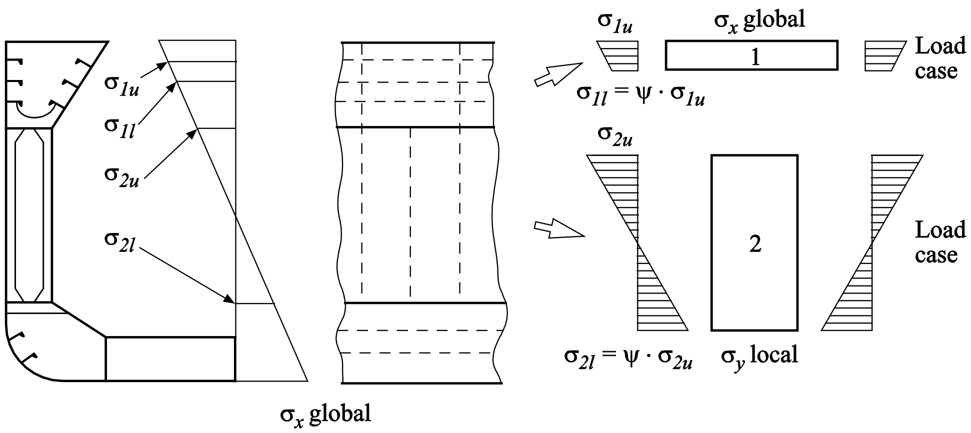
2.2.1

For plate buckling check, only the hull girder vertical bending stress and vertical shear stress are considered. Two combinations are considered taking into account the global bending of the hull and the maximum value of shear stress resulting from hull girder shear forces are not acting simultaneously (at the maximum values): one is with 100% of bending stress and 70% of shear stress; the other is with 70% of bending stress and 100% of shear stress. The combination ratio between normal and shear stress is based on society's long-term experience of the buckling assessment.

The following cases are to be used according to the type of stresses and framing system of the plating:

1. For the normal compressive stress:
   (a) For longitudinally framed plating: BLC1, the membrane stress in x-direction, σ_x being the normal stress, σ_{hg} defined in [2.1.1].
   (b) For transversely framed plating: BLC2, the membrane stress in y-direction, σ_y being the normal stress, σ_{hg} defined in [2.1.1].
2. For the shear stress:
   (a) BLC5, τ being the shear stress, τ_{hg} defined in [2.1.2].
   (b) BLC, Buckling Load Cases as defined in Ch 8, Sec 5, Table 2.

Figure 4: Idealisation of elementary plate panels



3 BUCKLING CRITERIA

3.1 Overall stiffened panel

3.1.1

It gives the criterion of overall stiffened panel which the maximum utilisation factor can be obtained as defined in Sec 5, [2.1].

3.2 Plates

3.2.1

It gives the criterion of plate elementary panel which the maximum utilisation factor can be obtained as defined in Sec5, [2.2]. For prescriptive requirements, only SP-A can be chosen to use.

This provision also applies to the vertically stiffened side shell plating (VSS plating) of single side bulk carriers, and the clamped short edge case for VSS plating in Ch 8, Sec 5, Table 2 should be used in the calculation is mentioned.

For transverse stress on VSS plating, since side shell plating are surrounded by the strong structures such as hopper tanks and topside tanks and the role of VSS plates is not so important for hull girder bending (see below), the average value is used, i.e. $0.5(\sigma_{y1} + \sigma_{y2})$ with $\psi_y = 1.0$ are used for plate buckling check.

A study has been done in order to assess the maximum impact on hull girder buckling by the removal of the stiffness in longitudinal direction of single side shell (P/S), only keeping the shear stiffness.

Based on this conservative assessment a maximum increase of buckling utilisation of 8% was found on side shell for the lower part in top side tank (top wing tank). Hence it may be concluded that that transverse buckling of SSS between top wing and hopper of BC have small impact on the overall hull girder buckling due to M_H and M_V. This shows that the single side between top side and hopper is not a critical element for hull girder buckling due to longitudinal stresses.

Accordingly, the new proposal of VSS plating is summarised as follows:

- Updated K_y for Case 2 and Case 9 in Ch 8, Sec 5, Table 2.
- Use clamped short edge, i.e. Case 9 in Ch 8, Sec 5, Table 2.
- Use F_{tran} = 1.15, as requested by Ch 8, Sec 5, [2.2.5].
- Use average stresses, i.e. $\Psi x = \Psi y = 1.0$, as requested by Ch 8, Sec 3, [3.2.1] for prescriptive buckling requirements and by Ch 8, Sec 4, [4.1.1] for "distributed longitudinal stress associated with vertical and shear stress" for FE buckling.

3.3 Stiffeners

3.3.1

It gives the criterion of stiffeners which the maximum utilisation factor can be obtained as defined in Sec 5, [2.3]. This provision also applies to the vertically stiffened side shell frame (VSS frame) of single side bulk carriers. In calculating, use the same σ_x, σ_y and τ as that of in the corresponding VSS plating.

3.4 Vertically corrugated transverse and longitudinal bulkheads

3.4.1

It gives the criterion of vertically corrugated transverse and longitudinal bulkheads and the formula of maximum shear corrugated utilisation factor.

- For longitudinal bulkheads, the hull girder stress defined in [2.1.2].
- For transverse bulkheads of bulk carrier, the shear stress defined in Pt 2, Ch 1, Sec 3, [3.2.1] for the flooded condition is checked.

3.5 Horizontally corrugated longitudinal bulkhead

3.5.1

It gives the criterion of horizontally corrugated longitudinal bulkhead. The extension of each corrugation is defined as "half flange + web + half flange". The criterion is based on column buckling.

3.6 Struts, pillars and cross ties

3.6.1

It gives the criteria of struts, pillars and cross ties, also η for different types. All requirements should be in accordance with the Ch 8, Sec 5, [3.1].

1 GENERAL

1.1 Scope

1.1.1

This section summarises the background for the buckling assessment of finite element analysis (FEA) subjected to compressive stress, shear stress and lateral pressure.

Note: Tensile stress components are still taken into account in the plate limit state and ultimate buckling capacity of stiffener with the condition as specified in the Rules.

1.1.2

All structural elements in the finite element analysis carried out according to Ch 7 are to be assessed individually for buckling assessments. It also means all stresses with the lateral pressure (when necessary) are based on the FE results.

It indicates which kinds of elements listed in this provision have to be checked with buckling requirements in FE analysis.

2 STIFFENED AND UNSTIFFENED PANELS

2.1 General

2.1.1

This section of the rules defines which structural member of the hull structure is to be modelled as a stiffened panel or an unstiffened panel and also applied to Method A or Method B respectively based on the locations those are related to the boundary condition of the panels. See Table 1 and Figure 1 to Figure 9 for details.

It is noted that only UP-A is used for the vertical panels on the top wing tank of bulk carriers shown in Figure 5 and Figure 7. For Method A and Method B methodology, please see the TB of Sec 1, [3.1.3] and "TB Rep_Pt1_Ch08_Sec04_In-plane Constraint Study".

2.1.2 Average thickness of plate panel

If the plate thickness along a panel is not constant, the weighted average thickness is to be used which is in line with the FEM procedure in Ch 7 for simplification.

2.1.3 Yield stress of the plate panel

For safety, the panel yield stress is taken as the minimum value of the specified yield stress of the elements within the panel.

2.2 Stiffened panels

2.2.1

It indicates the model extents of stiffened panel, i.e. one stiffener with its attached plate.

2.2.2

It indicates the way to deal with the stiffener properties or stiffener spacing varies within the stiffened panel. By using this way, the most unfavourable/critical buckling failure mode of the stiffened panel can be found.

2.3 Unstiffened panels

2.3.1 Irregular plate panels

Since there is no analytical solution for irregular panels to determine their buckling capacity, it is necessary to convert them into regular unstiffened panels those capacities have an equivalent/similar as replaced irregular one, and then perform buckling assessment.

2.3.2 Modelling of an unstiffened panel with irregular geometry

This provision shows the detailed procedure of modelling for an unstiffened polygon panel. They are from the CSR OT (July 2010).

2.3.3 Modelling of an unstiffened panel with triangular geometry

This provision shows the detailed procedure of modelling for an unstiffened triangular panel. By performing numerical simulations (FEM), the suitable idealised regular geometrical dimensions can be found based on an equivalent buckling capacity as the irregular panel. More detailed information refers to ”TB Rep_Pt1_Ch08_Sec04_Unstiffened Panel with Triangular Geometry”.

2.4 Reference stress

2.4.1

It emphasises that the stress with its distribution should be from the results of FE analysis and applied to the buckling mode.

2.4.2

The reference stresses is determined from Stress Based Method as defined in App 1 in the Rules.

2.5 Lateral pressure

2.5.1

Lateral pressures have effects on the buckling strength of stiffeners, so they are considered in the stiffener buckling strength assessment.

For plate buckling/ultimate capacity, such as in bottom shell and side shell, it is verified that the effect due to lateral pressure is very limited. Therefore, the pressure is ignored in the plate capacity. In the rule, the longitudinal stress to be considered has been modified for the buckling. The modified value is now the maximum stress taking account indirectly of the lateral pressure effect.

2.5.2

For simplicity, it is assumed to use the weighted average value to represents the non-uniform lateral pressure over a buckling panel.

2.6 Buckling criteria

2.6.1 UP-A

It gives the buckling criterion of unstiffened panel with Method A.

2.6.2 UP-B

It gives the buckling criterion of unstiffened panel with Method B.

2.6.3 SP-A

It gives the buckling criterion of stiffened panel with Method A. For the utilisation factor η_{SP-A}, the value should be taken as the maximum of the 3 buckling/ultimate strength failure modes (for plate capacity, use method A) considered in the Rules.

It is noted that the overall panel capacity is regarded as "threshold" for the checking of the buckling/ultimate capacity.

2.6.4 SP-B

It gives the buckling criterion of stiffened panel with Method B. For the utilisation factor η_{SP-B}, the value should be taken as the maximum of the 3 buckling/ultimate strength failure modes (for plate capacity, use method B) considered in the Rules.

It is noted that the overall panel capacity is regarded as "threshold" for the checking of the buckling/ultimate capacity.

2.6.5 Web plate in way of openings

It gives the buckling criterion of the web plate in way of openings.

3 CORRUGATED BULKHEAD

3.1 General

3.1.1

It indicates that 3 buckling failure modes (corrugation overall column buckling, flange panel and web panel buckling of corrugation) should be checked for the corrugated bulkheads.

3.2 Reference stress

3.2.1

It indicates that each corrugation flange and web panel should be checked.

3.2.2

It indicates to use the membrane stress at the element centred in FE buckling check. This requirement is consistency with that of FE yielding check.

3.2.3

It gives the reference stresses to consider in the buckling criteria for the 2 worst configurations, i.e. maximum normal stress parallel to the corrugation which could be found at the ends of the corrugations or within its mid span and maximum shear stress. It also defines the type of stress to be used for performing the buckling check, e.g. to take the average stress value calculated for flange and for the web at the locations selected with the 2 above mentioned configurations. (see Figure 4)

For the selection of the maximum normal stress at corrugation ends, the rules consider 2 different situations:

- The stress can be directly obtained at the read out point from the finite element,
- The stress cannot be directly obtained at the read out point from the finite element.

When the normal stress can be directly obtained from the FE at the read out point, the stresses σ_x, σ_y and τ are directly used, and averaged. However when the normal stress cannot be obtained directly from the FE, the stresses are to be interpolated at the read out point.

The read out point at corrugation end is different according to the fact that:

- The corrugation is not fitted with shedder plate or gusset plate,
- The corrugation is fitted with shedder plate or gusset plate.

When the corrugation is not fitted with shedder plate or gusset plate, the read out point is located at a distance equal to $b/2$ for the corrugation end. When the corrugation is fitted with shedder plate or gusset plate, the read out point is located at a distance equal to $b/2$ from the intersection of the shedder plate or the gusset plate, measured at the mid breadth of the flange or of the web.

The Figure 1, Figure 2 and Figure 3 show examples of read out points at $b/2$ from shedder plates or gusset plates. The distance $b/2$ for the read out point is considered for using a representative stress in the buckling criteria than the localised high stress due to the steep stress gradient occurring in the area near the end of the corrugation.

In order to get a more robust solution, the interpolation shall be in accordance with Ch 8, App 1, [1.2] for the regular panel on an equivalent buckling panel extending over $3b$. This means that the interpolation will be made using the 2nd order interpolation method for regular panel for the normal stress σ_x. For the shear stress linear interpolation between the elements most close to $b/2$ is applicable.

Figure 1: Read out point at *b*/2 for symmetrical and unsymmetrical shedder plates

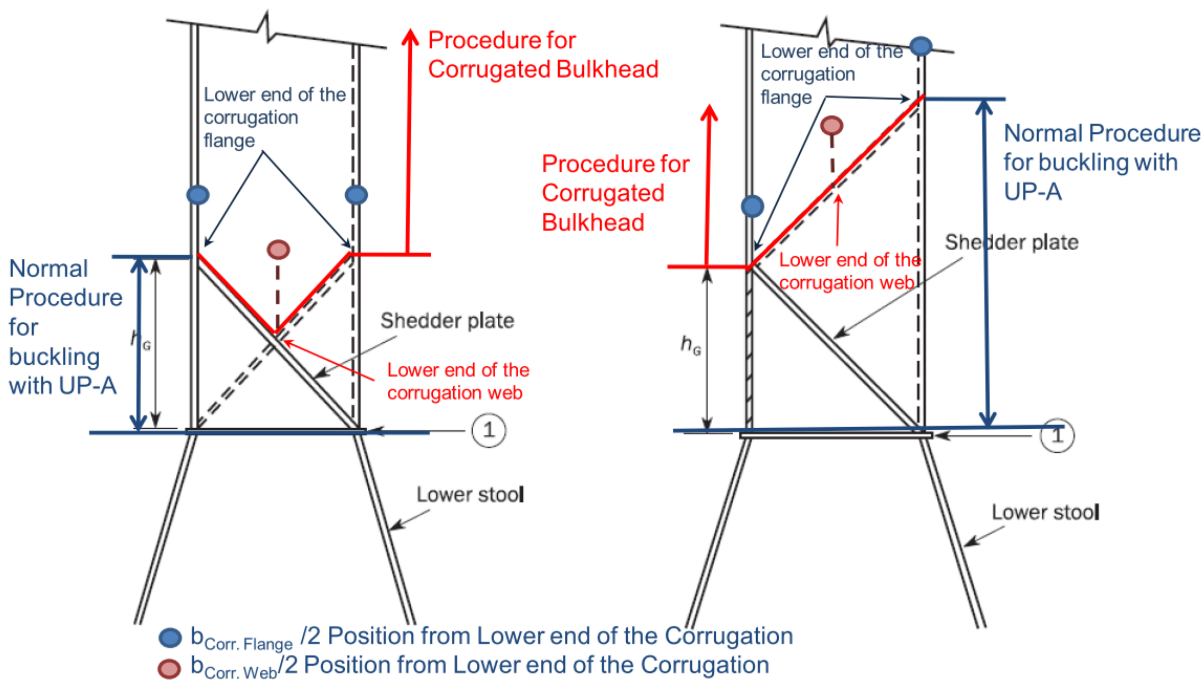


Figure 2: Read out points at *b*/2 for symmetrical and unsymmetrical gusset/shedder plates

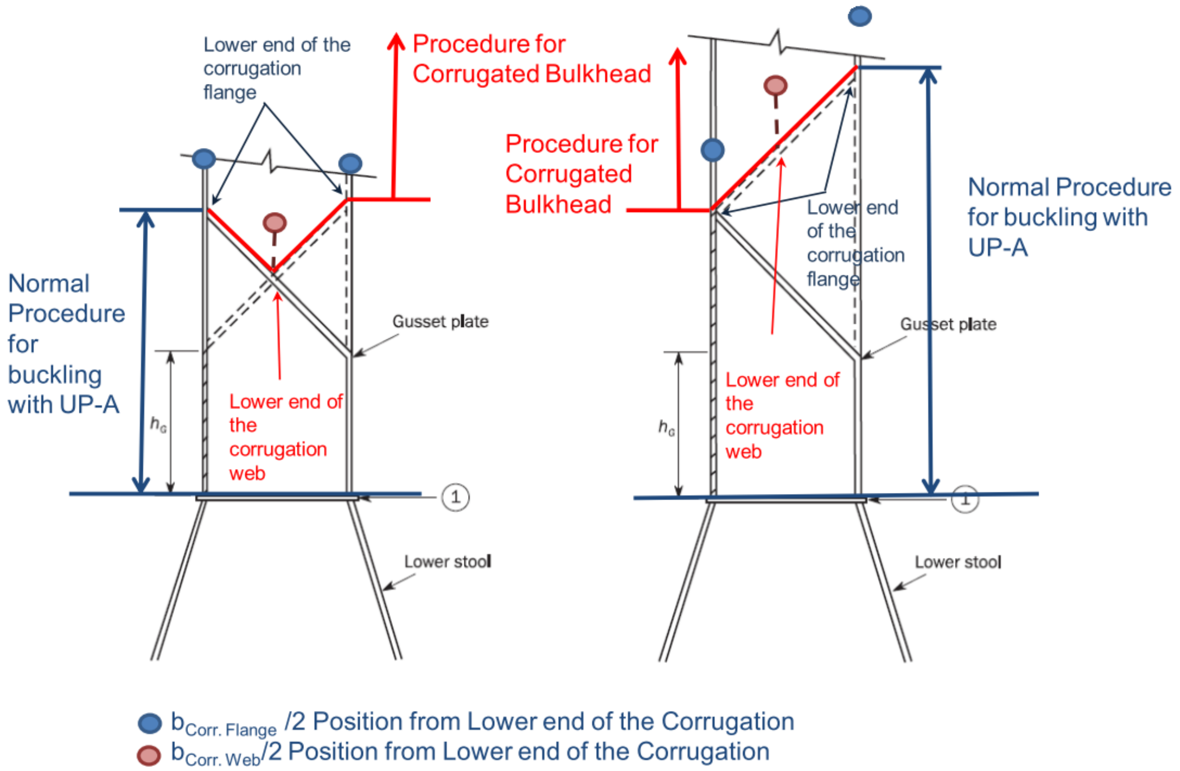


Figure 3: Read out points at *b*/2 for asymmetrical gusset/shedder plates

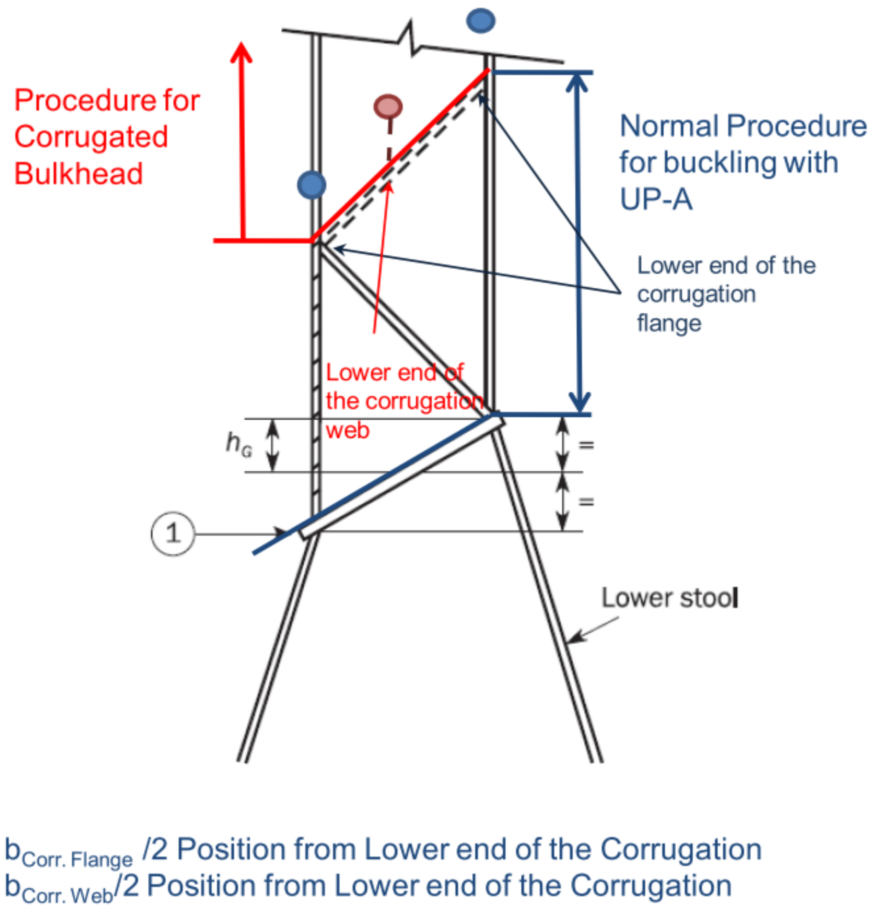
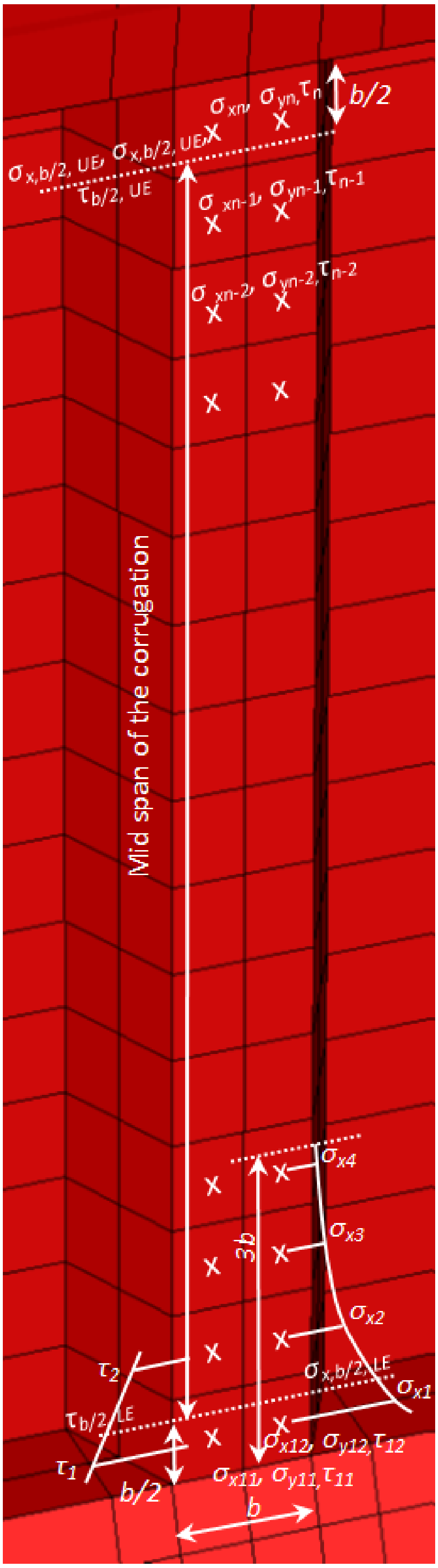


Figure 4: Detailed procedure for averaging the stresses

Detailed procedure for averaging the stresses

Averaging and Interpolation of Element Stresses for
Flange Panel Buckling of Vertically Corrugated Bulkhead



- Averaging element stresses in direction perpendicular to corrugation knuckles is to be done first over the flange width.
- Averaging element stresses in direction parallel to corrugation knuckles is not to be done.
- The “mid span of the corrugation” is shown in the left figure.
- The “interpolation” is to be applied where the stress values at $b/2$ from ends of the corrugation cannot be obtained directly from an element.
- After averaging the stresses over the flange width, and after obtaining the stresses at $b/2$ from lower and upper ends, the maximum stress is to be used for compliance with the buckling criteria.

σ_{x11}, σ_{x12}, σ_{x21}, σ_{x22}, …, σ_{xn1}, σ_{xn2}, σ_{y11}, σ_{y12}, σ_{y21}, σ_{y22}, … σ_{yn1}, σ_{yn2}: In plane membrane stresses, σ_x and σ_y, evaluated at element centroids;

τ_{11}, τ_{12}, τ_{21}, τ_{22}, …, τ_{n1}, τ_{n2}: Shear stress evaluated at element centroids

σ_{x1}, …, σ_{xn}: Weighted average stress from σ_{x11} and σ_{x12}, …, σ_{xn1} and σ_{xn2}

σ_{y1}, …, σ_{yn}: Weighted average stress from σ_{y11} and σ_{y12}, …, σ_{yn1} and σ_{yn2}

τ_1, …, τ_n: Weighted average stress from τ_{11} and τ_{12}, …, τ_{n1} and τ_{n2}

$\sigma_{x,b/2,LE}$, $\sigma_{y,b/2,LE}$: Stresses at $b/2$ at the lower end obtained by the interpolation between σ_{x1}, σ_{x2}, … and between σ_{y1}, σ_{y2}, … within $3b$ length from lower end of the corrugation

$\sigma_{x,b/2,UE}$, $\sigma_{y,b/2,UE}$: Stresses at $b/2$ at the upper end obtained by the interpolation between σ_{xn}, σ_{xn-1}, … and between σ_{yn}, σ_{yn-1}, … within $3b$ length from upper end of the corrugation

$\tau_{b/2,LE}$, $\tau_{b/2,UE}$: Shear Stresses at $b/2$ at the lower end and upper end of the corrugation obtained by linear interpolation between τ_1 and τ_2, and between τ_n and τ_{n-1}

$\sigma_{x,final}$ = Max ($\sigma_{x,b/2,LE}$, σ_{x2}, σ_{x3}, σ_{x4}, …, σ_{xn-1}, $\sigma_{x,b/2,UE}$)

τ_{final} = Max ($\tau_{b/2,LE}$, τ_2, τ_3, τ_4, …, τ_{n-1}, $\tau_{b/2,UE}$)

3.2.4

It gives the way to deal with varies thickness for the flange panel. This requirement is consistency with the [2.2.2].

3.3 Overall column buckling

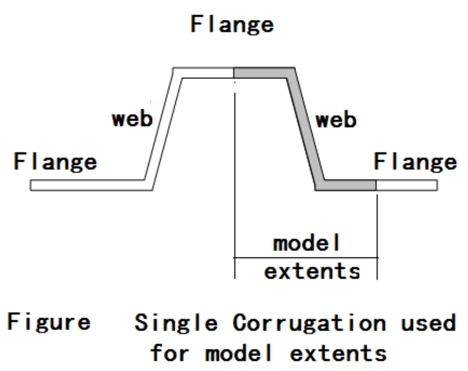
3.3.1

It gives the application of overall column buckling for corrugated bulkhead in Table 2 for detail, and special requirements for vertical corrugated bulkheads subjected to local vertical forces.

3.3.2

It gives the criterion of overall column buckling for each corrugated units. Figure 10 in Sec 4 and Figure 2 (grey shown below) give an illustration on the corrugation unit.

Figure 4: Illustration of corrugation unit



3.3.3

It indicates that the end constraint factor, fend, is corresponding to pinned ends. If in way of stool has the width exceeding 2 times the depth of the corrugation, it is to be regarded as fixed end support due to strong end constraint.

3.4 Local buckling

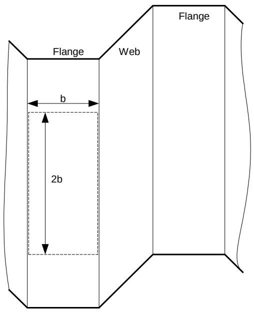
3.4.1

It gives the criterion of local buckling of corrugated bulkheads. In accordance with [3.2.3], two stress (normal and shear) combinations (max/in way of maximum of corresponding stress) are to be specified in details with the values and the location to be obtained.

The aspect ratio α =2, i.e. $b \times 2b$ of the buckling field is illustrated in Figure 6 below based on past experience. For safety, it also specifies to use the plate thickness where the maximum compressive / shear stress occur.

The attention is also drawn on the fact that the buckling assessment is to be performed for each thickness in case the corrugation is made with different thicknesses along the corrugation axis.

Figure 5: Illustration of buckling field with dimension $b \times 2b$



4 VERTICALLY STIFFENED SIDE SHELL OF SINGLE SIDE SKIN BULK CARRIER

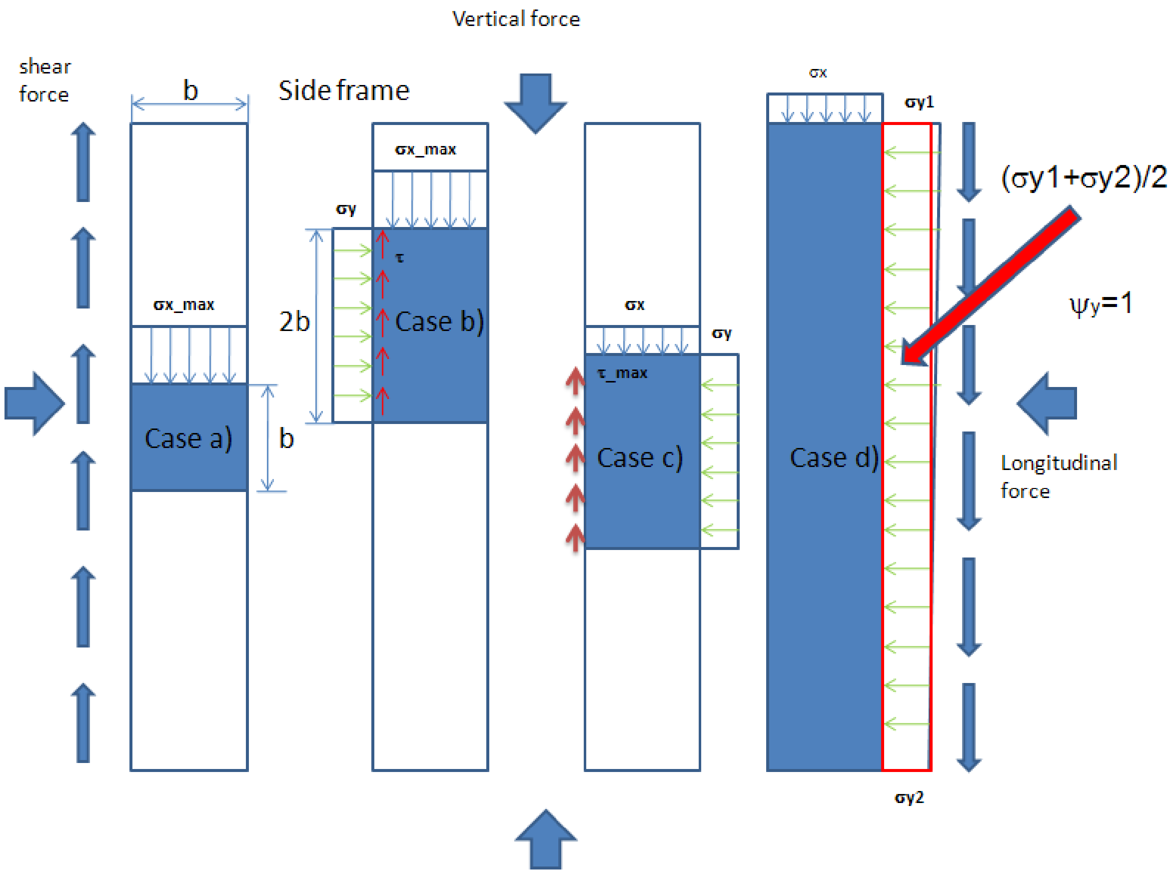
4.1 Buckling criteria

4.1.1 Side shell plating

It provides the criterion of vertically stiffened side shell plating of bulk carriers. It also indicates that 4 load combinations to be checked for buckling assessment in detail and Method A is applied only for the buckling check here.

Figure 7 below provides an illustration on the buckling assessment case (a), (b), (c) and (d) for side shell of bulk carriers, of which the reference stress models illustrate how reference stresses are taken from real side frame panels and buckling assessment models show the imaginary idealized panels to be used for buckling assessment.

Figure 6: Illustration of buckling fields [case (a), (b), (c) & (d)] for side shell



For transverse stress on VSS plating, average value is used in case (d), i.e. 0.5 (σ_{y1} + σ_{y2}) with ψ_y = 1.0 are used for plate buckling check. See also in TB, Ch 8, Sec 3, [3.2.1].

4.1.2 Side frames

The buckling assessment of side frames of single side skin bulk carriers is to be made according to the stiffener buckling requirement as defined in Ch 8, Sec 5, [2.3]. The side frames are considered with partially fixed ends due to the bracket requested at both ends. For the b_{eff} calculation the c_x coefficient to be used must correspond to the boundary condition of the plating used in [4.1.1].

5 STRUTS, PILLARS AND CROSS TIES

5.1 Buckling criteria

5.1.1

It is to clarify the application of buckling requirements for direct strength analysis of cross ties, to check not only overall column buckling mode but also local plate buckling mode.

1 GENERAL

1.1 Scope

1.1.1

This section is concerning the calculation of buckling capacities for structural members, e.g. plate panels, stiffeners, primary supporting members, struts, pillars, cross ties and corrugated bulkheads, etc. The application can be refers to [1.1.2].

Since buckling failure modes which the phenomenon are mainly excessive deformation, torsion, warping those are translational and/or rotational displacement, the anti-buckling design specified in the Rules (elastic buckling and ultimate buckling capacity requirements) can also have a function to prevent or control the deformation from compromising the integrity of ship's structure.

1.1.2

It states the sections for the buckling application on prescriptive requirements (Sec 3) and FE analysis requirements (Sec 4). Also, the applied loads/stresses (σ_x, σ_y and τ) used for different requirements should be obtained from corresponding required sections.

1.1.3 Ultimate buckling capacity

It gives the method of calculating ultimate buckling capacity for plate panels, PSM and stiffeners.

1.1.4 Buckling utilisation factor

The buckling utilisation factor η should be taken as the highest value of all buckling modes. The buckling utilisation factor η for a buckling mode is equal to the reciprocal of γ which can be obtained by appropriate iteration from the different buckling modes.

1.1.5 Lateral pressure

The lateral pressure contributes to bending stress and should be considered in stiffener buckling assessment. However, for typical plate panels, lateral pressure has only marginal effect on their buckling capacity and is not considered.

2 BUCKLING CAPACITY OF PLATES AND STIFFENERS

2.1 Overall stiffened panel capacity

2.1.1

It gives the limit state for the global elastic buckling of the stiffened panel. Refer to Ch 8 of TB for RCN 1 to CSR 01 Jan 2020.

2.1.2

It gives the stress multiplier factor $\gamma_{GEB,bi}$ for the stiffened panel subjected to biaxial loads. More details refer to Ch 8 of TB for RCN 1 to CSR 01 Jan 2020.

Rule has been further updated incorporating provision for calculating buckling capacity of stiffened panels fitted with U-type stiffeners. For more details refer to Ch 8 of TB for RCN 1 to CSR 01 Jan 2021.

Rule has been further updated to reduce the conservativeness for the buckling strength requirements for stiffened panels with slender/long stiffeners that are globally very slender. For more details refer to TB for RCN 1 to CSR 01 Jan 2022.

2.1.3

It gives the stress multiplier factor $\gamma_{GEB,\tau}$ for the stiffened panel subjected to pure shear load. More details refer to Ch 8 of TB for RCN 1 to CSR 01 Jan 2020.

2.1.4

It gives the stress multiplier factor $\gamma_{GEB,bi+\tau}$ for the stiffened panel subjected to combined loads. More details refer to Ch 8 of TB for RCN 1 to CSR 01 Jan 2020.

2.2 Plate capacity

2.2.1 Plate limit state

A new proof of plate capacity under combined in-plane loads is proposed. In order to evaluate this new proof, extensive non-linear finite element analyses (NLFEA) have been performed. Three (3) alternative proofs are first compared with the NLFEA results:

1) Existing CSR Proof (based on CSR BC)
2) Provisional CSR Proof (based on CSR-H, ER 01 April 2013 version)
3) Proof from Recent Literature (based on Paik and Thayamballi, 2003 publication)

Followed by the newly proposed proof:
4) Proposed CSR Proof (based on CSR-H, TC 01 November 2013 version).

On the basis of these comparisons, the newly proposed proof is shown to have significantly greater accuracy and precision than the alternative proofs over a broad range of plate aspect and plate slenderness ratios. More details refer to "TB Rep_Pt1_Ch08_Sec05_Formula of Plate Capacity".

For hatch cover with U type stiffeners, additional information is available in the TB report "Buckling assessment of hatch cover with U type stiffeners".

2.2.2 Reference degree of slenderness

The Table 2 is modified and supplemented (based on CSR BC and Society Rules) for the buckling factor *K* formulation and considering the clamped boundary condition at the short edge.

The reference degree of slenderness is relative value, and the formula is derived from the Euler-elastic and shown as follows:

$$\sigma_e = \frac{\pi^2 E}{K\lambda^2} \qquad \rightarrow \lambda_P = \pi\sqrt{\frac{E}{K\sigma_e}}$$

If slenderness related to the yield stress:

$$K\sigma_e = R_{eH\_P} \qquad \rightarrow \lambda_a = \pi\sqrt{\frac{E}{R_{eH\_P}}}$$

The reference degree of slenderness:

$$\lambda = \frac{\lambda_P}{\lambda_a} \qquad \rightarrow \sqrt{\frac{R_{eH\_P}}{K\sigma_e}}$$

K is buckling factor which depends on the aspect ratio α, the edge stress ratio ψ and on the correction factors F_{long} or F_{tran} which describes the boundary condition of the plate edge a. F_{long} = 1.0 for simply supported edge.

2.2.3 Ultimate buckling stresses

The C_x, C_y and C_τ are reduction factors related to ultimate capacity (yield collapse failure mode). In the CFM, the difference between Method A and Method B is how to take the c_1 coefficient in Case 2 in Sec 5, Table 3.

For method A, c_1 is taken as $c_1 = (1 - \frac{1}{\alpha}) \geq 0$, which comes from the condition where σ_y is "due to bending" in DIN formulation. For Method B, c_1 = 1.0, which comes from the condition where σ_y is "due to direct loads" that "corresponds to a plate panel which edges not restrained from pull-in which may result in non-straight edges" as described in CSR OT (July 2010).

The Case 1, 2 and 11 which represent the simply supported boundary condition are for general use. The Case 3, 4 and 5 are for different condition other than simply supported. For vertically stiffened single side skin of bulk carrier and corrugation of corrugated bulkheads, take UP-A.

It is mentioned that for vertically stiffened single side plating of bulk carrier, the clamped condition at short edge of the panel should be corresponding to the cases specified in the Table 3. More details concerning Method A and Method B refer to "TB Rep_Pt1_Ch08_Sec04 In-plane Constraint Study".

2.2.4 Correction factor F_{long}

As described in the Rules, F_{long} factors represent the degree of edge constraint affected by different types of the stiffener fitted on the panel edge (for unstiffened panel, the factor is 1.0 means no affection). These values in Sec 5, Table 2 (based on CSR) have been checked or updated by NLFEA studies. More details refer to "TB Rep_Pt1_Ch08_Sec05_Correction Factor F_{long}".

For hatch cover with U type stiffeners, additional information is available in the TB report "Buckling assessment of hatch cover with U type stiffeners".

2.2.5 Correction factor F_{tran}

The coefficient F_{tran} is specified for the effect on the "rotation restraint" boundary condition at the longer edge of the VSS plate panel provided by the side shell frame. For structures other than VSS plate, this effect is not considered, i.e. F_{tran} = 1.0.

More details of F_{tran} and clamped factors refer to "TB_Rep_Pt1_Ch08_Sec05_Correction Factor F_{tran}" and "TB Rep_Pt1_Ch08_Sec05_Buckling with Short Edge Clamped".

Rule has been further updated incorporating provision for calculating buckling capacity of stiffened panels fitted with U-type stiffeners. For more details refer to Ch 8 of TB for RCN 1 to CSR 01 Jan 2021.

2.2.6 Curved plate panels

The interactive formula in [2.2.1] is also applicable for Table 4. If the radius is larger than (R/tp > 2500), the curved plate can be taken as plane/flat plate and Table 2 is available.
For the application of cases 1 and 2 of the Table 4, the item "For curved single field" must be understood as a curved single field bounded by plane panels for example for a bilge strake as it is shown in Ch 6, Sec 4, Figure 1.

The general application of cases 1 and 2 is to be used for other structural arrangements such as longitudinal framing or when the curved single field is not directly bounded by plane panels. The Note 1 of that Table 3 is applicable to curved plate panel whatever the radius.
The C value is to be taken as the maximum value between the value for the panel considered as plane from Table 3 and the value of curved panel from Table 4.

2.2.7 Applied normal and shear stresses to plate panels

This provision provides the summary and procedure for how to take the normal and shear stresses for the overall stiffened panel capacity, plate and stiffener buckling assessment, such as in the prescriptive requirements and in FE buckling. For grillage analysis which method (beam theory) is different from the finite element analysis, the Poisson correction should be taken into account as described in the Rules.

However, Poisson effect is not considered in prescriptive buckling. More details refer to "TB Rep_Pt1_Ch08_Sec05_Poisson Effect".

In RCN 1 to CSR 01 Jan 2020, it has been amended to be able to consider the normal and shear stresses corresponding to the improved overall stiffened panel capacity formula.

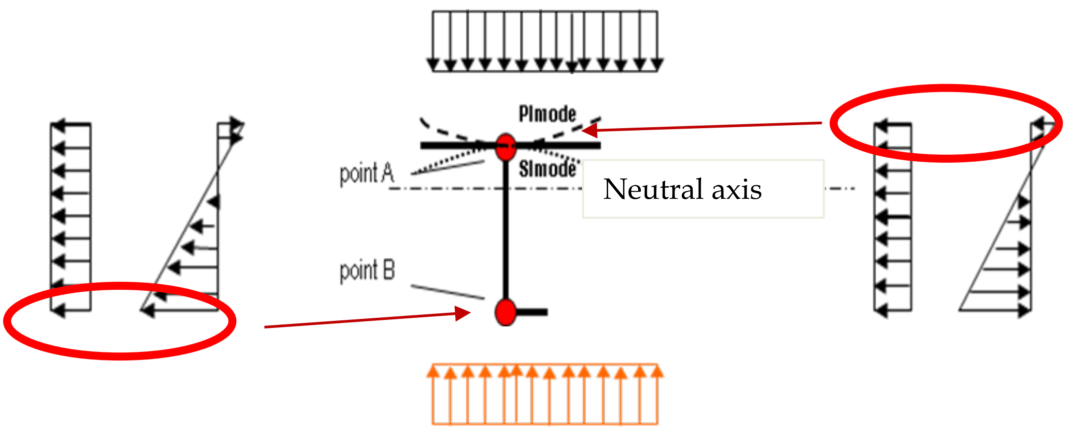
2.3 Stiffeners

2.3.1 Buckling modes

Two buckling failure modes of stiffener are to be checked because the resultant axial stress and compressive stress induced by lateral pressure in two different directions should be considered, see Figure 1.

- Stiffener induced failure (SI): check point B when this point is in compression.
- Associated plate induced failure (PI): check point A when this point is in compression.

Figure 1: Buckling modes



2.3.2 Web thickness of flat bar

The stiffness of Flat bars is decreased significantly more than other types of profiles due to local lateral deformation. To take into account this decrease, the web thickness of flat bar stiffener used in the stiffener buckling strength is to be reduced by using the following equation:

$$t_{w\_red} = t_w \left(1 - \frac{2\pi^2}{3}\left(\frac{h_w}{s}\right)^2 \left(1 - \frac{b_{eff1}}{s}\right)\right)$$

Based on Elastic Large Deflection Analysis (ELDA), the following relation related to elastic large deflection behaviour of plate can be obtained.

$$\varepsilon_p = \frac{\sigma_p}{E} + \frac{\pi^2}{8a^2} W_{pl}{}^2 \qquad (1)$$

where,

ε_p : Mean strain of plate after buckling.
σ_p : Mean stress of plate after buckling.
W_{pl} : Deflection coefficient of plate.

Also based on ELDA, the following relation related to elastic large deflection behaviour of flat-bar stiffener can be obtained.

$$\varepsilon_s = \frac{\sigma_s}{E} + \frac{m^2\pi^2}{12a^2} V_{s1}{}^2 \qquad (2)$$

where,

ε_s : Mean strain of stiffener after buckling.
σ_s : Mean stress of stiffener after buckling.
V_{s1} : Deflection coefficient of stiffener.

Further, due to the continuous condition of same angles of plate and stiffener at the connection, the following equation can be derived.

$$V_{s1} = \frac{\pi h}{b} W_{pl} \qquad (3)$$

where,

b : Breadth of plate.
h : Height of stiffener web.

Using the relation of Equation (3) from Equation (1) and (2), deleting W_{pl} and V_{s1}, mean stress of stiffener, σ_s can be expressed as follows:

$$\sigma_s = E\varepsilon_s - \frac{2\pi^2}{3}\left(\frac{h}{b}\right)^2 (E\varepsilon_p - \sigma_p) \qquad (4)$$

$$\frac{\sigma_s}{E\varepsilon_s} = 1 - \frac{2\pi^2}{3}\left(\frac{h}{b}\right)^2 \left(\frac{\varepsilon_p}{\varepsilon_s} - \frac{\sigma_p}{E\varepsilon_s}\right) \qquad (5)$$

Here, both effective width of plate, b_e and effective thickness of stiffener web, t_e are defined as follows:

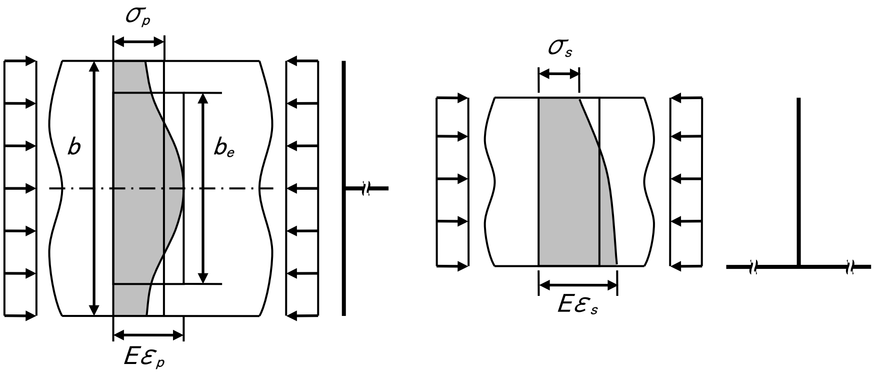
$$b_e = \frac{\sigma_p}{E\varepsilon_p} \times b \qquad (6)$$

$$t_e = \frac{\sigma_s}{E\varepsilon_s} \times t \qquad (7)$$

Assuming the mean strain $\varepsilon_p = \varepsilon_s$ until ultimate strength, and considering Equation (6) and (7) into the Equation (5), the effective thickness of stiffener web can be obtained as follows:

$$t_e = t[1 - \frac{2\pi^2}{3}(\frac{h}{b})^2(1 - \frac{b_e}{b})] \qquad (8)$$

Figure 2: Axial stress distribution of plate and stiffener web after local buckling



However, the equation of b_{eff}, defined in Ch 8, Sec 5, [2.3.5] is determined by not only the buckling of the attached plate, C_x but also the shear lag for stiffener bending χ_S. Therefore, if b_{eff} is determined by the shear lag, incorrect values such as negative may be obtained.

In order to solve the problem, we propose to define two types of effective width (breadth) of the attached plate, b_{eff1} in addition to b_{eff} and to use b_{eff1} for the calculation of effective thickness of flat bar.

- $b_{eff} = min(C_x b, \chi_s s)$
- $b_{eff1} = C_x b$

Related to the effective width of attached plating, the effective axial stress, σ_a also should be calculated with using b_{eff1} instead of b_{eff}. Because the axial stress can increases due to the buckling of the attached plate but shear lag for stiffener bending need not be taken into account when considering the response for nominal axial stress, σ_x.

The effective web thickness is explicitly used in [2.1] and [2.3.4] of RCN 1 to CSR 01 Jan 2020.

2.3.3 Idealisation of bulb profile

It gives the equivalent way to make the idealisation of the bulb bar. Also, this treatment of the bulb profile to be idealised as equivalent angle bar should be applied to this section.

2.3.4 Ultimate buckling capacity

In addition to the buckling analysis for single plate fields stiffeners must have sufficient buckling strength considering interactive lateral and warping (torsional induced) buckling modes.

For torsional buckling requirement, it has been amended as "RCN 1 to CSR 01 JAN 2020" to be able to evaluate appropriately the torsional buckling strength for the stiffeners with high webs of the ship structures, such as side frames of single side bulk carriers and enlarged stiffeners used as permanent means of access (PMA) without stiffeners on its webs.

For detail technical background as well as the consequence assessment result, refer to "Pt 1, Ch 8, Sec 5, Elastic torsional buckling" in TB for RCN 1 to CSR 01 Jan 2020.

In RCN 1 to CSR 01 Jan 2021 stress due to torsional deformation has been redefined by directly using parameter 'e_f'. Also, formula for moment of inertia about the axis perpendicular to attached plate has been updated to correctly calculate for L2 profile stiffener.

Rule has been further updated to reduce the conservativeness for the buckling strength requirements for stiffened panels with slender/long stiffeners that are globally very slender. For more details refer to TB for RCN 1 to CSR 01 Jan 2022.

The ultimate capacity formula for stiffeners sniped at one or both ends is updated to reduce the conservativeness for panels subjected to combined in-plane stress. See TB for RCN 1 to CSR 01 Jan 2022 for more details.

2.3.5 Effective width of attached plating

Two different approaches were used for the determination of the effective width of the attached plating for ordinary stiffeners. The minimum value determined for the two approaches have to be used for further calculations. The first approach multiplies the reduction factor C_x with the distance between the stiffeners b for longitudinal stiffeners.

The reduction factor for this approach is based on the plate buckling assessment for elementary plate panels. For the second approach (shear lag effect), a reduction factor χ_s is multiplied with the distance between the stiffeners s. The calculation of the reduction factor χ_s is dependent of an effective length of the stiffener l_{eff} (dependent from supporting conditions or moment distribution along the length of the stiffener). The calculation is with the assumption, that ordinary stiffeners are loaded by uniformly distributed loads.

For σ_x in tension (negative), there is no buckling problem, only shear lag effect. The formula for χ_s ;

$$\chi_s = min\left[\frac{1.04}{1+2/\left(\frac{l_{eff}}{s}\right)^2}; 1.0\right]$$

The TB for the formula is given in "TB Rep_Pt1_Ch03_Sec07_Effective Plate Breadth".

For flat bar, use $b_{eff1} = C_x b$, see [2.4.2]. For b_{eff} in FE analysis and prescriptive requirements, it gives the two different methods to deal with since they are two different calculation models.

2.3.6 FE corrected stresses for stiffener capacity

In RCN 1 to CSR 01 Jan 2020, it has been amended to consider the improved stiffener ultimate capacity formula. For detailed technical background as well as the consequence assessment result, refer to "Pt 1, Ch 8, Sec 5, Global Elastic Buckling" in TB for RCN 1 to CSR 01 Jan 2020.

2.4 Primary supporting members

2.4.1 Web plate in way of openings

The formulae for plate buckling are developed for regular geometry and idealised stress patterns, whereas the geometry and stress gradients around openings and cut-outs are rather complex. This complexity is taken into account by adoption of conservative assumptions for the formulae for plate buckling.

The important stress components for buckling control of the web plate in way of openings are the axial or tangential stress flow passing the hole and the shear stress. These stress components used in the buckling criterion should account for the stress increase due to the presence of the opening, see Sec 5, Table 6 in the Rules.

The normal stress component acting perpendicular to the opening is not considered critical for buckling and may be neglected in the buckling assessment. For openings without edge reinforcements, the calculation of the separate critical buckling compression stress, $C_\tau \sigma_{yd}$, assumes a plate buckling model of the web plate area in way of the opening with three edges simply supported and one edge free (towards the opening), see Sec 5, Table 65(a) in the Rules.

For opening with edge reinforcements, the calculation of the critical buckling stress, $C\sigma_{yd}$, assumes a plate buckling model with all four edges simply supported. The calculation of the separate critical shear buckling stresses, $C_\tau\sigma_{yd}/\sqrt{3}$, assumes a plate buckling model comprising the web panel including the opening with all four edges simply supported if the opening is not fitted with edge stiffeners, then Case 13 of Sec 5, Table 3 is assumed.

For the situation where the openings are fitted with edge stiffeners, then a plate buckling model comprising the web plate area in way of the opening and Case 11 is assumed. Case 11 and Case 13 are defined in Sec 5, Table 3 in the Rules. The buckling interaction formula is taken as [2.2.1] with: $\sigma_x = \sigma_{av}$, $\sigma_y = 0$, and $\tau = \tau_{av}$.

In this provision, with or without opening in the FE model are also be considered for obtaining the average shear stress since the correction due to the opening is "pre-considered" in the formulae of case 13 in Table 3.

2.4.2 Reduction factors of web plate in way of openings

The reduction factors of the plate panel(s) of the web adjacent to the opening is to be as:

C_x : Reduction factor according to Sec 5, Table 3, Case 1 or Case 3.
C_y : Reduction factor according to Sec 5, Table 3, Case 1.
C_τ : Reduction factor according to Sec 5, Table 3, Case 11 or Case 13.

RCN 1 to CSR 01 Jan 2022 improved the buckling strength requirements for plates with a free edge and plates with openings following feedback from industries indicating that for panels with openings, typically such as the web plates of primary supporting members with openings, the present plate buckling capacity formulae and related rule requirements in CSR may give inaccurate / conservative results and needed to be improved.
See Pt. 1, Ch. 8, Sec. 5, [2.4.2] and Table 6 in TB for RCN 1 to CSR 01 Jan 2022 for more details.

2.4.3

This provision is used for where web stiffeners are not connected to the intersecting stiffeners, by doing this way, the FE analysis is to represent the actual structure in order to derive realistic stress values for application to the equivalent rectangular panel.

3 OTHER STRUCTURES

3.1 Struts, pillars and cross ties

3.1.1 Buckling utilisation factor

It states that for struts, pillars and cross ties, the critical buckling stress should be taken as lesser of column and torsional buckling stress, and gives the criteria. Axial compressive stress can be use the average value.

For elastic buckling stresses exceeding 50% of stresses exceeding specified minimum yield stress of the material, the critical compressive stress for global buckling is derived using the Johnson-Ostenfeld plasticity correction factor.

Local buckling of the thin-walled part of the cross section is covered by slenderness requirements as shown in Sec 2. In the formulae for the global buckling modes, it is assumed that the cross sections are 100% effective.

Global buckling due to bending moments from lateral pressure is not considered.

3.1.2 Elastic column buckling stress

Column buckling (flexural buckling): Bending about the axis of least resistance of the cross section. This may be the critical buckling mode of slender pillars with double symmetrical cross sections or pillars not susceptible to twisting.

The formulae for the elastic buckling is based on "Buckling of Bars, Plates and Pillars", Brush and Almroth, McGraw-Hill, 1975. End constraint factors for calculation of effective span of the pillars are also considered.

3.1.3 Elastic torsional buckling stress

Torsional buckling: Twisting of cross section without bending. This buckling mode may be critical for some open, thin walled cross sections in which the shear centre and the centroid coincide.

It gives special requirements for checking cross ties. Local plate buckling of cross-ties is also checked using close-celled formulation as part of the cargo tank FEM strength verification procedure.

3.1.4 Elastic torsional/column buckling stress

Column (flexural)-torsional buckling: Simultaneous twisting and bending of cross section. This buckling mode is only relevant for cross section whose shear centre and the centroid do not coincide and which are torsionally weak.

3.2 Corrugated bulkhead

3.2.1

It gives special requirements for checking the flange and the web of corrugated bulkhead. An aspect ratio α equal to 2 is considered. The average stresses σ_x, σ_y and τ are also used for the buckling check, i.e. a ψ_x and ψ_y equal to 1 is taken into account in the plate buckling interaction formula defined in [2.2.1].

1 STRESS BASED METHOD

1.1 Introduction

1.1.1

This section shows the sample applications of Ch 8, Sec 4. The stress based method is that the stress distribution along edges of the considered buckling panel is determined by 2nd order polynomial curve, by linear approximation using least square method or by weighted average stress, depending on the case.

1.1.2 Definition

This requirement provides a definition for regular and irregular panels. The irregular panels are in line with Sec 4, [2.3.1].

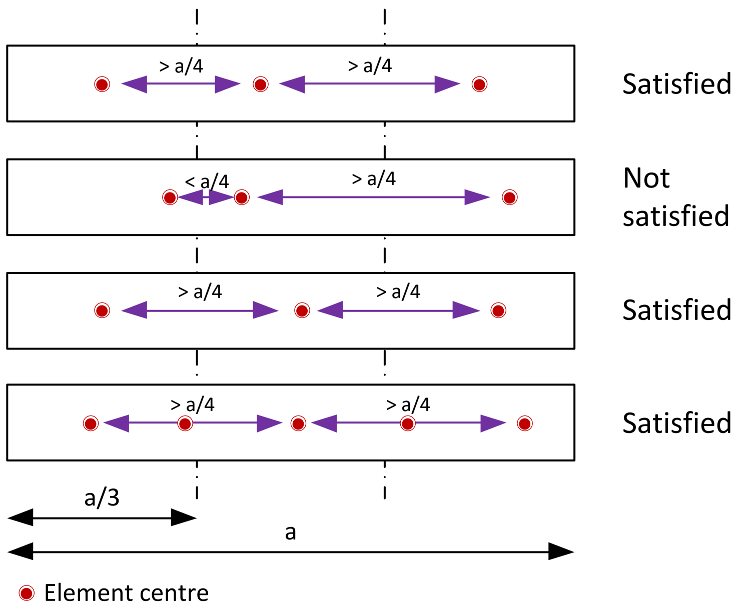
1.2 Stress Application

1.2.1 Regular panel

The reference stresses defined for a regular panel in [2.1.1] can be used if the following two conditions are both satisfied, otherwise average stress (irregular panel approach) should be used:

- at least, one plate element centre is located in each third part of the long edge "a" of a regular panel and
- 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.

Figure 1: Reference stress for Regular panel



1.2.2 Irregular panel

The reference stresses for irregular panel are defined in [2.2].

2 REFERENCE STRESSES

2.1 Regular panel

2.1.1 Longitudinal stress

For plate buckling assessment 2nd order polynomial curve is considered to estimate longitudinal stress of the buckling panel. At least three elements are required in lengthwise to assume the stress distribution otherwise it is considered as irregular panel. Stress distribution is assumed as 2nd order polynomial curve to consider bending effect. The area of element is considered as a weighting factor. The unknown coefficients *C*, *D* and *E* can be obtained.

$$
\begin{cases}
C = \dfrac{C_1C_3D_3 - C_2^2D_3 + C_2C_3D_2 - C_1C_4D_2 + C_2C_4D_1 - C_3^2D_1}{2C_2C_3C_4 + C_1C_3C_5 - C_2^2C_5 - C_1C_4^2 - C_3^3} \\
D = \dfrac{C_2C_3D_3 - C_1C_4D_3 + C_1C_5D_2 - C_3^2D_2 + C_3C_4D_1 - C_2C_5D_1}{2C_2C_3C_4 + C_1C_3C_5 - C_2^2C_5 - C_1C_4^2 - C_3^3} \\
E = \dfrac{-C_3^2D_3 + C_2C_4D_3 - C_2C_5D_2 + C_3C_4D_2 - C_4^2D_1 - C_3C_5D_1}{2C_2C_3C_4 + C_1C_3C_5 - C_2^2C_5 - C_1C_4^2 - C_3^3}
\end{cases}
$$

where,

$$C_1 = \sum_{i=1}^{n} A_i \text{ , } C_2 = \sum_{i=1}^{n} A_i x_i \text{ , } C_3 = \sum_{i=1}^{n} A_i x_i^2 \text{ , } C_4 = \sum_{i=1}^{n} A_i x_i^3 \text{ , } C_5 = \sum_{i=1}^{n} A_i x_i^4$$

$$D_1 = \sum_{i=1}^{n} A_i \sigma_{ix} \text{ , } D_2 = \sum_{i=1}^{n} A_i x_i \sigma_{ix} \text{ , } D_3 = \sum_{i=1}^{n} A_i x_i^2 \sigma_{ix}$$

For overall stiffened panel and stiffener buckling assessments, axial stress is to be calculated using a weighted average stress for avoiding considering bending stress twice.

2.1.2 Transverse stress

At least two elements are required in lengthwise to assume the stress distribution otherwise it is considered as irregular panel. Weighted least square method is considered to estimate linearly varying transverse stress of the buckling panel. The area of element is considered as a weighting factor. The unknown coefficients *A* and *B* can be obtained.

$$
\begin{cases}
A = \dfrac{\left(\sum_{i=1}^{n} A_i\right)\left(\sum_{i=1}^{n} A_i x_i \sigma_{iy}\right) - \left(\sum_{i=1}^{n} A_i x_i\right)\left(\sum_{i=1}^{n} A_i \sigma_{iy}\right)}{\left(\sum_{i=1}^{n} A_i\right)\left(\sum_{i=1}^{n} A_i x_i^2\right) - \left(\sum_{i=1}^{n} A_i x_i\right)^2} \\
B = \dfrac{\left(\sum_{i=1}^{n} A_i \sigma_{iy}\right)\left(\sum_{i=1}^{n} A_i x_i^2\right) - \left(\sum_{i=1}^{n} A_i x_i\right)\left(\sum_{i=1}^{n} A_i x_i \sigma_{iy}\right)}{\left(\sum_{i=1}^{n} A_i\right)\left(\sum_{i=1}^{n} A_i x_i^2\right) - \left(\sum_{i=1}^{n} A_i x_i\right)^2}
\end{cases}
$$

2.1.3 Shear stress

The weighted average approach is also applied to the calculating the shear stress.

2.2 Irregular panel

2.2.1 Reference stresses

When the panel is irregular, the weighted average approach for longitudinal, transverse and shear stresses is used.

PART 1 CHAPTER 9

FATIGUE

Table of Contents

SECTION 6
Detail Design Standard

1 RULE APPLICATION FOR FATIGUE REQUIREMENTS

1.1 Scope

1.1.1 General

This chapter is applied mandatory for double hull oil tankers, single side skin and double side skin bulk carriers having rule length *L* greater than 150m and less than 500m. For oil tankers, the rules apply to the hull structures having length *L* greater than 150m and less than 500m (refer to TB of Pt 1, Ch 1, Sec 1, [1.3.1]) and for bulk carriers, rules apply to hull structures having length *L* of 90 m or above (refer to TB of Pt 1, Ch 1, Sec 1, [1.2.1]). But, fatigue assessment is not applicable for bulk carriers less than 150 m because up to now fatigue damage has not been observed for those types of bulk carriers.

According to GBS requirements, the target fatigue life specified by the designer is not to be taken less than 25 years.

The fatigue assessment procedure is based on the following assumptions:

- A list of details to be mandatory checked by simplified analytical stress analysis or very fine finite element stress analysis in the cargo area only where accumulated service experience have allowed identification of critical structural details.
- A list of details that might be vulnerable to fatigue cracks if stress level becomes high enough is given to be checked by a screening procedure.
- The design life required by the Rules is to be taken as 25 years, refer to TB of Pt 1, Ch 1, Sec 2, [3.3.1].

North Atlantic wave environment data (1) is used to determine the fatigue design loads, refer to TB of Pt 1, Ch 1, Sec 2, [3.4.1]. Only quasi-static wave induced loads are applied in the fatigue assessment. Hull girder vibrations are implicitly accounted for the CSR-H fatigue requirements. The fatigue calculation procedure has been developed and verified based on experience with actual trading vessels. Hull girder vibrations have been present in trading vessels used in the development and verification of the procedure. The use of the North Atlantic wave environment provides a significant margin for the fatigue life of tankers on typical worldwide trade. This margin exceeds the contribution of hull girder vibrations to fatigue.

1.1.2 Assessed area

Most frequent fatigue failures modes in ship structures are:

1. Fatigue crack initiating from the weld toe and propagating into the base material is a frequent failure mode. The crack initiates at small defects or undercuts at the weld toe where the stress is highest due to the weld notch geometry. Generally, the fatigue crack at toe can be detected by in service inspection.
2. Fatigue crack initiating in the base material at free edge of hatch corner, radius of bracket, and growing into the base material. Fatigue cracks may initiate from surface roughness at free edge, e.g. cutting surface.
3. Fatigue crack initiating from the weld root and propagating through the weld throat. It is a failure mode that can lead to significant consequences because it is difficult to detect internal defects in fillet/partial penetration welds by NDE (non-destructive examination). They can not be discovered before the crack has propagated completely through the weld.

4. Fatigue crack initiating from the weld root and propagating into the plate section under the weld. The number of cycles until failure for this failure mode is of similar magnitude as fatigue cracking from the weld toe for common weld size. This means if fatigue life improvement of the weld toe is required, fatigue cracking from the weld root could become likely and it is also required to make improvement for the root, e.g. full penetration weld.

Fatigue strength assessment proposed in the present rules is intended for fatigue crack initiating from the weld toe and crack initiating in the base material at free edge, i.e. for cases 1 and 2 above.

There is no direct analysis methodology for root crack assessment in the present rules, i.e. for cases 3 and 4 above. Weld root cracking avoidance is ensured by design standards. Nevertheless, present rules provide welding requirement, e.g. minimum weld throat size at critical hot spots location of structural details in order to avoid root crack failure.

1.1.3 Structural details to be assessed

This Rules provides a list of mandatory details to be checked by simplified analytical stress analysis or finite element stress analysis in the cargo region. This approach is only appropriate where accumulated service experience has allowed such identification. Additional details may need to be analysed when non-standard details or arrangements are used.

Rules require the systematic identification of areas prone to fatigue throughout the entire ship. Fatigue evaluation is required for regions experiencing the most fatigue damages. Therefore assessment is focused on structural details within the cargo region which is the most critical region from fatigue point of view.

The details which have been selected to be checked by a complex analysis such as Finite Element Analysis, based on very fine mesh model, correspond to those which have been defined as the most critical from combined experience of IACS members supported by analytical and experimental findings.

In addition, the Rules require a list of details to be checked by a systematic screening procedure. The details which have been selected to be checked by a less complex method i.e. screening procedure correspond to those which have been defined as the less critical from experience feedback of fatigue damage in oil tankers and bulk carriers.

1.1.4 Detail design standard

Refer to TB [1.1.2].

1.1.5 Material

The fatigue assessment procedure is valid for steel material with specified minimum yield stress R_{eH} less than 390 N/mm^2 when steel material is in seawater environment or when steel is with free corrosion. [(2)] This limitation is due to the fact that the effectiveness of cathodic protection in relation to fatigue has not yet been proven for structural steel details with yield stress R_{eH} higher than 390 N/mm^2.

For steel with R_{eH} value higher than 390 N/mm^2 and for steels with improved fatigue performance, i.e. steels with an improved S-N curve, the appropriate S-N curve is to be agreed by the Society on a case-by-case basis. Depending on the properties of the steel material an appropriate S-N curve may be one of the curves presented in this rule, one of the curves presented by IIW, a curve presented by other published standards or a curve obtained from approved fatigue tests.

1.1.6 Wave loads

Refer to TB [1.1.1].

1.1.7 Loads other than wave loads

Fatigue due to low cycles such as cargo variations is not taken into account for trading ships because the number of loading/unloading sequences for trading ships is relatively low (less than 1000 cargo variation cycles during 25 years of service ship's life will lead to a negligible damage in comparison with the damage due to wave loads corresponding to around 10^8 cycles during the same duration).

Sloshing phenomenon very seldom in tanks/holds of oil tankers/bulk carriers because holds/tanks are usually fully loaded. In addition, oil tanker deck transverses act to minimise sloshing loads.

2 DEFINITION

2.1 Hot spots

2.1.1

Technical background is not considered necessary.

2.2 Nominal stress

2.2.1

Technical background is not considered necessary.

2.3 Hot spot stress

2.3.1

Technical background is not considered necessary.

2.4 Local stress at free edge

2.4.1

Technical background is not considered necessary.

2.5 Fatigue stress

2.5.1

Technical background is not considered necessary.

3 ASSUMPTIONS

3.1 General

3.1.1

Fatigue assessment is based on the following assumptions:

- Fatigue life calculation under random wave loading is based on design S-N curves approach under the assumption of linear cumulative damage (Palmgren-Miner's rule). This rule assumes that total damage experienced by the structure is expressed as the accumulated damage from each load cycle at different stress levels, independent of the stress cycles order.
- Design life assumed in the fatigue assessment of ships is to be taken as 25 years, refer to TB of Pt 1, Ch 1, Sec 2, [3.3.1]. Corrosion is accounted by use of net scantling concept. Moreover, it is assumed that corrosion protection is partially effective, i.e. that joints in way of water ballast, oil cargo hold and fuel oil holds, are efficiently protected against corrosion during a certain amount of time (called effective corrosion protection period) and during the remaining part of the design life, they are exposed to corrosive environment because the corrosion protection is more questionable. During the effective corrosion protection period (protected environment), the steel surface is protected from the corrosive environment. Then, the steel may be considered to be as in dry air condition. In this case, the fatigue strength may be assessed with the S-N curves in air, refer to Sec 2, [4] for the effective corrosion protection. During the remaining life when the joint is subjected to corrosive environment, fatigue strength is to be assessed with the S-N curves in corrosive environment, refer to Sec 2, [4].
- Long term distribution of stress range of a structural detail may be approximated by a two-parameter Weibull distribution. The parameters are the scaling factors and the shape parameter. The probability level of 10^{-2} has been selected for the determination of the scaling factor as it has been identified as the most contributing probability level to the fatigue damage, refer to [(3)], [1.1.4]. However, it has been demonstrated that if we consider the reference stress value at 10^{-2}, the assumption of the shape parameter has very low impact on the total fatigue damage. Therefore, the shape parameter can be constant, e.g. equal to 1.0.
- Quasi-static wave induced loads have been defined at 10^{-2} probability level by the EDW (Equivalent Design Wave) method, refer to [(3)], [1.1.4].
- The acceptance criterion is based on the fatigue life, calculated according to Pt 1, Ch 9 fatigue procedure, which has to be greater than the design fatigue life as defined in [1.1.1] above.

4 METHODOLOGY

4.1 Principles

4.1.1 General

Fatigue strength is checked by means of two sets of approaches:

- Fatigue strength assessment based on fatigue life calculation which include three different methods: simplified analytical stress analysis, finite element stress analysis and fatigue screening.
- Fatigue design standards which is a qualitative approach for the design of ship structural details used to improve fatigue performance of those details.

As mentioned in [1.1.4] above, fatigue strength assessment proposed in the present rules is intended for fatigue crack initiating from the weld toe and crack initiating in the base material at free edge, i.e. for cases 1 and 2 above.

For weld toe crack checking, fatigue assessment is based on hot spot stress approach. Hot spot stress approach is considered to be an efficient engineering methodology for fatigue analysis of welded structures at weld toe. For structural details to be checked mandatory, refer to Sec 6, [1] and [2], hot spot stress is calculated by simplified stress analysis or finite element stress analysis depending on the type of structural detail under consideration.

For crack initiating from the free edge of non-welded details, fatigue assessment is based on finite element stress analysis with specific meshing rules where local stress at free edge is calculated.

4.2 Simplified stress analysis

4.2.1

Simplified stress analysis is used to determine hot spot stress at stiffener end connections. Hot spot stress at stiffener end connections subjected to axial loading due to hull girder bending and local bending due to lateral pressures are calculated based on beam theory combined with tabulated Stress Concentrations Factors, SCF.

4.3 Finite element stress analysis

4.3.1

Finite element analysis is to be carried out for critical details where the loading and geometry are more complex.

For standard welded details except for web-stiffened cruciform joints, a procedure for determination of hot spot stress at weld toe is proposed. This procedure is based on the methodology developed during the “FPSO Fatigue Capacity JIP” (6), for derivation of hot spot stress at weld toes by use of shell elements applies to all structural details found in a ship structure, except for web-stiffened cruciform joint. During the “FPSO Fatigue Capacity JIP” (7), a proper link between the calculated hotspot stress and the fatigue capacity was established and recommendations for how to perform the fatigue assessment based on FE analysis stress results (5) combined with one S-N curve (8) was developed.

A specific procedure was developed particularly for web-stiffened cruciform joints for hot spot stress determination at plate flange connection and hot spot stress determination in way of the web of the web-stiffened cruciform joints. The procedure is specific for web-stiffened cruciform like welded hopper knuckle connections, horizontal stringer heel joint, lower stool-inner bottom connection to avoid too conservative results. (10)

4.4 Fatigue screening assessment

4.4.1

Fatigue screening assessment is to be carried out for a list of details corresponding to screening areas provided in Ch 7, Sec 3, [3] located in high stress area and/or high stress concentration area which are not included in the lists of critical details to be checked by simplified stress analysis or very fine mesh FE analysis.

The details checked by the screening method are considered less critical for fatigue compared to the details that are mandatory to be checked by very fine mesh FE. The details subjected to screening assessment are considered critical if the stress level becomes high. The screening assessment will select the details with high stress level for further fatigue assessment by very fine mesh FE.

This procedure allows detecting potential fatigue areas using fine mesh (50×50mm) finite element models, refer to Ch 7, Sec 3, already used for strength assessment. This procedure allows avoiding carrying out FE fatigue analysis based on very fine mesh (t_{n50}×t_{n50}) model, refer to Sec 4 which are time consuming and costly task.

4.5 Fatigue design standards

4.5.1

Fatigue design standards provide a qualitative approach that may be applied to the design of ship structural details to improve fatigue performance by providing guidance for the following items:

- Identification of the critical locations for each of the structural detail.
- Requirements on geometrical configurations, scantlings, welding requirements and construction tolerances.
- Provision of a set of alternative improved configurations from which a suitable option can be selected.
- Post fabrication methods of improving fatigue life, such as weld toe grinding

It is required that the structural details described in this section shall be designed according to the given design standard but alternative detail design configurations will be accepted subject to demonstration of satisfactory fatigue performance.

5 CORROSION MODEL

5.1 Net thickness

5.1.1 General

The "net thickness concept" is adopted in the strength requirements. The strength criteria are established so that the strength integrity can be maintained even though the thickness diminution due to corrosion during the design life may occur. Damage phenomena like yielding, buckling and ultimate strength are dominated by an excessive load. On the other hand, fatigue phenomenon is dominated by the cyclic fatigue loading during the long period. Therefore, the consideration of corrosion effect on fatigue strength is different from the consideration against yielding, buckling and ultimate strength.

Fatigue strength is assessed according to the linear cumulative fatigue damage which is proportional to the time. In this case, fatigue damage which is assessed based on the half of corrosion addition can be the almost compatible damage with the value which is assessed according to the consideration of corrosion progress. Therefore, the net thickness of local support members is appropriate to be obtained by deducting $0.5t_c$ from the gross thickness.

5.1.2 Stress correction

Corrosion amount is a spatial random variable which has wide scatter. Then, smaller the assessed object, the more the effect of probabilistic nature of corrosion becomes large. On the other hand, the more the assessed object is large, the more the effect of probabilistic nature of corrosion becomes small. Therefore, when assessing the strength of structure or hull girder, the assessment based on the corrosion model of average corrosion diminution is appropriate.

The average corrosion amount is almost corresponding to the half of corrosion addition. Therefore, the net thickness of hull girder section and structural members in FE model is appropriate to be obtained by deducting $0.25t_c$, which is the half of corrosion deduction of local support members, from the gross thickness. The evaluated stress according to the $0.25t_c$ corrosion model is confirmed to be 0.95 times the evaluated stress according to the $0.5t_c$ corrosion model. In order to apply one common approach for the net thickness of hull girder stress and structural members in FE model they should be based stress obtained by use of $0.5t_c$ and multiplying the stress with correction factor 0.95.

6 LOADING CONDITIONS

6.1 Description

6.1.1

Technical background is not considered necessary.

6.2 Loading conditions for oil tankers

6.2.1

The two most representative loading conditions are chosen. The oil tankers will normally operate in either fully loaded condition or normal ballast (IACS Rec 56, July 1999) [9].

6.3 Loading conditions for bulk carriers

6.3.1

For bulk carriers with different intended operations, the typical loading conditions were selected: Full load homogeneous condition, Full load alternate condition, Normal ballast condition and Heavy ballast condition.

The frequency of those typical loading conditions of standard bulk carriers is set based on questionnaires given to the shipping companies and on the comments received.

For the fraction of time in the heavy ballast loading condition for BC-B and BC-C ships with L < 200 m, a study, which includes an investigation and impact analysis, has been carried out. The conclusion shows that the fractions of time in the heavy ballast loading condition and normal ballast loading condition can be determined as 25% and 5% respectively. Technical Background report "TB Rep_CSR_URCN1_TBReport_for FR1-8/NC03: Fraction of time in heavy ballast loading condition for BC-B and BC-C ships with L < 200 m (2015 GBS audit IACS/2015/FR1-8/NC 03)" can be refered to.

7 LOADS CASES

7.1 Assumptions

7.1.1

Technical background is not considered necessary.

7.1.2 Predominant load case

Technical background is not considered necessary.

References:

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2. Health and Safety Executive, "Offshore Installations: Guidance on Design, construction and certification", Fourth Edition, 1995.
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6. Lotsberg, "Fatigue design of plated structures using finite element analysis", Journal of Ship and Offshore Structures, 2006, Vol. 1, No. 1, pp. 45-54.
7. Lotsberg, "Overview of the FPSO Fatigue Capacity JIP", OMAE 2001, Rio de Janeiro.
8. Maddox, "Recommended design S-N curve for fatigue assessment of FPSOs", Proceedings of the 11th ISOPE 2001, Stavanger.
9. IACS Rec 56, "Fatigue Assessment of Ship Structures", July 1999.
10. Lotsberg & al, "A procedure for fatigue design of web stiffened cruciform connections", Vol. 3, No. 2, pp. 113-126, SAOS, 2008.

1 SIMPLIFIED STRESS ANALYSIS

1.1 Structural details to be assessed

1.1.1

The critical structural details for fatigue assessment by simplified analysis are based on review by all Societies' Design Offices.

2 FINITE ELEMENT ANALYSIS

2.1 Structural details to be assessed

2.1.1 General

Technical background is not considered necessary.

2.1.2 Details to be checked by very fine mesh analysis

Summary of critical structural details for fatigue assessment by finite element method and their applicability provided in Table 1 and Table 3 are presented based on review by all Societies' Design Offices.

The details in Table 1 and Table 3 that are mandatory for very fine mesh FE analysis are selected based on their vulnerability for fatigue cracking, i.e. the most critical details in the vessels are verified by use of very fine FE analysis. Details may also be designed to limit possibilities for fatigue cracking. Very fine mesh FE analysis may be omitted for the details listed in Table 3 provided that the design standard given in Ch 9, Sec 6 is complied with. The design standards are based on accumulated in-service experience from all Societies.

Hot spots to be evaluated for critical structural details are provided in Table 4 to Table 19. Hot spots were chosen based on extensive experience in fatigue assessments by finite element method and reviewed by all Societies' Design Offices.

2.1.3 Details to be checked by screening fatigue assessment

The details in Table 2 correspond to screening areas provided in Ch 7, Sec 3, [2] located in high stress area and/or high stress concentration area which are not included in the lists of critical details to be checked by simplified stress analysis (Ch 9, Sec 2, [1]), FE analysis (Ch 9, Sec 2, [2]), or designed according to fatigue design standards (Ch 9, Sec 6), and opening in way of primary support member.

The details checked by the screening method are considered less critical for fatigue compared to the details that are mandatory to be checked by very fine mesh FE. The details subjected to screening assessment are considered critical if the stress level becomes high. The screening assessment will select the details with high stress level for further fatigue assessment by very fine mesh FE.

2.1.4 Details in accordance with detail design standard

Technical background is not considered necessary.

1 FATIGUE ANALYSIS METHODOLOGY

1.1 Cumulative damage

1.1.1

The cumulative damage is calculated using the "Palmgren-Miner" linear damage summation rule. The fatigue strength of the structure is formulated in terms of number of cycles to failure for a fixed stress range. For variable amplitude loading the long term stress range distribution may be divided into blocks with constant stress range. The damage corresponding to the number of cycles within each block is calculated and the summation is carried out linearly according to the Palmgren-Miner rule. The fatigue damage D is then written 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.

This model for linearly damage accumulation is usually attributed to Palmgren [(1)] and Miner (1945) [(29)], who independently proposed that failure will occur when the sum reaches unity. This model does not take into account cycles order. Although the Palmgren-Miner rule is a simple algorithm for predicting an extremely complex phenomenon (i.e., fatigue under random stress processes), results of tests, however, have suggested that the Palmgren-Miner rule is a reasonable engineering tool for predicting fatigue subjected to random loading.

1.1.2

With the assumption that the structural detail is subjected to N_D stress cycles during the design life, and these stress ranges are randomly distributed with the probability function $f(\Delta\sigma)$, the damage ratio is then:

$$D = \int_0^\infty \frac{N_D \cdot f(\Delta\sigma)}{N(\Delta\sigma)} \cdot d\Delta\sigma$$

For ship structures it is assumed that the probability density function of the long term distribution of stress range may be represented by a two-parameter Weibull distribution, given by:

$$f(s) = \frac{\xi}{k}\left(\frac{\Delta\sigma}{k}\right)^{\xi-1} exp\left(-\frac{\Delta\sigma}{k}\right)^{\xi}$$

where,

$\Delta\sigma$ = Stress range.
ξ = Shape parameter.
k = Characteristic value of stress range (slope parameter).

$$k = \frac{\Delta\sigma_R}{(ln N_R)^{1/\xi}}$$

N_R = Number of cycles corresponding to probability level of exceedance $1/N_R$.
$\Delta\sigma_R$ = Stress range with probability of exceedance $1/N_R$.

With long term Weibull distributed stress ranges and the number of cycles to failure, $N(\Delta\sigma)$ given by S-N curve, the closed form equation for fatigue damage ratio may be derived:

$$D = \frac{N_D}{K_2} \frac{\Delta\sigma_R^m}{(ln N_R)^{m/\xi}} \cdot \Gamma\left(1+\frac{m}{\xi}\right) \text{ for one-slope S-N curve}$$

$$D = \frac{N_D}{K_2} \frac{\Delta\sigma_R^m}{(ln N_R)^{m/\xi}} \cdot \mu \cdot \Gamma\left(1+\frac{m}{\xi}\right) \text{ for two-slope S-N curve}$$

where,

$$\mu = 1 - \frac{\left\{\gamma\left(1+\frac{m}{\xi}, \nu\right) - \nu^{-\Delta m/\xi} \cdot \gamma\left(1+(\frac{m+\Delta m}{\xi}), \nu\right)\right\}}{\Gamma(1+\frac{m}{\xi})}$$

$$\nu = \left(\frac{\Delta\sigma_q}{\Delta\sigma_R}\right)^{\xi} \cdot ln N_R$$

1.2 Fatigue strength assessment

1.2.1

Technical background is not considered necessary.

2 ACCEPTANCE CRITERIA

2.1 Fatigue life and acceptance criteria

2.1.1

Technical background is not considered necessary.

3 REFERENCE STRESSES FOR FATIGUE ASSESSMENT

3.1 Fatigue stress range

3.1.1

The fatigue stress range corresponds to the maximum stress range among the several load cases of each loading condition. The fatigue stress range corresponds to the range of cyclic stresses defined as the difference between a stress peak and valley. The stress range may be corrected to take into account several effects e.g. thickness effect [3.3], mean stress effect [3.2], etc.

3.1.2 Welded joints

The fatigue strength of welded joints is assessed based on the so called structural hot spot stress range. The stress does take into account the dimensions and geometry of the structural detail itself while the local non-linear stress caused by the notch at the weld toe is not accounted for. This notch effect is included in the hot spot S-N curve. The correct geometry of the actual weld is not known at design stage. To account for variation in the local weld geometry, a lower-bound S-N curve is used as the design curve and the lower bound quality of the weld toe geometry will be considered in the analysis.

The hot spot stress can in principle be directly derived from the performed very fine mesh FEA, or it can be derived through use of appropriate stress concentration factors and the nominal stress from analysis.

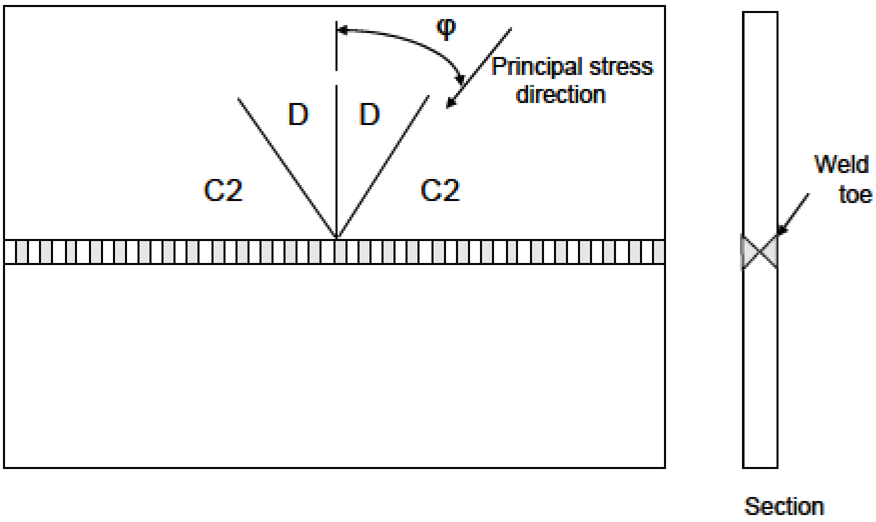
The hot spot stress concept is considered to be an efficient engineering methodology for fatigue analysis of plated structures. During the last years a methodology for derivation of hot spot stress based on FE analysis has been linked to a hot spot S-N curve giving a consistent fatigue assessment procedure. The concept has been supported by full scale measurements. The concept of structural hot spot stress is well documented trough work by International Institute of Welding (IIW) (6), (7) and the work performed in the "FPSO Fatigue capacity JIP" (2), (3), (4), (5).

Many fatigue design standards advise to use the largest principal stress range within ±45 ° to the normal to the weld toe together with an S-N curve derived for stress ranges normal to the weld toe for fatigue design. Reference is made to BS 5400 (1980), BS 7608 (1993) and DNV CN 30.7 (2008). In IIW (2007) (7), it was decided to change the angle for largest principal stress range direction from ±45 ° to ±60 ° which is now included in the present version of the IIW fatigue design guidelines. During actual design cases it has been found that the new IIW criterion can have significant impact on design of some special details and it is observed that designers have difficulties to meet the required fatigue life at these hot spots when using this procedure. Therefore, Lotsberg (18) decided to make a further assessment of recommended design criteria based on review of some relevant fatigue test data from the literature, Kim and Yamada (14).

The guideline suggested by Lotsberg (18) on how to calculate fatigue damage at weld toes based on S-N data when the principal stress direction is different from that of the normal to the weld toe has been adopted in CSR-H. With use of the hot spot stress methodology the method as presented in Figure 1 (from Lotsberg (18), *C2* = FAT100) is suggested.

The stress range in both the two principal directions should be assessed with respect to fatigue. For principal stress direction 45 ° < φ ≤ 90 ° an S-N curve for stress direction parallel with the weld can be used due to the effective stress reduction factor of 0.63 at φ = ±45 °as shown in Lotsberg (18). The S-N curve FAT100 is accounted for in CSR-H by applying a reduction factor 0.9 on the stress acting outside ±45 ° to the perpendicular to the weld toe.

Figure 1: S-N curve with hot spot stress methodology (*D*=FAT90, *C2*=FAT100)



Correction factor f_{warp} for warping stress effect is derived based on the study described in TB Report, "TB Rep_Pt1_Ch09_Sec04_Warping Effect Fatigue Longitudinal". Correction factor f_{warp} = 1.07 for the deck and top side sloping plate longitudinal stiffeners running next to the hatch opening at the location of the hatch corner, f_{warp} = 1.0 for all other longitudinal stiffeners and locations.

3.1.3 Base material free edge

Hot spots located at the free edge of base material are not affected by an artificial singularity in FE analysis. The relevant stress for fatigue could be read out directly at the hot spot location (peak stress along the free edge) without any extrapolation. In order to ensure that the hot spot stress is actually read out at the element edge it is required to use dummy beam element that will capture both axial and bending component at the plate edge.

For base material, it is recognised that the fatigue strength improves in proportion to the strength of the material such as tensile strength and yield strength. Figure 2 shows the relation between yield strength and fatigue strength at 2×10^6 cycles. Whereas the fatigue strengths of weld joints are constant regardless of the yield strength, the fatigue strength of base material clearly shows the correlation with the yield strength. Differences of fatigue strength among the weld joints are coming from the differences of stress concentration due to the joint type and the weld bead profile.

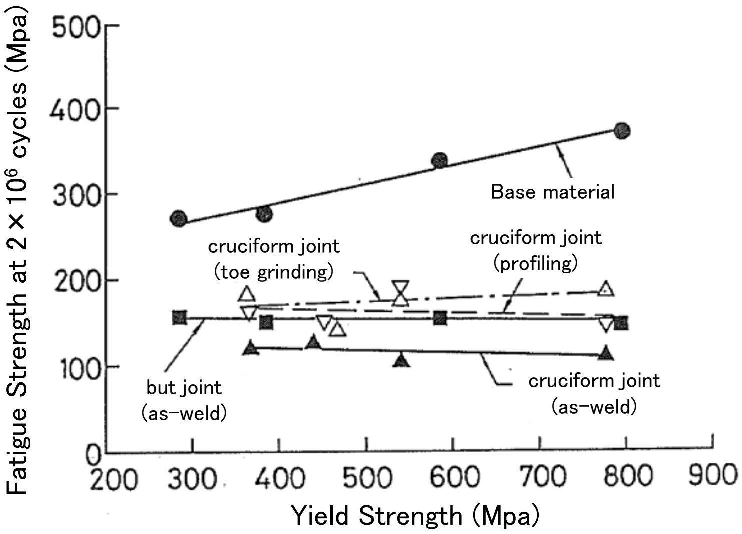
According to the results of base material, following regression result can be obtained:

$$\Delta\sigma(\sigma_Y) = 0.210\sigma_Y + 205$$

Then the correction factor for material can be defined as below:

$$f_{material} = \frac{\Delta\sigma(235)}{\Delta\sigma(\sigma_Y)} = \frac{254.35}{0.210\sigma_Y + 205} = \frac{1211.19}{\sigma_Y + 976.19} \cong \frac{1200}{\sigma_Y + 965}$$

Figure 2: Relation between yield strength and fatigue strength at 2×10^6



3.2 Mean stress effect

3.2.1 Correction factor for mean stress effect

Fatigue analysis of structures has a longer tradition related to land and offshore structures than for ship structures. Thus, it might be questioned why a fatigue procedure for ship structures are not more directly based on the experience from the existing fatigue assessment standards. The answer to this is that ship structures are normally subjected to different loading conditions during service life which may lead to more shake-down of residual stresses at significant hot spot areas and the effect of the mean stress on fatigue damage becomes more evident.

In case of ship structures, the experiences of fatigue damages clearly demonstrated the effect of mean stress on fatigue strength of welded structures, as presented by T. Yoneya, A. Kumano, N. Yamamoto and T. Shigemi, 1993 [21]. Effect of shakedown on residual stress is described by Syahroni and Berge, 2010 [11]. Laboratory measurements of residual stress after pre-load as described by Kim and Lotsberg, 2005 [14] have been applied in the development of the mean stress method.

The compressive part of the stress cycle that leads to crack closure is considered to provide less fatigue damage than a tensile stress cycle that leads to crack opening. The effective compression when considering crack closure is depending on residual tensile stress at the connection. As residual tensile stress is reduced, the compressive stress part of the stress cycle becomes less detrimental with respect to fatigue damage.

Even if the long term damage accumulation in ship structures is considered to be somewhat different from that of other types of structures as explained above, the experience from other industries and laboratory testing have been assessed in the harmonisation process of the IACS CSR rules on fatigue (July 2010). In addition the procedure has been calibrated against service experience in areas where other documented data are not available. These experience data relate especially to effect of shake-down and effect of compressive mean stresses at the hot spot areas. The mean stress correction factor on stress range in CSR-H is a further development of the two procedures applied in CSR OT [9] and CSR BC [10].

Figure 3: Illustration of mean stress correction factor applied for welded joints at longitudinal stiffeners

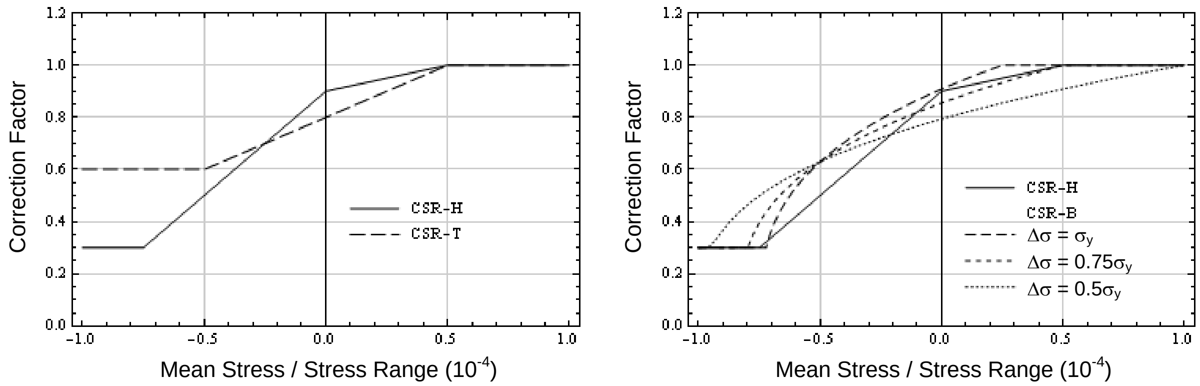
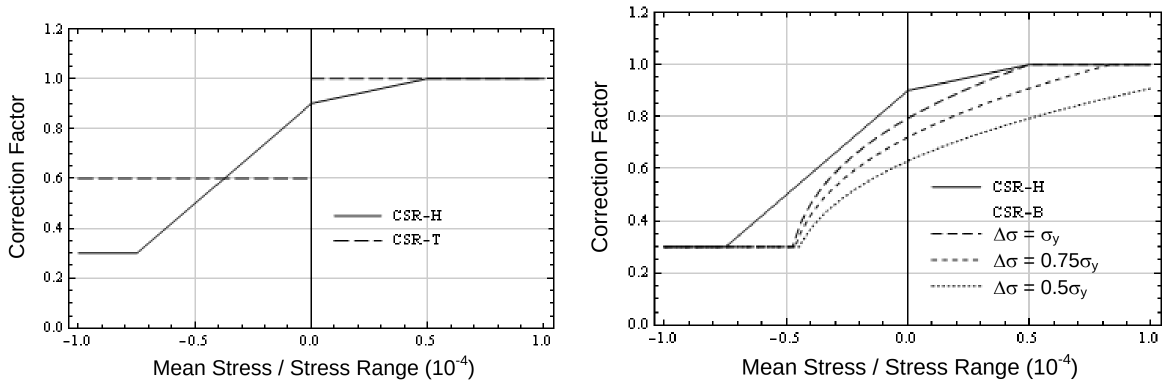


Figure 4: Illustration of mean stress correction factor applied for welded joints at primary support members



The mean stress correction factor developed for application in CSR-H is based on the following considerations:

For mean stress around zero in Figure 3, the correction factor according to CSR OT (July 2010) is given to be 0.8. This represents a situation with a detail with zero residual stress, i.e. a structure where shakedown of residual stresses to zero have already occurred. The correction factor of 0.8 around zero mean stress without residual stresses is based on test data in Gurney, 1992 (12), e.g. for stress relieved connections as referred to in TB Report, "TB Rep_Pt1_Ch09_Sec03_Mean Stress Effect".

If there are remaining residual stresses at the hot spot region, the correction factor should be larger (and closer to 1.0) around zero mean stress as observed from laboratory testing, refer to Lotsberg, 2006 (15) and Lotsberg et al, 2010 (16). A factor around 0.90 may also be argued with reference to a connection with medium residual stresses at the hot spot area in IIW, 2009 (20), described in TB Report, "TB Rep_Pt1_Ch09_Sec03_Mean Stress Effect". In this procedure for mean stress correction, the factor at zero mean stress is set to 0.9 in order to account for details with less shake-down of residual stresses. The correction factor at zero mean stress, equal 0.9, determines the correction factor for positive mean stress in Figure 3.

The actual stress range at 10^{-2} probability level is in the order only half of that at 10^{-4} level. With use of stress range at 10-2 probability level the procedure would be more sensitive to the actual level of remaining residual stress and of the mean stress than if the factor was derived at a larger stress range (some error in assessment of mean stress will lead to an increased error in the mean stress correction factor). In order to maintain the same sensitivity as in CSR OT and CSR BC the dynamic stress range at 10-2 probability level used for mean stress correction is increased with a factor 2.0. The factor 2.0 is the scaling factor to obtain the stress range at 10-4 probability level when assuming Weibull distributed stresses with shape parameter 1.0.

For the negative mean stress one do not want to lose the experience from the data base behind the bulk carrier procedure. The lower limit of 0.3 on mean stress correction factor is a result from calibration of the bulk carrier procedure against experience data. A lower limit equal 0.5 may be substantiated based on test data under constant amplitude loading without shake-down of residual stress, refer to Lotsberg and Landet, 2005 (17). This corresponds to the mean stress to stress range ratio of -0.5 where the maximum stress is equal to zero. The mean stress effect in this procedure goes through this point as shown in Figure 2. When the mean stress to stress range ratio is equal to -0.5 (i.e. entire stress cycle is in compression side based on mean (static) stress according to current procedure), the mean stress correction factor is equal 0.5. Full benefit on compression side (correction factor of 0.3) is obtained after further increase in compressive mean stress. The additional increase in compressive mean stress is necessary to overcome residual stress remaining at the hot spot, i.e. it is assumed that full shakedown has not occurred.

Above considerations are appropriate for the case that the value of mean stress is not so high like stiffener end connection and for the case that the mean stress condition changes from tension to compression due to the change in two loading conditions such as full loaded and ballast conditions typically seen in tankers.

For bulk carrier which has typical four loading conditions one will often have the case that the local tensile mean stress fully exceeds the material yield strength due to the large stress concentration factor at hot spot. In general, a compressive residual stress is locally induced after the application of large tensile stress larger than the material yield strength.

In order to take into account this effect in the fatigue assessment of primary support members of bulk carrier, the parameter "maximum stress" has been introduced in the mean stress method. The maximum stress is among all load cases and loading conditions the largest sum of the dynamic wave stress amplitude at 10^{-4} probability level and the mean stress level. In cases where this maximum stress exceeds the rule actual yield strength the method will assume that further shakedown (reduction) of the mean stress level will occur. This correction hardly affect to the case of stiffener end connection and primary support member of tankers. Since the dynamic wave stress amplitude at 10^{-4} probability level is identical to the dynamic wave stress range at 10^{-2} probability level (assuming Weibull shape parameter 1.0) the rule procedure is using the 10^{-2} probability level stress range to represent the 10^{-4} probability level stress amplitude.

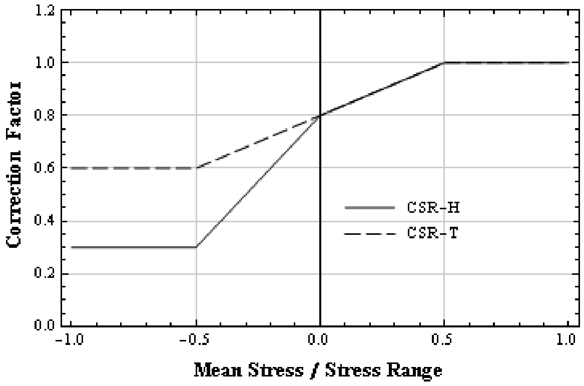
Stress range at 10^{-4} probability level is applied in the mean stress correction procedure. Larger stress ranges at another probability level may result in tensile stresses and shift the contribution of fatigue damage for larger compressive mean stresses. This shows that it is not possible by a simple procedure to fully represent the physical behaviour for all stress cycles and mean stress levels. It has to be accepted that the procedure is developed for a typical long term stress range distribution and that one should be cautious to use the procedure outside its intended use.

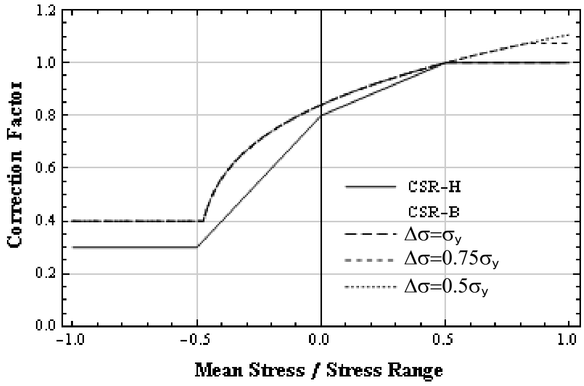
Effect of mean stress in welded joints appears when residual stress due to welding and restriction, which does not exceed the material yield strength, is relaxed due to loading and unloading. The amount of relaxation is comparable to the amount that the stress exceeds the material yield strength. Thus, when the applied loads are the same, residual stress after unloading in lower strength steel is lower than that in higher strength steel. In an extreme case that the large loads are loaded in the lower strength steel, compressive residual stress might be introduced. In the rule, the specified minimum yield stress is used, which is different from the actual yield strength. Thus, if the difference is large, the amount of relaxation of residual stress would be over-estimated. In case of high tensile steel for ship construction, the difference between actual yield strength and the specified minimum yield strength is not so large, but in case of mild steel, the difference is large. In addition, the actual yield strength of mild steel is generally higher than 235 MPa and this means that the evaluated amount of residual stress relaxation in mild steel according to the specified minimum yield strength would be over-estimated and the fatigue assessment of mild steel considering mean stress effect would be unconservative. Therefore, in the rule, for the safe side point of view, the yield strength of mild steel is assumed to be same as the yield strength of HT32 class steel.

At unwelded base material no residual stress will be evident and the situation is similar to that of a welded detail with full relaxation of residual stress. For mean stress around zero in Figure 3 the correction factor is given to be 0.8. The correction factor of 0.8 around zero mean stress without residual stresses is based on test data, refer to Gurney, 1992 [(12)], e.g. for stress relieved connections as referred to in TB Report, "TB Rep_Pt1_Ch09_Sec03_Mean Stress Effect".

For base material, a similar lower limit of 0.3 as used for welded joints is kept also for base material. The slope for negative mean stress is moved to the right compared to welded joints since no residual stress is present at the considered hot spot. Maximum benefit of mean stress effect is obtained at mean stress to stress range ratio of -0.5, i.e. when the entire stress cycle is in compression (maximum stress is equal to zero).

Figure 5: Illustration of mean stress correction factor applied for base material





3.2.2 Mean stress for base material free edge

In a given direction, the mean stress is equal to the average between the maximum stress and the minimum stress during a stress cycle. For base material free edge, the principal local stress range direction corresponds to the direction along the beam element coordinate system. So, the mean stress is directly the average between the local stresses due to static and dynamic load cases '*i1*' and '*i2*'.

3.2.3 Mean stress for simplified method

Technical background is not considered necessary.

3.2.4 Mean stress for FE analysis

For welded joints, the direction to be used corresponds to the principal hot spot stress range direction pX or pY (Figure 6). The principal direction pX is defined by the rotation of the x-direction (corresponding to the normal line to the weld toe) of the element coordinate system by the angle θ and the direction pY is defined by the rotation of the pX-direction by the angle 90°. The selected principal direction between pX and pY corresponds to this one associated to the maximum of the two hot spot principal stress ranges for weld toe with mean stress effect and thickness effect corrections.

For welded joints, mean stress corresponds to the average between the hot spot stress components due to static and dynamic load cases '*i1*' and '*i2*' in the above selected principal directions pX or pY (Figure 8).

Figure 6: Stress read out point element in the FEM model

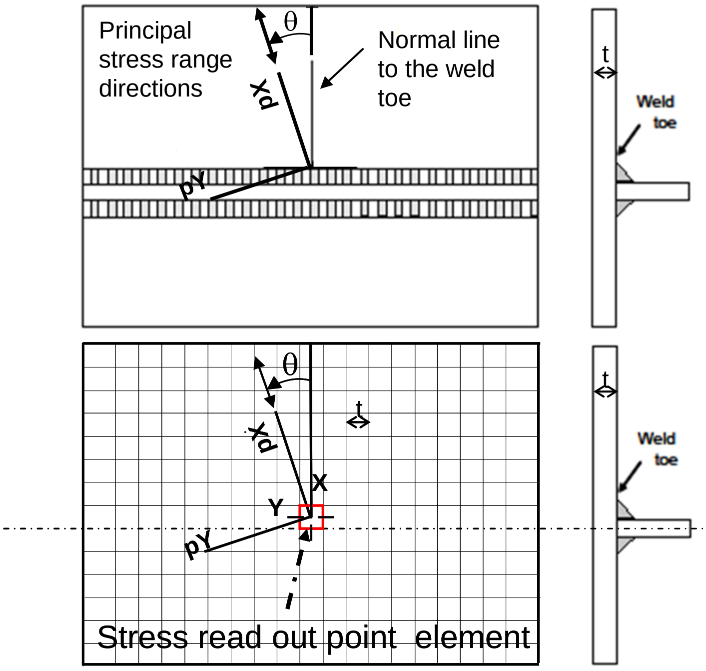


Figure 7: Hot spot stress components in the element coordinate system (*x*, *y*, *z*)

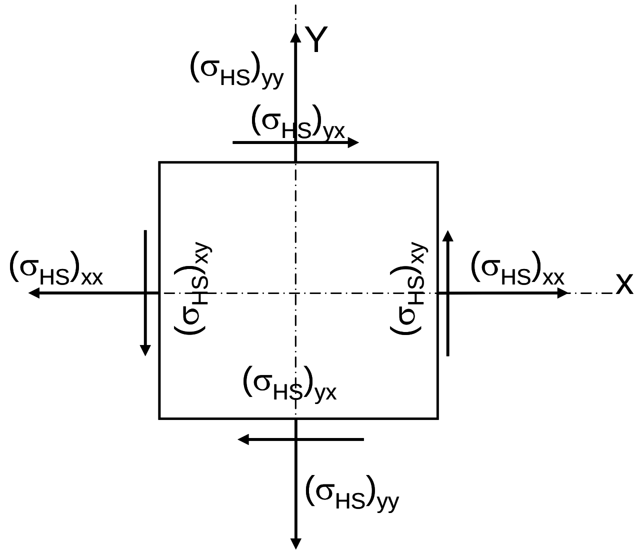
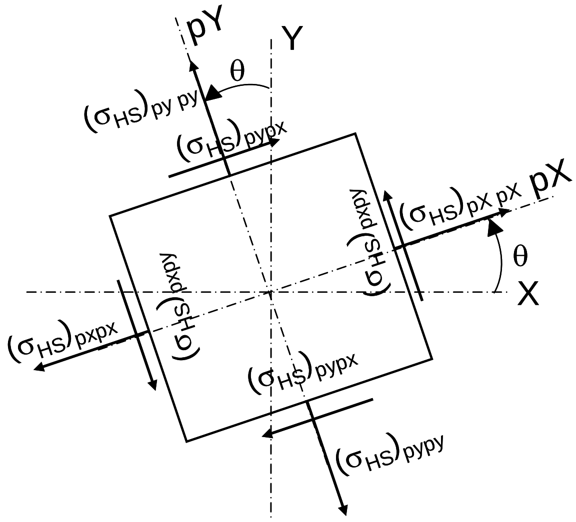


Figure 8: Hot spot stress components in the principal directions coordinate system (*pX*, *pY*, *pZ*)



3.3 Thickness effect

3.3.1

The thickness exponent is proposed based on original work by Gurney [22] where the thickness effect is taken care of by an exponential equation, '1/4 Rule' with reference to the fatigue strength of 22mm plates.

For $t > 22$mm, $S_t = S_{22}\left(\frac{22}{t}\right)^{1/4}$

where S_t is the fatigue strength of welded component of thickness t, S_{22} is the fatigue strength of welded component of reference thickness 22mm. In Hobbacher [20], the thickness exponent of n=1/4 was first derived for specimens with transverse welded attachments.

The work by Yamamoto [30] indicates that the thickness effect of cruciform joints is dominated by the stress concentration and stress gradient at weld toe which depend on the weld size. Therefore, the thickness effect of cruciform joints is sensitive to the attached plate thickness rather than the main plate thickness. Then, the IIW recommendation [23] is introduced for the cruciform joints.

Table 1 provides thickness exponents for number of welded details in as-welded condition with references to research (experimental and numerical) where the thickness exponent was obtained. Table 2 provides thickness exponents for cut edges of non-welded material.

Table 1: Thickness exponent in as-welded condition

No	Joint category description	n	Ref.
1	Cruciform joints, transverse T-joints, plates with transverse attachments	0.25	(22), (23), (30)
2	Transverse butt welds	0.2	(23)
4	Longitudinal welds or attachments to plate edges	0.1	(23)
5	Longitudinal attachments on the flatbar or bulb profile	0	n/a
6*	Longitudinal attachments and doubling plates	0.2	(24)
7	Longitudinal attachments and doubling plates supported longitudinally	0.1	(24)

* The example of stress analysis for longitudinal attachments and main plate of various thickness using effective notch stress approach is provided in TB Report, "TB Rep_Pt1_Ch09_Sec03_Thickness Effect for As Welded".

Table 2: Cut edges of non-welded material

No	Joint category description	n	Ref.
3a	Any cutting of edges by machine or flame cutting with a controlled procedure	0.1	(23)
3b	Any cut edges are to be subsequently machined or ground smooth*	0.0	(25)

* It was found in [25] that the thickness effect is not of significance between the specimens with edges machined with R=3mm and thickness varying from 22mm to 100mm if crack initiation and crack propagation through thickness are considered. The technical background for thickness exponents for welded joints improved by weld improvement methods are provided in TB documentation of Sec 5.

Table 3 provides thickness exponents for number of welded details with weld toe treated by weld improvement methods with references to research (experimental and numerical) where the thickness exponent was obtained.

Table 3: Thickness exponent for welded joints with weld after post-weld treatment

No	Joint category description	Reference
1	Cruciform joints, transverse T-joints, plates with transverse attachments	(23)
2	Transverse butt welds ground flush or weld toe treated by post-weld improvement method	(23)

3	Longitudinal attachments and doubling plates	(31)
4	Longitudinal attachments and doubling plates supported longitudinally, except longitudinal end connections	(31)

4 S-N CURVES

4.1 Basic S-N curves

4.1.1 Capacity

The basic S-N curves used in this Rules are based on DEn, 1990 (27) and HSE, 1995 (28).

4.1.2 Design S-N curves

It is an industry standard to use the design S-N curves, which correspond to the mean S-N curves (corresponding to 50% of survival of probability for relevant experimental data) minus two standard deviations. Therefore, the design S-N curves correspond to survival probability 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. Special consideration is to be give if the material yield stress is higher than 390N/mm^2. Refer to Sec 1, [1.1.5].

4.1.4 In-air environment

The basic design S-N curves of B, C and D classes in DEn, 1990 (27) are defined in terms of following parameters; constant related to the design S-N curve, inverse of slope with a change at N = 10^7 cycles. The change of inverse of slope at N = 10^7 cycles is called Haibach's effect, it corresponds to the fact that fatigue limit defined at N = 10^7 cycles under constant stress ranges is not valid in case of random stress range.

Actual fatigue limit decreases in case of random stress range and to take into account this phenomenon, a change of inverse of slope of S-N curve is performed at N = 10^7 cycles with a second inverse of slope lower than this one corresponding to the first part before N = 10^7 cycles. The change inverse of slope proposed by DEn, 1990 (27) is equal to m+2 with m is the inverse of slope of the first part of the S-N curve before N = 10^7 cycles.

4.1.5 Corrosive environment

The basic design curves in corrosive environment for D curve are adapted from the fatigue data published in the DEn, 1990. In the same guidance, the following is recommended; for unprotected joints exposed to seawater, the basic S-N curve is reduced by a factor of 2 on life for all joint classes. (Note: for high strength steels, i.e. σ_y > 400 N/mm^2, a penalty factor of 2 may not be adequate). In addition, there will be no slope change for the S-N curve in the case of unprotected joints in seawater.

The basic design curves in corrosive environment for B and C curves are adapted from the fatigue data published in HSE, 1995 (28) which correspond to a reduction factor of 3 on fatigue life without slope change.

4.2 Selection of S-N curves

4.2.1 Welded joints

For fatigue assessment of welded joints, it is recommended to apply D curve for in air and corrosive environment, respectively, with appropriate hot spot stress. The use of D curve as the "hot spot curve" was originally recommended through the work of Maddox [5] and Fricke [2] in the "FPSO fatigue capacity JIP". It should be noted that use of the D curve as the hot spot curve is closely linked to the procedure used for establishing hot spot stress from very fine element models and the requirements given to very fine element models.

4.2.2 Base material free edge

For fatigue assessment of base material at free edge, S-N curves "B" or "C" as defined in Table 2 of [4.1.4] and Table 3 of [4.1.5] are to be used for in-air and corrosive environment, respectively.

4.2.3 Surface finishing factor

The surface finishing factor K_{sf}, as defined in Table 3 (Table 4 of rule text Sec2 [4.2.3]), is a coefficient which depends on the cutting quality, post treatment and control quality of base material. K_{sf} is derived by converting the fatigue curve recommended in Hobbacher, 2009 [20] to the S-N curve applied in [4.1].

Three different surface finishing factors are given Table 3 due to different quality of surface finishing depending on the likelihood of notching from corrosion, wear and tear in service. The factors are derived as follows:

$$K_{sf} = \frac{Stress\ of\ SN\ curve\ at\ 2\cdot 10^6\ cycles}{CSR-H} \Big/ \frac{Stress\ of\ SN\ curve\ at\ 2\cdot 10^6\ cycles}{IIW\ FAT\ class}$$

Example Joint No. 1: $K_{sf} = {CSR-H: B\ curve}/{IIW\ FAT\ 160} = {149.91}/{160} = 0.94$

Table 4: Surface finishing factor

No	Description of joint	K_{sf}	S-N curve
1	Rolled or extruded plates and sections as well as seamless pipes, no surface or rolling defects. Recommended S-N curve is FAT 160 (m=4) in IIW, Hobbacher, 2009 (2029).	0.94	B
2	Plate edge sheared or machine-cut by a thermal process with surface free of cracks and notches, cutting edges chamfered or rounded. Stress increase due to geometry of cut-outs to be considered. Recommended S-N curve is FAT 140 (m=4) in IIW, Hobbacher, 2009 (20).	1.07	B
3	Plate edge not meeting the requirements of type 2, but free from cracks and severe notches.		

	Machine cut or sheared edge: Recommended S-N curve is FAT 125 (m=3.5) in IIW, Hobbacher, 2009 (20).	1.00	C
	Manually thermally cut: Recommended S-N curve is FAT 100 (m=3.5) in IIW, Hobbacher, 2009 (20).	1.24	C

5 FATIGUE DAMAGE CALCULATION

5.1 General

5.1.1

During the design life, the vessel and the structural details are subjected to different loading conditions of varying time fraction depending on the ship's type. Moreover, during the 25 year design life, a structural detail is assumed to experience two consecutive periods corresponding to in-air environment and corrosive environment respectively.

It is assumed that corrosion protection is partially effective, i.e. that joints in way of water ballast, oil cargo hold and fuel oil holds, are efficiently protected against corrosion during a certain amount of time (called effective corrosion protection period) and during the remaining part of the design life, they are exposed to corrosive environment because the corrosion protection is more questionable. During the effective corrosion protection period (associated to protected environment), the steel surface is protected from the corrosive environment. Then, the steel may be considered to be as in dry air condition.

In this case, the fatigue strength may be assessed with the S-N curves in-air, Sec 2, [4.1.4] for the effective corrosion protection. During the remaining life when the joint is subjected to corrosive environment, fatigue strength may be assessed with the S-N curves in corrosive environment, Sec 2, [4.1.5]. Then, design life may be divided into one interval with protected environment condition and one interval with unprotected environment condition. Each of these intervals is divided into different loading conditions depending on each ship's type.

As an example, the assumption made in the Rules is that coatings in ballast tanks are to be provided and maintained. Therefore, the structure is assumed to spend most of the time in a protected environment and the remaining time in a corrosive environment. The time in corrosive environment, T_C is assumed to be the last 5 years of the ship's design life (T_D = 25 years) when limited coating maintenance is expected.

5.1.2

According to the above information, total fatigue damage relative to the design life may be calculated as the sum of the damage accumulated during the period in air environment and the damage accumulated during the period in corrosive environment. Taking into account the linearity of the damage accumulation, Sec 2, [1.1], each loading condition is considered separately and is divided into a period of protected environment (called in-air) and a period of unprotected environment (called in corrosive environment).

Combined fatigue damage is calculated for each loading condition. It corresponds to the combination of damage accumulated in air and damage accumulated in corrosive environment during a specific loading condition. Damage accumulated during a specific loading condition associated to a specific environmental condition (air environment or corrosive environment) is calculated; it is called elementary fatigue damage.

5.2 Elementary fatigue damage

5.2.1

Elementary fatigue damage for each loading condition is calculated for both air and corrosive environment and is based on fatigue stress range obtained for the predominant load case, Sec 1, [6.2] and [6.3]. Elementary fatigue damage has a "closed form" format and is based on the assumption that long term distribution of stress range of a structural detail in a ship structure follows a two-parameter Weibull distribution with specific shape and slope parameter, Sec 1, [3].

Elementary fatigue damage calculation is performed for the number of wave cycles, IACS Recommendations No.56 (26) encountered during the design life corresponding to 25 years. However 85% of the ship's service life is considered as effective i.e. in operation at sea (26); the remaining time (15%) corresponds to the non-sailing time for operations such as cargo loading/unloading, inspection and maintenance. Elementary damage calculated for air environment is based on basic design S-N curves of B, C and D classes in air environment, UK DEn, 1990 (27) with change of inverse of slope at N = 10^7 cycles in order to take into account the Haibach's effect for small stress range. In the case of air environment, coefficient μ takes into account the change in inverse of slope of the S-N curve.

Elementary damage calculated for corrosive environment is based on basic design S-N curves of B, C and D classes in corrosive environment, UK DEn, 1990 (27) and HSE, 1995 (28) with a single inverse of slope m=3 for all stress ranges. In the case of corrosive environment, coefficient μ is taken to be 1.0.

5.3 Combined fatigue damage

5.3.1

The combined fatigue damage for each loading condition is the sum of damage accumulated during the period in-air environment (T_D-T_C) and damage accumulated during the period in corrosive environment, T_C. The damage accumulated during each period is calculated in proportion of time spent in each environmental condition.

Values of time spent in corrosive environment are given in Table 5 according to the weld joint or structural detail location. The values are consistent with the principles given in Pt 1, Ch 1, Sec 3 and Pt 2, Ch 3, Sec 3. The values are from the conclusion of a study that was conducted to determine the time in a corrosive environment is determined. Technical Background report "TB Rep_CSR_URCN1_TBReport_for FR1-8/NC04: Time in corrosive environment (2015 GBS audit IACS/2015/FR1-8/NC 04)" can be referred to.

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	10
Oil cargo tank	

Lower part[(1)] of bulk cargo hold and water ballast cargo hold	
Bulk cargo hold and water ballast cargo hold except lower part[(1)]	5
Void space and other areas	
(1) Lower part means cargo hold part below a horizontal level located at a distance of 300 mm below the frame end bracket for holds of single side skin construction or 300 mm below the hopper tank upper end for holds of double side skin construction.	

5.4 Total fatigue damage

5.4.1

Technical background is not considered necessary.

5.5 Fatigue life calculation

5.5.1

The calculated fatigue life, T_F is calculated from the total fatigue damage in air environment considering all loading conditions and the total fatigue damage in corrosive environment considering all loading conditions.

Two cases of calculation are considered due to the fact that the damage rate differs according to the environmental condition (air environment or corrosive environment) of the detail.

1. If the failure occurs during the period in-air, i.e. T_F is inferior or equal to (T_D-T_C), the calculated fatigue life, T_F is calculated from the total fatigue damage in air.
   $$T_F = \frac{T_D}{D_{air}} \text{ if } \frac{T_D}{D_{air}} \leq (T_D - T_C)$$
2. If the failure occurs during the period in corrosive environment, i.e. T_F is superior to (T_D-T_C), calculation of T_F requires to determine firstly the damage accumulated during the period in-air, i.e. (T_D-T_C) and secondly to determine the remaining damage accumulated during the period in corrosive environment. As the failure is assumed to occur when the damage is equal to unity, then the damage accumulated during the period in corrosive environment is equal to unity minus the last damage determined above. The calculated fatigue life, T_F is calculated as the sum of time spent in-air environment, i.e. (T_D-T_C) and the time spent in corrosive environment calculated from the damage accumulated during the period in corrosive environment.
   $$T_F = \left(Time\, in\ air = T_D - T_c\right) + \ (Life\ in\ corrosive\ environment)$$

The damage $D_{air,(Td\text{-}Tc)}$ accumulated during the time in air (T_D-T_C) is written as:

$$D_{air,(T_D - T_C)} = \frac{D_{air} \cdot (T_D - T_C)}{T_D}$$

The damage accumulated during the life in corrosive environment (before fracture) is equal to:

$$D = 1.0 - D_{air,(T_D - T_C)} = 1.0 - \left(\frac{D_{air} \cdot (T_D - T_C)}{T_D}\right)$$

As mentioned above:

$$T_F = (Time\,in\ air = T_D - T_c) + (Life\ in\ corrosive\ environment)$$

Life in corrosive environment is taken as:

$$\left(1.0 - \left(\frac{D_{air} \cdot (T_D - T_C)}{T_D}\right)\right) \cdot \frac{T_D}{D_{corr}}$$

Time in air-environment is taken as T_D-T_C. Combining time in air and life in corrosive environment the total fatigue life becomes:

$$T_F = T_D - T_C + \left(1.0 - \left(\frac{D_{air} \cdot (T_D - T_C)}{T_D}\right)\right) \cdot \frac{T_D}{D_{corr}}$$

$$T_F = T_D - T_C + \left(\frac{T_D}{D_{air}} - T_D + T_C\right) \cdot \frac{D_{air}}{D_{corr}}$$

where,

T_D = Design fatigue life.

T_C = Time in corrosive environment.

D_{air} = Damage during 25 years in air-environment.

D_{corr} = Damage during 25 years in corrosive-environment.

$D_{air,(Td-Tc)}$ = Damage during the actual time in air-environment.

6 WELD IMPROVEMENT METHODS

6.1 General

6.1.1

The post-weld treatments methods and procedures are based on recommendations by IIW [(32), (23)].

RCN 1 to CSR 01 Jan 2020 is based on feedback from the IMO audit regarding "IACS/2015/FR1-8/OB/17 (Post weld treatment)". Auditors are primarily concerned that a "corrosion free condition" as a prerequisite for the effectiveness of post weld treatment cannot be ensured in practice.

TB report, IACS/2015/FR1-8/OB/17 (Post Weld Treatment) Rev 0-2019-02-08, was made and approved to address this observation. In addition to TB report, the rule text is proposed to be amended to alleviate this concern.

6.1.2 Limitation of the benefit of post-weld treatment

The improvement factor on fatigue life that can be claimed on mild steel is 2.2 according to IIW [(32),(23)]. To avoid very high nominal stress level and low un-treated fatigue life it is required that the life before post-weld treatment exceeds 17 years. This requirement is adopted from CSR OT [(33)]. With this requirement the effective improvement factor becomes 1.47 for design life 25 years. However, due to very early damage in the corrosion protective coating on structural details inside a bulk cargo hold the calculated fatigue life at design stage excluding post-weld treatment effects is not to be less than 25 years.

6.1.3 Post-weld treatment at fabrication stage

The description of the basic post-weld treatment method to improve fatigue strength at the fabrication stage is adopted from IIW recommendations [(32), (23)].

6.1.4 Weld toe

The application of post-weld treatment methods to the weld toe is required according to IIW recommendations [32].

6.1.5 Weld type for post-weld treatment

Full or partial penetration welds with a minimum root face according to Ch 12, Sec 3, [2.4] is required based on recommendations by IIW [32].

6.2 Weld toe burr grinding

6.2.1

The requirements for weld toe burr grinding are adopted from IIW recommendations [1] and CSR OT [33].

6.2.2

The description of application of weld toe burr grinding is based on recommendations by IIW [32].

6.3 Fatigue improvement factor

6.3.1

Fatigue improvement factor for weld toe burr grinding is based on recommendations by IIW [32], [23].

6.4 Applicability

6.4.1

The limitations of post-weld improvement methods and fatigue improvement factors provided in this section are adopted as follows:

- High cycle fatigue limitation is based on IIW recommendations [32].
- Limitation on thickness is based on on IIW recommendations [32], [23].
- Consideration of burr grinding only is based on on IIW recommendations [32], [23].
- Longitudinal end connections are excluded from consideration as failure from weld toe cannot be ensured.
- Mechanical damages may introduce stress concentration area into weld toe improved by weld improvement technique therefore fatigue improvement factor may not be achieved.
- Treatment of inter-bead toes for large multi-pass welds is required based on recommendations by IIW [32].

7 WORKMANSHIP

7.1 Application

7.1.1

Technical background is not considered necessary.

7.2 Workmanship control for construction details

7.2.1 Building alignment and tolerance control

Technical background is not considered necessary.

7.2.2 Weld profile control

Technical background is not considered necessary. Refer to TB of Ch 9, Sec 5.

7.2.3 Post-weld treatment methods

Technical background is not considered necessary. Refer to TB of Ch 9, Sec 5.

7.2.4 Detail design standard

Technical background is not considered necessary. Refer to TB of Ch 9, Sec 7.

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1 GENERAL

1.1 Application

1.1.1
Technical background is not considered necessary.

1.1.2
Technical background is not considered necessary.

1.2 Assumptions

1.2.1
Technical background is not considered necessary.

1.2.2
Technical background is not considered necessary.

2 HOT SPOT STRESS

2.1 Hot spot stress range

2.1.1
Technical background is not considered necessary.

2.2 Hot spot mean stress

2.2.1
Technical background is not considered necessary.

3 HULL GIRDER STRESS

3.1 Stress due to hull girder wave bending moments

3.1.1
The wave induced hull girder stress should be considered in fatigue assessment. The nominal stress range is determined by beam theory and the stress concentration factor is considered in determining the hot-spot stress.

3.2 Stress due to still water hull girder bending moments

3.2.1
The hull girder stress due to still water bending moment should be considered as the mean stress effect in fatigue assessment. Still water bending moment is defined by permissible still water bending moment by a factor. The stress is determined from beam theory.

To avoid the consequence on fatigue life from changes in actual SWBM during design, still water bending moment was decided to use a fraction of permissible SWBM, based on the collected database of actual SWBM from nine societies.

4 LOCAL STIFFENER STRESS

4.1 Stress due to stiffener bending

4.1.1 Stress due to dynamic pressure

This is a procedure in which the nominal stress is assessed by beam theory, and multiplied by the stress concentration factor to assess the hot-spot stress. The stress assessment is performed by determining the stress by beam theory for each load component and superimposing the stresses. In this case, it should be noted that the sign of the stress varies with the direction in which the lateral pressure is applied.

When longitudinal stiffeners are connected by flat bars or brackets at the position where they pass through transverse bulkheads or transverse webs, the stress concentration due to structural discontinuity at the connections is to be considered. In the simplified procedure, assessment is performed by multiplying the nominal stress with the stress concentration factor. Since there have been many instances of design and construction of structural details of joints of longitudinal stiffener at these locations, stress concentration factors for these typical detailed joints are given for design assistance.

In the assessment of stress due to local dynamic pressure, the effect of increase in stress accompanying the tripping of stiffeners of asymmetric cross section is considered separate from the stress concentration factor due to the shape of the detailed joint, and the stress concentration factor determined from elastic beam theory is considered.

The wave induced pressure along ship side is modelled as shown in Figure 1. Amplitude of wave pressure depends on the vertical location and is proportional to the wave height in general. Therefore, if the subject point is above the waterline level, wave pressure acts when the wave crest is higher than the position. And, if the subject point is below the waterline level and is higher than the wave trough, there is the case that the wave pressure does not act.

The important point is that these phenomena depend on the relation between the vertical position to be evaluated and wave height, and the wave height is stochastic. Therefore, correction factor for wave induced pressure around the waterline is introduced by means of expectation considering the pressure and its occurrence probability.

The 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. This condition can be used when the loading manual requests specifically that the tanks on both sides of the stiffener are to be filled simultaneously. This is for example the case for the longitudinal bulkhead of oil tanker between oil tanks which must be full in full load conditions. For ballast tanks, the loading manual has to specify the obligation to have both tanks full at the same time.

b_{eff} : Effective breadth, in mm, of attached plating specified at the ends of the span and in way of end brackets and supports shall be taken as;

$$b_{eff} = s \cdot min\left[\frac{1.04}{1 + 3\Big/\left(\dfrac{l_{bdg}\left(1-\frac{1}{\sqrt{3}}\right)\cdot 10^3}{s}\right)^{1.25}};1.0\right]$$

The TB for the formula is given in TB Report, "TB Rep_Pt1_Ch03_ Sec07_Effective Plate Breadth".

4.1.2 **Stress due to static pressure**

Technical background is not considered necessary.

4.2 Stress due to relative displacement

4.2.1 **General**

At positions where longitudinal stiffeners pass through transverse bulkheads, the deformation of the entire cargo tank is constrained. Thus, secondary bending stress due to relative displacement occurs at the penetrating position of the bulkhead, and the penetrating positions of the forward and aft transverse bulkheads.

4.2.2 **Relative displacement definition**

Technical background is not considered necessary.

4.2.3 **Sign convention**

Technical background is not considered necessary.

4.2.4 **Oil tankers**

The stress factor, K_d, is derived based on cargo tank FEM study, considering the effect on bending stress in longitudinal stiffeners caused by relative displacement between supports.

4.2.5 **Bulk carriers**

In the case of bulk carriers, the simplified rule requirement like oil tankers is difficult because of the variety of tank arrangement, the complicated form of tanks, variety of loading conditions, etc. Therefore, in order to evaluate the effect of relative displacement, it is necessary to obtain the amount of displacement by the FE analysis.

4.2.6 **Stress due to relative displacement derived using FE method**

When the relative displacement of transverse web adjacent to the bulkhead is derived using FE analysis, an additional stress due to relative displacement can be established based on the theory of continuous beam.

Since the actual boundary condition of the continuous beam is the intermediate condition between fixed condition and simply support condition, the coefficient which represent the effect of boundary condition in the formula has been obtained based on the FE analysis, reference is given in TB Report, "TB Rep_Pt1_Ch09_Sec04_Relative Displacement by FE".

4.2.7 **Stress due to relative displacement in still water**

Technical background is not considered necessary.

5 STRESS CONCENTRATION FACTORS

5.1 Unsymmetrical stiffener

5.1.1

The stress concentration factors at the flange, K_n takes into account the warping effect due to unsymmetrical stiffener. When subjected to lateral pressure loads, the flange and web of panel stiffeners of unsymmetrical cross-section deflect sideways in warping in addition to the lateral stiffener deflection. The additional stress in the flange by the warping deflection has been expressed in terms of a warping stress concentration factor to the nominal flange bending stress, K_n. The warping response of a panel stiffener is reduced by the constraining stiffness of the attached plate flange.

The warping stress concentration factor, K_n formula that includes the constraint by the attached plate flange has been derived based on the theory of beams on elastic foundations (5). Comparison of K_n rule formula with finite element calculations (6), (7) of laterally loaded panels having stiffeners of unsymmetrical cross-section where the warping deflection is alternatively permitted/not permitted shows that the K_n analytical rule formula values and FEM results are in good agreement.

5.1.2 **Bulb profiles**

Technical background is not considered necessary.

5.2 Longitudinal stiffener end connections

5.2.1

The tabulated Stress Concentration Factors, SCF for stiffener end connection is based on the classification of details found in the CSR OT (3) except for details 1, 2 and 25. The classification given in Reference (3) and the equivalent SCFs adopted in this Rules are based on test data, very fine mesh finite element analysis, experience and engineering judgment performed and agreed upon among the Societies. SCF's for details 1, 2 and 25 are derived from strain gauge measurements and very fine mesh FE analysis as described in TB Report, "TB Rep_Pt1_Ch09_Sec04_SCF for Flatbar Web Stiffener".

The SCFs for longitudinal stiffener end connections presented in this Rules are derived as follows:

The SCF values, 1.14, 1.34 and 1.52 of K_a (geometrical stress concentration factor due to axial loading) used on the nominal stress to obtain a hot spot stress, together with the hotspot design S-N curve "D" for fatigue assessment is equivalent to use the nominal stress together with the design E-curve, F-curve and F2-curve of UK DEn (4) also referenced in IACS Rec 56 (July 1999) (2).

The (K_a) SCF values are derived as follow:

- SCF equivalent to SN-curve: $\sqrt[3]{K_2(Dcurve)/K_2(SNcurve)}$
- SCF equivalent to E-curve: $\sqrt[3]{1.52\cdot 10^{12}\ /\ 1.026\cdot 10^{12}} = 1.14$
- SCF equivalent to F-curve: $\sqrt[3]{1.52\cdot 10^{12}\ /\ 6.319\cdot 10^{11}} = 1.34$
- SCF equivalent to F2-curve: $\sqrt[3]{1.52\cdot 10^{12}\ /\ 4.330\cdot 10^{11}} = 1.52$

The SCF value of K_b (K-bending) is based on the K_a values with the following addition due to bending effects:

- All non-soft details (toes and heels) has a 10% increase in SCF, $K_b = 1.1K_a$

At connections where there is less than 8mm clearance between the edge of the stiffener flange and the face of the attachment (supporting bracket or web-stiffener), using the hot spot stress approach the SCF should be increased with 1.12, i.e. if the nominal stress approach is used the S-N curve should be upgraded one class [4]. As explained in UK HSE [5], an edge distance criterion exists to limit the possibility of local stress concentrations occurring at unwelded edges as a result, for example, of undercut, weld spatter, or accidental overweave in manual fillet welding.

When the welds are on or adjacent to the edge of the stressed member, the stress concentration is increased and the fatigue performance is reduced and this must be separately assessed and included in the calculation of applied stress by increasing the SCF.

It was also noticed that the geometrical stress concentration factor (SCF) for stress due to axial load (Ka) assigned to soft toes of tripping brackets (TB) is higher than that assigned to soft toes of flat bar web stiffeners (FB). This is a notable difference from the IACS CSR-BC and IACS CSR-OT Rules, which assign the same SCF (or fatigue joint class in the case of CSR-OT) to soft toes irrespective of whether it is on a tripping bracket or flat bar web stiffener. In addition, the International Institute of Welding (IIW) "Recommendations for Fatigue Design of Welded Joints and Components" assigns the same SN curve to soft toes without distinguishing between a tripping bracket or flat bar web attachment as long as the toe design complies with the recommendation. With this motivation, further investigation of the hot spot stress using finite element analysis was carried out and the stress concentration factors for ID17, 18, 19, 20, 21, 22, 23, 24, 29 and 30 are updated accordingly and included in Rules issued on Jan 2018. SCF's for details are derived from the direct analysis as described in TB Report, "TB Rep_Pt1_Ch09_Sec04_Table4, Change of Stress Concentration Factors (SCF)".

5.2.2 Other connection types

Technical background is not considered necessary.

5.2.3 Overlapped connection

Very fine mesh finite element analysis using solid elements and recommendations from IIW [1] shows that the hot spots stress will increase at overlapping end connection compared to inserted connection. For overlapped connection, IIW recommends to upgrade the S-N class corresponding to a SCF in the range of 1.13 to 1.43 depending on the type of longitudinal. Due to this poor fatigue strength of overlapping connections they should not be adopted.

5.2.4 End stiffener without connection to web stiffener

Technical background is not considered necessary.

5.2.5 Soft toe of web stiffener and backing bracket

Technical background is not considered necessary.

5.2.6 Recommended detail designs

Technical background is not considered necessary.

5.3 Alternative design

5.3.1 Derivation of alternative stress concentration factors

Technical background is not considered necessary.

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1 GENERAL

1.1 Applicability

1.1.1

The analysis of potential fatigue cracks at weld toes is according to the so-called hot spot stress approach. The hot spot stress does take into account the dimensions and geometry of the structural detail itself while the local non-linear stress caused by the notch at the weld toe is not accounted for. This notch effect is included in the hot spot S-N curve. The correct geometry of the actual weld is not known at design stage. To account for variation in the local weld geometry a lower-bound S-N curve is used as the design curve and the lower bound quality of the weld toe geometry will be considered in the analysis.

The structural hot spot stress approach applies to welded joints where the fluctuating principal stress predominately act perpendicular to the weld toe and the fatigue crack will initiate at the weld toe. The hot spot stress concept is considered to be an efficient engineering methodology for fatigue analysis of plated structures. During the last years a methodology for derivation of hot spot stress based on FE analysis has been linked to a hot spot S-N curve giving a consistent fatigue assessment procedure. The concept has been supported by full scale measurements. The concept of structural hot spot stress is well documented trough work by International Institute of Welding, IIW (3), (11) and various Societies during the last years including the work performed in the "FPSO Fatigue capacity JIP" (2), (4), (6), (10).

1.1.2

Technical background is not considered necessary.

1.1.3

Two different types of hot spot configurations may occur at structural connections (4), (12), (13). The two types of hot spots are defined depending on their position on the plate and their orientation to the weld toe. For hot spot type "a", the hot spot stress is transverse to the weld toe on the plate surface. The stress distribution in front of the weld toe will depend on the plate thickness and the stress read out position ($t_{n50}/2$) and element size is made dependent on the plate thickness. The stress distribution through the plate thickness changes in the vicinity of the type "a" hot spot. At a distance $0.4t_{n50}$ from the weld toe, on the plate surface, the non-linear stress component has vanished and the stress distribution through plate thickness is almost linear. This is exploited in the stress derivation technique used to derive the structural hot spot stress (12).

For hot spot type "b", the hot spot stress is transverse to the weld toe at the plate edge of an ending attachment (forming in-plane notches). The stress distribution is independent on the plate thickness and the stress read out points cannot be established as proportions of the plate thickness. The method adopted, proposed by IIW (12), is to defined the stress read out point at an absolute distance of 5mm from the weld toe, using a mesh with absolute element size 10×10 mm, independent of actual plate thickness (4), (12), (13).

1.1.4

Technical background is not considered necessary.

1.1.5

Technical background is not considered necessary.

1.1.6

Technical background is not considered necessary.

2 FE MODELLING

2.1 General

2.1.1

Technical background is not considered necessary.

2.1.2 Corrosion model

For fatigue assessment, ideally the cargo tank model is to be based on a thickness obtained by deduction of a quarter of the corrosion addition thickness from the gross thickness. However, this will require a cargo tank FE model different from that used for strength assessment to be built. Alternatively, the analysis may be based on the same cargo tank finite element model used for strength assessment, i.e. based on deduction of half of the corrosion addition thickness from the gross thickness in conjunction with a modelling correction factor, see Ch 9, Sec 1, [5.1.2] of the Rules.

Note that if the cargo tank finite element model for strength assessment is used, all structural parts, inside or outside of the localised corrosion zone, are to be modelled using a thickness obtained by deducting half corrosion addition from the gross thickness.

2.1.3 Separate local FE model

Since the stress concentration due to structural discontinuity depends on the surrounding structural arrangements, area where a very fine mesh is mounted is to be extended so that the effect of surrounding structural arrangements on stress concentration can be represented.

2.1.4

Since the stress concentration due to structural discontinuity is remarkable in the local area, the size of very fine mesh is to be determined so that the behaviour of stress concentration can be represented. The requirements to mesh refinement of the very fine mesh model are in accordance with guidance of IIW (4).

2.1.5

Technical background is not considered necessary.

2.1.6

Technical background is not considered necessary.

2.1.7

Technical background is not considered necessary.

2.2 Hopper knuckle welded connection

2.2.1

Technical background is not considered necessary.

2.2.2

Technical background is not considered necessary.

2.2.3

Technical background is not considered necessary.

2.2.4

Technical background is not considered necessary.

2.3 Horizontal stringer heel connection

2.3.1

Technical background is not considered necessary.

2.3.2

Technical background is not considered necessary.

2.3.3

Technical background is not considered necessary.

2.4 Lower stool – inner bottom connection

2.4.1

Technical background is not considered necessary.

2.4.2

Technical background is not considered necessary.

2.4.3

Technical background is not considered necessary.

2.5 Lower stool – corrugated bulkhead connection

2.5.1

Technical background is not considered necessary.

2.5.2

Technical background is not considered necessary.

2.5.3

Technical background is not considered necessary.

2.6 Side frame bracket to hopper sloping plate connections

2.6.1

Technical background is not considered necessary.

2.6.2

Technical background is not considered necessary.

2.6.3

Technical background is not considered necessary.

2.7 Side frame brackets to the upper sloping / flat bottom wing tank connection

2.7.1
Technical background is not considered necessary.

2.7.2
Technical background is not considered necessary.

2.7.3
Technical background is not considered necessary.

2.8 Hatch corners and hatch coaming end bracket

2.8.1
Technical background is not considered necessary.

2.8.2
Technical background is not considered necessary.

2.8.3
Technical background is not considered necessary.

2.8.4
Technical background is not considered necessary.

2.8.5
For a rounded hatch corner, 15 elements will generally suffice to describe the curvature of the hatchway radius plating (1). However, for an elliptical or parabolic corner, it is considered that finer elements need to be specified in way of the tighter curvature so as to capture the peak stress.Please refer to Sec 1 of TB Report, “TB Rep_Pt1_Ch09_Sec05_FE Mesh Free Plate Edge”. Furthermore, the expected location of crack initiation for elliptical corners has also been confirmed by in-service fatigue damage experience described in Sec 2 of TB Report, “TB Rep_Pt1_Ch09_Sec05_FE Mesh Free Plate Edge”.

2.9 Boundary conditions

2.9.1 Cargo hold model
The boundary conditions applied to the ends of the cargo tank finite element model are the same as those used for the strength assessment, see Ch 7, Sec 2, [2.4] of the Rules.

2.9.2 Separate local finite element model
For local finite element models, the most common method used is to apply the nodal displacements as prescribed boundary condition to the sub-model. Where nodal forces are applied, it is common to hold the model at certain point(s) on its boundary to prevent rigid body motion. As the system is itself in equilibrium, the net force at the fixed point(s) should be negligibly small. Where the sub-model has additional grid points between the common nodal points, multi-point constraint equations can be used to define the displacements at the additional grid points. Linear multi-point constraint equation is considered to be sufficient.

It is to be noted that multi-point constraint equations can appear in different forms in different finite element software. However, as long as the displacements at the nodes on the primary support members (such as girders and floors) are defined, the exact choice of multi point constraint equations should not have significant effect on the stresses at the area of interest, which should be located at adequate distance from the boundary of the model. In practice, prescribed nodal displacements will usually be applied, as most finite element software caters for this method.

3 HOT SPOT STRESS FOR DETAILS DIFFERENT FROM WEB-STIFFENED CRUCIFORM JOINTS

3.1 Welded details

3.1.1

The procedure for derivation of hot spot stress at weld toes by use of shell elements applies to all weld toes of structural details found in a ship structure, except for the hot spots at a so-called web-stiffened cruciform joint, see [4] and hot spot at bent hopper knuckle, [3.3].

The procedure used for derivation of hot spot stress is developed based on results from the "FPSO Fatigue Capacity JIP". The JIP was initiated with the objective of obtaining reliable fatigue design procedures for plated structures on FPSOs and involved 19 participants from oil companies, designers, shipyards and classification companies.

During the "FPSO Fatigue Capacity JIP" a proper link between the calculated hotspot stress and the fatigue capacity was established and recommendations for how to perform the fatigue assessment based on FE analysis combined with one S-N curve was developed.

- A hot spot stress S-N curve for cracking from weld toes of small scale test data was derived. The tested specimens were analyzed using FE for derivation of hotspot stress. And this derivation was linked to one S-N curve to obtain a consistent fatigue assessment procedure (3), (5).
- This S-N curve was supported by full scale fatigue test specimens.
- Based on the work recommendations to FE modelling and stress extrapolation were made.
- It was found less scatter when the using stress read out at $t_{n50}/2$ position only, instead of extrapolating from $t_{n50}/2$ and $3t_{n50}/2$ (5).

Traditionally, the hot spot stress is derived by extrapolating stresses from the position $t_{n50}/2$ and $3t_{n50}/2$ from the intersection line. The hot spot stress derived from an extrapolation is consistent with use of the D curve. It was concluded from the findings of the "FPSO Fatigue Capacity JIP" that use of the surface principal stress at the $t_{n50}/2$ position alone together with use of the E curve will give equivalent results to the traditional extrapolation procedure. In order to link the stress at $t_{n50}/2$ position to the D curve the stress is multiplied with a factor 1.12. The factor represents the ratio between the E curve and D curve. The main reason for preferring use of $t_{n50}/2$ alone without extrapolation is the methods easy use of only one read out point and no extrapolation. By use of 8 node elements, the method becomes very convenient since one with a $t_{n50}\times t_{n50}$ mesh can directly read out the element stress result at the element mid-node. Another reason for the preference is the experience from the "FPSO Fatigue Capacity JIP" showing less scatter in the hot spot stress results when using the $t_{n50}/2$ position only. The method is believed to reduce user misinterpretation and give more consistent results among different users.

The method is also adopted in the DNV CN 30.7 (2). The background for the procedure is explained by Lotsberg (5). With finite element modelling using shell elements arranged in the midplane of the structure the distance to stress read out position is to be measured from the midplane, also denoted intersection line. Since the weld is not modelled using shell elements it is recommended to measure the stress read out position ($t_{n50}/2$) from the structural intersection line (mid-plane) in order to avoid stress underestimation due to missing stiffness of the weld. In many cases the stress at the actual weld toe position will be too low due to the stiffness reduction in the shell element model compared with the real structure [(2), (4), (5), (12)]. The background of the two hotspot types "a" and "b" is given in [1.1.3].

3.1.2 Stress read out methods

The stress extrapolation procedure to establish the principal stress at the stress read out point $t_{n50}/2$ is dependent on the element type used. The better representation of displacement and stresses offered by the higher order elements in addition to the mid-node result located at $t_{n50}/2$ position is simplifying the procedure when a model is made of 8 node elements. The stress extrapolation procedure is based on guidance presented in DNV CN 30.7 [(2)].

3.1.3

Technical background is not considered necessary.

3.2 Base material

3.2.1

Hot spots located at the free edge of base material are not affected by a singularity in FE analysis. The hot spot stress could be read out directly at the hot spot location (peak stress along free edge) with out any extrapolation. The stress read out point is located at the hot spot point. In order to ensure that the hot spot stress is actually read out at the element edge it is required to use dummy beam element that will capture both axial and bending component at the plate edge [(2)]. The reason is that the stress calculation is generally performed at the Gaussian integration point and not all FE software has algorithms for extrapolation of the stresses to the element surface edge.

3.3 Bent hopper knuckle

3.3.1

Comparison study between finite element solid model and shell models shows that use of the "general" stress extrapolation procedure described in [3.1.2] will result in unreasonable conservative results for the bent hopper knuckle. The comparison study indicates that the use of hot spot stress derived at the so called X-shift position will give results of shell models more similar to solid model results. The X-shift is defined as the position located $t_{n50}/2$ away from the weld toe; X-shift = $t_{n50}/2 + X\text{-}wt$, where $X\text{-}wt$ is the weld leg length. The X-shift position is used to read stresses for hot spots at the flange (inner bottom), at transverse web and longitudinal girders.

3.3.2

Technical background is not considered necessary.

3.3.3

Technical background is not considered necessary.

4 HOT SPOT STRESS FOR WEB-STIFFENED CRUCIFORM JOINTS

4.1 Applicability

4.1.1

Technical background is not considered necessary.

4.1.2

Technical background is not considered necessary.

4.1.3

Technical background is not considered necessary.

4.2 Calculation of hot spot stress at the flange

4.2.1

The procedure is developed particularly for the plate flange connection of the so-called web-stiffened cruciform joints. The procedure is used for web-stiffened cruciform joints to avoid unreasonable conservative results as shown by Lotsberg et al (9). The "FPSO Fatigue capacity JIP" found that fatigue analysis using finite element models with shell elements and traditional extrapolation procedures showed good agreement with measured test results for details governed by global force flow through the structural detail. Less good agreement was found for details governed by local behaviour. The traditional extrapolation procedure is considered conservative for web-stiffened cruciform joints.

Lotsberg et al (9) developed a procedure for web-stiffened cruciform joints based results from the "FPSO Fatigue Capacity JIP" showing that an effective stress can be obtained by reducing the plate bending stress. The development is based on finite element analysis of stiffened cruciform joints typically found in ships like, e.g. hopper connections, stringer heels and joints connecting deck structures to vertical supports. The procedure will derive the hot spot stress as such connections using shell elements also taking into account the actual weld size and angle between plate flanges of the cruciform joint.

The main calibration of the procedure (Figure 1) was performed on tested specimens with $t_1 = t_2$ = 10mm. The readout position has been made dependent on the plate thickness t_1:

$$x_{shift} = \frac{t_{1-n50}}{2} + x_{wt} \qquad (1)$$

It has been questioned if the read out point should have been made a function of t_2, for example presented by:

$$x_{shift} = \frac{t_{2-n50}}{2} + x_{wt} \qquad (2)$$

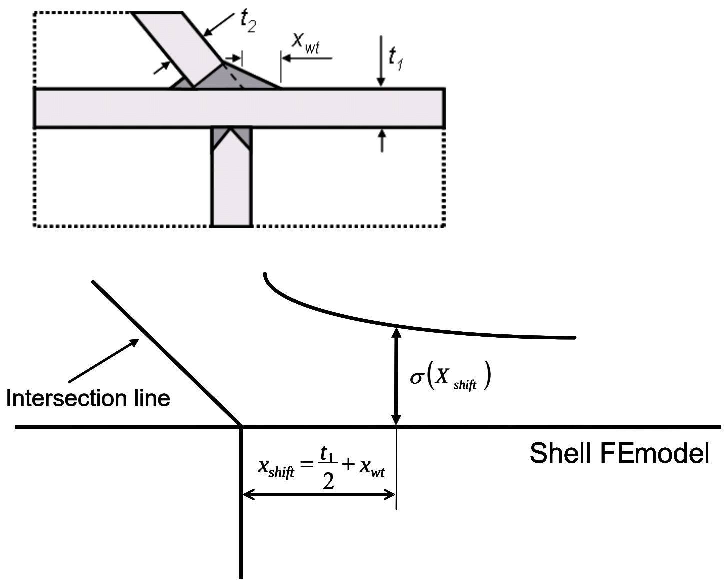
It is assessed that it is the stress in plate 1 that is governing for the fatigue capacity at the weld toe on plate 1 side of Figure 2 at hot spot 1. And it is the stress in the vertical plate 2 that is governing for the fatigue capacity of the weld toe on the transition from the weld to the plate 2 at hot spot 2. Thus for finite element modeling of the hot spot regions and read out of hot spot stress it would be the thickness t_1 that is governing for the stress at weld toe to plate 1 and it would be the thickness t_2 that is governing for the stress at weld toe to plate 2.

The stress distribution at a 45 deg hopper connection in Figure 2 is shown in Figure 4 without additional weld and in Figure 5 with additional weld. The local bending stress in the plate 1 is the major contribution to increase in hot spot stress as compared with nominal membrane. The membrane stresses and the bending stresses are extrapolated back to the weld toe for illustration (extrapolation from stresses at $t_1/2$ and $3t_1/2$ to the weld toe is shown).

The stress distribution at the hot spot 1 is not expected to change significantly even if the thickness t_2 is increased to a large value. However, one would shift the read out point to the right in the sketch of Figure 1 resulting in a corresponding reduced read out stress from the shell analysis model. Thus, this would provide a non-conservative hot spot stress. Based on this the thickness t_2 is not considered to be a relevant parameter governing the distance from the intersection line to the read out point of stress in the shell element analysis.

Further information is described in TB-report, "Correction Factor on Hot Spot Stress for Web Stiffened Cruciform Joint".

Figure 1: Illustration of procedure for derivation of hot spot stress using shell element model



$$\sigma_{hot\ spot} = (\sigma_{membrane}(x_{shift}) + \sigma_{bending}(x_{shift}) * 0.60) * \beta$$

Figure 2: Plates with hot spot at 90 deg cruciform connection

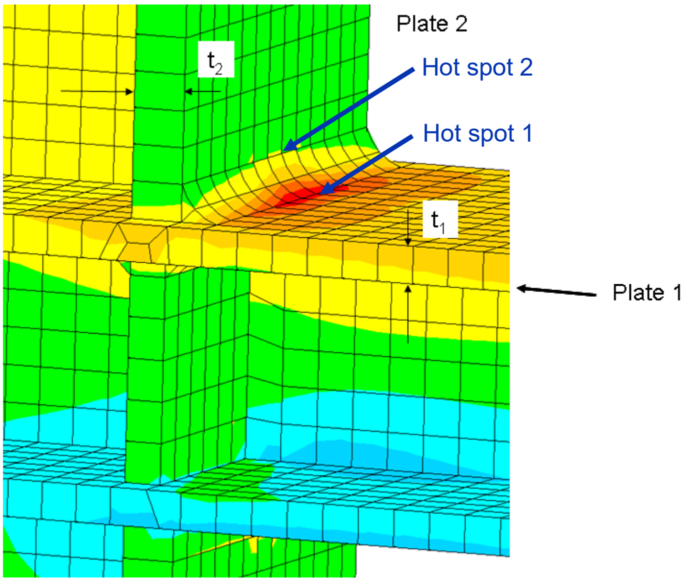
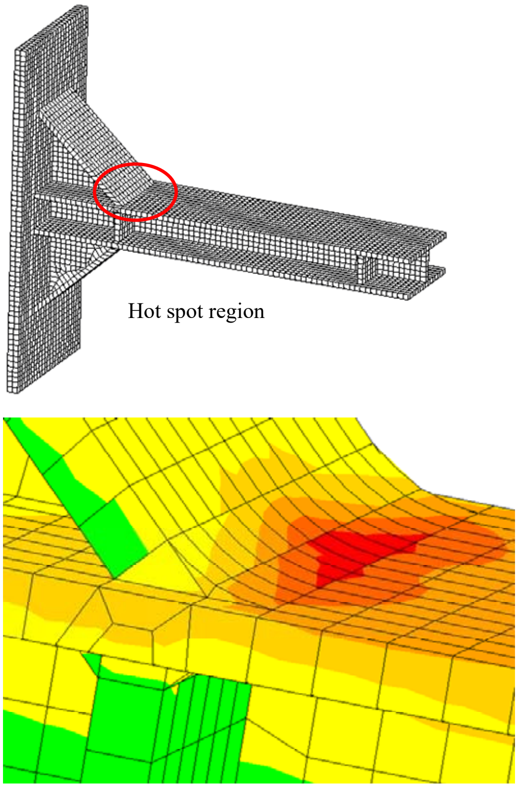


Figure 3: Solid element model of tested specimen



Solid model with t - size weld leg

Figure 4: Stress distribution in plate 1 wihtout additional weld

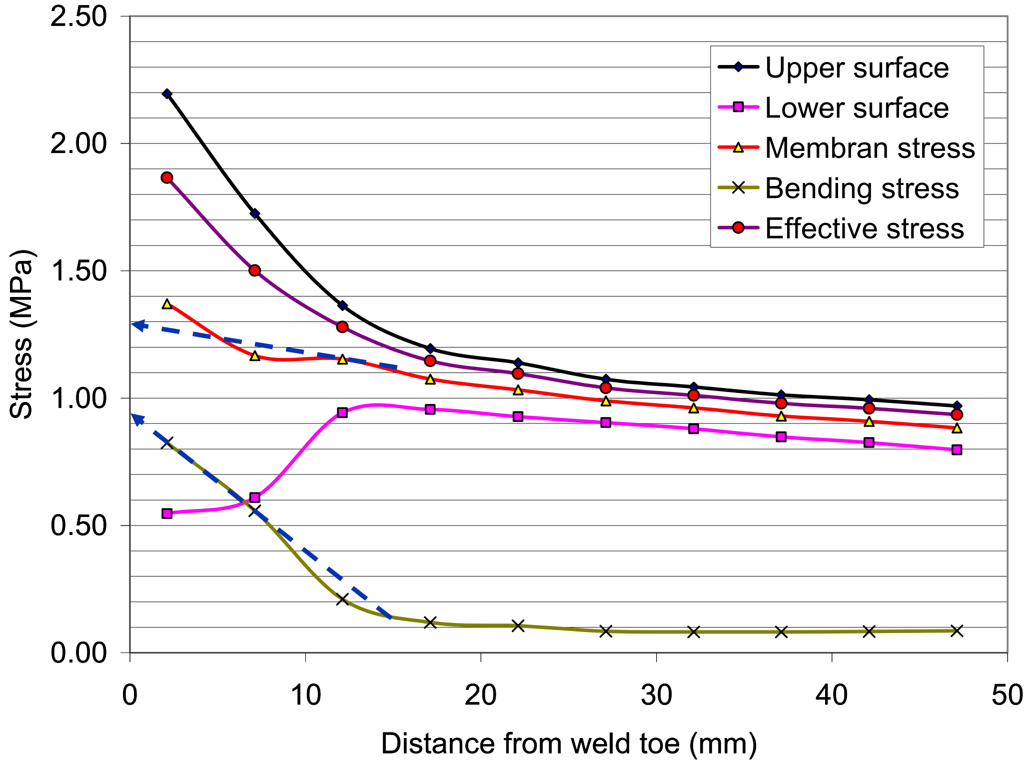
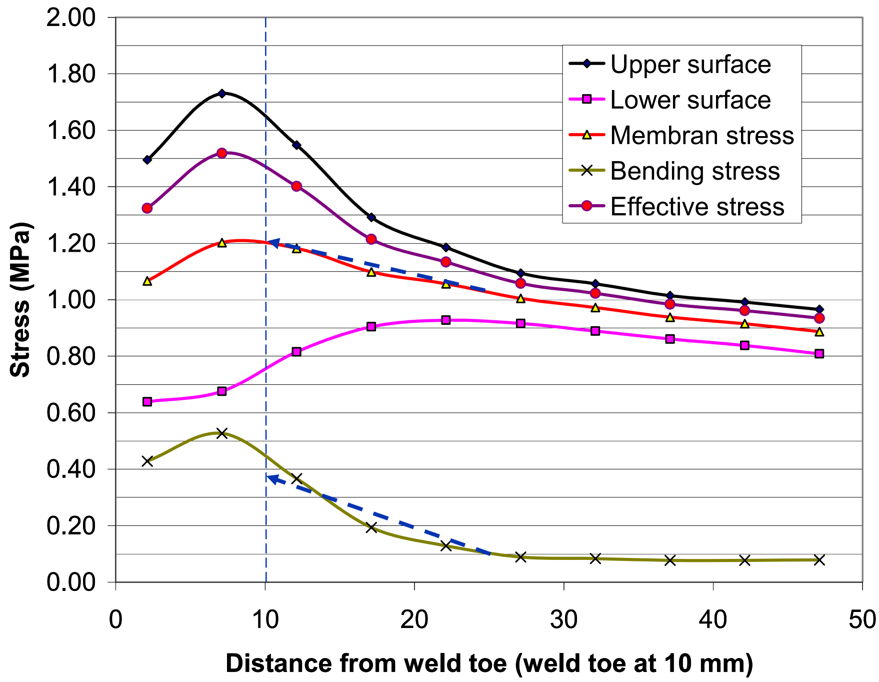


Figure 5: Stress distribution in plate 1 with additional weld leg 10mm



4.2.2

At hot spots with significant plate bending one might derive an effective hot spot stress. The reduction factor on the bending stress can be explained by redistribution of loads to other areas during crack growth while the crack tip is growing into a region with reduced stress.

The effect is limited to areas with a localised stress concentration, which occurs for example at a hopper corner. However, in a case where the stress variation along the weld is small, the difference in fatigue life between axial loading and pure bending is much smaller. Therefore it should be noted that it is not correct to generally reduce the bending part of the stress to 60 percent. This has to be restricted to cases with a pronounced stress concentration (where the stress distribution under fatigue crack development is more similar to a displacement controlled situation than that of a load controlled development).

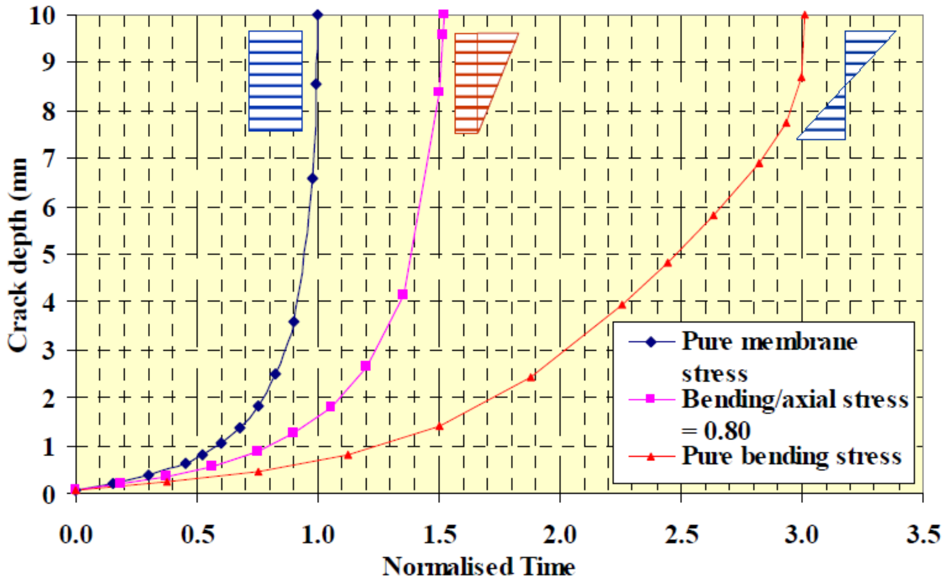
Studies show that fatigue test data of web-stiffened cruciform joint specimen is plotting high in the diagram of one hot spot S-N curve. This is likely due to local plate bending and stress gradient over plate thickness. This shows a limitation in the concept of hot spot stress in relation to one hot spot S-N curve. The reason for this is that the stress to be entered into an S-N curve for fatigue life assessment is that of surface stress without any information about the stress gradient into the thickness. Thus, details with the same hot spot stress but with different stress gradient will show the same fatigue lives based on S-N data while the actual lives might be very different.

This may be illustrated by crack growth analysis using fracture mechanics. Lotsberg and Sigurdsson (6) has investigated the problem and considering crack growth of a semi-elliptic crack. An example of a situation with the same hot spot stress, but with different stress gradients is shown in Figure 6 (6). It is seen from the results plotted in Figure 6 that the fatigue life is significantly increased in the situation of pure bending stress compared to pure membrane stress across the thickness. Based on fatigue test data under out of plane loading, a reduced effective stress was derived by Kang et al (14):

$$\Delta\sigma_{effective} = \Delta\sigma_{membrane} + 0.592 \cdot \Delta\sigma_{bending} \qquad (3)$$

where the bending stress at the hot spot is reduced by a factor. According to Lotsberg and Sigurdsson (6), the proposed equation gives results comparable with that of fracture mechanics.

Figure 6: Crack growth curves for same hot spot stress and different stress gradient (6)



The surface hot spot stress is increased by a plate angle correction factor β to account for the local bending due to presence of an additional weld leg length by the following equation:

$$\sigma_{HS} = \sigma(x_{shift}) \cdot \beta \qquad (4)$$

where,

$$\beta = \gamma + \alpha_1 \frac{x_{wt}}{t_{1-n50}} + \alpha_2 \left(\frac{x_{wt}}{t_{1-n50}} \right)^2 \qquad (5)$$

where t_1 is plate thickness at the considered hot spot region. The actual calculation of the factor β is based on Equation (6) which also includes the effect of reduced crack growth for bending load effect.

$$\sigma_{shift} = \left(\sigma_{membrane}(x_{shift}) + \sigma_{bending}(x_{shift}) * 0.60\right) * \beta \qquad (6)$$

The plate angle correction factor β for the 90° angle is in the current rule procedure adjusted compared to the factor originally developed by Lotsberg et al (9). The adjustment is done in order to calibrate the fatigue results towards experience from CSR (July 2010).

Finite element analysis using shell elements where the welds are not included in the analysis models do not account for the weld geometry which is considered to be a significant parameter for details with large stress concentrations. In the work by Lotsberg et al (9), a number of calibration analyses have been performed using three-dimensional solid elements that included the weld geometry and shell elements with 4-nodes and 8-nodes. Based on the results from these analyses a methodology for derivation of hot spot stress at welded connections using shell finite element models has been developed. The weld size is accounted for in the analysis procedure even if the weld is not included in the shell finite element model.

4.2.3

Technical background is not considered necessary.

4.3 Calculation of hot spot stress in the web

4.3.1

Comparison study between finite element solid model and shell models shows that use of the "general" stress extrapolation procedure described in [3.1.2] will result in unreasonable conservative results for the bent hopper knuckle. The comparison study indicates that the use of hot spot stress derived at the so called *X*-shift position will give results of shell models more similar to solid model results. The method is based on the procedure given in DNV CN 30.7 (2).

5 LIMITATIONS OF HOT SPOT STRESS APPROACH

5.1 Scope of application of hot spot stress approach

5.1.1

Technical background is not considered necessary.

5.1.2

Technical background is not considered necessary.

6 SCREENING FATIGUE ASSESSMENT

6.1 Screening procedure

6.1.1 Assumptions

The screening procedure assesses fatigue strength by calculating total fatigue damage as described in Ch 7, Sec 3, [3]. The fatigue damage is based on hot spot stress at weld toe of specified structural details obtained by multiplying the semi-nominal stresses obtained from available fine mesh finite element model, Ch 7, Sec 3 by tabulated stress magnification factor (η) of the classified detail, Ch 9, Sec 2, [3.1.2]. All correction factors describe in Ch 7, Sec 3 should also be accounted for in the screening assessment. Structural details that do not comply with the acceptance criteria, Ch 9, Sec 3, [2] should be checked with respect to fatigue strength assessment using a very fine mesh finite element model as described in Ch 9, Sec 5.

The stress magnification factor η is defined as:

$$\eta = \frac{\sigma_{txt-mesh}}{\sigma_{50x50-mesh}}$$

where $\sigma_{txt\text{-}mesh}$ is the principal stress obtained from $t_{n50} \times t_{n50}$ mesh model and $\sigma_{50\times 50\text{-}mesh}$ is the principal stress obtained by average membrane stress components obtained from 50mm×50mm mesh model.

6.1.2 Procedure

Technical background is not considered necessary.

6.1.3 Screening fatigue criteria

Technical background is not considered necessary.

6.2 Stress read out procedure

6.2.1 Bracket toe

Technical background is not considered necessary.

6.2.2 Knuckle detail

Technical background is not considered necessary.

6.2.3 Read out point stress

Technical background is not considered necessary.

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1 GENERAL

1.1 Purpose

1.1.1

Technical background is not considered necessary.

1.1.2

Technical background is not considered necessary.

1.2 Application

1.2.1

Technical background is not considered necessary.

2 STIFFENER-FRAME CONNECTIONS

2.1 Design standard A

2.1.1

Design standard A for stiffener-frame connections, i.e. cut outs for longitudinals in transverse webs where web stiffeners are omitted or not connected to the longitudinal flange is adopted from CSR OT (July 2010).

2.1.2

Technical background is not considered necessary.

2.2 Equivalent design of stiffener-frame connections

2.2.1

Verification procedure for equivalent alternative design of stiffener–frame connection is adopted from DNV CN 34.2 [2] also presented in Kaase [1]. Modelling of eccentric lug plate by shell elements is recommended according to DNV-RP-C206 [3].

2.2.2

Technical background is not considered necessary.

2.2.3

Technical background is not considered necessary.

2.2.4

Technical background is not considered necessary.

2.2.5

Technical background is not considered necessary.

3 SCALLOPS IN WAY OF BLOCK JOINTS

3.1 Design standard B

3.1.1

Design standard B of scallops in way of block joints is adopted from CSR OT (July 2010).

4 HOPPER KNUCKLE CONNECTION

4.1 Design standard C to H

4.1.1

Design standards C and D of the welded knuckle between hopper plating and inner bottom plating for double-hull oil tankers, with and without bracket, respectively, are adopted from CSR OT (July 2010) except for 'building tolerances' and 'welding requirements'. Building tolerances are adopted from IACS Recommendations (4) and LR FDA Level 1 (5).

For design standard C where grinding is required recommendations are made for full or partial penetration welding. Grinding is deemed to be meaningful only if used together with deep and full penetration welds, see Ch 9, Sec 3, [6]. Recommendations for weld extension and grinding are adopted from LR FDA Level 1 (5) and based on results of finite element analysis of stress distributions under fatigue loadcases.

For design standard D, full penetration welding is to be applied at bracket toes to allow for post weld treatment if necessary.

4.1.2

Design standard E of the welded knuckle between hopper plating and inner bottom plating for bulk carrier, is adopted from LR FDA Level 1 (5) and Reference (6).

4.1.3

Design standard F of the bent knuckle between hopper plating and inner bottom plating for double skin oil tanker, except VLCC is adopted from CSR OT (July 2010). Additional requirements 'Distance from side girder to centre of knuckle is to be as small as practicable, but generally not to exceed 70mm' is adopted from LR FDA Level 1 (5).

Design standard G of the bent knuckle between hopper plating and inner bottom plating for double skin oil tanker, VLCC is based on the study in Polezhayeva et.al. (7).

4.1.4

Design standard H of the bent knuckle between hopper plating and inner bottom plating for bulk carrier, is adopted from LR FDA Level 1 (5) and Reference (6).

4.1.5

Design standard I of the hopper corner connections employing radiused knuckle between side longitudinal bulkhead and hopper sloping plating is adopted from LR FDA Level 1 (5).

4.1.6

Technical background is not considered necessary.

5 HORIZONTAL STRINGER HEEL

5.1 Design standard I

5.1.1

Detail design improvement given in design standard J is recommended for reducing the stress level and increasing fatigue strength at the horizontal stringer heel location between transverse oil-tight and wash bulkhead plating and inner hull longitudinal bulkhead plating. This recommendation should be considered in association with fine mesh FE analysis as required in Ch 7, Sec 3.

The recommendation in design standard I is adopted from the CSR OT (July 2010) recommendation in way of this location. Based on feedback from application to CSR OT (July 2010), some amendments are proposed herewith, mainly the following:

- Removal of requirement for grade D thicker insert. Based on the observed stresses, this reinforcement is not considered necessary when a back bracket is fitted.
- Specifying the material grade of the back bracket to be minimum AH, which has an enhanced life for edge fatigue cracking based on higher material yield strength.
- Specifying full penetration weld in way of back bracket ends where high membrane stresses were observed.
- Adding requirement that scallops are to be avoided at bracket toe.

6 BULKHEAD CONNECTION TO LOWER AND UPPER STOOL

6.1 Design standard J, K and L

6.1.1

Survey on the fatigue damages experienced in bulkhead connection to lower stool was made and the following remarkable results were found.

- Damage occurred entirely in front and behind the corrugated bulkhead in the ballast hold.
- Most of the damage had occurred in the structure where the top plate of lower stool had a function of shedder plate.
- In cases where corrugated bulkheads had gusset plates, the damage accounted for only 5%.
- The cause of damage to corrugated bulkheads with gusset plates was due to the inappropriate shape of gusset plates and poor welding.

6.1.2

Survey on the fatigue damages experienced in bulkhead connection to upper stool was made and the following remarkable results were found.

- Ninety-nine percent of the damage occurred in front and behind the corrugated bulkhead in the ballast hold.
- In cases where corrugated bulkheads had gusset plates, the damage accounted for only 4%.
- Damage to corrugated bulkheads with no gusset plates occurred at the connections between the corners of the corrugated bulkhead and the bottom plate of the upper stool close to the centre line of the ship.

- The cause of damage to corrugated bulkheads with gusset plates was due to scallops in the stool web or the inappropriate shape of gusset plates or poor welding.

According to the above mentioned remarks and the results of survey of good existing designs, design standards for these structures are summarised. And the effectiveness of these designs was verified by the FE analysis.

7 BULKHEAD CONNECTION TO INNER BOTTOM

7.1 Design standard M

7.1.1

Survey on the fatigue damages experienced in bulkhead connection to inner bottom/hopper plating without stool was made and the following results were found.

The most damage occurred at the corner of corrugation knuckle. According to the results of survey of good existing designs which reduce the stress concentration around the corner of corrugation knuckle, design standards for these structures are summarised. And the effectiveness of these designs was verified by the FE analysis. The most important thing is to provide bracket in line with web of corrugation and keep the minimum size as indicated. No scallop has to be provided.

8 LOWER AND UPPER TOE OF HOLD FRAME

8.1 Design standard N

8.1.1

Survey on the fatigue damages experienced in end toe of hold frames was made and the following remarkable results were found.

Damage to hold frames accounted for 6 percent of damage sustained. The most damage occurred at the face end of the webs of hold frames and not at the connections between the web end of hold frames and the sloping plate of the hopper tank/top side tank. According to the results of survey of good existing designs which reduce the stress concentration around the face plate termination, design standards for these structures are summarised. And the effectiveness of these designs was verified by the FE analysis.

9 HATCH CORNER

9.1 Design standard O

9.1.1

The design standard for hatch corners and related formula in Pt 2 are based on IACS internal investigations. Bulk carriers of sizes from 50,000 dwt to 180,000 dwt have been covered by investigations using standard Rule assessment as well as spectral fatigue analysis. Design drivers are torsional load cases i.e. oblique wave loads.

References:

(1) Kaase, G.O., "Fatigue strength verification of stiffener-frame connections – DNV Class notation PLUS", PRADS 2010.
(2) Det Norske Veritas, DNV Classification Note 34.2, "PLUS – Extended fatigue analysis of ship details", Høvik, April 2009.
(3) Det Norske Veritas, DNV-RP-C206, "Fatigue Methodology of Offshore Ships", October 2006.
(4) IACS Recommendations, No.47, "Shipbuilding and Repair Quality Standard", 5 October 2010.
(5) Lloyd's Register, "Fatigue Design Assessment, Level 1 Procedure, Structural Detail Design Guide", May 2004.
(6) Interpretation of 1.3 of Ch 8, Sec 1, CSR BC Rules, January 2006, drafted by IACS PT1 Rule Maintenance team. (Email Ref: 07C1G0023_PMa, Design detail for members and locations subjected to fatigue strength assessment, IACS PT1 dated 26 July 2007).
(7) Helena Polezhayeva, Joong-Kyoo Kang, Joo-Ho Heo, "Adoption of a radiused hopper knuckle: Recommendations for design and fabrication", Journal of Offshore and Polar Engineering, Vol. 18, No. 3, 2008.

PART 1 CHAPTER 10

OTHER STRUCTURES

Table of Contents

1 GENERAL

1.1 Application

1.1.1

Technical background is not considered necessary.

2 STRUCTURAL ARRANGEMENT

2.1 Floors and bottom girders

2.1.1 Floors

The requirements contained in this sub-section are derived from the criteria and practice in portions of existing rule requirements.

2.1.2 Bottom girders

The requirements contained in this sub-section are derived from the criteria and practice in portions of existing rule requirements.

2.1.3 Alternative design verification

This sub-section enables alternative and new double bottom designs and prescribes the conditions of design verifications by means of FEA.

2.2 Wash bulkheads

2.2.1

The requirements contained in this sub-section are derived from the criteria and practice in portions of existing rule requirements.

2.3 Side shell supporting structure

2.3.1 Web frames

The requirements contained in this sub-section are derived from the criteria and practice in portions of existing rule requirements.

2.3.2 Stringers

The requirements contained in this sub-section are derived from the criteria and practice in portions of existing rule requirements.

2.3.3 Alternative design verification

Refer to TB [2.1.3].

2.4 Tripping brackets

2.4.1

The requirements of hold frames in the foremost part of the cargo hold according to IACS UR, S12 (Rev 5, May 2010) were adopted for the forward part in a transverse framing system.

2.5 Bulbous bow

All requirements in this sub-section are based on long term experience.

2.5.1 General

Technical background is not considered necessary.

2.5.2 Diaphragm plates

Technical background is not considered necessary.

2.5.3 Special bulbous bow designs

Technical background is not considered necessary.

2.5.4 Strengthening for anchor and chain cable contact

If a ship is swinging at anchor during hoisting operation, the chain and the anchor may scratch over parts of the bulbous bow causing accelerated abrasion.

3 STRUCTURE SUBJECTED TO IMPACT LOADS

3.1 General

3.1.1 Application

Technical background is not considered necessary.

3.1.2 General scantling requirements

Technical background is not considered necessary.

3.2 Bottom slamming

3.2.1 Application

Technical background is not considered necessary.

3.2.2 Extend for strengthening

The extent of strengthening is based on CSR OT (July 2010). Vertical extent of strengthening is taken as 500mm based on feedback from ships in operation damage experience.

3.2.3 Design to resist bottom slamming loads

The Rule text is intended to encourage the adoption of built in end constraints in design. Where arrangements do not achieve equivalent "built in" end fixity, then correction to the scantling requirements is required.

Attention is drawn to the need to ensure that the supporting structures provide an adequate load path to ensure the satisfactory transmission of load. Reference to good design practise is included.

3.2.4 Shell plating

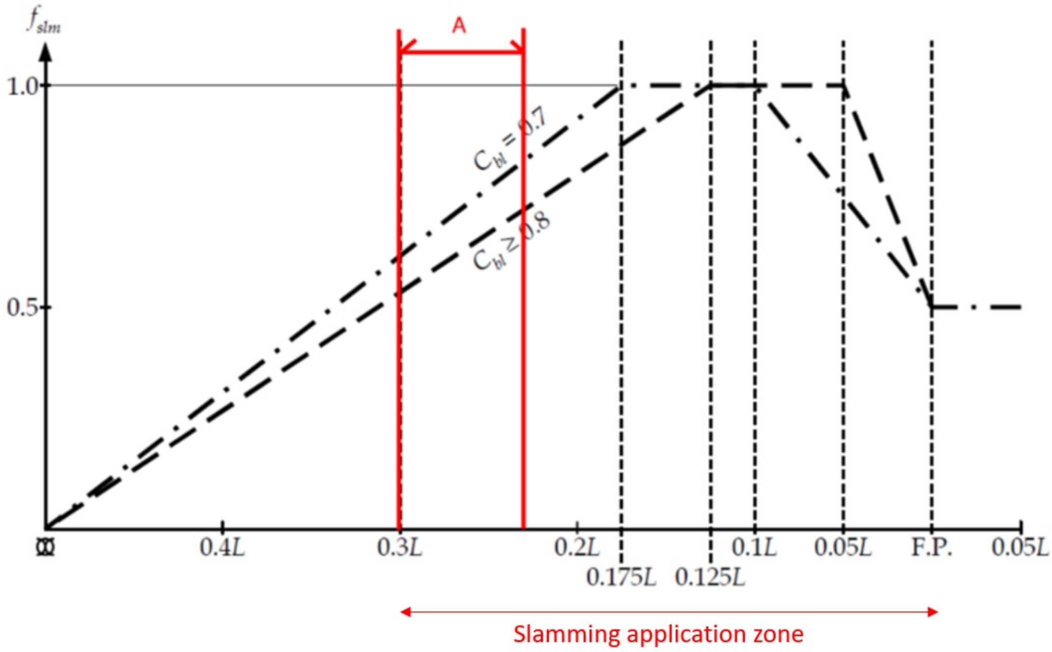
The plate bending capacity model for slamming loads was developed to be consistent with the plate bending capacity model adopted elsewhere in Ch 6 of the Rules.

The coefficient C_d implies a slightly increased acceptance level of permanent set in plate panels subject to impact loads at the bow, reflecting the uncertainty of the frequency of the slamming loads. The choice of coefficients C_d and C_a assume that the only load acting on the plate panel is the slamming impact pressure; hence hull girder and other membrane stresses are neglected in the formulation. C_a is maintained to be consistent with the standard plate thickness equation used elsewhere.

The value of C_d was finalised based on comparison with the existing plate bending capacity models used by in the existing slamming requirements introduced in CSR OT (July 2010).

This requirement is applicable for the flat of bottom and adjacent plating with attached stiffeners (Longitudinally stiffened panels) up to a height of 500 mm above the base line and not applicable for transversely stiffened bilge plating within the cylindrical part of the ship.

Transversely stiffened bilge plating within cylindrical part is most likely located between 0.23L and 0.3L from the F.P (See "A" below) and the slamming pressure in this area is not maximum. The maximum slamming pressure is between 0.175L and 0.05L and the technical background (LR Rules, Jan 2013) of bottom slamming pressure is described in TB rule reference for Pt 1, Ch 4, Sec 5, [3.2.1].



A direct fine mesh analysis with mesh size of 50 x 50 mm was carried out to prove that the capacity of bilge plating within cylindrical part of the ship has enough strength with respect to the bottom slamming pressure. A capsize bulk carrier was chosen since the large part of bilge plating within cylindrical part of the ship is still inside 0.3L from F.P (Slamming Zone). The local FE models are prepared in accordance with Pt 1, Ch 7 and includes all relevant structures within hopper tank as shown in Figure 1.

The slamming pressure is calculated in accordance with Pt 1, Ch 4, Sec 5, [3.2] at the location where the maximum pressure is expected for the bilge plating as shown in Figure 1 below.

The total surface stress including both bending and membrane stresses at the upper and lower plate surface together with the deformation were evaluated and plotted in Figure 2. The maximum stresses are found at the long edge of flat bottom plating due to the plate bending. However, the total stress level in way of the bilge plating is found to be much lower than that of the flat bottom plating since only the lower part of the bilge plating up to 500 mm from the base line is exposed to the slamming pressure and the plate bending stress is significantly reduced due to the curvature of the bilge plating, even if the membrane stress is increased slightly.

Figure 1: FE local model and load application

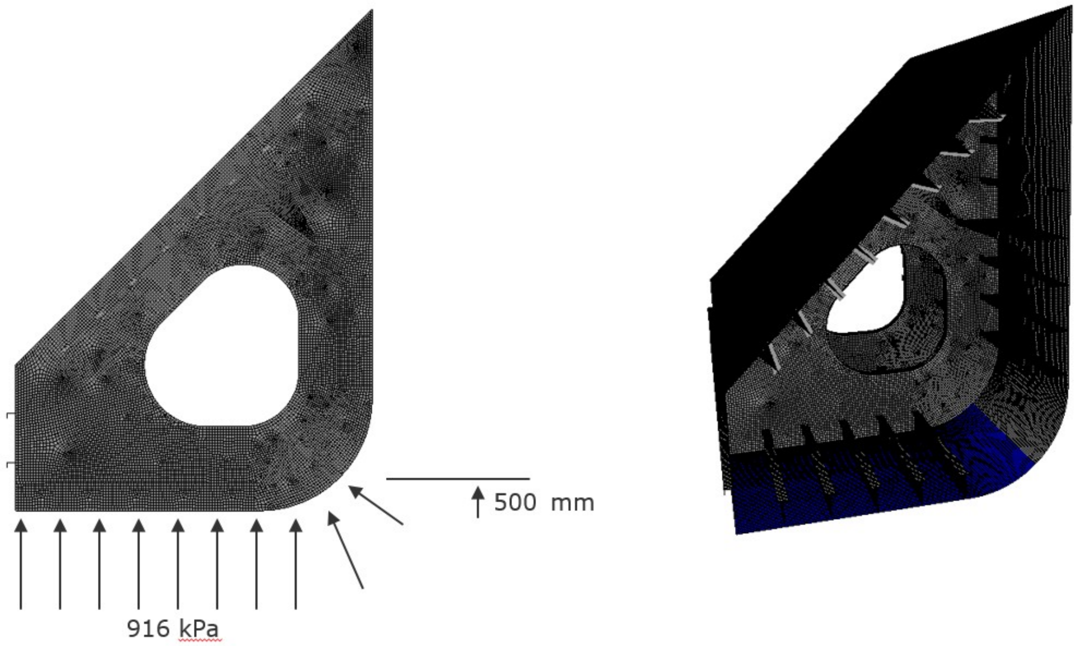


Figure 2: Stress plots for both surface

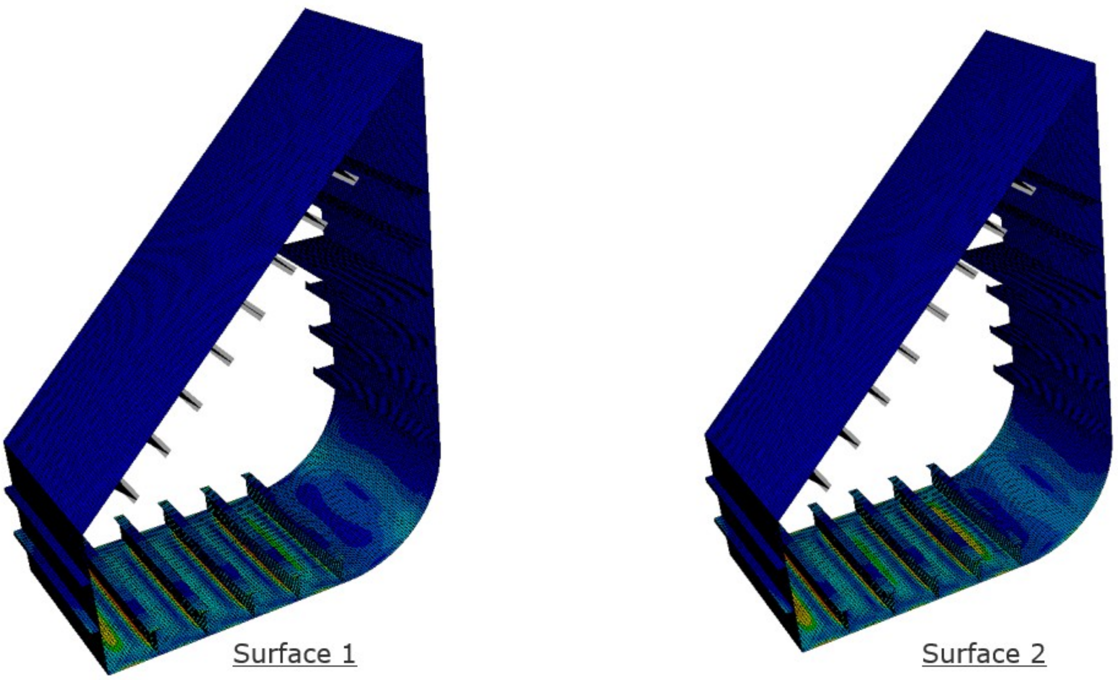
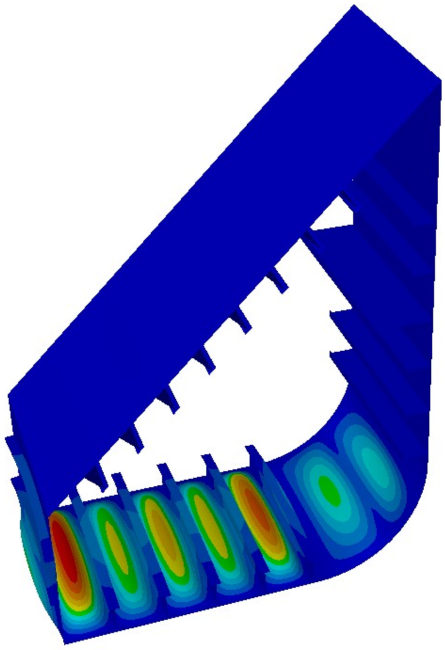


Figure 3: Deformation



3.2.5 Shell stiffeners

The stiffener bending capacity model was developed from an existing concept used by CSR-OT (July 2010). The three hinge plastic collapse model was adopted considering the normal failure modes seen in damage case history related to bottom slamming.

The capacity model features an explicit assumption of end fixity and utilisation factor of yield stress consistent with the design philosophy.

3.2.6 Bottom slamming load area for primary supporting members

Since impact phenomena is localised, non-stationary and time dependent, the magnitude of loads acting on a structure depend on the size of the structure being considered, in relation to its response to the applied load.

The extent of primary supporting members is assumed large in comparison to individual plating and stiffener components. Hence, the average load on the primary member during a "slam" event will be lower than the pressure value assumed to act on the plating or stiffener.

3.2.7 Primary supporting members

For double skin structures, the ultimate bending capacity of double bottom girders and floors has been shown by experience to be satisfactory, provided the scantlings of these items are derived by normal strength criteria. Hence, only an explicit control for shear area of primary supporting members, together with appropriate buckling control is included.

The Rules include a simplified method of predicting the worst case load distribution. This simplification is based on the assumption of a patch load, acting on a specific area of the primary supporting member and carried by on end only. In case of short primary supporting members (i.e. floors) the patch load is distributed to both ends. For such short primary supporting members the maximum extend of slamming load l_{SL} is limited to $0.5l_{shr}$.

The worst case load distribution can also be derived by direct calculations. Slenderness ratio for web plate of primary supporting members based on LR Rules (January 2013), Pt 3, Ch 5, Table 5.1.1 and adjusted for the net thickness model.

3.3 Bow impact

3.3.1 Application

The area of strengthening is defined based on long term experience.

3.3.2 Design to resist bow impact loads

The Rule text is intended to encourage the adoption of built in end constraints in design. Longitudinal/horizontal framing is particularly encouraged to be used because of the superior load response capacity of curved stiffened panels. Further, it is noted that longitudinal framing generally promotes superior structural details.

Where arrangements do not achieve equivalent "built in" end fixity, then correction to the scantling requirements is required.

Attention is drawn to the need to ensure that the supporting structures provide an adequate load path to ensure the satisfactory transmission of load. Reference to good design practise is included.

The stiffening direction of decks and bulkheads supporting shell frames is requested to be parallel to the direction of the compressive plate stress for improved buckling capacity.

3.3.3 Side shell plating

The plate bending capacity model for impact load is consistent with that adopted for slamming requirements.

In case of bow impact, the coefficient C_d is taken as one and hence not shown in the formula, reflecting the reduced tolerance of permanent set in plate panels subject to impact loads at the bow. The choice of coefficients C_d and C_a assume that the only load acting on the plate panel is the bow impact pressure, hence hull girder and other membrane stresses is neglected in the formulation. C_a is maintained to be consistent with the standard plate thickness equation used elsewhere.

The value of C_d was finalised based on:

- Comparison with the existing plate bending capacity models used by in the existing slamming requirements introduced in CSR for oil tankers.
- Verification is based on non-linear analysis.

3.3.4 Side shell stiffeners

The stiffener bending capacity model is consistent with that used in slamming. A three hinge plastic collapse model was adopted considering the normal failure modes seen in damage case history related to bottom slamming.

The capacity model features an explicit assumption of end fixity and utilisation factor of yield stress consistent with the design philosophy.

3.3.5 Bow impact load area for primary supporting members

Idealised impact load area concept is aligned with that adopted for slamming scantling criteria for simplicity.

3.3.6 Primary supporting members

These requirements are taken from CSR OT (July 2010).

- Minimum spacing for primary supporting members included in order to limit deflection of primary supporting members:
- Paragraph is intended to encourage good design details which ensure the structure is adequate for the Rule load.

The primary support member bending capacity model is in the form of applied bending moment over permissible stress. The factors $f_{bdg\text{-}pt}$ and f_{BI} give the maximum bending resulting from the application of an idealised uniformly distributed impact load anywhere within the span length of a fixed ended beam.

The primary support member shear capacity model is in the form of applied shear force divided by permissible stress. The factor f_{PL} gives the maximum shear force at the end of the shear span, resulting from the application of an idealised uniformly distributed impact load within the span length of a fixed ended beam.

The minimum web thickness formulation is to ensure that the critical buckling stress of web plating or deck/bulkhead plating in way or adjacent to the side shell is higher than the axial stress resulting from application of the idealised impact load.

4 ADDITIONAL SCANTLING REQUIREMENTS

4.1 Plate stem

4.1.1

The formula is based on experience and considers the impact of floating parts, like containers, trees or other drifting items and is taken from GL Rules. The minimum scantling requirement considers the material of the shell plating and the distance between horizontal supporting structures. The gradually reduction is based on the probability of impact in rough environmental conditions.

The formula is modified to fit with the net scantling approach.

4.1.2 Breasthooks and diaphragm plating

This requirement is based on experience and modified for net scantling approach applicable to bow impact zone.

4.2 Thruster tunnel

4.2.1

This requirement is based on experience and modified for net scantling approach.

1 GENERAL

1.1 Application

1.1.1

Technical background is not considered necessary.

2 MACHINERY SPACE ARRANGEMENT

2.1 Structural arrangement

2.1.1

The requirements of [2.1.1] to [2.1.3] are taken from CSR OT (July 2010). In view of the effect upon the structure of the necessary openings in the machinery space, the difficulty of securing adequate support for the decks, of maintaining the stiffness of sides and bottom and of distributing the weight of the machinery, special attention is directed to the need for arranging for the provision of plated through beams and such casing and pillar supports as are required to secure structural efficiency.

2.1.2

Refer to TB [2.1.1].

2.1.3

Refer to TB [2.1.1].

2.1.4

This requirement is taken from CSR OT (July 2010).

2.1.5

The requirements of [2.1.5] to [2.1.7] are taken from CSR BC (July 2010).

2.1.6

Refer to TB [2.1.5].

2.1.7

Refer to TB [2.1.5].

2.1.8

This requirement is taken from CSR OT (July 2010). Attention is drawn the importance for submittal of machinery foundation drawings to assure that the foundations for main propulsion units, reduction gears, shaft and thrust bearings, and the structure supporting those foundations are adequate to maintain required alignment and rigidity under all anticipated conditions of loading.

2.2 Double bottom

2.2.1 Double bottom height

Both CSR OT and CSR BC (July 2010) require double bottom to be fitted in machinery space. Double bottom is also required by SOLAS, Ch II-1, Reg. 9.1, (as amended) for bulk carriers. This reference is considered as Classification requirement for bulk carrier and oil tanker.

2.2.2 Centreline girder

The requirements contained in this sub-section are derived from the criteria and practice in portions of existing rule requirements, included in CSR OT and BC (July 2010).

2.2.3 Side bottom girders

Refer to TB [2.2.2].

2.2.4 Girders in way of machinery seatings

Refer to TB [2.2.2].

2.2.5 Floors in longitudinally stiffened double bottom

Refer to TB [2.2.2].

2.2.6 Floors in transversely framed double bottom

Refer to TB [2.2.2].

2.2.7 Manholes and wells

Refer to TB [2.2.2].

2.2.8 Inner bottom plating

Refer to TB [2.2.2].

2.2.9 Heavy equipment

Refer to TB [2.2.2].

3 MACHINERY FOUNDATIONS

3.1 General

3.1.1

The requirements [3.1.1] to [3.1.3] are taken from CSR OT (July 2010)/LR Rules.

3.1.2

Refer to TB [3.1.1].

3.1.3

Refer to TB [3.1.1].

3.2 Foundations for internal combustion engines and thrust bearings

3.2.1

Technical background is not considered necessary.

3.2.2

This requirement is taken from CSR OT (July 2010).

3.3 Auxiliary foundations

3.3.1

Technical background is not considered necessary.

1 GENERAL

1.1 Application

1.1.1

Technical background is not considered necessary.

2 AFT PEAK

2.1 Structural arrangement

2.1.1 Floors

The requirements are similar in CSR OT and BC (July 2010).

2.1.2 Platforms and side girders

These requirements are taken from CSR BC (July 2010).

2.1.3 Longitudinal bulkheads

Refer to TB [2.1.2].

2.1.4 Alternative design verification

The requirements in [2.1.1] to [2.1.3] are based on shipbuilding experience and provide a good structural arrangement. It is however not the intention to prevent design developments beyond what given in [2.1.1] to [2.1.3], though in such case more extensive design verification will be required.

2.2 Stiffening of floors and girders in aft peak

2.2.1

This requirement is to be applied to both the stiffener height requirement in [2.2.2] and the end bracket requirement in [2.2.3].

2.2.2

The requirements are taken from CSR OT (July 2010). The requirements have been introduced as a result of ships experiencing fatigue cracks in AP tanks due to propeller induced vibration. Typical 80–100 rpm for the propeller with 4-6 blades will result in a blade frequency in the range of 5.3–10 Hz.

To avoid vibration, it is generally recommended to keep the natural frequency 15% above the 2nd harmonic excitation frequency (equals to two times the blade frequency). Based on this, a vibration analysis has been carried out for typical stiffeners on floors and girders, assuming various end constraints (hinged to clamped). From this analysis, the criteria as given were obtained. Compared to CSR OT (July 2010) the application of the requirement is further refined to those areas prone to propeller induced vibration. Vibration is not found critical in empty spaces.

2.2.3

Refer to TB [2.2.2]

3 STERN FRAMES

3.1 General

3.1.1

The requirements are based on CSR OT (July 2010).

3.1.2

The requirements are based on CSR OT (July 2010).

3.2 Propeller posts

3.2.1 Gross scantlings of propeller posts

The requirements in [3.2.1] to [3.2.2] are taken from CSR BC (July 2010). However *L* is restricted to 250m to adjust to requirement to established stern frame designs for large tankers.

3.2.2 Propeller shaft bossing

Refer to TB [3.2.1].

3.3 Connections

3.3.1 Connections with hull structure

The requirements in [3.3.1] to [3.3.4] are based on CSR BC (July 2010) and the application area has been further clarified.

3.3.2 Connection with keel plate

Refer to TB [3.3.1].

3.3.3 Connection with transom floors

Refer to TB [3.3.1].

3.3.4 Connection with centre keelson

Refer to TB [3.3.1].

4 SPECIAL SCANTLING REQUIREMENTS FOR SHELL STRUCTURE

4.1 Shell plating

4.1.1 Shell plating connected with stern frame

The requirements in [4.1.1] to [4.1.3] are based on CSR OT (July 2010).

4.1.2 Heavy shell plates

Refer to TB [4.1.1].

4.1.3 Thruster tunnel plating

Refer to TB [4.1.1].

1 GENERAL

1.1 Application

1.1.1

The objective of the sloshing requirements given in the Rules is to ensure that tanks carrying liquid have adequate strength to withstand the pressures arising due to liquid movement in partially filled tanks.

1.2 General requirements

1.2.1 Filling heights of cargo and ballast tanks

In accordance with the principles and design basis of the Rules, all tanks are to be designed for unrestricted filling. The design basis for cargo tanks is unrestricted filling with cargo density of 1.025 t/m^3. In case of higher density than 1.025 t/m^3, filling restriction may be given.

1.2.2 Cargo holds of bulk carriers intended for the carriage of ballast water

Technical background is not considered necessary.

1.2.3 Structural details

Technical background is not considered necessary.

1.3 Application of sloshing pressure

1.3.1 General

The calculated sloshing pressures, $P_{slh-lng}$ and P_{slh-t} are only governing for large open tanks. For smaller tanks and tanks with a lot of internal structure, e.g. double skin tanks, the minimum sloshing pressure, $P_{slh-min}$ will be governing. Hence, only large open tanks are required assessed based on the calculated pressures.

1.3.2 Minimum sloshing pressure

The cut-off values of $0.03L$ and $0.32B$ for calculation of sloshing pressures, $P_{slh-lng}$ and P_{slh-t} respectively are derived from the formulae for the two sloshing pressures. For effective lengths and breadths below these limit values, the sloshing formulae give pressures that are less than the minimum sloshing pressure and hence will not be governing.

1.3.3 Structural members to be assessed

The structural elements to be assessed for the event of sloshing are given in Rules. Sloshing is assumed to be a local load effect and hence only local support members, e.g. plates, stiffeners on tight boundaries and web plating and web-stiffeners/tripping brackets on primary supporting members are required assessed based on sloshing.

Sloshing pressures are most significant around the actual filling height and will not act on the entire bulkhead simultaneously. Consequently, the shear and bending strength of primary supporting members are not required to be assessed based on sloshing loads.

1.3.4 Application of design sloshing pressure due to longitudinal liquid motion

The sloshing pressure due to longitudinal liquid motion, $P_{slh-lng}$ does not only act on the transverse bulkheads but also the panels attached to the bulkhead, e.g. deck, longitudinal bulkheads and stringers. The reason is that pressure in liquid acts in all directions and hence the pressure will act on the neighbouring surfaces as the moving liquid hits the transverse bulkhead. The extension of this effect is limited to the smallest of $0.25l_{slh}$ from the bulkhead and first transverse web frame.

Webs and stiffeners of internal transverse web frames close to (within $0.25l_{slh}$) the transverse bulkhead are required assessed for sloshing due to longitudinal liquid motion. This assessment is required in order to ensure that the web frame can withstand the pressures arising as the liquid is reflected off the transverse bulkhead.

1.3.5 Application of design sloshing pressure due to transverse liquid motion

The sloshing pressure due to transverse liquid motion, P_{slh-t} does not only act on the longitudinal bulkheads but also the panels attached to the bulkhead, e.g. deck, transverse bulkheads and girders/web frames/stringers. The reason is that pressure in liquid acts in all directions and hence the pressure will act on the neighbouring surfaces as the moving liquid hits the transverse bulkhead. The extension of this effect is limited to the smallest of $0.25b_{slh}$ from the bulkhead and first longitudinal web frame/girder.

Webs and stiffeners of internal longitudinal web frames close to (within $0.25b_{slh}$) longitudinal bulkhead are required assessed for sloshing due to transverse liquid motion.

1.3.6 Combination of transverse and longitudinal fluid motion

The sloshing pressures due to longitudinal and transverse liquid motion are assumed to be independent in the sense that one is zero when the other is maximum, and vice versa. Structural elements in areas subject to both longitudinal and transverse sloshing pressure are to be evaluated based on the maximum of the two and not the added pressure.

1.3.7 Additional sloshing impact assessment

For tanks with effective breadth and length less than $0.56B$ and $0.13L$ respectively, the high velocity impact pressure is not assumed to be governing and specific impact calculations are not required. For longer tanks such pressures might be governing for the scantlings, assessment is required in accordance with the rules of the society to which the actual vessel is under classification.

2 SCANTLING REQUIREMENTS

2.1 Plating

2.1.1 Net thickness

The sloshing pressures given in the rules are associated with a "normal" or "typical" load level, e.g. daily maximum. The evaluation of the structure against sloshing loads is covered by AC-S as shown in Table 1 of the Rules.

The sloshing loads, which are taken from the CSR OT (July 2010), are at a probability level of 10^{-4} and not 10^{-8} to which the dynamic loads related to AC-SD acceptance is applied. The sloshing loads in the Rules are hence given as the daily maximum and are therefore characterised as being frequent loads. Consequently the acceptance criteria related to frequent acting loads, AC-S, is more appropriate than AC-SD.

The allowable stress for sloshing assessment in the existing CSR OT (July 2010) is in the order of 0.67×yield and hence similar to that of the Rules. Structural assessment due to sloshing is done based on combining the stresses due to sloshing pressures and the stresses due to static hull girder loads.

Internal static and inertia pressures are not added as the sloshing pressure is only significant just above and below the free surface level where the mentioned other internal pressures are small. Sloshing is also an effect of the liquid moving towards a barrier while the static and inertia loads assume that the liquid remains in contact with the boundary.

Hull girder dynamic stresses (hull girder wave bending) are not added as they are assumed to be small when the sloshing pressure reaches its maximum. The background is that maximum sloshing occurs in an irregular sea state where the dynamic hull girder stresses are small. The maximum dynamic hull girder stress will arise in a sea state with regular long crested waves.

The sloshing assessment in the Rules is based on elastic design and capacity models. The use of plastic design criteria for assessment of sloshing is typically related to the high velocity sloshing impact that may occur in large tanks. For oil tankers of standard design with tanks with limited sloshing length and breadth, this phenomenon is not governing and the tanks are typically assessed for quasi static loads representing liquid movement in the tanks. The same is done in the Rules where the mandatory sloshing assessment is a quasi static approach based on elastic design criteria and a reference is given to each individual classification societies rules for assessment of high velocity impact loads for large tanks. The latter is typically related to a localised load and acceptance criteria based on plastic capacity.

2.2 Stiffeners

2.2.1 Net section modulus

A sloshing related shear requirement for the stiffeners is not included in the Rules as this is not governing for the scantling of the stiffeners. Refer to TB [2.1.1] for other information.

2.3 Primary supporting members

2.3.1 Web plating

It should be noted that only the local elements of the primary supporting members are assessed for the event of sloshing as sloshing is a local phenomenon. In other words, web plating between stiffeners is assessed, web stiffeners are assessed and tripping brackets supporting the web is assessed while the primary supporting member as a single component is not assessed for bending and shear assuming sloshing pressures on parts or all of the load area (span × load breadth). Refer to TB [2.1.1] for other information.

2.3.2 Stiffeners on web plating

Refer to TB [2.3.1].

2.3.3 Tripping brackets supporting primary supporting members

Refer to TB [2.3.1].

PART 1 CHAPTER 11

SUPERSTRUCTURE, DECKHOUSES AND HULL OUTFITTING

Table of Contents

1 GENERAL

1.1 Application

1.1.1

This requirement clearly specifies the articles to be applied for each superstructure or deckhouse structural element.

Application of rule requirements and associated loads for various structural elements, e.g. exposed, non-exposed decks, sides, end (fore and aft) bulkheads have been clarified in RCN 1 to CSR 01 Jan 2022 to avoid different interpretation and application of rule requirements.

1.1.2

Superstructures located in the middle part of the ship and having a length of more than 0.15*L*, which are affected by hull girder loads are not considered within this rules, because such designs are unusual today and have to be individually considered by the Society.

1.1.3

Technical background is not considered necessary.

1.2 Gross scantlings

1.2.1

When the side of superstructure is part of the side shell, the requirements of the exposed sides and exposed decks plating, stiffeners and primary supporting members are to be based on net scantling. All other scantling and dimensions referred to in Ch 11, Sec 1, [3] are gross.

2 STRUCTURAL ARRANGEMENT

2.1 Structural continuity

2.1.1 Bulkheads and sides of deckhouses

This requirement is based on CSR OT (July 2010).

2.1.2 Deckhouse corners

This requirement is based on CSR OT (July 2010).

2.2 End connections

2.2.1 Deck stiffeners

This requirement is based on CSR BC (July 2010).

RCN 1 to CSR 01 Jan 2022 excluded criteria for brackets in Pt 1, Ch 3, Sec 6, [3.2.4] which is based on the net required scantlings of the stiffeners, while the required scantlings in Ch 11, Sec 1 are given in gross.

2.2.2 Longitudinal and transverse deck girders

This requirement is based on CSR BC (July 2010).

2.2.3 End connections of superstructure frames

This requirement is based on CSR BC (July 2010).

2.3 Local reinforcement on bulkheads

2.3.1

This requirement is based on CSR BC (July 2010).

3 SCANTLINGS

3.1 Superstructures sides and decks

3.1.1 Exposed sides and exposed decks

This requirement specifies that the scantling of the various structural elements (plating, stiffeners and PSM) of superstructure sides and decks (exposed or unexposed), which are not covered by UR S3, are to meet the general requirements in Pt 1, Ch 6 (sides of superstructures are dealt with as per side shell, and the decks as per any other deck of the ship).

3.2 Deckhouses decks

3.2.1 Exposed deck plating

The scantling requirement is based on CSR OT (July 2010).

If a wooden sheathing is laid directly on a tightening and preserving compound on the deck, forming an effective additional corrosion protection, the required gross plating may be reduced by 1.5mm up to a minimum thickness of 5mm.

3.2.2 Unexposed deck plating

The scantling requirement is based on CSR OT (July 2010).

3.2.3 Beams and stiffeners

This requirement is based on CSR BC (July 2010).

3.2.4 Girders and transverses

This requirement is based on CSR BC (July 2010).

3.2.5 Alternative grillage analysis for girders and transverses

Paragraph is included to permit alternative means of analysis strength analyses, i.e. grillage analysis, to a defined alternative means and is based on CSR OT (July 2010). The allowable stress levels are based CSR BC (July 2010) and forms the basis for this paragraph.

3.3 Deckhouse walls and end bulkheads of superstructure

3.3.1 Application

The requirements in [3.3] apply to end bulkhead of superstructure and deckhouse walls forming the only protection for openings, as based on ICLL (as amended) and for accommodations. The reference to ICLL is given for information.

3.3.2 Plate thickness

This requirement is based on CSR BC (July 2010) coming from GL Rules.

3.3.3 Stiffeners

Refer to TB [3.3.2].

1 GENERAL REQUIREMENTS

1.1 Application

1.1.1

The requirements are based on ICLL, Annex I, Ch II, Reg. 25(2) (as amended). The requirement that guard rails are to be provided at the boundary of first tier deckhouses and ends of superstructures comes from IACS UI, LL14 (Rev 1, July 2008, Corr.1 Oct 2015). This reference to ICLL is considered as Classification requirement.

1.2 Minimum height

1.2.1

Bulwarks or guard rails are to be at least 1.0m in height measured above sheathing, and are to be constructed as required. The phrase "above sheathing" is taken from CSR OT (July 2010) and LR Rules Pt 3, Ch 8, [5.1.1] (January 2013), as it reflects the ICLL, Annex I, Ch II, Reg. 25(2) (as amended) intent (crew protection) more precisely. This reference to ICLL is considered as Classification requirement.

2 BULWARKS

2.1 General

2.1.1

It is realised that these are general requirements for bulwarks amidships and at the aft end of the ship. Fore end bulwarks are generally designed to be in excess of the rule requirements.

2.1.2

The phrase is taken from CSR OT (July 2010), and similar requirements are found in the societies rules.

2.1.3

Underdeck supports and reinforcement of bulwarks in way of openings and fittings - The requirements are taken from CSR OT (July 2010) and LR Rules (January 2013), Pt 3, Ch 8, [5.2].

2.1.4

The requirements come from CSR BC (July 2010) and BV Rules (January 2013), Ch 10, Sec 2, [2.2.2].

2.1.5

The requirements come from CSR BC (July 2010) and BV Rules (January 2013), Ch 10, Sec 2, [2.2.5].

2.1.6

The requirements come from CSR BC (July 2010) and BV Rules (January 2013), Ch 10, Sec 2, [2.2.6].

2.1.7

The requirements are taken from CSR OT (July 2010) and LR Rules (January 2013), Pt 3, Ch 8, [5.2.1].

2.2 Construction of bulwarks

2.2.1 Plating

The requirement for minimum thickness comes from CSR OT (July 2010) and DNV Rules (January 2013), Pt 3, Ch 1, Sec 10, D301 except the ABS minimum of 6.5mm thickness has been used in lieu of 6.0mm found in the DNV Rules.

2.2.2 Stays

Section modulus at deck - The requirements come from CSR OT (July 2010). The requirements are taken from LR Rules (January 2013), Pt 3, Ch 8, [5.2.3] with minor revision, but no change to the requirements.

2.2.3

The requirements come from CSR OT (July 2010) and LR Rules (January 2013), Pt 3, Ch 8, [5.2.1].

2.2.4

The requirements come from CSR BC (July 2010) and BV Rules (January 2013), Ch 10, Sec 2, [2.2.3].

3 GUARD RAILS

3.1 General

3.1.1

This requirement is the re-stated text of ICLL, Annex I, Ch II, Reg 26(7) (as amended) and considered as Classification requirement.

3.1.2

This regulation came from CSR OT (July 2010) and LR Rules Pt 3, Ch 8, [5.3.19] (January 2013) and based on the ICLL, Annex I, Ch II, Reg. 26(6) (as amended). This ICLL reference is considered as Classification requirement.

3.2 Construction of guard rails

3.2.1

These requirements are the re-stated text of ICLL, Annex I, Ch II, Reg. 25(3) a) and b) (as amended) and IACS UI LL47 (Rev 3, July 2008). This ICLL reference is considered as Classification requirement.

3.2.2

The “Size of openings” requirements come from CSR OT (July 2010). It is in line with the intent of ICLL, Annex I, Ch II, Reg. 25(3) (as amended for crew protection) which is believed to specify the clearance rather than centre to centre distance. The indicated title for this requirement is chosen to amplify this intent, as is clear from the reference to “opening” below the lowest course in the convention. The reference to ICLL is given as Classification requirement.

3.2.3

This regulation is according to CSR BC (July 2010) and BV Rules (January 2013), Ch 10, Sec 2, [3.1.5].

3.2.4

This regulation is according to CSR BC (July 2010) and BV Rules (January 2013), Ch 10, Sec 2, [3.1.6].

1 GENERAL

1.1 Application

Due to concerns raised by the industry in view of an increasing number of incidents, IACS decided to review and update Unified Requirement A1(Rev 6, October 2016), A2(Rev 6, October 2016) and Recommendation No. 10 "Anchoring, Mooring, and Towing Equipment" (Rev 3, October 2016). These changes have been reflected in Ch 11, Sec 3 and Sec 4 of Rules issued on 1 Jan 2018.

1.1.1

The text is in accordance with IACS UR A1 (Rev 6, October 2016), A1.1.1.

1.1.2

The text is in accordance with IACS UR A1 (Rev 6, October 2016), A1.1.2 and A1.1.3.

1.1.3

The text is in accordance with IACS UR A1 (Rev 6, October 2016), A1.1.4 and A1.1.5.

2 EQUIPMENT NUMBER CALCULATION

2.1 Requirements

2.1.1

The text is in accordance with IACS UR A1 (Rev 6, October 2016), A1.2.

2.1.2

This regulation is according to CSR BC (July 2010) and RINA Rules (January 2013), Pt B, Ch 10, Sec 4, [2.1.1].

3 ANCHORING EQUIPMENT

3.1 General

3.1.1 General

The text is in accordance with IACS UR A1 (Rev 6, October 2016).

3.1.2 Design

The text is in accordance with IACS UR A1 (Rev 6, October 2016), A1.4.

3.2 Ordinary anchors

3.2.1 Anchor mass

Anchor mass is in accordance with IACS UR (Rev 5, June 2005), A1.4.1 and Table 1.

3.3 High Holding power anchors

3.3.1 General

The requirements are in accordance with IACS UR A1 (Rev 6, October 2016), A1.4.1.2. SHHP anchors in IACS UR A1 (Rev 6, October 2016), A1.4.1.3 are not included since the use of SHHP anchors is limited to restricted service ships as defined by the Society.

3.3.2 HHP anchor mass

The requirements are in accordance with IACS UR A1 (Rev 6, October 2016), A1.4.1.

3.3.3 Application

The requirements are in accordance with IACS UR A1 (Rev 6, October 2016), A1.4.1.2.

The requirement [3.3.4] has been deleted with the RCN1 to 01 Jan 2017, due to the update of the Unified Requirement A1, A2 and Recommendation 10. For this reason, the reference to the required holding force in previous [3.3.4] is replaced by those required by the Society.

3.4 Chain cables

3.4.1 General

The requirements come from CSR BC (July 2010), RINA Rules (January 2013), Pt B, Ch 10, Sec 4, [3.3] and based on IACS UR (Rev 5, June 2005), A1.5.

3.4.2 Application

The requirements come from CSR OT (July 2010), ABS Rules (January 2013), Pt 3, Ch 5, Sec 1.1, LR Rules (January 2013), Pt 3, Ch 13, [7.4.5] and Table 1 is based on IACS UR (Rev 5, June 2005), A1.2.

3.5 Chain lockers and stowed anchors

3.5.1 General

The requirements are based on CSR OT (July 2010), DNV Rules (January 2013), Pt 3, Ch 3, Sec 3, B104, and LR Rules (January 2013), Pt 3, Ch 13, [7.8.4] and [7.8.5]. The use of the term "adequate" with respect to the size of the chain locker is noted as ambiguous, but is consistent with rule text. It may be retained for the present time.

3.5.2 Securing of the inboard ends of chain cables

The requirements come from CSR OT (July 2010). 15~30% of the breaking strength, which is identical to IACS Rec 10 (Rev 3, October 2016), 1.2.2(a) is used.

3.5.3 Securing of stowed anchors

The requirements are in accordance with IACS Rec 10 (Rev 3, October 2016), 1.3.3 (a).

3.6 Chain stoppers

3.6.1 General

The requirements come from CSR OT (July 2010), ABS Rules (January 2013), Pt 3, Ch 5, Sec 1.1 and LR Rules (January 2013), Pt 3, Ch 13, [7.8.2].

3.6.2 Application

The requirements come from CSR OT (July 2010) and LR Rules (January 2013), Pt 3, Ch 13, [7.8.2].

3.7 Windlass

3.7.1 General

The requirements come from CSR OT (July 2010), LR Rules (January 2013), Pt 3, Ch 13, Sec 7, [7.6], ABS Rules (January 2013), Pt 4, Ch 5, Sec 1, DNV Rules, Pt 3, Ch 3 , Sec 3F and IACS UR (Rev 5, May 2010), S27.

3.7.2 Application

The requirements come from CSR OT (July 2010) and similar requirements are found in the societies Rules.

3.7.3 Anchor windlass trial

The requirements come from CSR OT (July 2010) and similar requirements are found in the societies Rules.

3.8 Hawse pipes

3.8.1 General

The requirements come from CSR OT and BC (July 2010). Similar requirements are found in the societies Rules.

3.8.2 Application

The requirements come from CSR OT (July 2010). Similar requirements are found in the societies Rules.

3.8.3 Stowage and deployment arrangements for anchors

The requirements come from CSR OT (July 2010). Similar requirements are found in the societies Rules.

3.9 Towlines and mooring line

3.9.1 General

Technical background is not considered necessary.

1 GENERAL

1.1 Application

1.1.1

This section covers the most common and important items of deck equipment, commonly fitted on vessel designs.

1.1.2

Scantling criteria are developed for use with capacity assessment based on simplified engineering analysis.

1.2 Documents to be submitted

1.2.1

Technical background is not considered necessary.

2 ANCHORING WINDLASS AND CHAIN STOPPER

2.1 General

2.1.1

The requirements in the sub-section are based on existing practice and IACS UR, S27 (Rev 5, May 2010).

2.1.2

The requirements in the sub-section are based on existing practice and IACS UR, S27 (Rev 5, May 2010).

2.1.3

Design loads due to anchoring operation - in accordance with CSR OT (July 2010). Similar requirements are found in the societies Rules.

2.1.4

The net scantling is adopted to be in line with Pt 1. Ch 3, Sec 2. ”Net scantling approach”.

2.1.5

Design loads due to anchoring operation - in accordance with CSR OT (July 2010). Similar requirements are found in the societies Rules.

2.1.6

Design loads due to green seas in the forward 0.25*L* - taken from IACS UR, S27 (Rev 5, May 2010).

2.1.7

Calculation for the resultant force in the bolts due to green sea design loads is taken from IACS UR, S27 (Rev 5, May 2010). Scope of bolt scantlings limited to green seas in accordance with scope of IACS UR, S27 (Rev 5, May 2010).

2.1.8

Forces in supporting structure are based on existing practice of Societies Rules.

2.1.9

Refer to IACS UR, S27 (Rev 5, May 2010).

2.1.10

Forces in supporting structure are based on existing practice of Societies Rules.

2.1.11

Forces in supporting structure are based on existing practice of Societies Rules.

2.1.12

The requirements are in accordance with IACS UR A1 (Rev 6, October 2016), A1.7.3.

2.1.13

Allowable stresses for green sea design loads - Allowable stresses for bolts taken from IACS UR, S27, 5.2 (Rev 5, May 2010). According to IACS UR, S27 (Rev 5, May 2010), the safety factor against bolt proof strength is not to be less than 2.0. While "50% of bolt proof strength" is proposed in the text, "50% of yield strength of bolt material" for axial forces.

2.1.14

Technical background is not considered necessary.

2.1.15

Refer to TB [2.1.12].

3 MOORING WINCHES

3.1 General

3.1.1

The requirements in the sub-section are based on existing practice of societies and based on IACS UR, S27 (Rev 5, May 2010) appropriately modified to cater for the particular loads associated with mooring winches.

3.1.2 Foundation

Refer to TB [3.1.1].

3.1.3 Rated pull

Refer to TB [3.1.1].

3.1.4 Holding load

Refer to TB [3.1.1].

3.1.5 Supporting structure

The requirements are based on IACS UR, S27 (Rev 5, May 2010) but have been extended to include a common standard of classification societies for support structures of windlasses are introduced.

3.1.6 Corrosion model

The net scantling is adopted to be in line with Pt 1. Ch 3, Sec 2. ”Net scantling approach”.

3.1.7

Design loads due to mooring operation - design load is based on the maximum load for which the mooring winch rated. Design load with effective winch brake consistent with requirements for anchor windlass on the assumption that winch brake is designed to be stronger than the braking strength of the rope.

This requirement reflects 100% of the break holding load. The load of 125% of the breaking strength of the mooring line is in line with MSC.1/Circ. 1175 (§4.3.2) (24 May 2005) and required according to UR A2 [A.2.2.3 2)] (Rev.3 July 2007, Corr.1 Sept 2014). The reference to MSC.1/Circ 1175 is given for reference.

3.1.8

The requirements of IACS UR, S27 (Rev 5, May 2010) for holding down bolts of windlasses are applied to mooring winches within the forward 0.25*L*. It is considered that the environmental loads proposed within IACS UR, S27 (Rev 5, May 2010) are only applicable to the fore ship.

3.1.9

Refer to TB [3.1.7].

4 CRANES, DERRICKS, LIFTING MASTS AND LIFT SAVING APPLIANCES

4.1 General

4.1.1

Rules in this sub-section are only for the hull structures and not for lifting appliances. Criteria for application of the strength criteria are taken from CSR OT (July 2010) and DNV Rules (January 2013), Pt 3, Ch 3, Sec 5, A100.

4.1.2

The requirements have been developed based on the size and configuration of deck equipment/fittings typically found on tankers and bulk carriers. For this reason, the requirements are not suitable for application on other types of ships.

4.1.3

The requirements come from CSR OT (July 2010). Similar requirements are found in the societies Rules. Those requirements limited to the deck attachment of the appliance to the deck and support structure since treatment of the crane post/pedestal is different between each of societies.

4.1.4 SWL definition

The definition of SWL is taken from the existing practice of societies.

4.1.5 Self weight

Definition of self weight is defined by CSR OT (July 2010) and is considered consistent with present practice of societies.

4.1.6 Overturning moment

Definition of overturning moment is taken from the present practice of societies.

4.1.7

The requirements come from CSR OT (July 2010). Similar definitions are found in the societies Rules.

4.1.8

Technical background is not considered necessary.

4.1.9

Derrick masts and derrick posts - the criteria stated are generally common to modern tanker lifting appliances presently being used or approved.

Welding of non-continuous crane pedestals and heavily loaded under deck structure in way or crane pedestals are required to have full penetration welding as required in [4.1.15]. The requirement come from CSR OT (July 2010), and is required to facilitate NDE of these welds.

4.1.10

The requirements come from CSR OT (July 2010). Similar requirements are found in the societies Rules.

4.1.11

The requirements come from CSR OT (July 2010). Similar requirements are found in the societies Rules.

4.1.12

Technical background is not considered necessary.

4.1.13

The requirements come from CSR OT (July 2010) and DNV Rules (January 2013), Pt 3, Ch 3, Sec 5, A500.

4.1.14

The requirements come from CSR OT (July 2010) and DNV Rules (January 2013), Pt 3, Ch 3, Sec 5, A500 and are based on International Life-Saving Appliances (LSA) Code Chapter VI paragraph 6.1.1.5.

4.1.15

The requirements come from CSR OT (July 2010) and DNV Rules (January 2013), Pt 3, Ch 3, Sec 5, A600 and are based on International Life-Saving Appliances (LSA) Code Chapter VI paragraph 6.1.1.6:
"Structural members and all blocks, falls, padeyes, links, fastenings and all other fittings used in connection with launching equipment shall be designed with a factor of safety on the basis of the maximum working load assigned and the ultimate strengths of the materials used for construction. A minimum factor of safety of 4.5 shall be applied to all structural members, and a minimum factor of safety of 6 shall be applied to falls, suspension chains, links and blocks."
The safety factor for design load 2.2xSWL together with the maximum permissible normal stress $0.67R_{eH}$ and shear stress $0.39\ R_{eH}$ ensure safety factor above 4.5 considering typical ratios between yield stress and tensile stress.

5 BOLLARDS AND BITTS, FAIRLEADS, STAND ROLLERS, CHOCKS AND CAPSTANS

5.1 General

5.1.1

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.0.

5.1.2

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.0.

5.1.3

General statements have been taken from basic strength and structural continuity requirements presently contained in CSR OT (July 2010).

5.1.4

General statements have been taken from basic strength and structural continuity requirements presently contained in CSR OT (July 2010).

5.1.5

Technical background is not considered necessary.

5.2 Towing

5.2.1 Towing design loads

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.1.3.

5.2.2 Shipboard fittings

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.1.4.

5.2.3 Towing force acting point

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.1.5.

5.2.4 Safe Towing Load (TOW)

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.1.6.

5.3 Mooring

5.3.1 Mooring design loads

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.2.3.

5.3.2 Shipboard fittings

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.2.4.

5.3.3 Mooring force acting point

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.2.5.

5.3.4 Safe Towing Load (TOW)

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.2.6.

5.4 Supporting structure

5.4.1

General statements have been taken from basic strength and structural continuity requirements presently contained in CSR OT (July 2010).

5.4.2

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.1.5.

5.4.3

General statements have been taken from basic strength and structural continuity requirements presently contained in CSR OT (July 2010).

5.4.4

General statements have been taken from basic strength and structural continuity requirements presently contained in CSR OT (July 2010).

5.5 Acceptance criteria

5.5.1

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.1.5 and A2.2.5.

5.5.2

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.1.5 and A2.2.5.

5.5.3

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.1.5 and A2.2.5.

5.5.4

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.1.5 and A2.2.5.

5.6 Corrosion addition of the fittings

5.6.1

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.4.

5.6.2

The requirements are in accordance with IACS UR A2 (Rev 6, October 2016), A2.4.

5.7 Towing and mooring arrangements plan

5.7.1

The requirements are in accordance with IACS UR A2 (Rev.4 Corr.2 Mar 2017), A2.3.

5.7.2

The requirements are in accordance with IACS UR A2 (Rev.4 Corr.2 Mar 2017), A2.3.

5.7.3

UThe requirements are in accordance with IACS UR A2 (Rev.4 Corr.2 Mar 2017), A2.3.

5.7.4

The requirements are in accordance with IACS UR A2 (Rev.4 Corr.2 Mar 2017), A2.1.6 and A 2.2.6.

6 MISCELLANEOUS DECK FITTINGS

6.1 Support and attachment

6.1.1

Technical background is not considered necessary.

6.1.2

Technical background is not considered necessary.

1 GENERAL

1.1 Application

1.1.1

Hatches on CSR ships are cargo hatches on bulk carriers or can be categorised as small hatches. Pt 1, Ch 11 only shown detailed requirements for small hatches and refers to Pt 2, Ch 1, Sec 5 if other type of hatches need to be considered.

1.2 Materials

1.2.1

Technical background is not considered necessary.

1.2.2

Technical background is not considered necessary.

1.3 Height of hatch coamings

1.3.1

Technical background is not considered necessary.

1.3.2

Technical background is not considered necessary.

1.4 Small hatchways

1.4.1

Definition of small hatches is taken from IACS UR, S26 (Rev 4, May 2010).

1.4.2

These requirements are taken from CSR BC (July 2010) and BV Rules (January 2013).

1.4.3

These requirements are taken from CSR BC (July 2010) and BV Rules (January 2013).

1.4.4

This requirement comes from CSR BC (July 2010) and is based on minimum net thickness required in ICLL, Annex I, Ch II, Reg. 16, § (5), (c), as amended (MSC Res 143(77)). The net thickness, in mm, of the plating forming the top of the hatch cover is not to be less than the greater of the following values:

- t = 1% of the spacing of stiffeners = 10 s (with s: stiffener spacing in m)
- t = 6

Converting this into a gross scantling requirement as used in this Ch 11, Sec 5, with 2.0 mm as the minimum corrosion margin, the gross thickness of the top plate of the hatch cover becomes 8.0 mm for stiffener spacing equal to or below 600 mm. The reference to ICLL is given for reference.

1.4.5

The requirements are taken from CSR BC (July 2010) and BV Rules (January 2013).

1.5 Cargo tank access hatchways

1.5.1

The requirements in [1.5.1] to [1.5.4] are taken from CSR OT (July 2010) and LR Rules (January 2013). The text about large covers and those configured with our well rounded shape is based on present practice and was added as a result of comments received from industry.

1.5.2

Refer to TB [1.5.1].

1.5.3

Refer to TB [1.5.1].

1.5.4

Refer to TB [1.5.1].

1.6 Gaskets

1.6.1

The requirements are taken from CSR BC (July 2010) and BV Rules (January 2013).

1.6.2

The requirements are taken from CSR BC (July 2010) and BV Rules (January 2013).

2 SMALL HATCHWAYS FITTED ON THE EXPOSED FORE DECK

2.1 General

2.1.1

The requirements in [2] are technically the same requirements taken from IACS UR, S26 (Rev 4, May 2010), CSR BC and OT (July 2010).

2.1.2

Refer to TB [2.1.1].

2.1.3

Refer to TB [2.1.1].

2.2 Strength

2.2.1

Refer to TB [2.1.1].

2.2.2

Refer to TB [2.1.1].

2.2.3

Refer to TB [2.1.1].

2.2.4

Refer to TB [2.1.1].

2.3 Primary securing devices

2.3.1

Refer to TB [2.1.1].

2.4 Requirement to primary securing

2.4.1

Refer to TB [2.1.1].

2.4.2

Refer to TB [2.1.1].

2.4.3

Refer to TB [2.1.1].

2.4.4

Refer to TB [2.1.1].

2.4.5

Refer to TB [2.1.1].

2.5 Secondary securing devices

2.5.1

Refer to TB [2.1.1].

PART 1 CHAPTER 12

CONSTRUCTION

Table of Contents

1 GENERAL

1.1 Workmanship

1.1.1

The text was developed based on CSR OT (July 2010), Sec 6/4.1.1 (based on ABS Rules (January 2013), Pt 3, Ch 1, Sec 2, 9) and the statement on defect repairs is in accordance with CSR OT (July 2010), Sec 6/4.1.1 (as amended and based on LR Rules (January 2013), Pt 3, Ch 1, 8.2.1).

1.2 Fabrication standard

1.2.1

IACS Rec 47 (Rev 5, October 2010), Shipbuilding and repair quality standard is included as the basic requirement for an acceptable fabrication standard. However, it is also realised that other recognised fabrication standards exist that have a proven record of satisfactory performance. The rules permit continued acceptance of these recognised fabrication standards.

1.2.2

Technical background is not considered necessary.

1.2.3

The scope of items to be included in the fabrication standard was taken from the contents of IACS Rec 47 (Rev 5, October 2010).

2 CUTS-OUTS, PLATE EDGES

2.1 General

2.1.1

This requirement is typical precautions related to forming cut-outs and edge preparation.

2.1.2

The fatigue strength for hatch corner is checked in accordance with Ch 9, Sec 7. The stress concentration factor depends on the edge treatment as well as hatch corner configuration. Since the stress concentration factor of hatch corners without machine cut is too large to comply with the fatigue requirement, hatch corner without machine cut should be accepted. Furthermore, this practice is in accordance with the practice of shipyards.

3 COLD FORMING

3.1 Special structural members

3.1.1

Cold forming of special structural members is in accordance with CSR OT (July 2010), Sec 6/4.2.1 (based on ABS Rules (January 2013), Pt 2, Ch 4, Sec 1, 3.13 with slight modification to accommodate LR and DNV practice). A minimum radius of 10 times the thickness, which corresponds to a cold deformation of approximately 5% is used in the Rules and is based on DNV acceptance of this for offshore structures.

Additional requirements related to acceptance of lesser radiuses are contained in CSR OT (July 2010), Sec 6/4.2.3 (which is generally in accordance with DNV Rules (January 2013), Pt 3, Ch 1, Sec 3, C1102). Criteria for stainless steels are not applicable here and are left to the individual society.

3.2 Corrugated bulkheads and hopper knuckles

3.2.1

Cold forming for corrugated bulkheads and hopper knuckles is in accordance with CSR OT Sec 6/4.2.2 (based on DNV Rules (January 2013), Pt 3, Ch 1, Sec 3, C1100). Additional requirements related to acceptance of lesser radiuses are contained in CSR OT (July 2010), Sec 6/4.2.3 (which is generally in accordance with DNV Rules (January 2013), Pt 3, Ch 1, Sec 3, C1102). Criteria for stainless steels are not applicable here and are left to the individual society.

3.3 Low bending radius

3.3.1

Cold forming for other members is in accordance with CSR OT (July 2010), Sec 6/4.2.3 (based on DNV Rules (January 2013), Pt 3, Ch 1, Sec 3, C1002). The criteria have been slightly modified from the DNV source criteria to satisfy LR and ABS views.

4 HOT FORMING

4.1 Temperature requirements

4.1.1

General precaution for hot forming is in accordance with CSR OT (July 2010), Sec 6/4.3.1 (based on ABS Rules (January 2013), Pt 2, Ch 4, Sec 1, 3.13 and LR Rules (January 2013), Pt 3, Ch 1, 8.2.1).

4.1.2

The requirements concerning TMCP plates are in accordance with CSR OT (July 2010), Sec 6/4.3.1 (based on ABS Rules (January 2013), Pt 2, Ch 4, Sec 1, 1.9).

4.2 Line or spot heating

4.2.1

Line or spot heating is in accordance with CSR OT (July 2010), Sec 6/4.3.2 (based on LR Rules (January 2013), Pt 3, Ch 10, 2.12.17).

5 ASSEMBLY AND ALIGNMENT

5.1 General

5.1.1

Technical background is not considered necessary.

5.1.2

Typical misalignment standards for weld joints in IACS Rec 47 (Rev 5, October 2010) are described here. With regard to this matter, considering that the IACS Recommendations is not a mandatory requirement, and reflecting the opinion of the industry that reliable standards such as the Japanese Shipbuilding Quality Standard should be approved, it was decided that the classification society could approve standards if it deems them appropriate.

1 GENERAL

1.1 Application

1.1.1

Technical background is not considered necessary.

1.2 Limits of application to welding procedures

1.2.1 Weld type, size and materials

Technical background is not considered necessary.

1.2.2 Preparation, execution and inspection

Technical background is not considered necessary.

2 WELDING PROCEDURES, WELDING CONSUMABLES AND WELDERS

2.1 General

2.1.1

Technical background is not considered necessary.

3 WELD JOINTS

3.1 General

3.1.1

Technical background is not considered necessary.

3.1.2

Technical background is not considered necessary.

3.1.3

Technical background is not considered necessary.

3.1.4

For the calculation purpose, the gap in welds is taken equal to 2.0mm (see Ch 12, Sec 3).

3.1.5

Technical background is not considered necessary.

3.1.6

Technical background is not considered necessary.

3.1.7

Technical background is not considered necessary.

3.1.8

Technical background is not considered necessary.

3.1.9 Arrangements at junctions of welds

Technical background is not considered necessary.

3.1.10 Leak stoppers

Technical background is not considered necessary.

4 NON-DESTRUCTIVE EXAMINATION (NDE)

4.1 General

4.1.1

Technical background is not considered necessary.

4.1.2

Technical background is not considered necessary.

1 GENERAL

Welding requirements in this section are primarily derived from the individual Common Structural Rules (CSR) for Oil Tankers and those for Bulk Carriers (July 2010). The rules and procedures related to welding in the aforementioned Rules were in themselves based on practices of IACS member class societies involved in the development of the specific CSR.

Welding procedures and rules for determining weld sizes of these class societies have proven reliable through application and historical service performance. The current harmonised CSR has attempted to adopt the best practices from the individual CSR OT, and those for Bulk Carriers.

1.1 Application

1.1.1

Text is derived from CSR OT (July 2010), Sec 6/4.4.2.1.

1.1.2

Technical background is not considered necessary.

1.1.3

Technical background is not considered necessary.

1.2 Alternatives

1.2.1

Text is derived from CSR OT (July 2010), Sec 6/5.11.

2 TEE OR CROSS JOINT

2.1 Application

2.1.1

The graphical representation of typical tee or cross joints is given.

2.1.2

Improved welding in high stressed areas is requested.

2.2 Continuous fillet welds

2.2.1

The list of locations where continuous fillet welding is CSR OT (July 2010), Sec 6/5.3.2 and Table 6.5.1 combined with corresponding requirements from CSR BC (July 2010) from Ch 11, Sec 2, Table 2 and elsewhere from both CSR.

2.3 Intermittent fillet welds

2.3.1

Technical background is not considered necessary.

2.3.2

The source of this requirement is mainly CSR OT (July 2010), Sec 6/5.3.3.2 adjusted in accordance with typical shipyard practice.

2.3.3 Dry spaces

Light intermittent weld in dry spaces is acceptable if not affected by significant loads.

2.3.4 Size for one side continuous weld

Strength requirement is taken from intermittent weld requirement.

2.4 Partial or full penetration welds

2.4.1 High stress area definition

The improved welding is required in high stressed areas. The definition of high stressed area based on the fine mesh yield analysis is given.

2.4.2 Partial or full penetration welding

The improved welding is required in high stressed areas. The definition of full and partial penetration welds is given.

2.4.3 One side partial penetration weld

Technical background is not considered necessary.

2.4.4 Extent of full or partial penetration welding

The 300mm distance is the default requirement, adding "unless otherwise specifically stated" in Rules issued 1 Jan 2018 is to reflect deviant requirements such as the 150mm distance in 2.4.7.

2.4.5 Locations required for full penetration welding

The list of critical locations is the combination of CSR OT (July 2010), Sec 6/5.3.4.3, CSR BC (July 2010), Ch 11, Sec 2, 2.4.1 and elsewhere in both CSR with input from IACS documents (Bulk Carrier Repair Guidelines), individual Societies, shipyards and industry input.

Locations of d), e), g), h) and i) were added in Rules issued on 1 Jan 2018 with following reasons:

a) Localized fractures have been encountered in pre-CSR vessels.

b) Feedback from vessel operators from the IACS Knowledge Centre database shows several requests regarding the weld detail connections of corrugated bulkhead since 2013. The following sentence is a typical request extracted from the database:

"Welding requirements in the CSR-H should change. Full penetration welding is to replace partial or deep penetration welding for the critical areas unless advanced fracture mechanics analysis is to be undertaken."

c) Feedback from the IMO GBS audit team, see GBS observation IACS/2015/FR1-8/OB/07 as follows:

Statement of facts
Pt 1, Ch 12, Sec 3, [2.4.5 (d)] in Rules issued Jan 2017 "Connection of vertical corrugated bulkhead to top plating of lower stool." requires full penetration welding for the connection

of vertical corrugated bulkhead to top plating of lower stool, while Sec 3, [2.4.6 (c), (d) and (e)] in Rules issued Jan 2017 allows the choice of full or partial penetration welding for the connection between: lower stool side plating to lower stool top plate (c); lower stool side plating to inner bottom (d); and lower stool supporting floors to inner bottom (e).

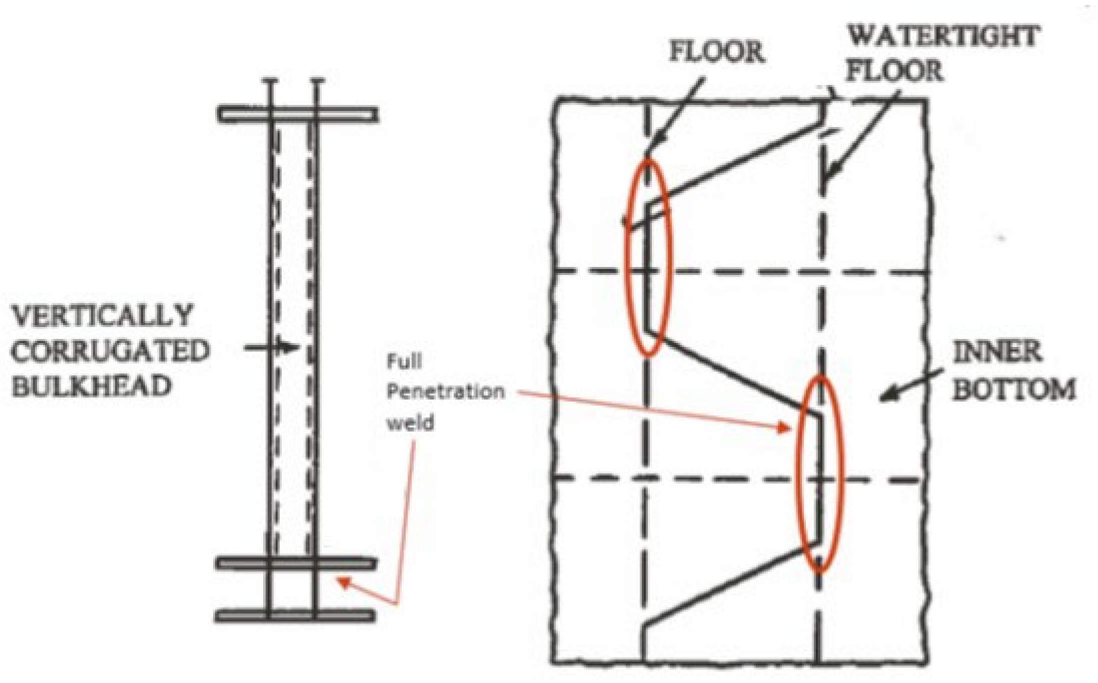
Observation
The technical background offers no explanation or justification as to why partial penetration welding may suffice in these critical areas that are prone to cracking.
Whereas partial penetration welding in way of the areas described above is in line with the current version of IACS UR S18 (18.4.1(a), Rev.9 April 2014), it deviates from the requirements in the original UR S18 of 1997, which required: “corrugations and stool side plating are generally to be connected to the stool top plate by full penetration welds. The plating of the lower stool and supporting floors is generally to be connected to the inner bottom by full penetration welds.” It needs to be noted that compliance with the original UR S18 was referenced by resolution 3, Recommendations on compliance with SOLAS regulation XII/5, adopted by the 1997 SOLAS Conference.
Furthermore, the provision giving the choice to the shipbuilder between full and partial penetration welding needs to be contrasted with IACS Rec. No.76 and Rec. No.96 which presently require the much safer full penetration welding for the repair of critical areas in bulk carriers and tankers.

d) Feedback from the Greek Administration in paper MSC 96/5/9 “Auditors observed that the version of URS-18 as referred to Res.3 (1997) requires full penetration welding for certain critical areas, whereas CSR have replaced that with "full or partial" penetration. IACS' proposed corrective action includes a provision of "more explanations"; however, Greece would agree with the auditors that the IMO-approved URS-18 version should be immediately applied in CSR. Any other versions should be submitted to IMO and applied after approval.”

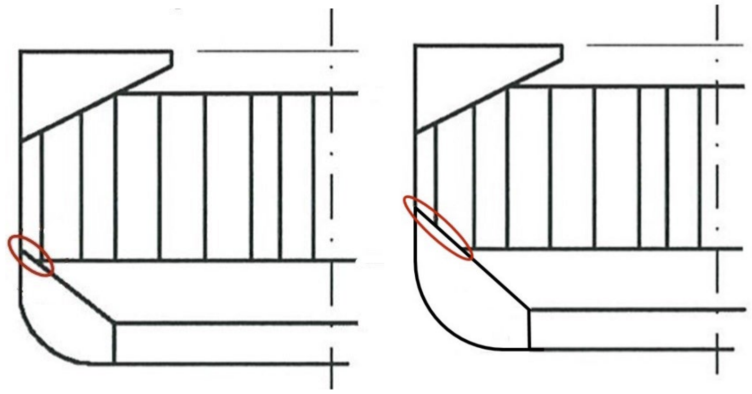
e) Reference is made to Area 4 of IACS Recommendation No. 76 “Bulk Carriers – IACS Guidelines for Surveys, Assessment and Repair of Hull Structure”, and Group 5 of No. 96 “Double Hull Oil Tankers –Guidelines for Surveys, Assessment and Repair of Hull Structures” which illustrate common fractures collected by IACS from several classed vessels and full penetration welds used during repair. Feedback from vessel owners has indicated that rather than to provide full penetration welding during repairs of areas known to experience fractures, the full penetration welds should be provided at the time of new construction.

The proposed amendments are made in Rules issued 1 Jan 2018 because of the above feedback and experience.

The following sketches are provided for a better understanding of the new locations described in [2.4.5]



Location e):



Location g):
Sketch not considered necessary since this item relocated from [2.4.6 c] in Rules issued on Jan 2017.

Location h):
Sketch not considered necessary since this item relocated from [2.4.6 d] in Rules issued on Jan 2017.

Location i):
Sketch not considered necessary since this item is included in Figure 3 in Rules issued on Jan 2018.

2.4.6 Locations required for partial penetration welding

Refer to TB [2.4.5].

"full or partial" changed to "partial" in Rules issued on 1 Jan 2018 with following reasons:

It is intended that partial penetration welding be provided in the locations included in Pt 1, Ch 12, Sec 3, [2.4.6]. The original rule text indicating "full or partial penetration welding"

was intended to reflect that designers may select full penetration welding. However, it was pointed out that including the text covering both options caused confusion. Therefore, only partial penetration will be clearly stated in the rule
heading and in Figure 3. While the rule has been clarified to indicate partial penetration, welding is acceptable, designers may still optionally select full penetration welding in these locations.

In Rules issued on 1 Jan 2018, two locations covering the corrugated bulkhead lower stool side plating to lower stool top plate and to the inner bottom were moved from [2.4.6] to [2.4.5], and also partial penetration welding is replaced with full penetration welding for the connection of the inner bottom plate to structural elements in double bottom in holds intended for the carriage of liquid at sea in way of 300 mm of the side plating of the lower stool.

The amendments in Rules issued on 1 Jan 2018 are also made as a result of the feedback mentioned in [2.4.5] above and the IMO GBS Audit carried out in 2014-2015, Observation No. IACS/2015/FR1-8/OB/07.

For clarity, RCN 1 to CSR 01 Jan 2020 is to make the application of partial penetration welding for the end connection of backing bracket and buttress structure, where applicable.

2.4.7 Fine mesh finite element analysis

Represents the strong industry demand of having the clear criteria where at least partial penetration welding should be applied where fine mesh FEM analysis is carried out.

2.4.8 Shedder plates

The source of this rule is CSR BC (July 2010), Ch 11, Sec 2, 2.4.2.

2.5 Weld size criteria

2.5.1

Technical background is not considered necessary.

2.5.2

The scantlings of fillet welds are based on as-built thickness of the abutting members. As-built thickness includes the net thickness of the member, the corrosion addition and the owner's addition. Thus, the strength of welds is checked both in "net" and in "as-built" (corrosion addition adjustment is considered).

The formulas to determine the size of welds are similar to CSR OT (July 2010). The values of weld factors are adjusted by comparing the welds scantlings of similar structures given by CSR OT (July 2010), Sec 6/5.7.1.2 and Table 6.5.1 with CSR BC (July 2010), Ch 11, Sec 2, 2.6.1 and Ch 11, Sec 2, Table 1 and Table 2. The weld factors are such that the impact on the existing CSR is minimised.

The corrosion addition adjustment is included in the formulas implicitly. BC rules give an explicit corrosion addition refinement. Table 1 gives the values of implicit corrosion addition adjustment in these Rules. Numbers in bold mean that the BC refinement is satisfied, numbers in italic mean that the BC refinement is not satisfied, however the difference is negligible.

Table 1: Corrosion addition adjustment and its comparison with BC adjustment

	t_c, mm								
f_{weld}	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
0.20	**0.36**	**0.43**	**0.50**	**0.57**	**0.64**	**0.71**	*0.78/1.0*	*0.85/1.0*	*0.92/1.0*
0.24	**0.43**	**0.51**	**0.60**	**0.68**	**0.77**	**0.85**	*0.94/1.0*	**1.02**	**1.11**
0.30	**0.53**	**0.64**	**0.75**	**0.85**	**0.96**	**1.07**	**1.17**	**1.28**	**1.38**
0.38	**0.67**	**0.81**	**0.94**	**1.08**	**1.21**	**1.35**	**1.48**	**1.62**	**1.75**
0.48	**0.85**	**1.02**	**1.19**	**1.36**	**1.53**	**1.70**	**1.87**	**2.04**	**2.22**
0.51	**0.91**	**1.09**	**1.27**	**1.45**	**1.63**	**1.81**	**1.99**	**2.17**	**2.35**
Note: - Figures in bold: former CSR BC rules satisfied - Figures in italic: former CSR BC rules not satisfied - Cell with 2 values: value for CSR BC & OT / value for CSR BC									

The correction factor taking into account the yield strength of the weld deposit is accepted as presented in CSR OT (July 2010), Sec 6/5.7.1.2 in order to meet the strong industry demand.

Minimum weld scantlings requirement was considered necessary and presented in the rules. The source of this requirement is CSR OT (July 2010), Table 6.5.2 but adjusted in order to be applicable to both types of ships. The minimum leg length in water and ballast and fresh water tanks is increased by 0.5mm. The gap in welds is limited to 2mm.

The corrosion addition specified in Pt 1, Ch 3, Sec 3, Table 1 has the categorization of "Within 3m below top of tank" for cargo oil tanks and ballast tanks. The corrosion addition in CSR-OT and CSR-BC basically follow the same philosophy and it is understandable that the top part of tanks would be a more corrosive environment compared with "Elsewhere" in the tank due to the presence of high salty and humid vapour during hot weather (sun effects).

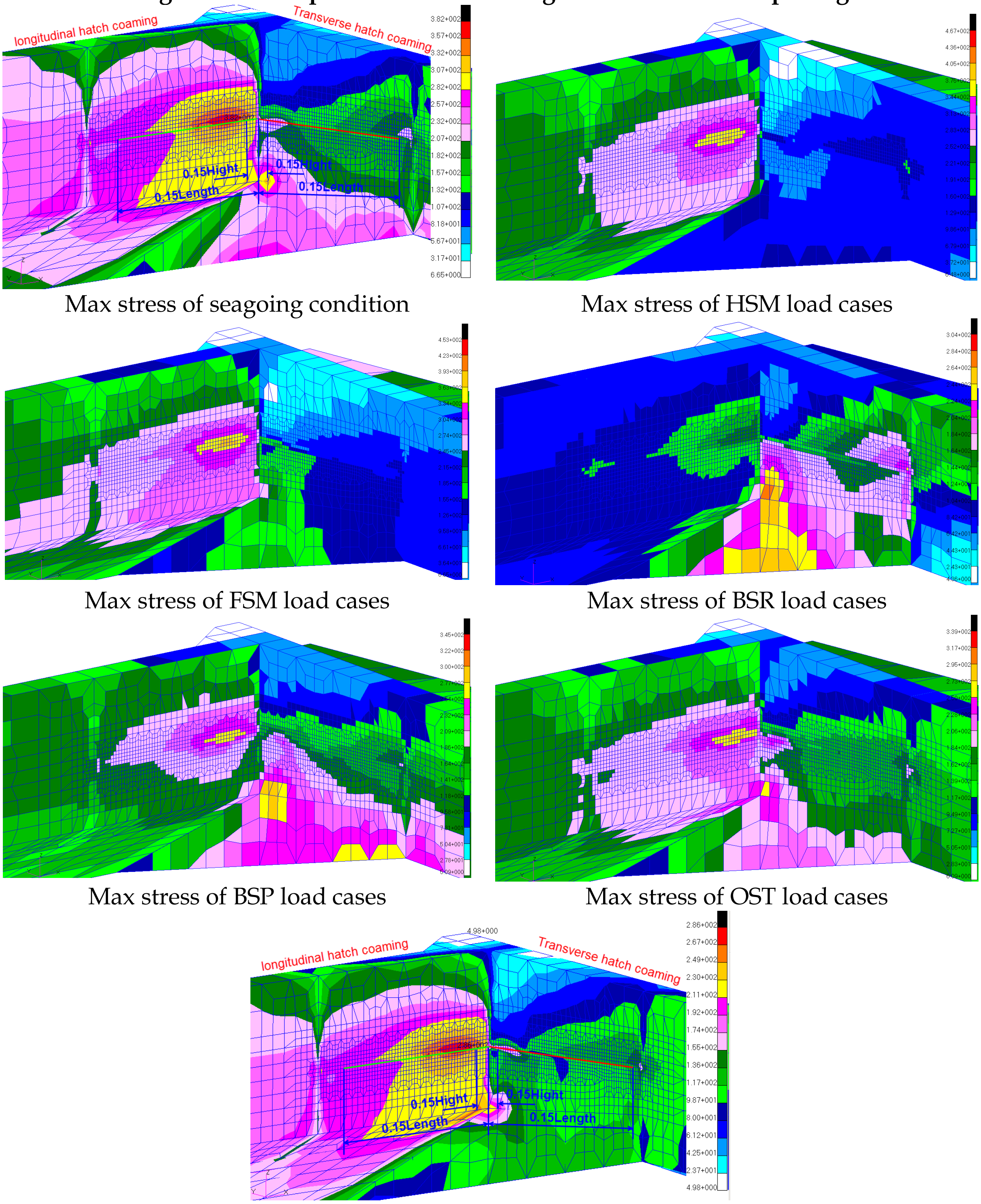
In Pt 1, Ch 12, Sec 3, Table 1, additional leg length of 0.5mm is required for areas within 3m below top of a compartment. This requirement is originally taking into account the excessive corrosion of this area as same as corrosion additions. Therefore, application of additional requirement of "Within 3m below top of tank of compartment" is limited to cargo oil tanks and water ballast tanks with weather deck as tank top.

Specific requirement for superstructures and deckhouses in Pt 1, Ch 12, Sec 3, Table 1 is based on the relevant requirements specified in CSR-BC and CSR-OT.

In Pt 1, Ch 12, Sec 3, Table 2, for the connection of the longitudinal hatch coaming to deck plating at corners of hatchways a full penetration welding is required, and the extent of full penetration welding is to be in line with the requirement of connection of hatch coaming end bracket to the deck plating, which is 15% of the hatch coaming height in Pt 1, Ch 12, Sec 3, [2.4.5] (m) and the minimum extent of full penetration welding described in Pt 1, Ch 12, Sec 3, [2.4.4] and [2.4.7].

A fine mesh FEM study is carried out to analyse the stress level of such connections in consideration of all relevant EDWs. The stress plots are shown in Figure 1. The connection of the longitudinal hatch coaming to deck plating is shown in a green line, and the connection of the transverse coaming to deck is shown in a red line. The maximum utilization factors, which is represented by λ_f / λ_{fperm}, refer to Pt 1, Ch 7, Sec 3, [6.2], of elements in way of connection are about 0.75-0.78, as listed in Table 2.

Figure 1. Stress plots of hatch coaming connection to deck plating



Max stress of seagoing condition

Max stress of HSM load cases

Max stress of FSM load cases

Max stress of BSR load cases

Max stress of BSP load cases

Max stress of OST load cases

Max stress of harbour condition

Table 2. Maximum utilization factors of hatch coaming connection to deck plating

Location	Seagoing condition	Harbour condition
Longitudinal hatch coaming	0.78	0.73
Transverse hatch coaming	0.75	0.78

According to the study, the stress levels of these connections based on 50 x 50 mm mesh size are within a reasonable range. Therefore, full penetration welding can be limited to a local area only, and 15% of hatch coaming height is in line with the principle of full/partial penetration welding for the local peak stress area in accordance with Pt 1, Ch 12, Sec 3, [2.4.4] and [2.4.7]. In addition, Non Destructive Examination (NDE) is less reliable in fillet welding compared with a full penetration welding as crack propagation from the root is difficult to detect before the crack reach the surface so the fillet welding for such critical locations i.e. hatch corner should be avoided for better quality control.

The remaining part of the connection within 15% of the longitudinal hatch length should follow the general requirement of watertight plate to boundary plating with welding factor of 0.48.

In Pt 1, Ch 12, Sec 3, Table 2, the superstructure and deck house, as well as the bulkheads of these structures, are in the same category for considering weld factors.

In Table 3, the welding factor f_{weld} for cleats and fittings on hatch coaming and hatch cover has been adjusted based on the investigation. (See Ch 12, Sec 3, [2.5.2] of TB for RCN 1 to CSR 01 Jan 2020).

RCN 1 to CSR 01 Jan 2022 reintroduced upper limit of intermittent weld leg length which was missing and lead to abnormally high leg length requirement. Upper limit is defined as per in CSR OT: "leg length for intermittent welding is not to exceed the greater of 6.5mm or 0.62*tas_built".

Further, length of weld also generally not to be less than 75 mm and also length of no weld zone not to exceed 150 mm.

In order to be in line with the requirements of CSR OT and CSR BC, Figure 4 was updated in RCN 1 to CSR 01 Jan 2022 to set the length of weld to not less than 75 mm and also the length of no weld zone to not more than 150 mm.

2.5.3

Technical background is not considered necessary.

2.5.4

This requirement is applicable for locations not listed in [2.5.2]. This approach is similar to CSR BC (July 2010), Ch 11, Sec 2, Table 2. The requirements of CSR OT (July 2010), Table 6.5.4 were considered not appropriate as they give the small leg length for primary supporting members.

2.5.5

This requirement is taken from CSR OT (July 2010), Sec 6/5.7.1.5.

2.5.6

This requirement is taken from CSR OT (July 2010), Sec 6/5.7.3.2.

2.5.7 Shear area of primary supporting member end connections

This criteria is taken from CSR OT (July 2010), Sec 6/5.7.4.1 but adjusted to clarify the meaning of rule gross thickness of primary supporting members.

2.5.8 Longitudinals

This requirement is taken from CSR OT (July 2010), Sec 6/5.7.5.1.

2.5.9 Deck longitudinals

This requirement is taken from CSR OT (July 2010), Sec 6/5.7.5.2.

2.5.10 Longitudinal continuity provided by brackets

This requirement is taken from CSR OT (July 2010), Sec 6/5.7.5.4.

2.5.11 Unbracketed stiffeners

This requirement is taken from CSR OT (July 2010), Sec 6/5.7.5.6.

2.5.12 Reduced weld size

This requirement is taken from CSR OT (July 2010), Sec 6/5.9.3.1 as it is more detailed than CSR BC (July 2010), Ch 11, Sec 2, 2.6.4.

2.5.13 Reduced weld size justification

Technical background is not considered necessary.

3 BUTT JOINT

3.1 General

3.1.1

Text and sketches are taken from CSR OT (July 2010), Sec 6/5.2.1.1.

3.2 Thickness difference

3.2.1 Taper

Text is derived from CSR BC (July 2010), Ch 11, Sec 2, 2.2.2 and CSR OT (July 2010), Sec 6/5.2.2.

4 OTHER TYPES OF JOINTS

4.1 Lapped joints

4.1.1 Areas

Text is derived from CSR BC (July 2010), Ch 11, Sec 2, 2.7.1.

4.1.2 Overlap width

Text is derived from CSR OT (July 2010), Sec 6/5.4.1.2.

4.1.3 Overlap for lugs

Text is derived from CSR OT (July 2010), Sec 6/5.4.1.3.

4.1.4 Lapped end connections

Text is derived from CSR OT (July 2010), Sec 6/5.4.2.1.

4.1.5 Overlapped seams

Text is derived from CSR OT (July 2010), Sec 6/5.4.3.1.

4.2 Slot welds

4.2.1

Text is derived from CSR BC (July 2010), Ch 11, Sec 2, 2.8.1.

4.2.2

Text is derived from CSR OT (July 2010), Sec 6/5.5.1.2. The figure and the specific information on the slot geometry and spacing of slots are taken from IACS Rec 47 (Rev 5, October 2010), "Shipbuilding and Repair Quality Standard".

4.2.3 Closing plates

Text is derived from CSR OT (July 2010), Sec 6/5.5.2.1.

4.2.4

Text is derived from CSR OT (July 2010), Sec 6/5.5.2.2.

4.3 Stud welds

4.3.1

Text is derived from CSR OT (July 2010), Sec 6/5.6.1.1.

5 CONNECTION DETAILS

5.1 Bilge keels

5.1.1

Text is derived from CSR OT (July 2010), Sec 11/3.3.4.1. Welding requirements for connections of bilge keels are derived from CSR OT (July 2010), Sec 11/3.3.4.1 and Table 11.3.1. The figures are taken from CSR BC (July 2010), Ch 11, Sec 2, 3.1.3 and CSR OT (July 2010), Sec 11/3.3.4.3.

5.1.2

Text is derived from CSR OT (July 2010), Sec 11/3.3.4.2.

5.1.3

Text is derived from CSR BC (July 2010), Ch 11/Sec 2, 3.1.3.

5.1.4

Text is derived from CSR OT (July 2010), Sec 11/3.3.4.3.

5.2 Bulk carrier side frames

5.2.1

Technical background is not considered necessary.

5.2.2

Text is derived from CSR BC (July 2010), Ch 11, Sec 2, 2.6.1. The figure is taken from CSR BC (July 2010), Ch 3, Sec 6, 8.3.1.

5.2.3

Text is derived from CSR BC (July 2010), Ch 3, Sec 6, 8.5.1 and Ch 11, Sec 2, Table 2.

5.3 End connections of pillars and cross ties

5.3.1

Text is derived from CSR OT (July 2010), Sec 6/5.10.1.1. The equation for sizing welds for pillars and cross-ties is based on a weld area calculation, i.e. effective throat area times weld length. The equation includes an allowance for the weld deposit material strength as indicated in the DNV Rules (January 2010), Pt 3, Ch 1, Sec 12, C303 consistent with Sec 6/5.7.1.2 of the CSR OT (July 2010).

5.4 Abutting plate with small angles

5.4.1

Text is derived from CSR BC (July 2010), Ch 11, Sec 2, 2.6.3. And adjustment made such that for angles over 75 deg no increase in weld is necessary.

5.4.2

The philosophy behind this rule is that it is not possible to ensure the good painting in areas where the angle is too small.

PART 1 CHAPTER 13

SHIP IN OPERATION - RENEWAL CRITERIA

Table of Contents

1 PRINCIPLES

1.1 Application

1.1.1
Technical background is not considered necessary.

1.1.2
Technical background is not considered necessary.

1.1.3
Technical background is not considered necessary.

1.1.4
Technical background is not considered necessary.

1.2 Corrosion allowance concept

1.2.1 Corrosion allowance
Technical background is not considered necessary.

1.2.2 Assessment
Technical background is not considered necessary.

1.2.3 Steel renewal
Technical background is not considered necessary.

1.3 Requirements for documentation

1.3.1 Plans
Technical background is not considered necessary.

1.3.2 Hull girder sectional properties
Technical background is not considered necessary.

2 HULL SURVEY REQUIREMENTS

2.1 General

2.1.1 Minimum hull survey requirements
Technical background is not considered necessary.

1 GENERAL

1.1 Application

1.1.1
Technical background is not considered necessary.

1.2 Definition

1.2.1 Deck zone
The requirement is based on IACS UR, Z10 (July 2011).

1.2.2 Bottom zone
The requirement is based on IACS UR, Z10 (July 2011).

1.2.3 Neutral axis zone
Technical background is not considered necessary.

2 RENEWAL CRITERIA

2.1 Local corrosion

2.1.1 Renewal thickness of local structural elements
The requirement is identical to CSR BC and OT (July 2010).

2.1.2 Renewed area
The requirement is identical to CSR OT (July 2010), Sec 12/1.4.2.5.

2.1.3 Alternative solutions
The requirement is identical to CSR BC (July 2010), Ch 12, Sec 2, 1.2 and CSR OT (July 2010), Sec 12/1.2.2.3.

2.2 Global corrosion

2.2.1 Application
The requirement, the ship's longitudinal strength is to be evaluated, during special surveys, for ships over 10 years of age is based on IACS UR, Z10.4 (Rev 10, July 2011) for OT, Table IX(v) and Annex III (as amended).

The requirement identical to CSR for Bulk Carriers is adopted. In these Rules, the term "Special Survey" is used in line with IACS UR, Z10 (July 2011). However, according to IACS UR, Z10 (July 2011), some Societies use the term "Renewal Survey" instead.

2.2.2 Renewal criteria
(a) Deck and bottom zones:
The global strength assessment may be performed either by the calculation of the hull girder sections or by the calculation of zone areas which constitute the hull girder flanges and which provide a simplified, but accurate enough, evaluation of the hull girder section modulus.

The allowable limit of 90% of either the section moduli or the deck and bottom zone areas is based on CSR BC and IACS UR Z10.4 (Rev 10, July 2011) for oil tankers. The harmonisation for the 2 ship types is based on CSR BC (July 2010) and no need to request the inertia, I_y and the hull girder section modulus about the vertical axis.

(b) Neutral axis zone:
The harmonisation is made to allow a pragmatic verification by surveyors for hull girder shear area through the calculation of the neutral axis zone area. The allowable limit for this area is the area calculated with the $t_{g\text{-}off}$ - $0.5t_c$ on all the platings considered in the neutral axis zone. This allowable limit is the same as the one considered in the calculations performed at newbuilding stage for FE analysis and hull girder prescriptive evaluations.

The penultimate sentence of the requirements means that if all items of a transverse section comply individually with its zone area criteria, the global assessment of the transverse section is made. There is no need to perform the area calculation on each zone. The criteria referring to the gross offered thickness are to give the owner the benefit of voluntary additional thicknesses that he could have requested to the shipbuilder.

PART 2

SHIP TYPES

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PART 2 CHAPTER 1

BULK CARRIERS

Table of Contents

1 FORECASTLE

1.1 General

1.1.1

This regulation is in accordance with IACS UR, S28.1 (Rev 3, May 2010), paragraph 1 and UR, S28.2 (Rev 3, May 2010), paragraphs 1 and 2 (as amended).

1.1.2

This regulation is in accordance with IACS UR, S28.2 (Rev 3, May 2010), paragraph 3.

1.1.3

This regulation is in accordance with IACS UR, S28.2 (Rev 3, May 2010), paragraph 4.

1.1.4

This regulation is in accordance with IACS UR, S28.2 (Rev 3, May 2010), paragraph 5.

2 ACCESS ARRANGEMENTS

2.1 Special arrangements for bulk carriers

2.1.1

Refer to TB Pt.2, Ch 2, Sec 1, [4.1.1].

This paragraph transposes the applicable requirements that are already present for Oil Tankers in the CSR into the relevant place for Bulk carriers. The specific content was amended slightly to recognise that Bulk carriers typically do not have a similar pump room arrangement and there is a reduced risk profile associated with duct keels and pipe tunnels as they are less likely to be exposed to volatile organic compounds (VOCs) which may become trapped in these enclosed spaces.

2.1.2

Refer to TB [2.1.1].

1 APPLICATION

1.1 General

1.1.1

Technical background is not considered necessary.

2 CORROSION PROTECTION

2.1 General

2.1.1 Void double side skin spaces

Technical background is not considered necessary.

2.1.2 Cargo holds and ballast holds

Technical background is not considered necessary.

2.2 Protection of void double side skin spaces

2.2.1

It is reminded that it is the responsibility of the builder to provide an efficient corrosion prevention system, such as hard protective coatings or equivalent in the void spaces of the cargo area. The builder attention is drawn that SOLAS, Ch II-1, Reg. 3-2, §2 (as amended) provides requirements for the protection against corrosion of the structures of void double side skin spaces in the cargo length area for bulk carriers having a length (LLL) of not less than 150 m..

2.3 Protection of cargo hold spaces

2.3.1 Coating

This regulation is in accordance with IACS UR, Z9 (Corr. 1, 1997).

2.3.2 Application

Refer to TB [2.3.1].

2.3.3 Side areas to be coated

Refer to TB [2.3.1].

2.3.4 Transverse bulkhead areas to be coated

Refer to TB [2.3.1].

3 STRUCTURAL DETAIL PRINCIPLES

3.1 Double bottom structure

3.1.1 Application

Technical background is not considered necessary.

3.1.2 Girders spacing

This requirement ensures that the spacing between double bottom girders is not too large in ships the structure of which is not assessed through a finite element calculation. The formulae in this article are empirical.

3.1.3 Floors spacing

This requirement ensures that the spacing between double bottom floors is not too large in ships the structure of which is not assessed through a finite element calculation. The formulae in this article are empirical.

3.2 Single side structure

3.2.1 Application

All the requirements in this sub-article are base on IACS UR, S12 (Rev 5, May 2010), considering the net scantling approach.

3.2.2 General arrangement

Refer to TB [3.2.1].

3.2.3 Side frames

Refer to TB [3.2.1].

3.2.4 Upper and lower brackets

Refer to TB [3.2.1].

3.2.5 Tripping brackets

Refer to TB [3.2.1].

3.2.6 Support structure

Refer to TB [3.2.1].

3.3 Deck structures

3.3.1 Web frame spacing in topside tanks

This requirement ensures that the spacing between top side tank webs is not too large in ships the structure of which is not assessed through a finite element calculation. The formulae in this article are empirical.

3.3.2 Cross deck between hatches of bulk carriers

Technical background is not considered necessary.

3.3.3 Topside tank structures

Technical background is not considered necessary.

3.3.4 Openings in strength deck – Corner of hatchways

For ships with hatches longitudinally arranged elliptical hatch corners are beneficial in case of pure vertical bending. In case of torsional loads the deck strips between the hatches are bent and in this case transversely arranged elliptical hatch corners are beneficial. Large BCs are affected by vertical bending as well as by torsion and consequently circular shaped hatch corners are a good compromise.

3.3.5 Protection against wire rope

This regulation is based on the paragraph 2 for SOLAS regulation XII/6.5.1 in SLS. 14/Circ. 250 as well as IACS Unified Interpretation SC208.

3.3.6 Protection of cargo hatch opening corners against mechanical damage

In URCN to Jan 2014, the surface finishing factor was modified provided that adequate protective measures are taken as well as refined stress range calculation are carried out.

At the GBS maintenance audit, Auditors requires further clarification of "adequate protective measurement" as an observation.

To address this observation, it is considered necessary to clarify the Rule requirement in respect of protection of the hatch corner from mechanical damage e.g. grooving by grab wire. For this purpose, the rule text is proposed to be amended to alleviate this concern.

Protective measure, e.g. fitting a round bar diagonally across the corner slightly above or below the upper deck level, is to be provided by designers for approval.

1 CARGO HOLD SIDE FRAMES OF SINGLE SIDE BULK CARRIERS

1.1 Strength criteria

1.1.1 Net section modulus and net shear sectional area

This requirement is based on requirement stated in IACS UR, S12.4.1 (Rev 5, May 2010). This text considers the net section modulus and the minimum net web thickness under the following forms:

- Net section modulus: $$Z = C_3 \frac{m_m \; P_{frame} \; h}{\sigma_F}$$
- Net web thickness: $$t_w = \frac{1000 \; C_s \; P_{frame}}{d_b \; \sin\phi \; \tau_a} \cdot \frac{h - 2h_B}{h}$$

These formulae have been expressed in terms of symbols specific to harmonised CSR for bulk carriers:

- Net section modulus: $$Z = 1.125\alpha_m \frac{Ps\ell_{SF}^{\,2}}{f_{bdg} C_s R_{eH}} 10^3$$
- Net shear sectional area: $$A_{sh} = 1.1\alpha_S \frac{5Ps\ell_{SF}}{C_t \tau_{eH} \sin\phi} \left(\frac{\ell_{SF} - 2\ell_B}{\ell_{SF}} \right)$$

The shear force at the lower end of the side frame span is obtained, by assuming that the sum of the still water and wave pressures is uniform along the span. It is also assumed that the percentage of total lateral force on the frame that is carried by the lower end support is equal to:

- 60%, in general,
- 66%, for the side frames of holds specified to be empty in ships assigned with the BC-A notation, as defined in IACS UR, S25 (which is no more in force). This greater value is due to the effect of the hopper tank rotation induced by the sea pressure on the double bottom, not counterbalanced by any internal cargo (see below).

The shear force at section (b) is assumed to be equal to that at section (a) multiplied by a factor. The factor is equal to the frame span "*h*" minus twice the length of the lower bracket divided by "*h*" (it is assumed here that the upper and the lower brackets have the same length).

The minimum net web thickness of the side frame is evaluated at the section (b), considering the angle of the inclination of the web to the shell plating. The bending moment acting on the side frame is obtained by multiplying the total lateral force on the frame by the frame span and by coefficients "m_m" that gives the factor of the maximum bending moment along the side frame span.

The "m_m" values depend on the loading condition of the hold to which the frame under consideration belongs. Finite element calculations have shown that the maximum bending moment for the side frames of ore holds is at the mid-span; for empty holds the maximum bending moment is at the lower end.

On the basis of finite element calculations, "m_m" values are assumed to be 70 for BC-A ships, as defined in IACS UR, S25 (which is no more in force), and 60 for other cases; the value of 70 for the loaded holds of BC-A ships is equivalent to the bending moment of the frame assumed simply supported inside the brackets.

For the empty holds of BC-A ships, an higher values of the coefficient "m_m" has been included considering that in non-homogeneous loading conditions (i.e. at the maximum draft) the sea pressure acting on the double bottom is not counterbalanced by internal cargo. This induces significant rotation of the hopper tanks and hence of the side frame lower ends, that increases the bending moment at the lower end.

The required net section modulus of the side frame is evaluated in the elastic domain; a reduction of 20%, incorporated using coefficient C3 equal to 0.83, was included in the formula for the required modulus to permit some plastic behaviour under extreme loads.

1.1.2 Side frames in ballast holds

This requirement is based on requirements stated in IACS UR, S12.4 (Rev 5, May 2010). The requirement to side frame in [1.1.1] considers bulk cargoes and sea loads. For side frames in ballast holds, ballast pressure may be governing and strength shall be checked the same way as required for stiffeners on other tank boundaries.

1.1.3 Additional strength requirements

This requirement is based on requirement stated in IACS UR, S12.4.2 (Rev 5, May 2010) and shown as follows:

Service record of bulk carriers and other type of ships reports that vertical crack occurs on side shell plating along the line of collision bulkhead. In case where brackets are fitted on side shell between collision bulkhead and a hold frame abaft the bulkhead, those brackets crack or side shell plating cracks along the hold frame abaft the brackets fitted.

It is considered that deformation of hold frame due to repeated wave load induces bending of side shell plating between collision bulkhead and the hold frame thereafter and this bending of side shell plating induces fatigue crack on side shell plating along the line of collision bulkhead. Cracks of brackets or of side shell plating abaft brackets are considered to occur for the same reason.

A formula to require a moment of inertia of hold frame is specified to control the deformation of the frame within 3/1000 × (frame space) at its mid-span where a sea pressure force, P_{frame}, acts on the side shell plating.

1.2 Lower bracket of side frame

1.2.1

This requirement is based on requirements of IACS UR, S12.4 (Rev 5, May 2010).

1.2.2

This requirement is based on requirements of IACS UR, S12.4 (Rev 5, May 2010).

1.2.3

This requirement is based on requirements of IACS UR, S12.4 (Rev 5, May 2010).

1.2.4

This requirement is based on requirements IACS UR, S12.6 and S12.8 of the IACS UR, S12 (Rev 5, May 2010) and shown as follows:

The limit values for the web depth to thickness ratio are introduced for lower brackets, in addition to those already specified in IACS UR, S12 (Rev 5, May 2010), which are valid for the side frames. The limits for the web depth to thickness ratio of lower brackets take into account that, in order to comply with the requirements for the section modulus of the brackets in IACS UR, S12.6 (Rev 5, May 2010), the web depth increases more in the lower bracket than the shear force, with respect to the corresponding value at the top of the lower bracket. As a consequence, the shear stresses in the lower bracket are lower than in the span (the highest shear stress values occur at the top of the lower bracket).

When calculating the web depth to the thickness ratio, the web depth of the lower bracket may be measured from the intersection between the sloped bulkhead of the hopper tank and the side shell plate, perpendicularly to the face plate of the lower bracket.

The thickness $t_{d/t}$, which satisfies the web dept to thickness ratio, can be reduced to $t'_{d/t}$ = $\sqrt[3]{t_{d/t}{}^2 t_w}$ for the frames immediately abaft the collision bulkheads, which are often oversized for the purpose of providing a smooth stiffness transition between the fore peak structure and the hold side structures. For these frames, when the required minimum net web thickness t_w is such that the side frame web works in the elastic domain, the formula for $t'_{d/t}$ accounts for the fact that the working shear stress is lower than the admissible one.

The formula for $t'_{d/t}$ is derived as reported in the following:

The relationship between critical shear stresses and the web plate thickness is given by the Equation (1).

$$\tau_{cr} = K \frac{\pi^2 E}{12(1-\upsilon^2)} \left(\frac{t}{b}\right)^2 = S_f \tau_a \qquad (1)$$

where,

t = $t_{d/t}$, web thickness satisfying the required shear buckling criteria corresponding to the assumed allowable shear stress τ_a with safety factor.

τ_a = Allowable shear stress (= $0.5\sigma_y$).

S_f = Safety factor.

In case where working shear stress, τ_{work} is less than the allowable shear stress, τ_a the corresponding critical shear stress, τ_{cr}' while maintaining the same safety factor, is given by:

$$\tau_{cr}' = K \frac{\pi^2 E}{12(1-\upsilon^2)} \left(\frac{t'_{d/t}}{b}\right)^2 = S_f \tau_{work} \qquad (2)$$

where $t'_{d/t}$ is the web plate thickness giving the critical shear stress τ_{cr}'. On the other hand, the working shear stresses τ_{work} is given by Equation (3).

$$\tau_{work} = \frac{t_w}{t'_{d/t}} \tau_a \qquad (3)$$

where, t_w is as given in IACS UR, S12.4.1 or in S12.5 (Rev 5, May 2010), whichever is the greater.

The following equation is obtained by substituting τ_{work} in Equation (2) by that of Equation (3):

$$K \frac{\pi^2 E}{12(1-\upsilon^2)}\left(\frac{t'_{d/t}}{b}\right)^2 = S_f \frac{t_w}{t'_{d/t}}\tau_a = S_f \tau_a \frac{t_w}{t'_{d/t}} \qquad (4)$$

Combining Equations (1) and (4) give the following relationship between $t_{d/t}$ and $t'_{d/t}$:

$$\left(\frac{t'_{d/t}}{b}\right)^2 = \frac{t_w}{t'_{d/t}}\left(\frac{t_{d/t}}{b}\right)^2 \qquad (5)$$

Equation (5) gives $t'_{d/t}$ as follows:

$$t'_{d/t} = \sqrt[3]{t_{d/t}^2 t_w} \qquad (6)$$

$t'_{d/t}$ given by the Equation (6) gives the web thickness for side frames and lower brackets satisfying the shear buckling criteria corresponding to the working shear stresses, where $t_{d/t}$ is greater than t_w.

The formula for $t'_{d/t}$ is based on the formulation of the elastic shear buckling stress, which is valid for shear stress lower than $\frac{1}{2\cdot\sqrt{3}}\cdot\sigma_F$, that is 0.29 of the material yielding. As t_w is based on the admissible shear stress equal to 0.5 of the material yielding, when the thickness $t_{d/t}$ is greater than 0.5/0.29 of t_w, that is $1.73t_w$, the side frame web works in the elastic domain and $t'_{d/t}$ will be obtained by the following formula:

$$t'_{d/t} = \sqrt[3]{{t_{d/t}}^2 t_w}$$

Furthermore, in the requirements for asymmetrically flanged frames the higher strength steel k factor has been removed, as the same IACS UR, S12 (Rev 5, May 2010) allows such frames to be adopted only if made in normal strength steel.

1.3 Upper bracket of side frame

1.3.1

This requirement is based on requirements of IACS UR, S12.4 (Rev 5, May 2010).

1.3.2

This requirement is based on requirements of IACS UR, S12.4 (Rev 5, May 2010).

1.4 Provided support at upper and lower connections of side frames

1.4.1 Net section modulus

This requirement is based on requirements stated in IACS UR, S12.7 (Rev 5, May 2010). This draft text considers the relation ship between net section modulus and distances under the following form:

$$\sum_n \left(Z_i \cdot a_i\right) \geq \frac{1000\, C_t\, P_{frame}\, h\, \ell_1^2}{16\, s\, \sigma_F}$$

This formula has been then expressed in terms of symbols specific to CSR BC (July 2010):

$$\sum_n Z_i d_i \geq \alpha_T \frac{P_{BC}\ell_{SF}{}^2 \ell_1^2}{16 R_{eH}}$$

The section modulus of the longitudinals is required to have sufficient bending strength to support the end fixing moment of the side frame about the intersection point of the sloping bulkhead and the side shell.

The end fixing moment of the side frame is that induced by the external sea pressure acting on the side frame (end brackets excluded) and the deflection and rotation of the end support due to the loading on the hopper and the double bottom.

The sea pressure loading on the end brackets is not included because the sea pressure loading on this and on the connecting structure of the hopper and topside tank are assumed to cancel.

The end fixing moment, M_{ef}, in Nm, of the side frame about the intersection point of the sloping bulkhead and the side shell in Nm is given as:

$$M_{ef} = 1000 \cdot P_{frame} \cdot h \cdot C_m + h_B \cdot 1000 \cdot P_{frame} \cdot C_s \cdot \frac{h - 2h_B}{h}$$

where,

- C_m is the bending moment coefficient at the lower end or at the upper end of the side frame.
- C_s is the fraction of the total sea pressure force, which is carried by the lower end or the upper end of the side frame.

The end fixing moment, M_{ef}, gives rise to the line loads, q_{ef}, in N/m, on the longitudinals of the side shell and sloping bulkhead that support the lower and upper connecting brackets, given as:

$$q_{ef} = \frac{M_{ef}}{s\ a} = \frac{1000\ P_{frame}\ h}{s\ a}\left(C_m + \frac{h_B}{h} \cdot \frac{h - 2h_B}{h} C_s\right)$$

The line load, q_{ef}, gives rise to the plastic bending moments, M_c, in Nm, in the longitudinals that support the lower and upper connecting brackets, given as:

$$M_c = \frac{q_{ef}\ \ell_l^2}{16} = \frac{1000\ P_{frame}\ h\ \ell_l^2}{16\ s\ a}\left(C_m + \frac{h_B}{h} \cdot \frac{h - 2h_B}{h} C_s\right)$$

Hence, assuming an allowable stress equal to yield, the section modulus requirement for a connected side or sloping bulkhead longitudinal in cm³ becomes:

$$Z = \frac{M_c}{\sigma_F} = \frac{1000\ P_{frame}\ h\ \ell_l^2}{16\ s\ a\ \sigma_F}\left(C_m + \frac{h_B}{h} \cdot \frac{h - 2h_B}{h} C_s\right)$$

The above expression assumes a single connected longitudinal. For more than one connected longitudinal, the plastic bending moment, M_c is to be supported by the sum of the connected longitudinals and the requirement becomes:

$$\sum_n (Z_i \cdot a_i) = \frac{1000\ P_{frame}\ h\ \ell_l^2}{16\ s\ \sigma_F}\left(C_m + \frac{h_B}{h} \cdot \frac{h - 2h_B}{h} C_s\right)$$

The above expression, assuming,

$C_T = \left(C_m + \frac{h_B}{h} \cdot \frac{h - 2h_B}{h} C_s\right)$ becomes:

$$\sum_n (Z_i \cdot a_i) = \frac{1000\, P_{frame}\, h\, \ell_l^2}{16 \quad s \quad \sigma_F} C_T$$

On the basis of the finite element calculations, C_m is assumed equal to 0.07 for the lower end and 0.02 for the upper end. For a lower bracket length of 0.125 the side frame span, considering the value for C_S equal to 0.66, as defined in IACS UR, S12 (Rev 5, May 2010).

The term $\frac{h_B}{h} \cdot \frac{h - 2h_B}{h} C_s$ is, conservatively assumed equal to 0.08 for the lower brackets; hence C_T is assumed equal to 0.15 for the longitudinal stiffeners supporting the lower connecting brackets.

Assuming that the shear force supported by the upper end is 2/3 of that supported by the lower end, the term $\frac{h_B}{h} \cdot \frac{h - 2h_B}{h} C_s$ is, conservatively equal to 0.05 for the upper brackets; hence C_T is assumed equal to 0.075 for the longitudinal stiffeners supporting the upper connecting brackets.

1.4.2 Net connection area of brackets

The longitudinals are required to have sufficient section modulus and thus bending strength to support the end fixing moment of the side frame at the intersection point of the sloping bulkhead and the side shell.
The end fixing moment of the side frame is that induced by the external sea pressure acting on the side frame (end brackets excluded) and the deflection and rotation of the end support due to the loading on the hopper and the double bottom.
The sea pressure loading on the end brackets is not included because the sea pressure loading on this and on the connecting structure of the hopper and topside tank are assumed to cancel.
The end fixing moment, M_{ef}, of the side frame about the intersection point of the sloping bulkhead and the side shell in Nm is given as:

$$M_{ef} = \alpha_T \cdot P \cdot s \cdot l_{SF}^2 \cdot 10^{-3} \qquad (1)$$

Where

α_T : The coefficient determined by the results of FEA considering the moments transferred from the topside structure or bilge hopper structure.

- α_T=150 for the longitudinal stiffeners supporting the lower connecting brackets.
- α_T=75 for the longitudinal stiffeners supporting the upper connecting brackets.

P : Pressure, in kN/m², at the side frame to be considered.
s : The space, in mm, of the side frame
l_{SF} : The span, in m, of the side frame

The end fixing moment, M_{ef}, gives rise to line loads on the connected side and sloping bulkhead stiffeners, q_{efi}, in N/m such that:

$$M_{ef} = s \cdot \sum_i q_{efi} \cdot d_i \cdot 10^{-3} \qquad (2)$$

Where,

d_i : Distance, in m, of the i-th longitudinal stiffener from the intersection point of the side shell and topside/bilge hopper tank.

The line load, q_{efi}, gives rise to plastic bending moments in the connected side and sloping bulkhead stiffeners, M_{ci}, in Nm, given as:

$$M_{ci} = \frac{q_{efi} \cdot l_1^2}{16} \qquad (3)$$

Where,

l_1 : Spacing, in m, of transverse supporting webs in topside / bilge hopper tank.

Hence, assuming an allowable stress of the i-th longitudinal stiffener equal to yielding stress, $R_{eH,lg-i}$, in N/mm², the required section modulus, $z_{i,r}$, for a connected side or sloping bulkhead longitudinal in cm³ becomes:

$$z_{i,r} = \frac{M_{ci}}{R_{eH,lg-i}} \qquad (4)$$

Injecting the expression of M_{ci} from (3) into (4), putting q_{efi} into (2) and M_{ef} into (1), we obtain:

$$\sum_i z_{i,r} \cdot d_i \cdot R_{eH,lg-i} = \frac{M_{ef} \cdot l_l^2}{16s} \cdot 10^3 = \frac{\alpha_T \cdot P \cdot l_{SF}^2 \cdot l_1^2}{16} \qquad (5)$$

The above expression allows the required section modulus of the connected longitudinals to be determined and is given as:

$$\sum_i z_{pli} \cdot d_i \cdot R_{eH,lg-i} \geq \sum_i z_{i,r} \cdot d_i \cdot R_{eH,lg-i} = \frac{M_{ef} \cdot l_l^2}{16s} \cdot 10^3 = \frac{\alpha_T \cdot P \cdot l_{SF}^2 \cdot l_1^2}{16} \qquad (6)$$

Where,

z_{pli} : The offered net plastic modulus, in cm³, of the i-th longitudinal stiffener

If the lowest value of specified yield stress, $R_{eH,lg}$, in N/mm², is applied, among the materials of the longitudinal stiffeners of side shell and hopper/topside tanks that support the lower/upper end connecting bracket of the side frame. Then the formula (6) can be changed to:

$$\sum_i z_{pli} \cdot d_i \geq \frac{\alpha_T \cdot P \cdot l_{SF}^2 \cdot l_1^2}{16 \cdot R_{eH,lg}} \qquad (7)$$

The connecting force Q_{efi}, in N, is transferred through shear between the brackets and the longitudinals, with:

$$Q_{efi} = s \cdot q_{efi} \cdot 10^{-3} \qquad (8)$$

Assuming an allowable shear stress of the connecting bracket of the i-th longitudinal stiffener equal to $0.5R_{eH,bkt-i}$, in N/mm², which is safe side comparing with the ultimate shear stress $R_{eH}/\sqrt{3}$. If $A_{i,r}$, in cm², is the required connection area of the bracket connecting with the i-th longitudinal, following formula is educed:

$$0.5R_{eH,bkt-i} = \frac{Q_{efi}}{100A_{i,r}} = \frac{s \cdot q_{efi}}{100A_{i,r}} \cdot 10^{-3} \qquad (9)$$

Injecting q_{efi} from (3) and (4) inside (9), we obtain:

$$A_{i,r} \cdot R_{eH,bkt-i} = 0.32 \frac{s \cdot z_{i,r} \cdot R_{eH,lg-i}}{l_1^2} \cdot 10^{-3} \qquad (10)$$

Because $z_{i,r}$ cannot be obtained directly, the formula (10) is changed to:

$$\sum_i A_{i,r} \cdot d_i \cdot R_{eH,bkt-i} = 0.32 \frac{s}{l_1^2} \sum_i z_{i,r} \cdot d_i \cdot R_{eH,lg-i} \cdot 10^{-3} \qquad (11)$$

According to (5)， (11) can be changed as:

$$\sum_i A_{i,r} \cdot d_i \cdot R_{eH,bkt-i} = 0.02\alpha_T \cdot P \cdot s \cdot l_{SF}^2 \cdot 10^{-3} \qquad (12)$$

The requirement of the connecting area of the brackets is following:

$$\sum_i A_i \cdot d_i \cdot R_{eH,bkt-i} \geq 0.02\alpha_T \cdot P \cdot s \cdot l_{SF}^2 \cdot 10^{-3} \qquad (13)$$

Where,

A_i : The offered net connection area of the bracket connecting with the i-th longitudinal, in cm².

As an example, a representative Capesize bulk carrier is assessed to illustrate the consequences of the Rule Change. Cross sections of the upper and lower connections of side frame are provided as Figure 1.

The pressure, space and span of the side frame are following:

P=195.1 kN/m²
s=910 mm
l_{SF}=7.83 m

According to the formula (13), the consequence assessment for the upper and lower connections of side frame is shown in Table 1 and Table 2 respectively.

According to the consequence assessment in Table 1 and Table 2, there is no impact in scantlings.

Figure 1. The upper and lower connections of side frame

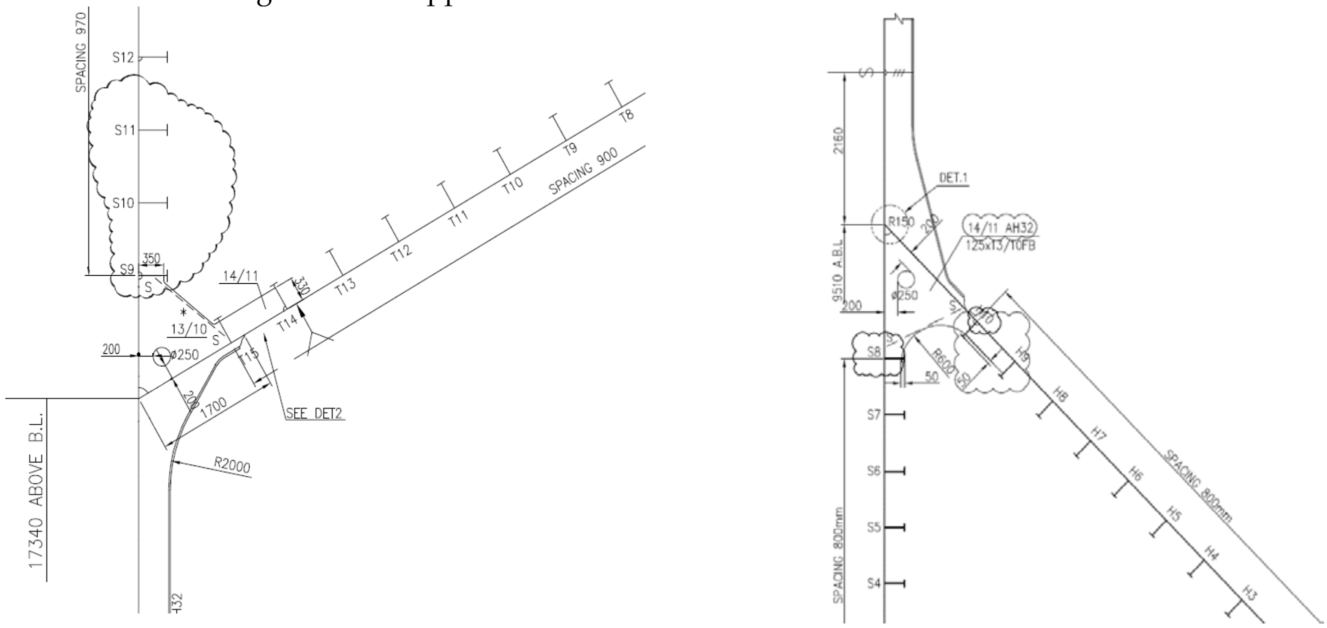


Table 1. The upper connections of side frame

i	Position	A_i (cm²)	d_i (m)	$R_{eH,bkt-i}$ (N/mm²)	$A_i \cdot d_i \cdot R_{eH,bkt-i}$
1	T15	33.0	1.512	235	11725.6
2	S9	35.0	1.640	235	13489.0
$\sum_i A_i \cdot d_i \cdot R_{eH,bkt-i}$					25214.6
$0.02\alpha_T \cdot P \cdot s \cdot l_{SF}^2 \cdot 10^{-3}$					16324.5
$\sum_i A_i \cdot d_i \cdot R_{eH,bkt-i} > 0.02\alpha_T \cdot P \cdot s \cdot l_{SF}^2 \cdot 10^{-3}$ The results show that the bracket areas of upper connections of side frame satisfy the rule requirement.					

Table 2. The lower connections of side frame

i	Position	A_i (cm²)		d_i (m)	$R_{eH,bkt-i}$ (N/mm²)	$A_i \cdot d_i \cdot R_{eH,bkt-i}$
1						
2	H10	27.5		1.956	315	16943.9
3	S8	27.5		1.910	315	16545.4
	$\sum_i A_i \cdot d_i \cdot R_{eH,bkt-i}$					33489.2
	$0.02\alpha_T \cdot P \cdot s \cdot l_{SF}^2 \cdot 10^{-3}$ Note: α_T=150					32649.0
	$\sum_i A_i \cdot d_i \cdot R_{eH,bkt-i} > 0.02\alpha_T \cdot P \cdot s \cdot l_{SF}^2 \cdot 10^{-3}$ The result shows that the bracket areas of lower connections of side frame satisfy the rule requirement.					

2 STRUCTURE LOADED BY STEEL COILS ON WOODEN DUNNAGE

2.1 General

2.1.1

In dimensioning the plating and ordinary stiffeners, static and dynamic loads due to dry bulk cargoes and liquid acting on the plating and ordinary stiffeners are considered as uniformly distributed loads. On the other hand, as steel coils are loaded on a wooden support (dunnage) provided on the inner bottom plating and bilge hopper plating, the concentrated loads due to steel coils act on the plating through the dunnage.

However, as the location of concentrated loads and the distance between concentrated loads depend on the loading pattern and size of dunnage, it is assumed that the concentrated load is transformed to a line load with a small breadth (hereinafter referred to as "rectangular load") which acts on the most severe conditions (load point and distance between load points). Based on this assumption, the specific formulae for dimensioning the plating and ordinary stiffeners under steel coil loading are given in Pt 2, Ch 1, Sec 3, [2].

The specific requirements for plating are specified in Pt 2, Ch 1, Sec 3, [2.3.1] and [2.4.1], and those for ordinary stiffeners are specified in Pt 2, Ch 1, Sec 3, [2.3.2] and [2.4.2].

The technical background of loads due to steel coils is common for plating and ordinary stiffeners and given in the TB related to Pt 1, Ch 4, Sec 6, [4].

These requirements are based on the assumption that steel coils are loaded on a wooden support and secured in the standard manner. These assumptions are given in Figure 2 in Pt 2, Ch 1, Sec 3.

2.2 Load application

2.2.1 Design load sets

Design load sets for steel coil cargo are defined in the same manner as other load sets as given in Pt 1, Ch 6, Sec 2, [2].

2.3 Inner bottom

2.3.1 Inner bottom plating

(a) Load model:
Steel coils are usually secured to each other by means of steel wires. Heavier steel coils are loaded with one or two tiers, and lighter ones are loaded with two or more tiers. Examples of steel coil loading are shown in Figure 1 and Figure 2.

Figure 1: Loading conditions of one tier

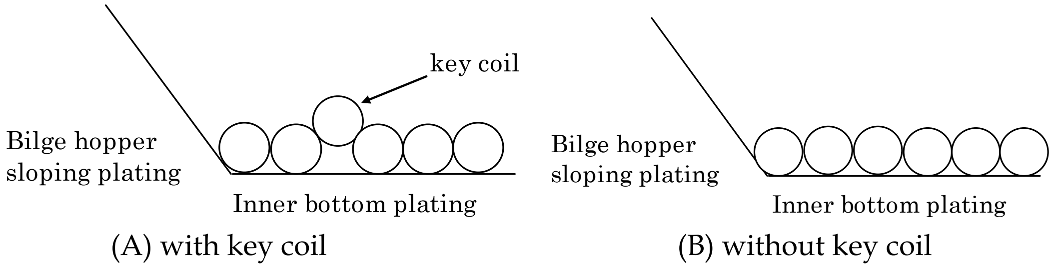
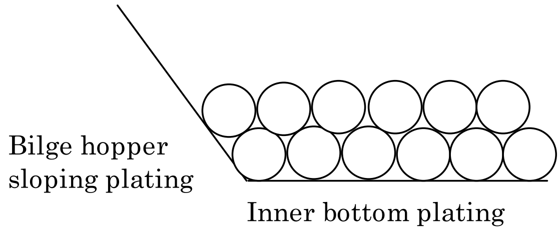


Figure 2: Loading conditions of two tiers

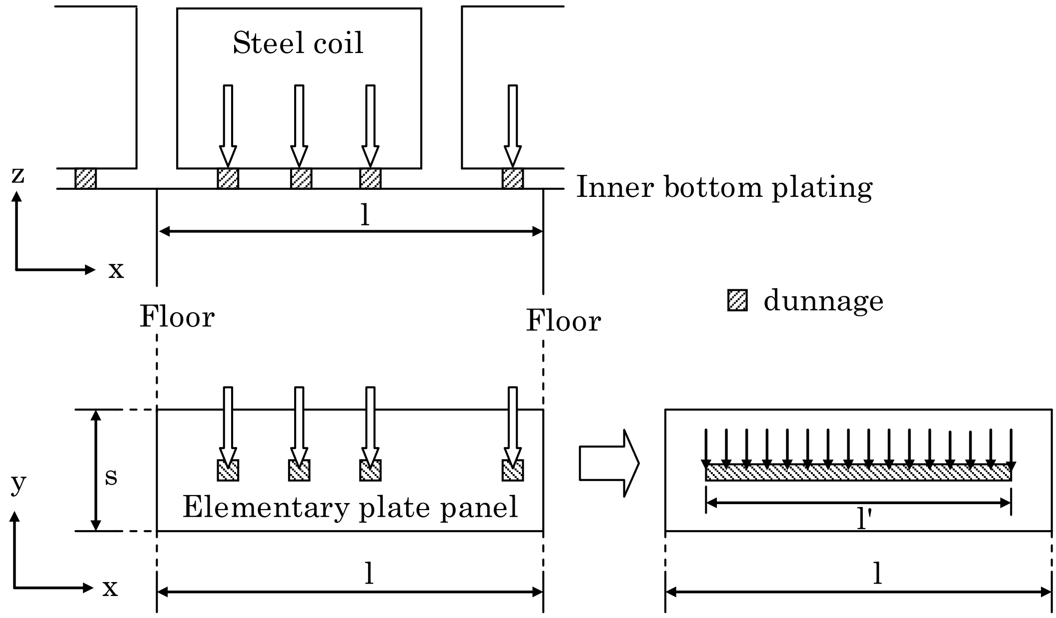


The load due to steel coils acts on an elementary plate panel as a concentrated load through dunnages. However, it is difficult to treat concentrated loads directly because the location of concentrated loads and the distance between concentrated loads depend on the loading pattern and size of dunnages.

Then, the following assumptions regarding the loads due to steel coils are considered:

- Loads due to steel coils act along a centreline of a plate panel.
- A rectangular load instead of concentrated loads is used in order to be on the safer side considering the interaction between concentrated loads.

Figure 3: Convert concentrated loads to rectangular loads



As it is the most severe when loads act on the inner bottom vertically, the vertical acceleration is considered for the scantling formula of inner bottom structures. The position of the centre of gravity is given by the following.

x : (a) For the hold of which the mid position is located forward of $0.45L$ from AE:
$x_{G\_SC} = 0.75\ l_H$ forward of aft bulkhead, and
(b) For the hold of which the mid position is located afterward of $0.45L$ from AE:
$x_{G\_SC} = 0.75\ l_H$ afterward of fore bulkhead.

y : $\varepsilon B_h/4$, measured from the centreline.

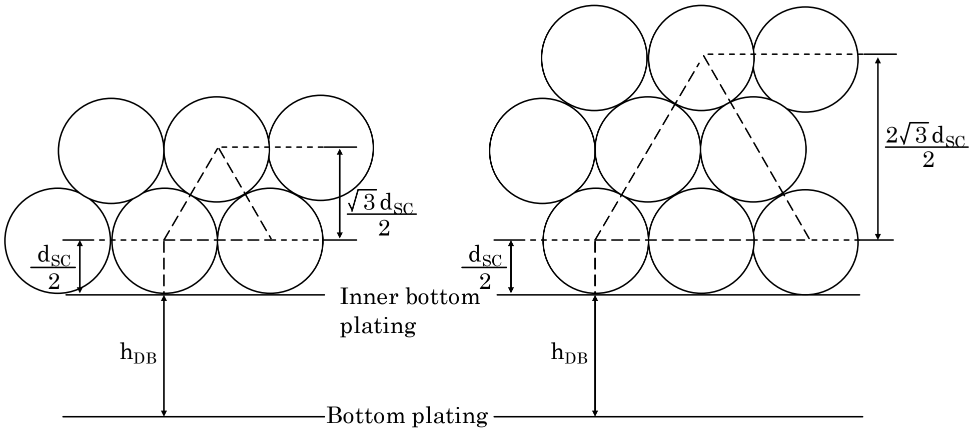
z : $h_{DB} + \left(1 + (n-1)\sqrt{3}/2\right) d_{SC}/2$

where,

ℓ_H : Cargo hold length.

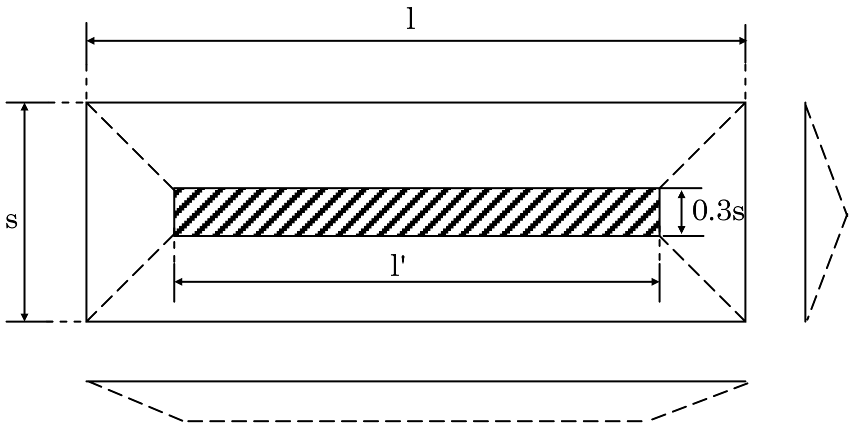
d_{SC} : Diameter of steel coil in m.
h_{DB} : Height of double bottom in m.
B_h : Breadth of hold at the mid of the hold in m.

Figure 4: The height of steel coils



(b) Structural model:
As mentioned in item (a) of [2.3.1], the rectangular load acts along the centreline of the panel. Its length ℓ' is determined by the panel length ℓ, the length of a steel coil ℓ_S, the number of load points n_2 and the number of dunnages supporting one steel coil n_3, and its width $0.3s$ is derived from dunnage width based on the actual loading data. Of course, the axial stress due to hull girder bending is considered in addition to the lateral rectangular load due to the steel coils. An elementary plate panel is collapsed like Figure 5. The boundary conditions of an elementary plate panel are that all sides are considered fixed.

Figure 5: Rectangular load and collapsed mode



Coefficient K_1 and K_2:
The coefficients K_1 and K_2 are derived from the principle of virtual work based on material physics.

Formula for required thickness of inner bottom plating:
Finally, the scantling formula for inner bottom plating is given as follows.

$t = K_1 \sqrt{\frac{F_{sc-ib-s}}{C_a R_{eH}}}$, applicable for design load set BC-9.

$t = K_1 \sqrt{\dfrac{F_{sc-ib}}{C_a R_{eH}}}$, applicable for design load set BC-10.

where,

$F_{sc-ib-s}$: Static force, in kN, as defined in Pt 1, Ch 4, Sec 6, [4.3.1].

F_{sc-ib} : Total force, in kN, as defined in Pt 1, Ch 4, Sec 6, [4.2.1].

2.3.2 Stiffeners of inner bottom plating

(a) Load model:

The structural model for ordinary stiffeners is based on the simple elastic beam theory. Therefore, the load model for ordinary stiffeners is based on concentrated loads due to steel coils acting through the dunnage. The calculation of acceleration is based on the same assumption for plating. The parameter and coefficients are also the same for plating.

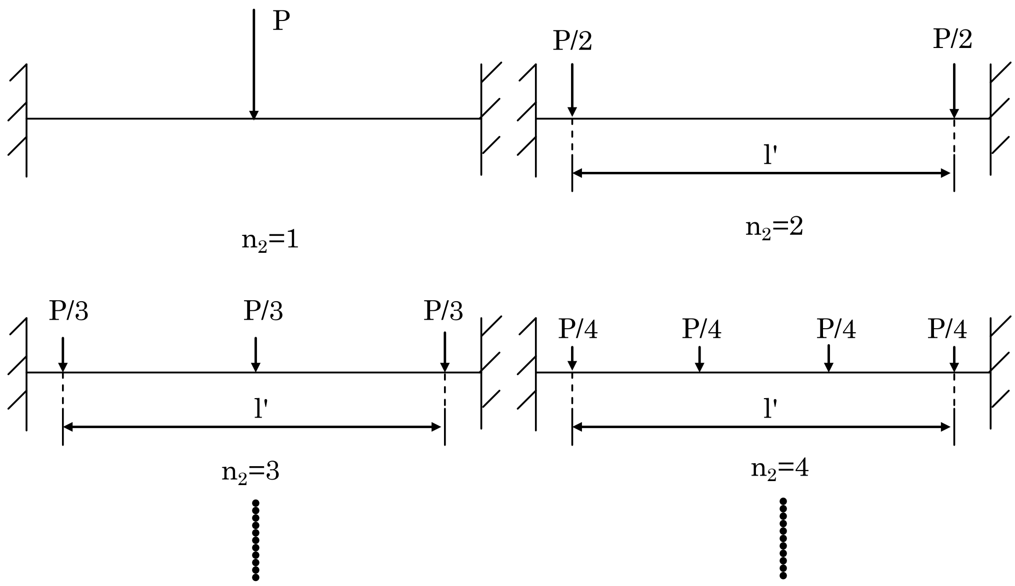
(b) Structural model:

Structural model of ordinary stiffeners is based on the simple beam theory with the boundary condition that both ends of beams are fixed.

Coefficient K_3:

The coefficient K_3 is derived from the ratios of moments at ends of stiffeners against n_2=1 when load points of the concentrated loads are located evenly between l' as shown in Figure 6. When n_2 is over 10, the coefficient K_3 is 2/3.

Figure 6: Load points on an ordinary stiffener



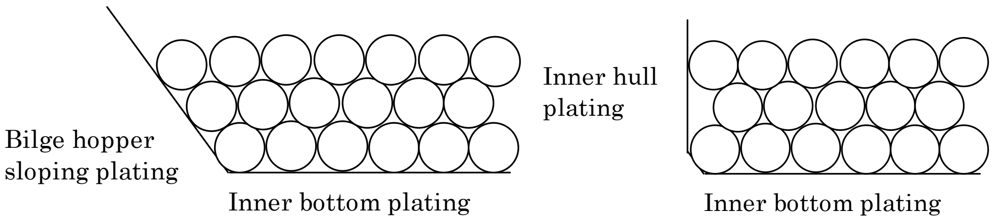
2.4 Hopper tank and inner hull

2.4.1 Hopper side plating and inner hull plating

(a) Load model:

This load model is the same for the inner bottom. The vertical component of the load is supported by the inner bottom directly or by other coils.

Figure 7: The examples of steel coil loading conditions



(b) Structural model:
The structural model for bilge hopper sloping plating and inner hull plating is the same for inner bottom plating.

2.4.2 Stiffeners of hopper side plating and inner hull plating

(a) Load model:
The concentrated load is considered as specified in item (a) of TB [2.3.2] and the acceleration due to roll motion is considered as specified in Pt 1, Ch 4, Sec 6, [4.4].

(b) Structural model:
Structural model of an ordinary stiffener is specified in item (b) of TB [2.3.2].

3 TRANSVERSE VERTICALLY CORRUGATED WATERTIGHT BULKHEADS SEPARATING CARGO HOLDS IN FLOODED CONDITION

3.1 Net thickness of corrugation

3.1.1 Cold formed corrugations

This requirement specifies the thickness required under flooded condition for plating of transverse vertically corrugated watertight bulkheads separating cargo holds. This requirement is based on CSR BC (July 2010) and IACS UR, S18.4.7 (Rev 8, May 2010). The capacity formulas apply for consideration of an accidental load and shall prevent progressive flooding. The requirements are therefore different from local strength requirements for corrugation plating in Pt 1, Ch 6, Sec 4 [1.2.1], which shall prevent repeated yielding or permanent deformations with regular static or dynamic tank loads.

3.1.2 Built-up corrugations

Refer to TB [3.1.1].

3.1.3 Lower part of corrugation

This part of the Rules is based on CSR BC (July 2010) and IACS UR, S18.4.1 (Rev 8, May 2010).

3.1.4 Middle part of corrugation

Refer to TB [3.1.3].

3.2 Bending, shear and buckling check

3.2.1 Bending capacity and shear capacity

This part of the Rules is based on CSR BC (July 2010) and IACS UR, S18 (Rev 8, May 2010).

3.2.2 Shear buckling check of the bulkhead corrugation webs

This part of the Rules is based on CSR BC (July 2010) and IACS UR, S18 (Rev 5, May 2010).

3.3 Net section modulus at the lower end of the corrugations

3.3.1 Effective flange width

This part of the Rules is based on CSR BC (July 2010) and IACS UR, S18 (Rev 8, May 2010).

3.3.2 Webs not supported by local brackets

Refer to TB [3.3.1].

3.3.3 Effective shedder plates

Refer to TB [3.3.1].

3.3.4 Effective gusset plates

Refer to TB [3.3.1].

3.3.5 Sloping stool top plate

Refer to TB [3.3.1].

4 ALLOWABLE HOLD LOADING FOR BC-A & BC-B SHIPS IN FLOODED CONDITIONS

4.1 Evaluation of double bottom capacity and allowable hold loading

4.1.1 Shear capacity of the double bottom

This part of the Rules is based on CSR BC (July 2010) and IACS UR, S20 (Rev 5, May 2010).

4.1.2 Floor shear strength

Refer to TB [4.1.1].

4.1.3 Girder shear strength

Refer to TB [4.1.1].

4.1.4 Allowable hold loading

Refer to TB [4.1.1].

1 GENERAL

1.1 Application

1.1.1

Technical background is not considered necessary.

2 STRUTS CONNECTING STIFFENERS

2.1 Scantling requirements

2.1.1 Net sectional area and moment of inertia

In case that the two parallel beams are connected by struts at their span, the applied force on the beam deforms the whole structure and causes a reaction distribution which depends on the rigidity ratio of each member.

For the treatment of struts between primary supporting members (floors) in a double bottom structure, CSR BC (July 2010) has been incorporated. Provision of struts is not approved in ships of length 120m and greater.

3 TRANSVERSE CORRUGATED BULKHEADS OF BALLAST HOLDS

3.1 Plate thickness

3.1.1

Technical background is not considered necessary.

3.2 Net section modulus

3.2.1

This requirement applies to corrugated bulkhead of ballast hold for ships having a length less than 150m. It indicates the section modulus of corrugation and it is based on CSR BC (July 2010). For ships longer than 150m, bending capacity of the corrugation of ballast hold is assessed using direct strength analysis in accordance relevant parts of the Rules.

4 PRIMARY SUPPORTING MEMBERS

4.1 Application

4.1.1

For primary supporting members in ships of length below 150m, strength formulae are specified with the focus on shear and buckling strength.

4.1.2

Technical background is not considered necessary.

4.2 Design load sets

4.2.1 Application

Technical background is not considered necessary.

4.2.2 Loading conditions

Technical background is not considered necessary.

4.3 Centre girders and side girders

4.3.1 Net web thickness

This regulation is based on CSR BC (July 2010). Required thickness by t_1 formula is based on overall shearing capacity of girders. However, 100% of total corrosion addition is applied because web height of girders of this size of bulk carriers is so small that corrosion may be global not localised.

According to Rules' principle, full corrosion addition is to be added to required thickness by t_2 formula based on buckling capacity.

4.4 Floors

4.4.1 Net web thickness

Refer to TB [4.3.1].

4.5 Stringer of double side structure

4.5.1 Net web thickness

Refer to TB [4.3.1].

4.6 Transverse web in double side structure

4.6.1 Net web thickness

Refer to TB [4.3.1].

4.7 Primary supporting member in bilge hopper tanks and topside tanks

4.7.1 Boundary conditions

Technical background is not considered necessary.

4.7.2 Net section modulus, net shear sectional area and web thickness

Webs of primary supporting members in bilge hopper tanks and topside tanks are generally stiffened with free-edged flanges. Therefore, bending strength is assessed in addition to shear and buckling strength. Refer to TB of Pt 1, Ch 6, Sec 5 for the background of bending and shear formulae.

Symbols

Based on careful investigation and discussions both within IACS and Industry, in RCN 1 to CSR 01 Jan 2021, it is proposed to remove the isolated beam method and grillage method for hatch cover analysis which are theoretically not as accurate as finite element method. This will also avoid potential troubles caused by applying two different methods. For more details refer to Pt2, Ch 1, Sec 5 of TB for RCN 1 to CSR 01 Jan 2021. Accordingly, primary support members requirement in [3.2.1] has been removed. Hence, respective parameters deleted from symbols.

1 GENERAL

1.1 Application

1.1.1

The positions 1 and 2 are defined in Pt 1 Ch 1 Sec 4 [3.2]. The requirements of this section are based on IACS UR S21 (Rev 4, Jul 2004, Corr.1 Oct 2004) and UR S26 (Rev 3, Aug 2006). When internal pressure of ballast water in the ballast hold is considered, the hatch cover is to be treated as not being acted upon by hydrostatic pressure from the air vent installed in the hatch coaming.

The loads due to ballast water in the ballast hold are divided into hydrostatic pressure and dynamic pressure, the hydrostatic pressure is multiplied by 0 and the dynamic pressure by 0.9.

1.2 Materials

1.2.1 Steel

Technical background is not considered necessary.

1.2.2 Other materials

Technical background is not considered necessary.

1.3 Net scantlings

1.3.1

The requirements are based on IACS UR S21 (Rev 5, May 2010).

1.4 Corrosion additions

1.4.1

The requirements are based on IACS UR, S21 (Rev 5, May 2010).

1.5 Allowable stresses

1.5.1

This requirement is in accordance with ICLL, as amended, (MSC Res. 143(77)) Annex 1, Ch II, Reg. 16 (5). The buckling utilisation factor is to be used as a measure of safety margin against buckling strength failure by using the ratio between the applied loads and the corresponding ultimate capacity or buckling strength. This definition gives the unified buckling utilisation factor calculations especially for combined loads, e.g. under the applied loads of both axial and transverse compressive stresses.

In RCN 1 to CSR 01 Jan 2021, allowable stress for hatch cover in Table 2 under other loads category is added as $0.72R_{eH}$ for static load combination, which is 0.8 times of limit for S+D load combination same as cargo hold Direct Strength Analysis. Further, in Table 3, buckling utilisation factor for S+D load combination subject to other loads has been updated to 0.9 following corresponding requirements in UR S21A with a safety factor of 1.1. Correspondingly, buckling utilisation factor is updated to 0.72 for load combination S, which is 0.8 times of the limit for S+D load case.

UR S21A safety factors for the buckling strength assessment are based on the net scantling approach and this is justified by more sophisticated buckling strength approach compared to approach in UR S21.

2 ARRANGEMENTS

2.1 DELETED

2.2 Hatch covers

2.2.1

This requirement is based on IACS UR, S21 (Rev 5, May 2010).

2.2.2

This requirement is based on IACS UR, S21.1 (Rev 5, May 2010).

2.2.3

This requirement is based on IACS UR, S21.3.5 (Rev 5, May 2010).

2.2.4

This requirement is based on IACS UR S21 (Rev 5, May 2010).

2.2.5

This requirement is based on IACS UR, S21 (Rev 5, May 2010).

2.3 Hatch coamings

2.3.1

This requirement is based on IACS UR, S21 (Rev 5, May 2010).

2.3.2

Refer to TB [2.3.1].

2.3.3

Refer to TB [2.3.1].

2.3.4

This requirement specifies the structural continuity under transverse coamings.

3 WIDTH OF ATTACHED PLATING

3.1 Stiffeners

3.1.1

Refer to TB [2.3.1].

3.2 DELETED

In RCN 1 to CSR 01 Jan 2021, it is proposed to remove the isolated beam method and grillage method for hatch cover analysis which are theoretically not as accurate as finite element method. This will also avoid potential troubles caused by applying two different methods. For more details refer to Pt2, Ch 1, Sec 5 of TB for RCN 1 to CSR 01 Jan 2021. Accordingly, primary support members requirement in [3.2.1] has been removed.

4 LOAD MODEL

4.1 Lateral pressures and forces

4.1.1 General

This requirement is based on IACS UR, S21.2 (Rev 5, May 2010).

4.1.2 Sea pressures

This requirement is based on IACS UR, S21.2 (Rev 5, May 2010).

4.1.3 Internal pressures due to ballast water

Refer to TB [2.3.1].

4.1.4 Pressures due to uniform cargoes

Refer to TB [2.3.1].

4.1.5 Pressures or forces due to special cargoes

Refer to TB [2.3.1].

4.1.6 Forces due to containers

Refer to TB [2.3.1].

4.2 Load point

4.2.1 Wave lateral pressure for hatch covers on exposed decks

This requirement is based on IACS UR, S21.2 (Rev 5, May 2010).

4.2.2 Lateral pressures other than the wave pressure

Refer to TB [2.3.1].

5 STRENGTH CHECK

5.1 General

5.1.1 Application

In RCN 1 to CSR 01 Jan 2021, following the finite element modelling requirements specific to hatch cover in UR S21 and S21A, more detailed modelling guidelines are included in a new subsection [5.6.1] replacing the original simplified general description in [5.1.1].

5.1.2 Hatch covers supporting containers

This requirement specifies that container loads are to be considered, if any. As no container loads are defined in CSR BC, they are to be determined by each Society.

5.1.3 Hatch covers subjected to special cargoes

Refer to TB [2.3.1].

5.2 Plating

5.2.1 Net thickness

This requirement is based on IACS UR, S21.3.3 (Rev 5, May 2010).

5.2.2 Minimum net thickness

This requirement is in accordance with ICLL, MSC Res. 143(77), Reg. 16 (5), c). The reference to ICLL is given as Classification requirement.

5.2.3 Buckling strength

In RCN 1 to CSR 01 Jan 2021, buckling strength requirements for plating are directed to a new subsection [5.6.3], which follows the requirements for buckling assessment as given in CSR Pt 1, Ch8, Sec4.

5.3 Stiffeners

5.3.1

In RCN 1 to CSR 01 Jan 2021, slenderness requirements are referred to CSR Pt 1, Ch8, Sec2 [3.1.1] and [3.1.2].

5.3.2 Minimum net thickness of web

Refer to TB [2.3.1].

5.3.3 Net section modulus and net shear sectional area

This requirement is based on IACS UR, S21.3.4 (Rev 5, May 2010).

5.3.4 Buckling strength

In RCN 1 to CSR 01 Jan 2021, buckling strength requirements for stiffeners are directed to a new subsection [5.6.3], which follows the requirements for buckling assessment as given in CSR Pt 1, Ch8, Sec4.

5.4 Primary supporting members

5.4.1 Application

This requirement is based on IACS UR, S21.3.5 (Rev 5, May 2010).

5.4.2 Minimum net thickness of web

Refer to TB [2.3.1].

5.4.3 VOID

In RCN 1 to CSR 01 Jan 2021, it is proposed to remove the isolated beam method and grillage method for hatch cover analysis which are theoretically not as accurate as finite element method. This will also avoid potential troubles caused by applying two different methods.

5.4.4 VOID

In RCN 1 to CSR 01 Jan 2021, it is proposed to remove the isolated beam method and grillage method for hatch cover analysis which are theoretically not as accurate as finite element method. This will also avoid potential troubles caused by applying two different methods.

5.4.5 Deflection limit

This requirement is based on IACS UR, S21.3.7 (Rev 5, May 2010).

5.4.6 Buckling strength of the web panels of the primary supporting members

In RCN 1 to CSR 01 Jan 2021, buckling strength requirements for web panels of the primary supporting members are directed to a new subsection [5.6.3] which follows the requirements for buckling assessment as given in CSR Pt 1, Ch8, Sec4.

5.4.7 Slenderness criteria

Refer to TB [2.3.1].

5.5 Finite element model and buckling assessment

5.5.1 Finite element model

In RCN 1 to CSR 01 Jan 2021, following finite element modelling requirements specific to hatch cover structures in UR S21 and S21A, more detailed modelling guidelines are included in this section to replace original simplified general description in [5.1.1].

5.5.2 Yield strength assessment

In RCN 1 to CSR 01 Jan 2021, requirements for yield strength assessment of hatch cover structure are specified following corresponding UR S21A requirements and the yield strength assessment as given in CSR Pt 1, Ch 7, Sec 2, [5.2].

5.5.3 Buckling strength assessment

In RCN 1 to CSR 01 Jan 2021, buckling requirements for general case are developed following the requirements for buckling assessment as given in CSR Pt 1, Ch8, Sec4.

5.5.4 Buckling assessment of stiffened panels with U-type stiffeners

In RCN 1 to CSR 01 Jan 2021, buckling requirements for designs of hatch covers with U-type stiffeners are developed following the requirements for buckling assessment as given in CSR Pt 1, Ch8, Sec4.

6 HATCH COAMINGS

6.1 Stiffening

6.1.1

This requirement is based on IACS UR, S21.1 (Rev 5, May 2010).

6.1.2
Refer to TB [2.3.1].

6.1.3
Refer to TB [2.3.1].

6.1.4
Refer to TB [2.3.1].

6.1.5
Refer to TB [2.3.1].

6.2 Load model

6.2.1
This requirement is based on IACS UR, S21.4.1 (Rev 5, May 2010).

6.2.2
This requirement is based on IACS UR, S21.4.1 (Rev 5, May 2010).

6.2.3
This requirement is based on IACS UR, S21.4.1 (Rev 5, May 2010).

6.2.4
Refer to TB [2.3.1].

6.3 Scantlings

6.3.1 Plating
This requirement is based on IACS UR, S21.4.2 (Rev 5, May 2010).

6.3.2 Stiffeners
This requirement is based on IACS UR, S21.4.3 (Rev 5, May 2010).

6.3.3 Coaming stays
This requirement is based on IACS UR, S21.4.4 (Rev 5, May 2010).

In RCN 1 to CSR 01 Jan 2021, figure numbering is adjusted suitably considering additional figures added in [5.6.3].

6.3.4 Local details
This requirement is based on IACS UR, S21.4.5 (Rev 5, May 2010).

7 WEATHERTIGHTNESS, CLOSING ARRANGEMENT, SECURING DEVICES AND STOPPERS

7.1 Weathertightness

7.1.1 Minimum net thickness

This requirement is based on ICLL, MSC Res. 143(77), Reg. 16 (1). The reference is given for information.

7.1.2

Technical background is not considered necessary.

7.2 Gaskets

7.2.1

Technical background is not considered necessary.

7.2.2

Technical background is not considered necessary.

7.2.3

Technical background is not considered necessary.

7.2.4

Technical background is not considered necessary.

7.2.5

Technical background is not considered necessary.

7.2.6

Technical background is not considered necessary.

7.3 Closing arrangement, securing devices and stoppers

7.3.1 General

This requirement is based on IACS UR, S21.5.1 (Rev 5, May 2010).

7.3.2 Arrangements

This requirement is based on IACS UR, S21.5.1 (Rev 5, May 2010).

7.3.3 Spacing

Refer to TB [2.3.1].

7.3.4 Construction

This requirement is based on IACS UR, S21.5.1 (Rev 5, May 2010).

7.3.5 Area of securing devices

This requirement is based on IACS UR, S21.5.1 (Rev 5, May 2010).

7.3.6 Inertia of edges elements

This requirement is based on IACS UR, S21.5.1 (Rev 5, May 2010).

7.3.7 Diameter of rods or bolts

This requirement is based on IACS UR, S21.5.1 (Rev 5, May 2010).

7.3.8 Stoppers

This requirement is based on IACS UR, S21.5.2 (Rev 5, May 2010).

7.4 Cleats

7.4.1

Technical background is not considered necessary.

7.4.2

Technical background is not considered necessary.

8 DRAINAGE

8.1 Arrangement

8.1.1

Technical background is not considered necessary.

8.1.2

Technical background is not considered necessary.

8.1.3

Technical background is not considered necessary.

8.1.4

Technical background is not considered necessary.

1 GENERAL

1.1 Application

1.1.1

This requirement is a mandatory requirement for BC-A and BC-B ships and optional for other kinds of ships.

To clearly denote the mass of the grab considered when assigning the additional class notation, the mass of the grab considered is affixed after "GRAB". A minimum value is considered depending of the ship length (Refer to Pt 1, Ch 1, Sec 1, [3.2.2]).

For additional class notation assigned with a grab weight higher than the minimum, the strength requirements are to be checked for the grab impact loads.

1.1.2

Technical background is not considered necessary.

2 SCANTLINGS

2.1 Plating

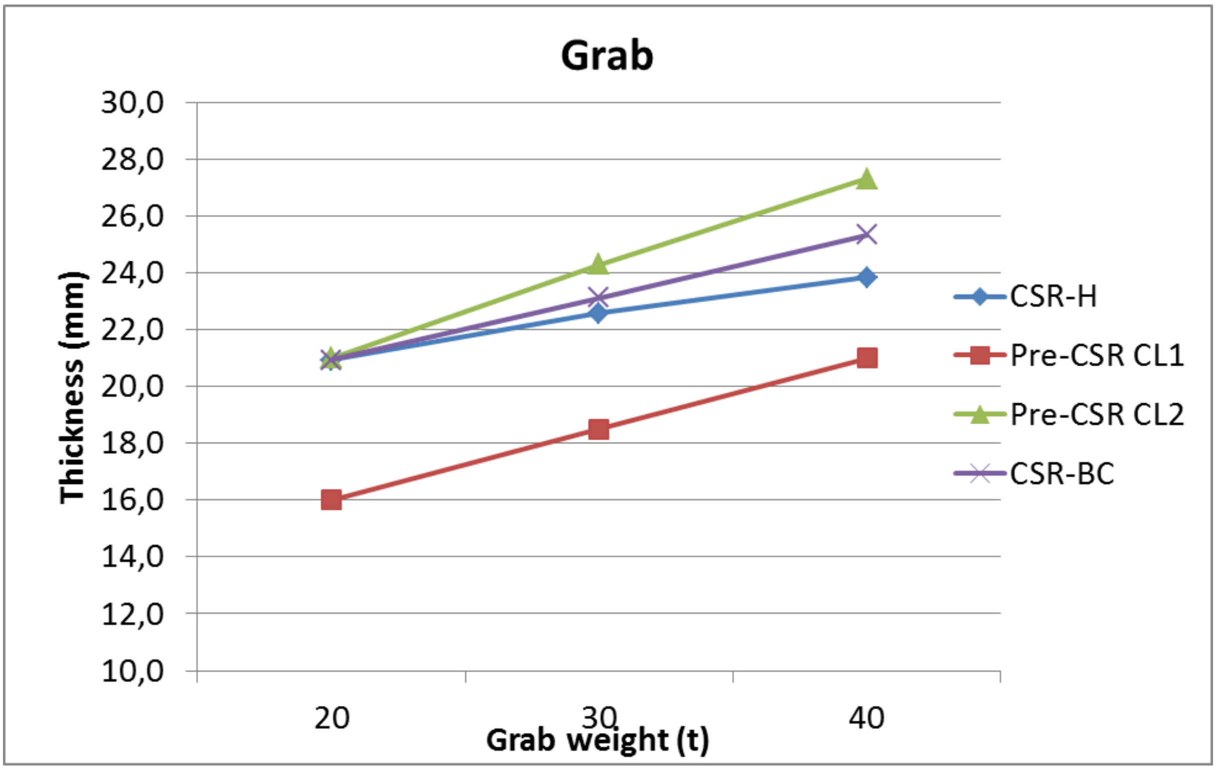
2.1.1 General

Technical background is not considered necessary.

2.1.2 Inner bottom plating

A simplified formula using grab mass, material used, and longitudinal spacing was given after studying regulations related to grabs of IACS Societies. Figure 1 shows a comparison of inner bottom GRAB requirements. The formulas for inner bottom and hopper plates have been modified compared to CSR BC as a result of increased design grab weights in CSR-H for BC with L > 200m. The increased grab weights will reduce the probability that weight of grab used for discharging is equal to design grab weight and the modified formulas allow for a higher utilisation of capacity compared to CSR BC when the design weight is above 20t.

Figure 1: Comparison of inner bottom grab requirements



Based on the mandatory minimum grab weights given in Pt 1, Ch 1, Sec 1, [3.2.2], the grab requirement will normally be the governing rule requirement for inner bottom thickness in empty hold for vessels with L > 200m. For ore holds the grab requirement will normally not give increased inner bottom thickness.

Table 1 shows a summary of scantling impacts on 6 different vessels.

Table 1: Scantling impact

Summary of scantling impact						
Vessel ID*	BC-1	BC-2	BC-3	BC-4	BC-5	BC-6
Grab weight according to Pt1 Ch1 Sec1 [3.2.2]	35	35	35	30	30	30
Ore hold thickness [mm] **	-	-	-	-	-	-
Empty hold thickness [mm] ***	+1.5	+0.5	+1.0	+0.5	+1.0	+1.0
* The ID refers to the vessels used in the CSR-H Consequence assessment. See Table 2 for vessel information.						
** Grab requirement is not governing						
*** Compared to as built thickness. As built thickness complies with CSR BC.						

Table 2: Vessel information

Vessel information						
ID	ID	L_{pp}	B	T_{sc}	D	DWT
BC-1	Capesize 1	285	46	18	25	180200
BC-2	Capesize 2	284	45	18	25	180000
BC-3	Capesize 3	293	50	18	25	205000
BC-4	Baby Cape 1	240	43	15	21	114500
BC-5	Baby Cape 2	248	43	15	20	115000
BC-6	Panamax 1	225	32	14	20	82000

Vessels with L < 200m will normally be designed for steel coil loading, and such loading will be the governing rule requirement.

2.1.3 Vertical and sloped cargo hold boundaries

A simplified formula was given as similar to [2.1.2].

PART 2 CHAPTER 2

OIL TANKERS

Table of Contents

1 GENERAL

1.1 General

1.1.1

Technical background is not considered necessary.

2 SEPARATION OF CARGO TANKS

2.1 General

2.1.1

The designer's attention is drawn on SOLAS, Ch II-2, Reg. 4.5.1 (as amended) for the separation of the cargo oil tanks arrangement.

3 DOUBLE HULL ARRANGEMENT

3.1 General

3.1.1

The Rule text requires that the oil tankers be provided with double bottom and double hull (tanks or spaces) as defined in Pt 1, Ch 2, Sec 3, in compliance with the applicable regulations in MARPOL 73/78, Reg. 19, as amended. The MARPOL reference is given as Classification requirement.

3.1.2

The Rule text provides a general requirement. The designer's attention is drawn on the regulations relevant to the limitation of size and arrangement of cargo tanks stated in MARPOL 73/78, Annex I, Ch 4, Reg. 24 to 26 (as amended). The reference to MARPOL is given for information.

4 ACCESS ARRANGEMENTS

4.1 Special requirements for oil tankers

4.1.1

The designer's attention is drawn on the SOLAS, as amended, Ch II-1, Reg. 3-6, as required by the Flag Administration, for the access into and within spaces in, and forward of, the cargo tank region and for details and arrangements of openings and attachments to the hull structure.

The present rule requirements come from CSR OT Sec 5 [5.1.1.2]. Those texts are based on LR Rules (January 2013), Pt 4, Ch 9, 13.2 and ABS Steel Vessel Rules (January 2013), Pt 5, Ch 1, Sec 1, 5.1.

4.1.2

The present rule requirements come from CSR OT Sec 5 [5.1.1.3]. Refer to TB [4.1.1].

4.1.3

The present rule requirements come from CSR OT Sec 5 [5.1.1.5]. Refer to TB [4.1.1].

1 CORROSION PROTECTION

1.1 General

1.1.1 Cathodic protection systems in cargo tanks

Technical background is not considered necessary.

1.1.2 Paint containing aluminium

Technical background is not considered necessary.

1.2 Internal cathodic protection systems

1.2.1

This requirement is in accordance with CSR OT (July 2010), Sec 6/2.1.2.1 (based on DNV Rules (January 2013), Pt 3, Ch 3, Sec 7, B300 and LR Rules (January 2013), Pt 3, Ch 2, 3.3 and 3.4).

1.2.2

This requirement is in accordance with CSR OT (July 2010), Sec 6/2.1.2.2 (based on DNV Rules (January 2013), Pt 3, Ch 3, Sec 7, B300 and LR Rules (January 2013), Pt 3, Ch 2, 3.3 and 3.4) and IACS UR F2.

1.2.3

This requirement is in accordance with CSR OT (July 2010), Sec 6/2.1.2.3 (based on DNV Rules (January 2013), Pt 3, Ch 3, Sec 7, B300 and LR Rules (January 2013), Pt 3, Ch 2, 3.3 and 3.4) and IACS UR F2.

1.2.4

This requirement is in accordance with CSR OT (July 2010), Sec 6/2.1.2.8 (based on DNV Rules (January 2013), Pt 3, Ch 3, Sec 7, B300 and LR Rules (January 2013), Pt 3, Ch 2, 3.3 and 3.4).

1.3 Paint containing aluminium

1.3.1

This requirement is in accordance with CSR OT (July 2010), Sec 6/2.1.3.1 (based on LR Rules (January 2013), Pt 4, Ch 9, 2.3.3) and IACS UR F2.

1.3.2

This requirement is in accordance with CSR OT (July 2010), Sec 6/2.1.3.1 (based on LR Rules (January 2013), Pt 4, Ch 9, 2.3.3).

1 PRIMARY SUPPORTING MEMBERS IN CARGO HOLD REGION

1.1 General

1.1.1

Technical background is not considered necessary.

1.1.2

This section specifies the structural elements/configurations covered by the requirements for primary supporting members contained in this Rules. For other structural elements or configurations, the required scantlings are to be obtained by the direct calculation methods. Typical structural elements to be calculated by direct calculation methods are deck transverses fitted above the upper deck and horizontal stringers on transverse bulkheads fitted with buttresses or other intermediate supports, etc.

1.1.3

Refer to TB [1.1.2].

1.1.4

Technical background is not considered necessary.

1.1.5

This requirement is based on CSR OT (July 2010).

1.1.6

This requirement is based on CSR OT (July 2010).

1.1.7

Technical background is not considered necessary.

1.2 Design load sets

1.2.1

For static plus dynamic sea pressure in seagoing condition (AC-SD), the draught at $0.9T_{sc}$ is used for the double bottom floors and girders and side transverses considering the less probability of loading up to full draught with the cargo tank empty. However, if a ship is intended to be operated in seagoing loading condition where the net static upward load on the double bottom exceeds that given with the combination of an empty cargo tank and a mean ship's draught of $0.9T_{sc}$, such conditions are to be specially approved.

For deck transverse, the draught at $1.0T_{sc}$ is used to maximise the green sea pressure.
For static sea pressure in full load condition (AC-S), the draught at $1.0T_{sc}$ is used to have the envelope value. It is considered appropriate to use the envelop value in static condition.

For static sea pressure in harbour or tank test condition (AC-S), the draught at $0.25T_{sc}$ (for ships with one centreline longitudinal bulkhead) or $0.33T_{sc}$ (for ships with two inner longitudinal bulkheads) is used to calculate the "net" pressure difference between the internal and external pressures for evaluation of double bottom floors and girders.

1.3 Floors in double bottom

1.3.1 Structural arrangement

Technical background is not considered necessary.

1.3.2 Net shear area

The requirements are based on CSR OT (July 2010). The shear force distribution factors in Table 2 of the Rules have been adjusted based on the calibration with the sample ships.

1.4 Girders in double bottom

1.4.1 Structural arrangement

Technical background is not considered necessary.

1.4.2 Net shear area of centre girders

The requirements are based on CSR OT (July 2010).

1.4.3 Net shear area of side girders

Refer to TB [1.4.2].

1.5 Deck transverses

1.5.1 Web depth

The requirements of the web depth of deck transverses indicated are based on CSR OT (July 2010).

1.5.2 Net section modulus fitted below the upper deck

The requirements of section modulus of deck transverses indicated in this Rules are based on CSR OT (July 2010).

Since the phasing between the maximum sea load imposed on the side transverse and the maximum green sea pressure imposed on the deck transverse may be different, "carry-over" bending moment from the side transverse to the deck transverse is not applied for green sea load.

1.5.3 Net shear area fitted below the upper deck

The requirements of shear area of deck transverses indicated in [1.5.2] of this Rules are based on CSR OT (July 2010).

Deck transverses in one cross section are forming "transverse ring" of the hull structure. Therefore, the required section modulus and shear area for deck transverses in accordance with [1.5.2] and [1.5.3] of this Rules are to be constantly applied over the clear of end brackets, i.e. no reduction of the requirements is allowed towards the mid-span.

1.5.4 Deck transverse adjacent to transverse bulkhead

Technical background is not considered necessary.

1.6 Side transverses

1.6.1 Net shear area

The requirements of shear area of side transverses of [1.6.1] of the Rules are based on CSR OT (July 2010). Specific instructions have been added in the definition of effective length of upper bracket of the side transverse, h_u and location to be taken for the design pressure, P_u for the structure where deck transverses are fitted above deck and the inner hull longitudinal bulkhead is arranged with a large top wing structure.

1.6.2 Shear area over the length of the side transverse

This section specifies the distribution of the required shear area of side transverse. The same distribution of the required shear area is also applied for vertical web on longitudinal bulkhead.

1.7 Vertical web frames on longitudinal bulkhead

1.7.1 Web depth

The requirements of the web depth of vertical web frames on longitudinal bulkheads of the Rules are based on CSR OT (July 2010).

1.7.2 Net section modulus

The requirements of section modulus of vertical web frames on longitudinal bulkheads indicated in [1.7.2] of this Rules are based on CSR OT (July 2010).

1.7.3 Section modulus over the length of the vertical web frame

This section specifies the distribution of the required section modulus of vertical web frame on longitudinal bulkhead. Similar distribution of the required section modulus is also applied for horizontal stringer on transverse bulkhead.

1.7.4 Net shear area

The requirements of shear area of vertical web frames on longitudinal bulkheads are based on CSR OT (July 2010).

1.7.5 Shear area over the length of the vertical web frame

This section specifies the distribution of the required shear area of vertical web frame on longitudinal bulkhead. The same distribution of the required shear area is also applied for side transverse.

1.8 Horizontal stringers on transverse bulkheads

1.8.1 Web depth

The requirements of the web depth of horizontal stringers on transverse bulkheads indicated are based on CSR OT (July 2010). The minimum effective bending span for the calculation of the required web depth has been adjusted based on the calibration with the sample ships.

1.8.2 Net section modulus

The requirements of section modulus of horizontal stringers on transverse bulkheads indicated in [1.8.2] of this Rules are based on CSR OT (July 2010).

1.8.3 Section modulus over the length of horizontal stringers

This section specifies the distribution of the required section modulus of horizontal stringers on transverse bulkhead. Similar distribution of the required section modulus is also applied for vertical web frame on longitudinal bulkhead.

1.8.4 Net shear area

The requirements of shear area of horizontal stringers on transverse bulkheads indicated in [1.8.4] of this Rules are based on CSR OT (July 2010).

1.8.5 Shear area at mid effective shear span

This section specifies the distribution of the required shear area of horizontal stringers on transverse bulkhead.

1.9 Cross ties

1.9.1 Maximum applied design axial load

The requirements for cross ties indicated in [1.9.1] of this Rules are based on CSR OT (July 2010). The working compressive loads are to be obtained based on Table 1 of this Rules with averaging the pressure at both ends of cross tie. The permissible compressive loads are to be obtained based on the criteria as given in Pt 1, Ch 8, Sec 5, [3] of the Rules.

For the cross tie, torsional buckling mode is generally found most critical, and the utilisation factors for cross tie have been adjusted based on the calibration with the sample ships. In order to verify the formula, non-linear finite element analysis has been carried out. A typical cross tie design was modelled with two different lengths (Figure 1). The longest beam has same length as the effective span for cross tie on a reference vessel. The torsional buckling capacity was calculated using prescriptive formula in Pt 1, Ch 8, Sec 5, [3.1.3] and then compared with result from non-linear FE analysis.

In addition, a non-linear FE analysis was carried out using a model as shown in Figure 2 and including adjacent structure to an extent found necessary to determine the end constraint of the cross ties. Pressure loads were gradually applied at bulkhead plates in each end of the model until axial compression in the cross tie caused failure. The comparison carried out with fixed and hinged ends gave consistent results and both analyses confirm end constraint fixed (f_{end} = 4) is found not realistic for this failure. The rules therefore require f_{end} to be taken 2 which is almost hinged.

With the buckling capacity in Pt 1, Ch 8, Sec 5, [3.1.3] and allowable utilisation factors in this section, the buckling capacity calculations for cross tie provide accurate results and ensure cross tie which are robust.

Figure 1: Reference beam

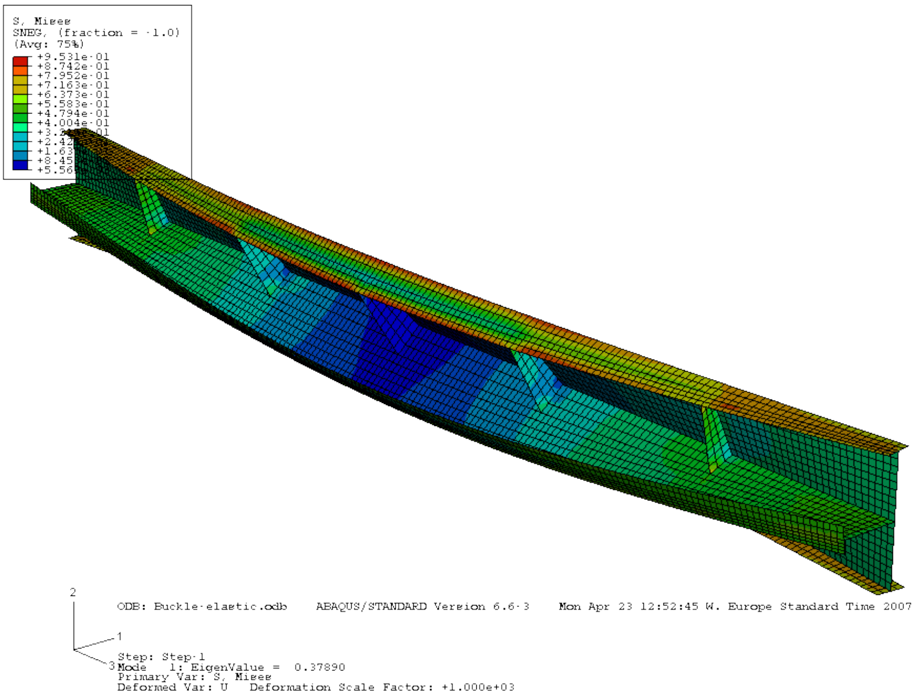


Figure 2: Cross tie

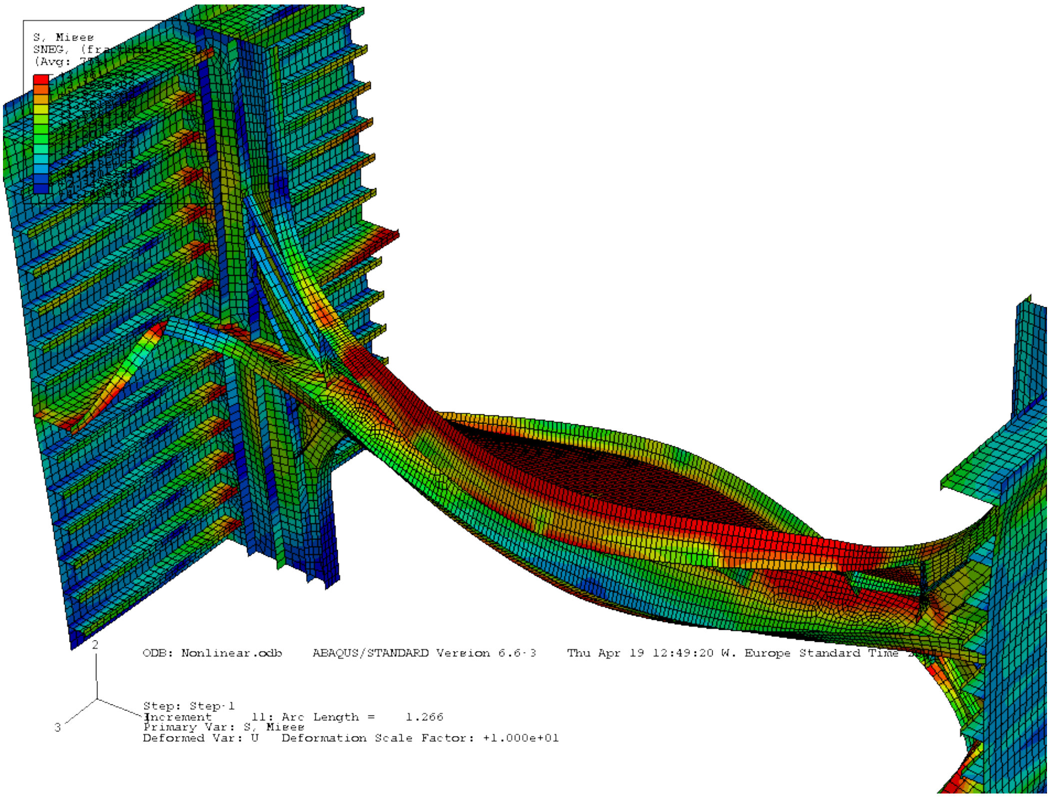


Figure 3: Cross tie with additional tripping bracket on stringer

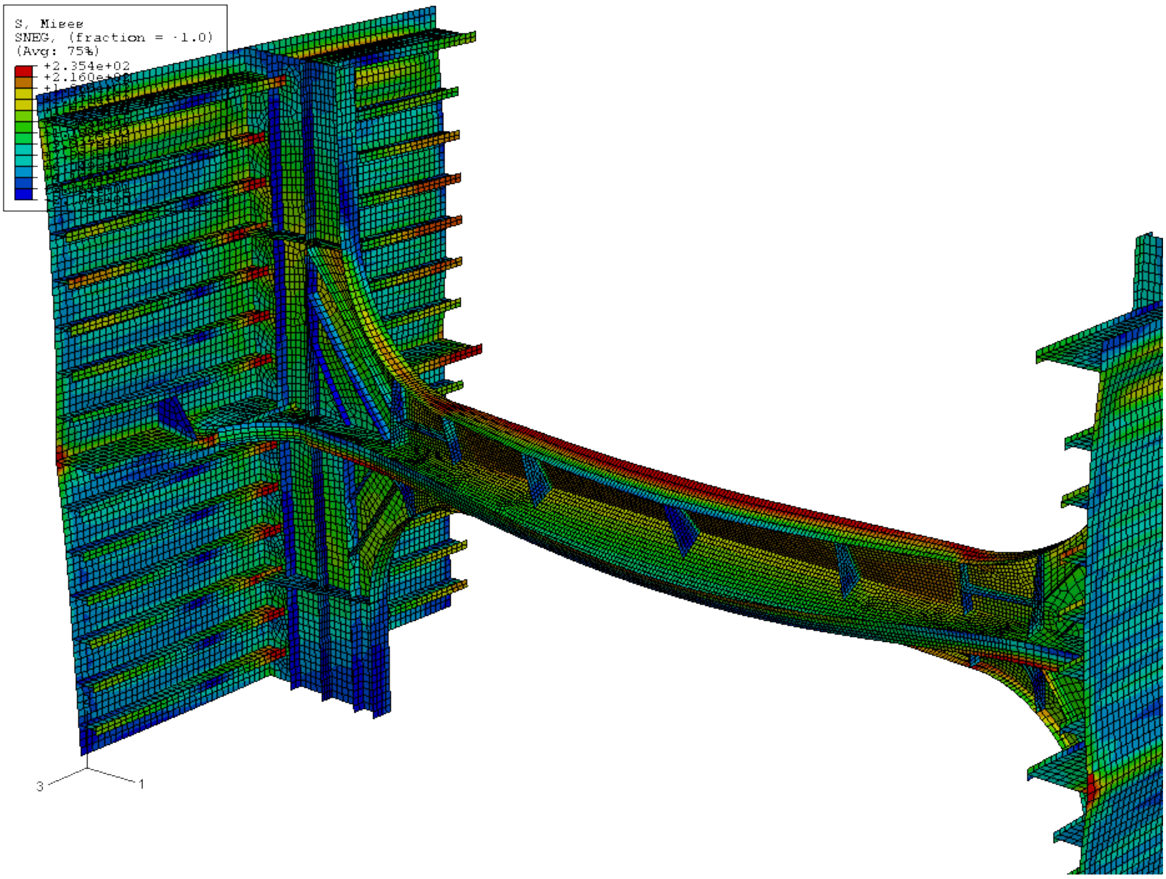


Table 1: Comparison torsional buckling formula in CSR and non-linear FEA

Model	f_{end}	CSR OT, Sec 10/3.5.1.4		Non-linear analysis	
		Elastic buckling	Critical Stress	Elastic buckling	Critical Stress
Full model (Figure 2)	2	149	142	151	142
Full model with tripping brackets (Figure 3)	2			171	150
Reference model, short 15m	1	152	144	147	131
	4	520	208	469	216
Reference model, long 20m (Figure 1) same as span for cross tie in Figure 2	1	89	89	89	-
	2	149	142	-	-
	4	271	184	252	188

Table 2: Results obtained for 5 reference ships

		5 VLCC reference ships				
		1	2	3	4	5
AC1	Actual stress – equal to or less than allowable according to individual class society rules before CSR.	139	129	113	107	118
	Utilisation factor	0.65	0.65	0.65	0.65	0.65
	f_{end} = 2					
	Allowable column buckling	149	147	142	148	149
	Allowable torsion buckling	121	105	85	110	103
	$\sigma_{act}/\sigma_{allow}$	114%	123%	133%	97%	115%

1.9.2 Welded connections

Technical background is not considered necessary.

1.9.3 Horizontal stiffeners

Technical background is not considered necessary.

2 VERTICALLY CORRUGATED BULKHEADS

2.1 Application

2.1.1

Technical background is not considered necessary.

2.2 Scantling requirements

2.2.1 Net plate thickness over the height

The requirements are based on the CSR OT (July 2010). Similar requirements are also contained in IACS UR, S18.4.1 (Rev 8, May 2010).

2.2.2 Net web plating thickness over the height

The requirements address shear strength, which are based on CSR OT (July 2010). The shear force is only a concern over the lower portion of the bulkhead, so the application requirements are limited to the lower 15% of the corrugated bulkhead height, consistent with the application of similar requirements in IACS UR, S18 (Rev 8, May 2010). These requirements are not applicable to corrugated bulkheads without a lower stool.

2.2.3 Net thicknesses of the flanges over the height

The requirements are based on the CSR OT (July 2010). The formula for thickness in the Rules is based on calculations that are performed to check the buckling strength of the corrugated bulkhead. This is a local buckling strength criterion for the corrugation flange, which determines the overall buckling strength of the corrugation as a beam column.

The formulas in the Rules are based on results of experimental and theoretical work on buckling strength of corrugated bulkheads. Of particular note, the plate buckles as a result of lateral load and not because of in-plane compression.

2.2.4 Net section modulus over the height

The requirements are based on the CSR OT (July 2010). The formula for required section modulus is based on simple beam theory and the basic understanding that the vertically corrugated bulkhead can be considered as consisting of separate vertically oriented beam-columns (i.e. corrugations) working independently. The loading on the corrugated bulkhead consists of the following three major components:

1. Lateral pressure.
2. "Carry-over" bending moments due to bending of the double bottom.
3. Vertical axial force in the corrugation due to double bottom bending and loads on deck.

The formulae explicitly consider the boundary conditions for the two corrugation ends, which are addressed in the formulations provided in Table 7. The requirements were calibrated against FEM calculations.

The formulae for corrugated bulkheads without lower stools were derived from the formulae for corrugated bulkheads with lower stools and deck boxes. After the coefficients, C_i (for the lower end and mid-span of transverse and longitudinal bulkheads) were calculated for numerous values of the parameter R_b (lower stool parameter) within the wide range of the selected A_d/b_d ratio, analytical equations for the coefficients C_i as a function of the parameter R_b have been developed.

A corresponding value of C_i using the analytical equations can be obtained when R_b is 0 (i.e. no lower stool exists). Then from the derived values of C_i for case when R_b = 0, the corresponding curves for C_1, C_{m1}, C_3 and C_{m3} as a function of the ratio A_d/b_d were built for transverse and longitudinal bulkheads.

Figure 4: C_1 and C_{m1} for corrugated transverse bulkheads without bottom stools

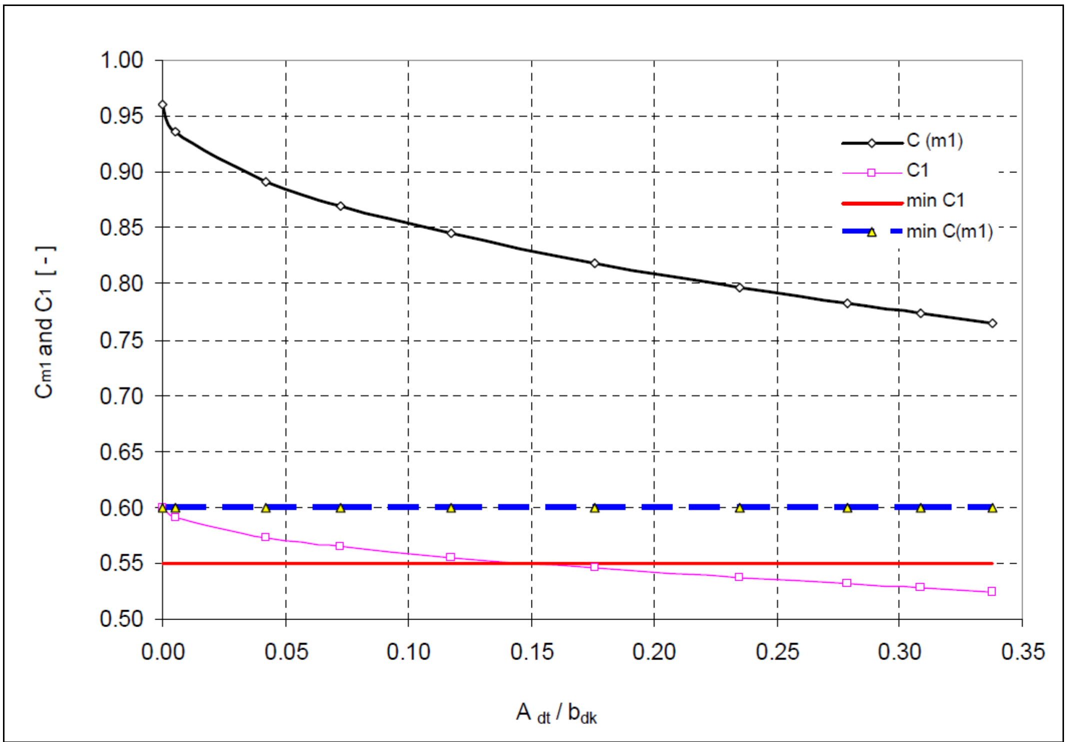
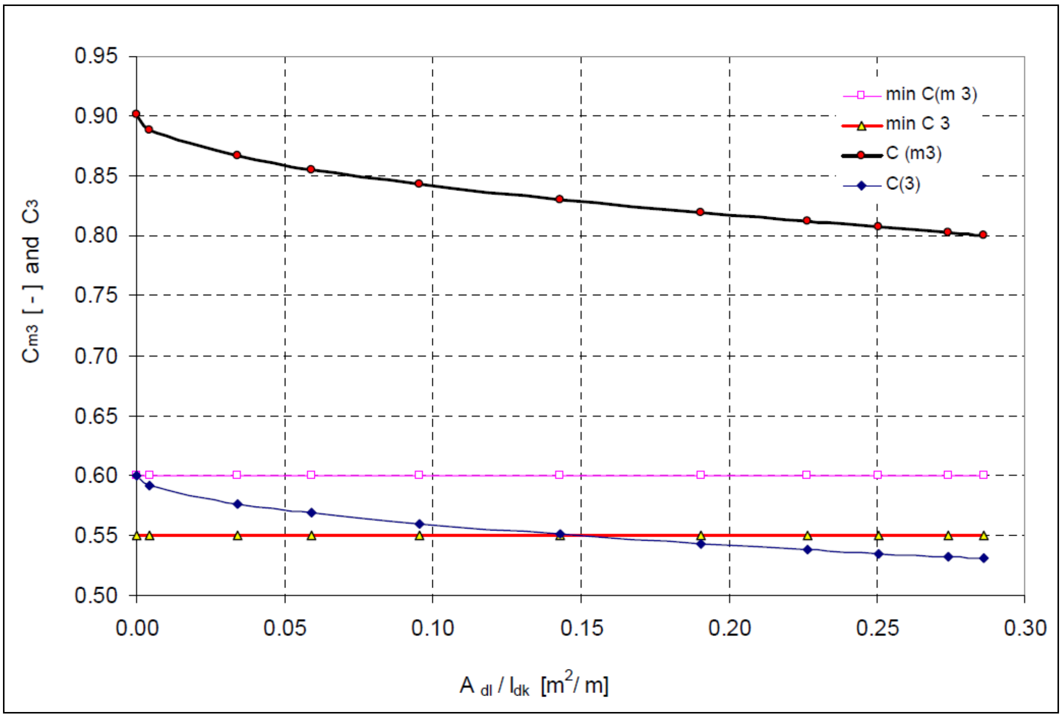


Figure 5: C_3 and C_{m3} for corrugated longitudinal bulkheads without bottom stools



1 SUPPORTING STRUCTURES FOR COMPONENTS USED IN EMERGENCY TOWING ARRANGEMENTS

1.1 General

1.1.1

It is reminded that the shipbuilder is responsible for providing the ship design and arrangement complying with the requirement of SOLAS, Ch II-1, Reg. 3-4 (as amended) and guidelines for emergency towing arrangements for tankers, adopted by the MSC Res 35(63), as amended.

1.1.2

This requirement is a reminder to the shipbuilder that the design and construction of the towing arrangements shall be approved by the Flag Administration.

1.2 Documents to be submitted

1.2.1

Technical background is not considered necessary.

1.3 Structural arrangement

1.3.1 Continuity of strength

Refer to TB [1.1.1].

1.3.2 Stress concentrations

Refer to TB [1.1.1].

1.4 Minimum thickness requirements

1.4.1 Deck plating

Refer to TB [1.1.1].

1.5 Loads

1.5.1 Safe working loads

Refer to TB [1.1.1].

1.5.2 Load case

Refer to TB [1.1.1].

1.6 Scantling requirements

1.6.1 General

Refer to TB [1.1.1].

1.6.2 Calculation procedure

Refer to TB [1.1.1].

1.6.3 Permissible stresses

Refer to TB [1.1.1].

2 MISCELLANEOUS DECK ATTACHMENTS

2.1 Cargo manifolds

2.1.1 Cargo manifold support

Technical background is not considered necessary.