RULES
FOR THE CLASSIFICATION OF SHIPS

Part 2 – HULL
July 2020
By the decision of the General Committee of Croatian Register of Shipping,

RULES FOR THE CLASSIFICATION OF SHIPS
Part 2 – HULL

have been adopted on 30th June 2020 and shall enter into force on 1st July 2020
REVIEW OF AMENDMENTS IN RELATION TO PREVIOUS EDITION OF THE RULES

RULES FOR THE CLASSIFICATION OF SHIPS
Part 2 – HULL

All major changes throughout the text in respect to the Rules for the classification of ships, Part 2 – Hull, edition July 2019, as amended with by Amendments No. 1, edition January 2020, throughout the text are shaded.

Items not being indicated as corrected have not been changed.

The grammatical and print errors, have also been corrected throughout the text of subject Rules but are not indicated as a correction.
This Part of the Rules includes the requirements of the following international Organisations:

**International Maritime Organization (IMO)**

**Conventions:**
- International Convention for the Safety of Life at Sea 1974 (SOLAS 1974) and all subsequent amendments up to and including the 2012 amendments (MSC.341(91), 342(91))
- International Convention for the Prevention of Pollution from Ships 1973, as modified by the Protocol of 1988 thereto (MARPOL 73/78) and all subsequent amendments up to and including the 2006 amendments ((MEPC.141(54))

**International Association of Classification Societies (IACS)**

**Unified Requirements (UR):**
- **F1 (Rev.1, 2002), F2 (Rev.2, 2012), M76 (2016), S1 (Rev.7, 2010), S1A (Rev.6, 2010), S2 (Rev.2, June 2019), S3 (Rev.1, 2010), S4 (Rev. 4, 2017), S5 (Rev.1, corr. 1, June 2019), S6 (Rev.8, 2015), S7 (Rev.4, 2010), S10 (Rev.6, Sep 2019), S11 (Rev.9, June 2019), S11A (2015), S12 (Rev.5, 2010), S13 (Rev.2, Corr.1, 2014), S14 (Rev.6, 2016), S17 (Rev.10, Mar 2019), S18 (Rev.10, Mar 2019), S19 (Rev.5, 2004), S20 (Rev.6, 2014), S22 (Rev.3, 2004), S23 (Rev.4, 2007), S28 (Rev.3, 2010), S31 (Rev.4, 2007), S33 (Rev.2, Dec 2019), S34 (2015), W31 (Rev.2, Dec 1997), Z8 (Rev.1, 1995), Z9 (Rev.2, 1997), Z10.1 (Rev.24, May 2019), Z10.2 (Rev. 36, May 2019), Z10.4 (Rev.16, May 2019)**

**Unified Interpretations**

**Recommendations**

**Other requirements**
- Finnish-Swedish Ice Class Rules, 2017
- Guidelines for the Application of the Finnish - Swedish Ice Class Rules, 14 November 2017
# RULES FOR THE CLASSIFICATION OF SHIPS

## PART 2

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1 GENERAL REQUIREMENTS

1.1 APPLICATION

1.1.1 The present Part of the Rules applies to steel ships and floating facilities of welded construction, whose ratios of main dimensions are taken within the limits given in Table 1.1.1.

For areas of navigation see Rules for the classification of ships, Part 1 - General requirements, Chapter 1- General information, Section 4.2.

Table 1.1.1

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Area of navigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length/depth L/D</td>
<td>1  2  3  4  5-8</td>
</tr>
<tr>
<td>Breadth/depth B/D</td>
<td>1.25 2.5 3 3 4</td>
</tr>
</tbody>
</table>
| (1) For vessels of dredging fleet, not more than 3.0. For floating cranes, not less than 4.5

1.1.2 The scantlings of hull members, essential to the strength of ships and floating facilities whose construction and dimensions are not regulated by the present Rules are subjected to special consideration by the CROATIAN REGISTER OF SHIPPING (hereafter referred to as: the Register).

1.2 DEFINITIONS

Definitions and explanations relating to the general terminology of the Rules are given in the Rules, Part 1 - General requirements, Chapter 1- General information.

For the purpose of the present Part of the Rules the following definitions have been adopted.

1.2.1 Types of ships

For the types of ships see Rules, Part 1 - General requirements, Chapter 1- General information, Section 4.2

1.2.2 Basic definitions

1.2.2.1 Summer load waterline - waterline on the level of the centre of the freeboard mark, for ship's position without permanent trim and heel

1.2.2.2 Forward perpendicular - is the perpendicular at the intersection of the summer load waterline with the fore side of the stem.

1.2.2.3 After perpendicular - is the perpendicular at the intersection of the summer load waterline with the after side of the rudder post. For the ships without a rudder post, the A.P. is the perpendicular at the intersection of the waterline with the centreline of the rudder stock.

1.2.2.4 Midship section - the hull section at the middle of ship's length L.

1.2.2.5 Midship region - the part of ship's length: 0.2 L aft and 0.2 L forward of amidship (unless expressly provided otherwise).

1.2.2.6 Ship's ends - portions of the ship's length from 0.05L abat perpendiculars to the ship's ends.

1.2.2.7 Machinery space aft - corresponds to the position of the mid-length of the machinery space beyond 0.3 L aft of amidships.

1.2.3 Main dimensions

1.2.3.1 Rule length of ship, L - distance, in [m], measured on the waterline at the scantling draught from the fore side of the stem to the after side at the rudder post, or the centre of the rudder stock, if there is no rudder post. L is not to be less than 96%, and need not be greater than 97%, of the extreme length on the waterline at the scantling draught.

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

In ships with unusual stem or stern arrangements the Rule length L will be considered on a case by case basis and agreed with the Register.

This requirement does not apply to CSR Bulk Carriers and Oil Tankers.

1.2.3.2 Breadth of ship, B - greatest moulded breadth, in [m], measured amidships at the scantling draught, ds.

1.2.3.3 Depth of ship, D - the vertical distance, in [m], measured amidships from the base line, to the top of the deck beam at side on the uppermost continuous deck. In ships having a rounded gunwale, the depth is measured to the point of intersection of the moulded lines of upper deck and side, the lines extending as though gunwale of angular design.

1.2.3.4 Draught of ship, d - the vertical distance, in [m], measured amidships from the top of the plate keel or bar keel to the summer load waterline.

1.2.3.5 Scantling draught of ship, ds - draught, in [m], at which the strength requirements for the scantlings of the ship are met and represents the full load condition. The scantling draught is to be not less than that corresponding to the assigned freeboard.

1.2.4 Decks and platforms

1.2.4.1 Upper deck - the uppermost continuous deck extending the full length of the ship

1.2.4.2 Strength deck - the deck forming the upper flange of the hull girder. The uppermost continuous deck or the deck of a midship superstructure of an effective length may be considered as the strength deck (see 4.1.3).

1.2.4.3 Bulkhead deck - the deck to which the main transverse watertight bulkheads are carried.

1.2.4.4 Freeboard deck - the deck from which the freeboard is calculated as stated in the ICLL (International Convention on Load Lines, 1966, as amended).

1.2.4.5 Lower decks - the decks located below the upper deck. Where the ship has several lower decks, they are called: second deck, third deck etc., counting from the upper deck.

1.2.4.6 Platform - lower deck which is extending over portions of the ship's length or breadth.
1.2.4.7 **Superstructure deck** - deck forming the top of tier of superstructure. Where the superstructure has several tiers, the superstructure decks are called as follows: first tier superstructure deck, second tier superstructure deck, counting from the upper deck.

1.2.4.8 **Deckhouse top** - deck forming the top at a tier of a deckhouse. Where the deckhouse has several tiers, the deckhouse tops are called as follows: first tier deckhouse top, second tier deckhouse top, etc.

1.2.5 **Erections**

1.2.5.1 **Superstructure** - a decked structure on the upper deck, extending from side to side of the ship or with the side plating not being inboard of the shell plating more than 4% of the breadth of the ship B.

1.2.5.2 **Deck house** - a decked structure on the upper deck or superstructure deck with its side plating, one side at least, being inboard of the shell plating by more than 4% of the breadth of the ship B and provided with doors, windows or other similar openings in the external bulkheads.

1.2.5.3 **Raised quarter deck** - an aft part of upper deck, raised by deck, break to a height less than the standard height of superstructure.

1.2.5.4 **Trunk** - a deck structure on the upper deck, not reaching at least one of the sides by a distance exceeding 4% of the breadth B and having no doors, windows or other similar openings in the external bulkheads.

1.2.6 **Explanations**

1.2.6.1 **Block coefficient** $C_\text{s}$ - moulded coefficient corresponding to the waterline at scantling draught $d_\text{sc}$, based on Rule length $L$ and moulded breadth $B$, determined from the formula:

$$C_\text{s} = \frac{\text{Moulded displacement}, \text{m}^3, \text{at} \text{scantling draught} \ d_\text{sc}}{L \cdot B \cdot d_\text{sc}}$$

This requirement does not apply to CSR Bulk Carriers and Oil Tankers.

1.2.6.2 **Effective flange** - is to have following size, unless provided otherwise:

- **Thickness**: equal to the thickness of the associated plating in the designed section;
- **Width**: equal to one sixth of the span of half the distance between the nearest framing members located on both sides of the given member, whichever is less. In separate cases, the effective flange of a different width may be adopted upon special agreement with the Register.

1.2.6.3 **Section modulus and moments of inertia** - of framing members (about the central axis perpendicular to the plane of bending) apply to rolled and built-up framing members with on effective flange, in [cm$^3$] and [cm$^4$], respectively.

1.2.6.4 **The design characteristic of ship's hull material** - is considered to be the yield stress $R_{yH}$, in [N/mm$^2$].

1.2.6.5 **Rounding of the scantlings** - of structural members (except for plates) is to be made in direction of increase. Plate thickness is to be rounded to the full or half millimetres up to 0,2 or 0,7; above 0,2 or 0,7 mm they are to be rounded up. Decreasing of the values for rolling materials is to be in accordance with the standard approved by Register.

1.2.6.6 **Watertight structure** - is structure, which is watertight for liquids (cargo, ballast, fresh water etc.).

1.2.6.7 **Ship's speed**, $v$ - max. Ship's speed, in [kN], at summer water line in calm water.

1.2.6.8 **Frame spacing**, $s$ - is spacing measured from moulding edge to moulding edge adjacent frames, in [m].

1.2.7 **Navigation area limitations**

For determining the scantlings of the longitudinal and transverse structures of ships intended to operate within one of the restricted service areas, the dynamic loads may be reduced as specified in Section 3 and 4.

Navigation areas are defined in the Rules, Part I - General requirements, Chapter 1 - General information, Section 4.2.

### 1.3 SCOPE OF SUPERVISION

1.3.1 **The general provisions for supervision of the hull are set in the Rules, Part 1 - General requirements, Chapter 2 - Supervision during construction.**

1.3.2 **All structures stated in following Sections shall be subjected to the supervision of the Register. Shipyards and manufacturers shall ensure easy access to the tested structure.**

1.3.3 **Prior to beginning the manufacture of structures stated in 1.3.2 the technical documentation for the ship's hull should be submitted for approval according to the Rules, Part 1 - General requirements, Chapter 2 - Supervision during construction and initial survey.**

1.3.4 **During manufacture the structures mentioned in 1.3.2 are subject to inspection for compliance with the requirements of Rules, Part 24 - Non-metallic materials, Part 25 - Metallic materials, Part 26 - Welding and for compliance with the approved technical documentation listed in the Rules, Part 1 - General requirements, Chapter 2 - Supervision during construction and initial survey.**

1.3.5 **The pressure test of hull structures is to be carried out according to the Rules, Part 1 - General requirements, Chapter 2 - Supervision during construction and initial survey.**

### 1.4 MATERIALS

1.4.1 **The materials used for hull structures regulated by this Section are to comply with the Rules, Part 25 - Metallic materials and Part 26 - Welding.**

Manufacturing of the materials has to be supervised by the Register.

1.4.2 **Hull structural steel**

1.4.2.1 **The material grade requirements for hull structural members of each class depending on the thickness are defined in Table 1.4.2.1. This Section provides for normal strength structural steel of grades CRS-A, CRS-B, CRS-D and CRS-E with yield strength $R_{yH} = 235$ N/mm$^2$, high strength structural steel of grades CRS-A32, CRS-D32, CRS-E32 with yield strength $R_{yH} = 315$ N/mm$^2$, CRS-A36, CRS-D36, CRS-E36 with yield strength $R_{yH} = 355$ N/mm$^2$, CRS-D40 and CRS-E40 with yield strength $R_{yH} = 390$ N/mm$^2$.**
In Table 1.4.2.1 grades of the higher tensile steels are marked by the letter \(H\).

### Table 1.4.2.1 Material grade requirements for classes I, II and III

<table>
<thead>
<tr>
<th>Thickness, [mm]</th>
<th>MS</th>
<th>HT</th>
<th>MS</th>
<th>HT</th>
<th>MS</th>
<th>HT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(t \leq 15)</td>
<td>CRS - A</td>
<td>CRS - AH</td>
<td>CRS - A</td>
<td>CRS - AH</td>
<td>CRS - A</td>
<td>CRS - AH</td>
</tr>
<tr>
<td>(15 &lt; t \leq 20)</td>
<td>CRS - A</td>
<td>CRS - AH</td>
<td>CRS - A</td>
<td>CRS - AH</td>
<td>CRS - B</td>
<td>CRS - AH</td>
</tr>
<tr>
<td>(20 &lt; t \leq 25)</td>
<td>CRS - A</td>
<td>CRS - AH</td>
<td>CRS - A</td>
<td>CRS - AH</td>
<td>CRS - D</td>
<td>CRS - DH</td>
</tr>
<tr>
<td>(25 &lt; t \leq 30)</td>
<td>CRS - A</td>
<td>CRS - AH</td>
<td>CRS - D</td>
<td>CRS - DH</td>
<td>CRS - D</td>
<td>CRS - DH</td>
</tr>
<tr>
<td>(30 &lt; t \leq 35)</td>
<td>CRS - B</td>
<td>CRS - AH</td>
<td>CRS - D</td>
<td>CRS - DH</td>
<td>CRS - E</td>
<td>CRS - EH</td>
</tr>
<tr>
<td>(35 &lt; t \leq 40)</td>
<td>CRS - B</td>
<td>CRS - AH</td>
<td>CRS - D</td>
<td>CRS - DH</td>
<td>CRS - E</td>
<td>CRS - EH</td>
</tr>
<tr>
<td>(40 &lt; t \leq 50)</td>
<td>CRS - D</td>
<td>CRS - DH</td>
<td>CRS - E</td>
<td>CRS - EH</td>
<td>CRS - E</td>
<td>CRS - EH</td>
</tr>
</tbody>
</table>

### 1.4.2.2 Material factor, \(k\),

#### 1.4.2.2.1 For normal hull structural steel with yield strength \(R_{yH} = 235\ N/\text{mm}^2\) and a tensile strength \(R_m = 400 - 520\ N/\text{mm}^2\), the material factor, \(k\), in the formulae of the following Sections is to be taken 1.0.

#### 1.4.2.2.2 The material factor, \(k\), for groups of higher tensile hull structural steel is defined as follows:

These requirements do not apply to CSR Bulk Carriers and Oil Tankers.

- \(k = 0.78\), for steel with \(R_{yH} = 315\ N/\text{mm}^2\).
- \(k = 0.72\), for steel with \(R_{yH} = 355\ N/\text{mm}^2\).
- \(k = 0.66\), for steel with \(R_{yH} = 390\ N/\text{mm}^2\) provided that a fatigue assessment of the structure is performed to verify compliance with the requirements of the Register.
- \(k = 0.68\), for steel with \(R_{yH} = 390\ N/\text{mm}^2\) in other cases.

For higher tensile hull structural steel with other nominal yield strength (\(235 < R_{yH} < 390\ N/\text{mm}^2\) and \(R_{yH} \neq 315\) or \(355\ N/\text{mm}^2\)), the material factor \(k\) may be determined by the following formula:

\[
k = \frac{295}{R_{yH} + 60}
\]

### 1.4.2.3 Materials in the various strength members are not to be of lower grade than those corresponding to the material classes and grades specified in Table 1.4.2.1 to Table 1.4.2.7. General requirements are given in Table 1.4.2.3, while additional minimum requirements are given in the following:

- Table 1.4.2.4: for ships with length exceeding 150 m and single strength deck.
- Table 1.4.2.5: for ships with length exceeding 250 m.
- Table 1.4.2.6: for single side bulk carriers subjected to SOLAS regulation XII/6.5.3.
- Table 1.4.2.7: for ships with ice strengthening.

These requirements do not apply to CSR Bulk Carriers and Oil Tankers.

For strength members not mentioned in Tables 1.4.2.3 to 1.4.2.7, grade A/AH may generally be used. The steel grade is to correspond to the as-built plate thickness and material class.

### 1.4.2.4 Plating materials for sternframes supporting the rudder and propeller boss, rudders, rudder horns and shaft brackets are in general not to be of lower grades than corresponding to Class II. For rudder and rudder body plates subjected to stress concentrations (e.g. in way of lower support of semi-spade rudders or at upper part of spade rudders) class III is to be applied.

Mechanical properties of clad steel, if it is used, are not to be less than defined in Table 1.4.2.1.

Base material has to be of shipbuilding steel, in accordance with the Rules, Part 25 - Metallic materials, 3.2.

### 1.4.2.5 In case of high local stresses in the thickness direction, use of “Z” grade of steel (steel with guaranteed properties in thickness direction) is recommended.

### 1.4.2.6 Forged steel and cast steel

Forged steel and cast steel for stem, stern frame, rudder post as well as other structural components, which are subject of this Rule, are to comply with the Rules, Part 25 - Metallic materials.

The tensile strength of forged steel and of cast steel is not to be less than 400 N/mm². While selecting forged steel and cast steel toughness requirements and weldability are to be considered beside the strength properties.
Table 1.4.2.3 Material classes and grades for ships in general

<table>
<thead>
<tr>
<th>STRUCTURAL MEMBER CATEGORY</th>
<th>MATERIAL CLASS/GRADE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SECONDARY:</td>
<td></td>
</tr>
<tr>
<td>A1. Longitudinal bulkhead strakes, other than that belonging to the Primary category</td>
<td>- Class I within 0.4L amidships - Grade A/AH outside 0.4L amidships</td>
</tr>
<tr>
<td>A2. Deck plating exposed to weather, other than that belonging to the Primary or Special category</td>
<td></td>
</tr>
<tr>
<td>A3. Side plating</td>
<td></td>
</tr>
<tr>
<td>PRIMARY:</td>
<td></td>
</tr>
<tr>
<td>B1. Bottom plating, including keel plate</td>
<td>- Class II within 0.4L amidships - Grade A/AH outside 0.4L amidships</td>
</tr>
<tr>
<td>B2. Strength deck plating, excluding that belonging to the Special category</td>
<td></td>
</tr>
<tr>
<td>B3. Continuous longitudinal plating of strength members above strength deck, excluding hatch coamings</td>
<td></td>
</tr>
<tr>
<td>B4. Uppermost strake in longitudinal bulkhead</td>
<td></td>
</tr>
<tr>
<td>B5. Vertical strake (hatch side girder) and uppermost sloped strake in top wing tank</td>
<td></td>
</tr>
<tr>
<td>SPECIAL:</td>
<td></td>
</tr>
<tr>
<td>C1. Sheer strake at strength deck 1)</td>
<td>- Class III within 0.4L amidships - Class II outside 0.4L amidships - Class I outside 0.6L amidships</td>
</tr>
<tr>
<td>C2. Stringer plate in strength deck 1)</td>
<td></td>
</tr>
<tr>
<td>C3. Deck strake at longitudinal bulkhead, excluding deck plating in way of inner-skin bulkhead of double-hull ships 1)</td>
<td></td>
</tr>
<tr>
<td>C4. Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configurations</td>
<td>- Class III within 0.4L amidships - Class II outside 0.4L amidships - Class I outside 0.6L amidships - Min. Class III within cargo region</td>
</tr>
<tr>
<td>C5. Strength deck plating at corners of cargo hatch openings in bulk carriers, ore carriers, combination carriers and other ships with similar hatch opening configurations</td>
<td>- Class III within 0.6L amidships - Class II within rest of cargo region</td>
</tr>
<tr>
<td>C5.1 Trunk deck and inner deck plating at corners of openings for liquid and gas domes in membrane type liquefied gas carriers</td>
<td></td>
</tr>
<tr>
<td>C6. Bilge strake in ships with double bottom over the full breadth and length less than 150 m 1)</td>
<td>- Class II within 0.6L amidships - Class I outside 0.6L amidships</td>
</tr>
<tr>
<td>C7. Bilge strake in other ships 1)</td>
<td>- Class III within 0.4L amidships - Class II outside 0.4L amidships - Class I outside 0.6L amidships</td>
</tr>
<tr>
<td>C8. Longitudinal hatch coamings of length greater than 0.15L</td>
<td>- Class III within 0.4L amidships - Class II outside 0.4L amidships - Class I outside 0.6L amidships - Not to be less than Grade D/DH</td>
</tr>
<tr>
<td>C9. End brackets and deck house transition of longitudinal cargo hatch coamings</td>
<td></td>
</tr>
</tbody>
</table>

Notes:

1) Single strakes required to be of Class III within 0.4L amidships are to have breadths not less than 800+5L (mm), need not be greater than 1800 (mm), unless limited by the geometry of the ship's design.
Table 1.4.2.4 Minimum material grades for ships with length exceeding 150 m and single strength deck

<table>
<thead>
<tr>
<th>STRUCTURAL MEMBER CATEGORY</th>
<th>MATERIAL GRADE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal plating of strength deck where contributing to the longitudinal strength. Continuous longitudinal plating of strength members above strength deck.</td>
<td>Grade B/AH within 0.4L amidships</td>
</tr>
<tr>
<td>Single side strakes for ships without inner continuous longitudinal bulkhead(s) between bottom and the strength deck</td>
<td>Grade B/AH within cargo region</td>
</tr>
</tbody>
</table>

Table 1.4.2.5 Minimum material grades for ships with length exceeding 250 m

<table>
<thead>
<tr>
<th>STRUCTURAL MEMBER CATEGORY</th>
<th>MATERIAL GRADE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheer strake at strength deck</td>
<td>Grade E/EH within 0.4L amidships</td>
</tr>
<tr>
<td>Stringer plate in strength deck</td>
<td>Grade E/EH within 0.4L amidships</td>
</tr>
<tr>
<td>Bilge strake</td>
<td>Grade D/DH within 0.4L amidships</td>
</tr>
</tbody>
</table>

Notes:
1) Single strakes required to be of Grade E/EH and within 0.4L amidships are to have breadths not less than 800+5L (mm), need not be greater than 1800 (mm), unless limited by the geometry of the ship’s design.

Table 1.4.2.6 Minimum material grades for single-side skin bulk carriers subjected to SOLAS regulation XII/6.5.3

<table>
<thead>
<tr>
<th>STRUCTURAL MEMBER CATEGORY</th>
<th>MATERIAL GRADE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower bracket of ordinary side frame</td>
<td>Grade D/DH</td>
</tr>
<tr>
<td>Side shell strakes included totally or partially between the two points located to 0.125L above and below the intersection of side shell and bilge hopper sloping plate or inner bottom plate</td>
<td>Grade D/DH</td>
</tr>
</tbody>
</table>

Notes:
1) The term "lower bracket" means webs of lower brackets and webs of the lower part of side frames up to the point of 0.125L above the intersection of side shell and bilge hopper sloping plate or inner bottom plate.
2) The span of the side frame, L, is defined as the distance between the supporting structures.

Table 1.4.2.7 Minimum material grades for ships with ice strengthening

<table>
<thead>
<tr>
<th>STRUCTURAL MEMBER CATEGORY</th>
<th>MATERIAL GRADE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell strakes in way of ice strengthening area for plates</td>
<td>Grade B/AH</td>
</tr>
</tbody>
</table>

1.4.3 Material selection for structural members which are continuously exposed to low temperatures

1.4.3.1 The material for structural members, which are continuously exposed to temperatures below 0°C, e.g. refrigerated cargo holds, is selected by the design temperature of the structural members. The design temperature is determined by means of a temperature distribution taking into account the design environmental temperatures. For unrestricted service the design environmental temperatures are:

- air: +5°C
- sea water: 0°C

1.4.3.2 For ships intended to operate in areas with low air temperatures (below -10°C) e.g. regular service during winter seasons to Arctic or Antarctic waters, the materials in the exposed structural members shall be selected based on the design temperature to which is taken as defined in 1.4.3.3. The material grade requirements for hull members of each class depending on thickness and design temperature are defined in Table 1.4.3.2.

For design temperatures \( t_0 < -55°C \), materials are to be specially considered.
1.4.3.3 Design temperature, \( t_D \), shall be taken as the lowest mean daily average temperature in the area of operation:

**Mean:** Statistical mean value over observation period.

**Average:** Average during one day and night.

**Lowest:** Lowest during year.

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

For the purpose of issuing a polar ship certificate in accordance with the Polar Code, the design temperature \( t_D \) shall be no more than 13°C higher than the polar service temperature (PST) of the ship.

In the polar regions, the statistical mean over observation period is to be determined for a period of at least 10 years.

Fig. 1.4.3.3 illustrates the temperature definition.

\[
\text{MDHT} = \text{Mean Daily High (or maximum) Temperature} \\
\text{MDAT} = \text{Mean Daily Average Temperature} \\
\text{MDLT} = \text{Mean Daily Low (or minimum) Temperature}
\]

**Figure 1.4.3.3** Commonly used definitions of temperatures

1.4.3.4 Materials in the various strength members above the lowest ballast water line (BWL) exposed to air (including the structural members covered by the note 5 of Table 1.4.3.4) and materials of cargo tank boundary plating for which 1.4.3.5 is applicable are not to be of lower grades than those corresponding to classes I, II and III, as given in Table 1.4.3.4, depending on the categories of structural members (SECONDARY, PRIMARY and SPECIAL).

For non-exposed structures (except as indicated in Note 5 of Table 1.4.3.4) and structures below the lowest ballast water line see 1.4.2.

Single strakes required to be of class III or of grade E/EH or FH have breadths not less than 800 + 5 \( L \), [mm], maximum 1800 mm.

Plating materials for stern frames, rudder horns, rudders and shaft brackets are not to be of lower grades than those corresponding to the material classes given in 1.4.2.

<table>
<thead>
<tr>
<th>Structural member</th>
<th>Within 0.4 ( L ) amidships</th>
<th>Outside 0.4 ( L ) amidships</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SECONDARY:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deck plating exposed to weather, in general</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>Side plating above BWL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse bulkheads above BWL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cargo tank boundary plating exposed to cold cargo</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PRIMARY:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength deck plating</td>
<td>II</td>
<td>I</td>
</tr>
<tr>
<td>Continuous longitudinal members above strength deck, excluding longitudinal hatch coamings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal bulkhead above BWL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top wing tank bulkhead above BWL</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SPECIAL:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sheer strake at strength deck</td>
<td>III</td>
<td>II</td>
</tr>
<tr>
<td>Stringer plate in strength deck</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deck strake at longitudinal bulkhead</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous longitudinal hatch coamings</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Plating at corners of large hatch openings is to be specially considered. Class III or grade E/EH is to be applied in positions where high local stresses may occur.
2. Not to be less than grade E/EH within 0.4 \( L \) amidships in ships with length exceeding 250 m.
3. In ships with breadth exceeding 70m at least three deck strakes to be class III.
4. Not to be less than grade D/DH.
5. Applicable to plating attached to hull envelope plating exposed to low air temperature. At least one strake is to be considered in the same way as exposed plating and the strake width is to be at least 600 mm.
6. For cargo tank boundary plating exposed to cold cargo for ships other than liquefied gas carriers, see 5.6.4.

1.4.3.5 Cold cargo for ships other than liquefied gas carriers

For ships other than liquefied gas carriers, intended to be loaded with liquid cargo having a temperature below -10°C, e.g. loading from cold onshore storage tanks during winter conditions, the material grade of cargo tank boundary plating is defined in Table 1.4.3.4 based on the following:

- \( t_c \) design minimum cargo temperature in °C
- Steel grade corresponding to Class I as given in Table 1.4.3.4.

The design minimum cargo temperature, \( t_c \), is to be specified in the loading manual.
## Class I

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>t ≤ 10</td>
<td>A AH</td>
<td>A AH</td>
<td>B AH</td>
<td>D AH</td>
<td>D DH</td>
<td>D DH</td>
<td>D DH</td>
<td>D DH</td>
<td>D DH</td>
</tr>
<tr>
<td>10 &lt; t ≤ 15</td>
<td>A AH</td>
<td>B AH</td>
<td>D DH</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
</tr>
<tr>
<td>15 &lt; t ≤ 20</td>
<td>A AH</td>
<td>B AH</td>
<td>D AH</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
</tr>
<tr>
<td>20 &lt; t ≤ 25</td>
<td>B AH</td>
<td>D DH</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
</tr>
<tr>
<td>25 &lt; t ≤ 30</td>
<td>B AH</td>
<td>D DH</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
</tr>
<tr>
<td>30 &lt; t ≤ 35</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
</tr>
<tr>
<td>35 &lt; t ≤ 45</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
</tr>
<tr>
<td>45 &lt; t ≤ 50</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
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</tbody>
</table>

Ø = Not applicable

## Class II

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>t ≤ 10</td>
<td>A AH</td>
<td>B AH</td>
<td>D DH</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
</tr>
<tr>
<td>10 &lt; t ≤ 20</td>
<td>B AH</td>
<td>D DH</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>É FH</td>
<td>E EH</td>
</tr>
<tr>
<td>20 &lt; t ≤ 30</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
</tr>
<tr>
<td>30 &lt; t ≤ 40</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
</tr>
<tr>
<td>40 &lt; t ≤ 45</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
</tr>
<tr>
<td>45 &lt; t ≤ 50</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
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</table>

Ø = Not applicable

## Class III

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</tr>
</thead>
<tbody>
<tr>
<td>t ≤ 10</td>
<td>B AH</td>
<td>D DH</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
</tr>
<tr>
<td>10 &lt; t ≤ 20</td>
<td>B AH</td>
<td>D DH</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
<td>E EH</td>
</tr>
<tr>
<td>20 &lt; t ≤ 25</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
</tr>
<tr>
<td>25 &lt; t ≤ 30</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
</tr>
<tr>
<td>30 &lt; t ≤ 35</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
</tr>
<tr>
<td>35 &lt; t ≤ 40</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
<td>Ø FH</td>
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</tr>
<tr>
<td>40 &lt; t ≤ 50</td>
<td>D DH</td>
<td>E EH</td>
<td>E EH</td>
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</tr>
</tbody>
</table>

Ø = Not applicable
1.4.4 Aluminium alloy

1.4.4.1 Use of seawater resisting aluminium alloys is permitted, by these Rules, as follows:
- ships with length \( L < 12 \) m - for hull, superstructure and deckhouses;
- ships with length \( L > 40 \) m - for superstructure and deckhouses.

1.4.4.2 The conversion of the structural elements from steel into aluminium alloy is to be specially considered taking into account the smaller modulus of elasticity \( E \), as compared with steel, and the fatigue strength aspects, specifically those of the welded connections.

1.4.4.3 The smaller modulus of elasticity \( E \) is to be taken into account when determining the buckling strength of structural elements subjected to compression. This is to be applied accordingly to structural elements for which maximum allowable deflections have to be adhered to.

1.4.4.4 The conversion from steel to aluminium scantlings is to be carried out by using the material factor:

\[
k_{\text{Al}} = \frac{635}{R_{\text{p}0.2} + R_{\text{m}}}
\]

where:
- \( R_{\text{p}0.2} \) = 0,2% proof stress of the aluminium alloy, in [N/mm²];
- \( R_{\text{m}} \) = tensile strength of the aluminium alloy, in [N/mm²].

Method of conversion:
- section modulus: \( W_{\text{Al}} = W_{\text{st}} \cdot k_{\text{Al}} \)
- plate thickness: \( t_{\text{Al}} = t_{\text{st}} \cdot \sqrt{k_{\text{Al}}} \)

\( W_{\text{st}}, t_{\text{st}} = \) section modulus and plate thickness of steel, respectively.

1.4.5 Corrosion protection

1.4.5.1 General

For the corrosion protection of seagoing steel ships in general, see the Rules, Part 24 - Non-metallic materials, Section 4 and Part 1 - General requirements, Chapter 5.

1.4.5.2 Corrosion prevention for bulk carriers, tankers and combination carriers

1.4.5.2.1 Corrosion protection coating for salt water ballast spaces

At the time of new construction, all salt water ballast spaces having boundaries formed by the hull envelope shall have an efficient protective coating, epoxy or equivalent, applied in accordance with the manufacturer’s recommendations.

The scheme for the selection, application and maintenance of the coating system should follow the requirements of IMO Resolution A.798(19) and contain, as a minimum, the following documentation:

1. Owner’s, coating manufacturer’s and shipyard’s explicit agreement to the scheme for coating selection, application and maintenance.
2. List of seawater ballast tanks identifying the coating system for each tank, includ-

ing coating colour and whether coating system is a hard coating.

3. Details of anodes, if used.
4. Manufacturer’s technical product data sheet for each product.
5. Manufacturer’s evidence of product quality and ability to meet Owners requirements.
6. Evidence of shipyard’s and/or its subcontractor’s experience in coating application.
7. Surface preparation procedures and standards, including inspection points and methods.
8. Application procedures and standards, including inspection points and methods.
10. Manufacturer’s product safety data sheets for each product and owner’s, coating manufacturer’s and shipyard’s explicit agreement to take all precautions to reduce health and other safety risks which are required by the authorities.
11. Maintenance requirements for the coating system.

Coating of any colour may be accepted, unless otherwise instructed by the flag Administration. “Light colour” coating is preferable, and includes colours, which facilitate inspection or are easily distinguishable from rust.

1.4.5.2.2 Corrosion protection coating for cargo holds spaces on bulk carriers and combination carriers

1.4.5.2.2.1 At the time of new construction, all internal and external surfaces of hatch coamings and hatch covers, and all internal surfaces of the cargo holds, excluding the flat tank top areas and the hopper tanks sloping plating approximately 300 mm below the side shell frame and brackets, are to have an efficient protective coating (epoxy coating or equivalent) applied in accordance with the manufacturer’s recommendation. In the selection of coating due consideration is to be given by the owner to intended cargo conditions expected in service.

1.4.5.2.2.2 A corrosion prevention system is normally considered either:

1. a full hard coating, or
2. a full hard coating supplemented by anodes.

Protective coating should usually be hard (epoxy) coating or equivalent. Other coating systems may be considered acceptable as alternatives provided that they are applied and maintained in compliance with the manufacturer’s specification.

NOTE: Where soft coatings (solvent-free coatings based of wool grease, grease, mineral oils and/or wax that remains soft so that it wears off when touched) have been applied, during mandatory surveys of ship in service safe access is to be provided for the Surveyor to verify the effectiveness of the coating and to carry out an assessment of the conditions of internal structures which may include spot removal of the coating. When safe access cannot be provided, the soft coating is to be removed.
1.4.5.2.3 Additional requirements for corrosion prevention on tankers and combination carriers

1.4.5.2.3.1 Impressed current systems are not permitted in oil cargo tanks.

1.4.5.2.3.2 Magnesium or magnesium alloy anodes are not permitted in oil cargo tanks.

1.4.5.2.3.3 Aluminium anodes are only permitted in cargo tanks of tankers in locations where the potential energy does not exceed 275 J. The height of the anode is to be measured from the bottom of the tank to the centre of the anode, and its weight is to be taken as the weight of the anode as fitted, including the fitting devices and inserts. However, where aluminium anodes are located on horizontal surfaces such as bulkhead girders and stringers not less than 1 m wide and fitted with an upstanding flange or face flat projecting not less than 75 mm above the horizontal surface, the height of the anode may be measured from this surface. Aluminium anodes are not to be located under tank hatches or “Butterworth” openings (in order to avoid any metal parts falling on the fitted anodes), unless protected by adjacent structure.

1.4.5.2.3.4 There is no restriction on the positioning of zinc anodes.

1.4.5.2.3.5 The anodes should have steel cores and these should be sufficiently rigid to avoid resonance in the anode support and be designed so that they retain the anode even when it is wasted.

1.4.5.2.3.6 The steel inserts are to be attached to the structure by means of a continuous weld of adequate section. Alternatively they may be attached to separate supports by bolting, provided a minimum of two bolts with locknuts are used. However, approved mechanical means of clamping will be accepted.

The supports at each end of an anode should not be attached to separate items, which are likely to move independently. When anode inserts or supports are welded to the structure, they should be arranged so that the welds are clear of stress raisers.

1.4.5.2.3.7 The use of aluminium coatings containing greater than 10 percent aluminium by weight in the dry film is prohibited in cargo tanks, cargo tank deck area, pump rooms, cofferdams or any other area where cargo vapour may accumulate.

1.4.5.2.3.8 Aluminised pipes may be permitted in ballast tanks, in inerted cargo tanks and, provided the pipes are protected from accidental impact, in hazardous areas on open deck.

1.4.5.3 Protective coatings of dedicated seawater ballast tanks in all types of ships and double-side skin spaces of bulk carriers

1.4.5.3.1 All dedicated seawater ballast tanks arranged in all type of ships of not less than 500 gross tonnage and double-side skin spaces arranged in bulk carriers of 150 m in length and upwards shall be coated during construction in accordance with the Performance standard for protective coatings for dedicated seawater ballast tanks in all types of ships and double-side skin spaces of bulk carriers, adopted by the Maritime Safety Committee by resolution MSC.215(82) as amended by resolution MSC.341(91).

1.4.5.3.2 For application of SOLAS Regulation II-1/3-2, protective coatings on dedicated seawater ballast tanks in all types of ships and double-side skin spaces of bulk carriers, see IACS Unified Interpretation SC223. This IACS Unified Interpretation shall be read in conjunction with the IMO Performance Standard for Protective Coatings (PSPC), Resolution MSC.215(82) as amended by resolution MSC.341(91).

1.4.5.3.3 The ability of the coating system to reach its target useful life depends on the type of coating system, steel preparation, application and coating inspection and maintenance. All these aspects contribute to the good performance of the coating system.

1.4.5.3.4 Inspection of surface preparation and coating processes shall be agreed upon between the shipowner, the shipyard and the coating manufacturer and presented to the Register for review. Clear evidence of these inspections shall be reported and be included in the Coating Technical File (CTF), see 1.4.5.3.5.

1.4.5.3.5 Specification of the coating system applied to the seawater ballast tanks and double-side skin spaces, record of the shipyard’s and shipowner’s coating work, detailed criteria for coating selection, job specifications, inspection, maintenance and repair shall be documented in the Coating Technical File (CTF), and the Coating Technical File shall be reviewed by the Register.

1.4.5.3.6 Maintenance of the protective coating system shall be included in the overall ship’s maintenance schedule. The effectiveness of the protective coating system shall be verified during the life of a ship by the Register, based on the appropriate guidelines.

1.4.5.4 Corrosion protection of cargo oil tanks of crude oil tankers (Resolution MSC.291(87))

1.4.5.4.1 All cargo oil tanks of crude oil tankers shall be:

.1 coated during the construction of the ship in accordance with the Performance standard for protective coatings for cargo oil tanks of crude oil tankers, adopted by the Maritime Safety Committee by resolution MSC.288(87) as amended by resolution MSC.342(91); or;

.2 protected by alternative means of corrosion protection or utilisation of corrosion resistance material to maintain required structural integrity for 25 years in accordance with the Performance standard for alternative means of corrosion protection for cargo oil tanks of crude oil tankers, adopted by the Maritime Safety Committee by resolution MSC.289(87).

1.4.5.4.2 Requirements in 1.4.5.4.1 shall apply to crude oil tankers, as defined in regulation 1 of Annex I to the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto, of 5,000 tonnes deadweight and above:

.1 for which the building contract is placed on or after 1 January 2013; or

.2 in the absence of a building contract, the keels of which are laid or which are at a similar stage of construction on or after 1 July 2013; or

.3 the delivery of which is on or after 1 January 2016.

1.4.5.4.3 The Administration may exempt a crude oil tanker from the requirements in 1.4.5.4.1 to allow the use of
novel prototype alternatives to the coating system specified in 1.4.5.4.1.1, for testing, provided they are subject to suitable controls, regular assessment and acknowledgement of the need for immediate remedial action if the system fails or is shown to be failing. Such exemption shall be recorded on an exemption certificate.

1.4.5.4 The Administration may exempt a crude oil tanker from the requirements in 1.4.5.4.1 if the ship is built to be engaged solely in the carriage of cargoes and cargo handling operations not causing corrosion. Such exemption and conditions for which it is granted shall be recorded on an exemption certificate.

1.4.5.5 For application of SOLAS Regulation II-1/3-11, Performance standard for protective coatings for cargo oil tanks of crude oil tankers (PSPC-COT), adopted by Resolution MSC.288 (87) as amended by resolution MSC.342 (91), see also IACS Unified Interpretation SC259.

1.4.5.6 For application of SOLAS Regulation II-1/3-11, Performance standard for alternative means of corrosion protection for cargo oil tanks of crude oil tankers, adopted by Resolution MSC.289 (87), see also IACS UI SC 258.

1.4.6 Requirements for use of extremely thick steel plates in container ships

1.4.6.1 Application

1.4.6.1.1 General

1.4.6.1.1.1 These requirements are to be complied with for container ships incorporating extremely thick steel plates having steel grade and thickness in accordance with 1.4.6.1.2 and 1.4.6.1.3 respectively.

1.4.6.1.1.2 These requirements identify when measures for the prevention of brittle fracture of extremely thick steel plates are required for longitudinal structural members.

1.4.6.1.1.3 These requirements define the following methods to apply to the extremely thick plates of container ships for preventing the crack initiation and propagation:

- non-destructive testing (NDT) during construction detailed in 1.4.6.2,
- periodic NDT after delivery detailed in 1.4.6.3,
- brittle crack arrest design detailed in 1.4.6.4.

The application of the measures specified in 1.4.6.2, 1.4.6.3 and 1.4.6.4 is to be in accordance with 1.4.6.5.

1.4.6.1.4 These requirements give the basic concepts for application of extremely thick steel plates to longitudinal structural members in the upper deck region.

1.4.6.1.5 For the application of these requirements, the upper deck region means the upper deck plating, hatch side coaming plating, hatch coaming top plating and their attached longitudinals.

1.4.6.1.2 Steel Grade

1.4.6.1.2.1 These requirements are to be applied when any of YP36, YP40 and YP47 steel plates are used for the longitudinal structural members in the upper deck region.

1.4.6.1.2.2 In case YP47 steel plates are used for longitudinal structural members in the upper deck region, the steel plates are to be of EH47 grade as specified in the Rules, Part 25-Metallic materials, Section 3.4.2.

Note: YP36, YP40, and YP47 refers to the minimum specified yield strength of steel 355, 390 and 460 N/mm², respectively as defined in the Rules, Part 25-Metallic materials, Section 3.2 and 3.4.

1.4.6.1.3 Thickness

1.4.6.1.3.1 For steel plates with thickness of over 50mm and not greater than 100 mm, the measures for prevention of brittle crack initiation and propagation specified in 1.4.6.2, 1.4.6.3 and 1.4.6.4 are to be taken.

1.4.6.1.3.2 For steel plates with thickness exceeding 100 mm, appropriate measures for prevention of brittle crack initiation and propagation are to be taken in accordance with the Register’s procedures.

1.4.6.1.4 Hull structures (for the purpose of design)

1.4.6.1.4.1 Material factor

The material factors of YP36 and YP40 are defined in 1.4.2.2.

The material factor of YP47 steel for the assessment of hull girder strength is to be taken as $k=0.62$.

1.4.6.1.4.2 Fatigue assessment

The fatigue assessment of the longitudinal structural members is to be performed in accordance with the Register’s procedures.

1.4.6.1.4.3 Details of construction design

Special consideration is to be paid to the construction details where extremely thick steel plates are applied to structural members such as connections between outfitting and hull structures. Connections details are to be in accordance with the Register’s requirements.

1.4.6.2 Non-destructive testing during construction (measure No.1 of 1.4.6.5)

Where non-destructive testing (NDT) during construction is required in 1.4.6.5, the NDT is to be in accordance with 1.4.6.2.1 and 1.4.6.2.2. Enhanced NDT as specified in 1.4.6.3.1(e) is to be carried out in accordance with an appropriate standard.

1.4.6.2.1 General

1.4.6.2.1.1 Ultrasonic testing (UT) in accordance with IACS Rec.20 or Part 26-Welding, 2.3 is to be carried out on all block-to-block butt joints of all upper flange longitudinal structural members in the cargo hold region. Upper flange longitudinal structural members include the topmost strakes of the inner hull/bulkhead, the sheer strake, main deck, coaming plate, coaming top plate, and all attached longitudinal stiffeners. These members are defined in Fig.1.4.6.2.1.1.
Figure 1.4.6.2.1.1 Upper flange longitudinal structural members

### 1.4.6.2.2 Acceptance criteria of UT

1. **1.4.6.2.2.1** Acceptance criteria of UT are to be in accordance with IACS Rec.20 or the Register’s practice.

2. **1.4.6.2.2.2** The acceptance criteria may be adjusted under consideration of the appertaining brittle crack initiation prevention procedure and where this is more severe than that found in IACS Rec.20, the UT procedure is to be amended accordingly to a more severe sensitivity.

### 1.4.6.3 Periodic NDT after delivery (measure No.2 of 1.4.6.5)

Where periodic NDT after delivery is required, the NDT is to be in accordance with 1.4.6.3.1, 1.4.6.3.2 and 1.4.6.3.3.

1. **1.4.6.3.1 General**

2. **1.4.6.3.2 Timing of UT**

3. **1.4.6.3.3 Acceptance criteria of UT**

4. **1.4.6.4 Brittle crack arrest design (measures No.3, 4 and 5 of 1.4.6.5)**

#### 1.4.6.4.1 General

The brittle crack arrest steel method detailed in 1.4.6.4 may be used when the measures No. 3, 4 and 5 of 1.4.6.5 are applied and the steel grade material of the upper deck is not higher than YP40. Otherwise other means for preventing the crack initiation and propagation shall be agreed with the Register.

#### 1.4.6.4.2 Functional requirements of brittle crack arrest design

1. **1.4.6.4.2.1** The purpose of the brittle crack arrest design is aimed at arresting propagation of a crack at a proper position and to prevent large scale fracture of the hull girder.

   (a) **The locations of most concern for brittle crack initiation and propagation are the block-to-block butt weld joints either on hatch side coaming or on upper deck plating. Other locations in block fabrication where joints are aligned may also present higher opportunity for crack initiation and propagation along butt weld joints.**

   (b) **Both of the following cases are to be considered:**

      (i) where the brittle crack runs straight along the butt joint, and

      (ii) where the brittle crack initiates in the butt joint but deviates away from the weld and into the plate, or where the brittle crack initiates from any other weld (see the Figure 1.4.6.4.2.1 for definition of other welds) and propagates into the plate.

   **“Other weld” includes the following (refer to Fig. 1.4.6.4.2.1):**

   1. fillet welds between hatch side coaming plating, including top plating and longitudinals;
   2. fillet welds between hatch side coaming plating, including top plating and longitudinals, and attachments. (e.g. fillet welds between hatch side top plating and hatch cover pad plating);
   3. fillet welds between hatch side coaming top plating and hatch side coaming plating;
   4. fillet welds between hatch side coaming plating and upper deck plating;
   5. fillet welds between upper deck plating and inner hull/bulkheads;
   6. fillet welds between upper deck plating and longitudinal; and
   7. fillet welds between sheer strakes and upper deck plating.
1.4.6.4.3 Concept examples of brittle crack arrest design

1.4.6.4.3.1 The followings are considered acceptable examples of measures that can be used on a brittle crack arrest design to prevent brittle crack propagations. The detail design arrangements are to be submitted to the Register for approval. Other measures may be considered and accepted for review by the Register.

Brittle crack arrest design for 1.4.6.4.2.1(b) (ii):

(a) Brittle crack arresting steel is to be used for the upper deck plating along the cargo hold region in a way suitable to arrest a brittle crack initiating from the coaming and propagating into the structure below.

Brittle crack arrest design for 1.4.6.4.2.1(b) (i):

(b) Where the block to block butt welds of the hatch side coaming and those of the upper deck are shifted, this shift is to be greater than or equal to 300mm. Brittle crack arrest steel is to be provided for the hatch side coaming plating.

(c) Where crack arrest holes are provided in way of the block-to-block butt welds at the region where hatch side coaming weld meets the deck weld, fatigue strength of the lower end of the butt weld is to be assessed. Additional countermeasures are to be taken for the possibility that a running brittle crack may deviate from the weld line into upper deck or hatch side coaming. These countermeasures are to include the application of brittle crack arrest steel in hatch side coamings plating.

(d) Where Arrest insert plates of brittle crack arrest steel or Weld metal inserts with high crack arrest toughness properties are provided in way of the block-to-block butt welds at the region where hatch side coaming weld meets the deck weld, additional countermeasures are to be taken for the possibility that a running brittle crack may deviate from the weld line into upper deck or hatch side coaming. These countermeasures are to include the application of brittle crack arrest steel in hatch side coamings plating.

(c) The application of enhanced NDT particularly time of flight diffraction (TOFD) technique using stricter defect acceptance in lieu of standard UT technique specified in 1.4.6.2 can be an alternative to (b), (c) and (d).

1.4.6.4.4 Selection of brittle crack arrest steels

1.4.6.4.4.1 The brittle crack arrest steels fitted in the upper deck region of container ships are to comply with Table 1.4.6.4.4.1 where suffixes BCA1 and BCA2 are defined in the Rules, Part 25-Metallic materials, Section 3.4.2.

**Table 1.4.6.4.4.1**

<table>
<thead>
<tr>
<th>Structural members plating</th>
<th>Thickness, [mm]</th>
<th>Brittle crack arrest steel requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper deck</td>
<td>$50 &lt; t \leq 100$</td>
<td>Steel grade YP36 or 40 with suffix BCA1</td>
</tr>
<tr>
<td>Hatch coaming side</td>
<td>$50 &lt; t \leq 80$</td>
<td>Steel grade YP 40 or 47 with suffix BCA1</td>
</tr>
<tr>
<td></td>
<td>$80 &lt; t \leq 100$</td>
<td>Steel grade YP 40 or 47 with suffix BCA2</td>
</tr>
</tbody>
</table>

(*) Excluding their attached longitudinals

1.4.6.4.4.2 The brittle crack arrest steel property is to be selected for each individual structural member with thickness above 50 mm according to Table 1.4.6.4.4.1.

1.4.6.4.4.3 When brittle crack arrest steels as specified in Table 1.4.6.4.4.1 are used, the weld joints between the hatch coaming side and the upper deck are to be partial penetration weld details approved by the Register.

In the vicinity of ship block joints, alternative weld details may be used for the deck and hatch coaming side connection provided additional means for preventing the crack propagation are implemented and agreed by the Register in this connection area.

1.4.6.5 Measures for extremely thick steel plates

The thickness and the yield strength shown in the following table apply to the hatch coaming top plating and side plating, and are the controlling parameters for the application of countermeasures given in 1.4.6.4.3.1. These controlling parameters are not applicable for the upper deck.

If the as built thickness of the hatch coaming top plating and side plating is below the values contained in the Table 1.4.6.5, countermeasures are not necessary regardless of the thickness and yield strength of the upper deck plating.
Table 1.4.6.5

<table>
<thead>
<tr>
<th>Yield strength, [kgf/mm²]</th>
<th>Thickness, [mm]</th>
<th>Option</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>50 &lt; t ≤ 85</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>85 &lt; t ≤ 100</td>
<td>-</td>
<td>X</td>
<td>N.A.</td>
</tr>
<tr>
<td>40</td>
<td>50 &lt; t ≤ 85</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>85 &lt; t ≤ 100</td>
<td>A</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>X*</td>
</tr>
<tr>
<td>47 (FCAW)</td>
<td>50 &lt; t ≤ 100</td>
<td>A</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>X*</td>
</tr>
<tr>
<td>47 (EGW)</td>
<td>50 &lt; t ≤ 100</td>
<td>-</td>
<td>X</td>
</tr>
</tbody>
</table>

"X" means "to be applied"
"N.A." means "Need not to be applied"
"A", "B": selectable options
*: see 1.4.6.4.3.1 (e)
**: may be required at the discretion of the Register

Measures:
1  NDT other than visual inspection on all target block joints (during construction), see 1.4.6.2.
2  Periodic NDT other than visual inspection on all target block joints (after delivery), see 1.4.6.3.
3  Brittle crack arrest design against straight propagation of brittle crack along weldline to be taken (during construction), see 1.4.6.4.3.1 (b), (c) and (d).
4  Brittle crack arrest design against deviation of brittle crack from weldline (during construction), see 1.4.6.4.3.1 (a).
5  Brittle crack arrest design against propagation of cracks from other welds such as fillets and attachment welds, as defined in 1.4.6.4.2.1 (b), (during construction). See 1.4.6.4.3.1 (a).
1.5 WATER LEVEL DETECTORS ON SINGLE HOLD CARGO SHIP OTHER THAN BULK CARRIERS (SOLAS 1974, CH. II-1, REG. 25)

1.5.1 For the purpose of this regulation, freeboard deck has the meaning defined in the International Convention on Load Lines in force.

1.5.2 Ships having a length (L) of less than 80 m, and a single cargo hold below the freeboard deck or cargo holds below the freeboard deck which are not separated by at least one bulkhead made watertight up to that deck, shall be fitted in such space or spaces with water level detectors*

1.5.3 The water level detectors required by 1.5.2 shall:

1. give an audible and visual alarm at the navigation bridge when the water level above the inner bottom in the cargo hold reaches a height of not less than 0.3 m, and another when such level reaches not more than 15% of the mean depth of the cargo hold; and

2. be fitted at the aft end of the hold, or above its lowest part where the inner bottom is not parallel to the designed waterline. Where webs or partial watertight bulkheads are fitted above the inner bottom, Administrations may require the fitting of additional detectors.

1.5.4 The water level detectors required by 1.5.2 need not be fitted in ships complying with regulation XII/12, or in ships having watertight side compartments each side of the cargo hold length extending vertically at least from inner bottom to freeboard deck.

1.5.5 For application of these requirements see also IACS UI SC 180.

* Refer to the Performance standards for water level detectors on bulk carriers and single hold cargo ships other than bulk carriers, adopted by the Maritime Safety Committee by resolution MSC.188(79).
2 DESIGN PRINCIPLES

2.1 GENERAL

2.1.1 This Section contains definitions and principles for using formulas and explanations of definitions which are related to the structural member details.

2.1.2 Permissible stresses and required sectional properties

In the following Sections permissible stresses have been stated in addition to the formulæ for calculating the section moduli and cross sectional areas of webs of frames, beams, girders, stiffeners etc. and may be used when determining the scantlings of those elements by means of direct strength calculations. The permissible stresses may be increased by up to 10% where exact stress analyses are carried out in accordance with approved calculation methods, e.g. where the finite element method is applied or else proof is presented by full scale measurements.

The required section moduli and web areas are related on principle to an axis which is parallel to the connected plating.

For profiles usual in the trade and connected vertically to the plating in general the appertaining sectional properties are given in tables.

Where webs of stiffeners and girders are not fitted vertically to the plating (e.g. frames on the shell in the flaring fore body) the sectional properties (moment of inertia, section modulus and shear area) have to be determined for an axis which is parallel to the plating.

For bulb profiles and flat bars the section modulus of the inclined profile including plating can be calculated simply by multiplying the corresponding value for the vertical profile by sin\(\frac{\alpha}{2}\), where \(\alpha\) is the smaller angle related on principle to an axis which is parallel to the connected plating.

**Note:**

For bulb profiles and flat bars in general needs only be taken into account where \(\alpha\) is less than 75°.

2.1.3 Plate panels subjected to lateral pressure

The formulae for plate panels subjected to lateral pressure as given in the following Sections are based on the assumption of an un-curved plate panel having a aspect ratio \(b/a \geq 2,24\).

For curved plate panels and/or plate panels having aspect ratio smaller than \(b/a \geq 2,24\), the thickness may be reduced as follows:

\[ t = C \cdot a \sqrt{p \cdot k \cdot f_1 \cdot f_2 + t_k} \quad [\text{mm}] \]

where:

- \(C\) = constant (e.g. \(C = 1,1\) for tank plating):
  - \(f_1 = 1 - \frac{a}{2r}\);
  - \(f_{\text{min}} = 0,75\);
  - \(f_2 = \sqrt{1,1 - 0,5 \left( \frac{a}{b} \right)^2}\);
  - \(f_{\text{max}} = 1,0\);
- \(r\) = radius of curvature, in \([\text{m}]\);
- \(a\) = smaller breadth of plate panel, in \([\text{m}]\);
- \(b\) = larger breadth of plate panel, in \([\text{m}]\);
- \(p\) = applicable design load, in \([\text{kN/m}^2]\);
- \(t_k\) = corrosion addition in accordance to 2.9.

This does not apply to plate panels subjected to ice pressure according to Section 14 and to longitudinally framed side shell plating according to Section 5.

2.1.4 Fatigue strength

Where a fatigue strength analysis is required for structures or structural details this is to be in accordance with requirements of Section 16

2.2 UPPER AND LOWER HULL FLANGE

2.2.1 All continuous longitudinal structural members up to \(H_{sg}\) below the strength deck and up to \(H_{sd}\) above base line are considered to be the upper and lower hull flange respectively.

2.2.2 Where the upper and/or lower flange are made from ordinary hull structural steel their vertical extent \(H_{sg} = H_{sd}\) equals \(0,1 \cdot D\).

On ships with continuous longitudinal structural members above the strength deck an assumed depth \(D_1\) is considered, as follows:

\[ D_1 = Z_0 + Z'_g \quad [\text{m}] \]

where:

- \(Z_0\) = distance between neutral axis of the midship section and base line; in \([\text{m}]\)
- \(Z'_g\) = see 4.3.1.2.

2.2.3 The vertical extent \(Z\) of the upper and lower hull flange respectively made from higher tensile steel is not to be less than:

\[ H_1 = Z_{sd} \left( 1 - f \cdot k \right) \quad [\text{m}] \]

\[ H_{\min} = 0,1 \cdot D \text{ or } 0,1 \cdot D_1 \quad [\text{m}] \]

where:

- \(H_1 = H_{sg}\) or \(H_{sd}\) (see Fig. 4.3.5-1)
- \(Z_{sd}\) = actual distance of deck at side (\(Z_s\)) or of the base line (\(Z_b\)) from the neutral axis of the midship section. For ships with continuous longitudinal structural members above the upper deck see Section 4.3.1.2.
- \(f = W_{sd}/W\)
- \(W_{sd}\) = actual deck or bottom section modulus, \([\text{cm}^3]\)
- \(W = \) Rule deck or bottom section modulus, according to Section 4.3, \([\text{cm}^3]\)
- \(k =\) material factor, according to 1.4.2.2.

Where two different steel grades are used it has to be observed that at no point the stresses are higher than the permissible stresses in accordance to 4.3.2.

2.3 UNSUPPORTED SPAN

2.3.1 Stiffeners and frames

The unsupported span \(l\) is the true length of the stiffeners between two supporting girders or else their length including end attachments (brackets).
The frame spacings and spans are normally assumed to be measured in a vertical plane parallel to the centreline of the ship. However, if the ship’s side deviates more than 10° from this plane, the frame distances and spans shall be measured along the side of the ship.

Instead of the true length of curved frames the length of the chord between the supporting points can be selected.

### 2.3.2 Corrugated bulkhead elements

The unsupported span \( l \) of corrugated bulkhead elements is their length between bottom or deck and their length between vertical or horizontal girders. Where corrugated bulkhead elements are connected to box type elements of comparatively low rigidity, their depth is to be included into the span \( l \) unless otherwise proved by calculations.

#### 2.3.3 Transverses and girders

The unsupported span \( l \) of transverses and girders is to be determined according to Fig. 2.3.3.1 depending on the type of end attachment (bracket).

In special cases, the rigidity of the adjoining girders is to be taken into account when determining the unsupported span of girder \( l \).

![Figure 2.3.3.1](image)

### 2.4 END ATTACHMENTS

#### 2.4.1 Definitions

For determining scantlings of stiffeners and girders the terms constraint and simple support is to be used.

Constraint will be assumed where for instance the stiffener are rigidly connected to other members by means of brackets or are running throughout over supporting girders.

Simple support is to be assumed where for instance the stiffener ends are sniped or the stiffeners are connected to plate only (see 2.4.3).

#### 2.4.2 Brackets

##### 2.4.2.1

For the scantlings of brackets the required section modulus of the section is decisive. Where sections of different section moduli are connected to each other, the scantlings of the brackets are generally governed by the smaller section.

##### 2.4.2.2

The thickness of brackets is not to be less than:

\[
t = c \sqrt{\frac{W}{k} + t_k}, \quad [\text{mm}]
\]

where:

- \( c = 1.2 \) for non-flanged brackets;
- \( c = 0.95 \) for flanged brackets;
- \( k = \) material factor, according to 1.4.2.2;
- \( t_k = \) corrosion addition according to 2.9.1, [mm];
- \( W = \) section modulus of smaller section, [cm³];
- \( t_{\text{min}} = 5 + t_a, \) mm;
- \( t_{\text{max}} = \) web thickness of smaller section, [mm].

For minimum thicknesses \( t_{\text{min}} \) in tanks and in cargo holds of bulk carriers see Section 11.1.7 or 17.2.5.

##### 2.4.2.3

The arm lengths of brackets, measured from plating to the brackets toe, are not to be less than:

\[
a \geq 0.8 l \\
b \geq 0.8 l \\
a + b \geq 2 l
\]

where:

\[
l = 46.2 \sqrt[3]{\frac{W \cdot t \cdot k_2}{t_v \cdot k_1}}, \quad [\text{mm}]
\]

\( l_{\text{min}} = 100 \) mm;

- \( t_a = \) "as built" thickness of bracket, [mm]
- \( t = \) thickness of bracket according to 1.4.2.2, [mm]
- \( W = \) see 2.4.2.2;
- \( k_2 = \) material factor \( k \) for the bracket according to 1.4.2.2.
- \( k_1 = \) material factor \( k \) for the section, according to 1.4.2.2.

The arm length \( l \) is the length of the welded connection.

##### 2.4.2.4

The free edge of bracket have to be flanged, when \( l > 50 t \).

The width of flange is to be determined according to the following formula:
2.4.2.5 The throat thickness $a$ of the welded connection is to be determined according to Section 15.

2.4.3 Sniped ends of stiffeners

Stiffeners may be sniped at the ends, if the thickness of the plating supported by stiffeners is not less than:

$$t = e \cdot \sqrt{\frac{p \cdot s \cdot (l - 0.5 \cdot s)}{R_{elH}}}.$$  

where:
- $p = \text{design load, [kN/m}^2\text{]}$;
- $l = \text{unsupported length of stiffener, [m]}$;
- $s = \text{spacing of stiffeners, [m]}$;
- $R_{elH} = \text{minimum nominal upper yield point of the plating’s material, [N/mm}^2\text{]}$;
- $e = 15.8$ for watertight bulkheads and for tank bulkheads when loaded by $p_2$, according to 3.4.1.2;
- $e = 19.6$ otherwise.

2.4.4 Corrugated bulkhead elements

Care is to be taken that the forces acting at the supports of corrugated bulkheads are properly transmitted in-

2.5 EFFECTIVE WIDTH OF PLATING

2.5.1 Frames and stiffeners

Generally, the spacing of frames and stiffeners may be taken as effective width of plating.

2.5.2 Girders

2.5.2.1 The effective width of plating $b_m$ of frames and girders may be determined according to Table 2.5.2.1 considering the type of loading.

Special calculations may be required for determining the effective width of non-symmetrical flanges.

2.5.2.2 The effective cross sectional area of plates is not to be less than the cross sectional area of the face plate.

2.5.3 Cantilevers

Where cantilevers are fitted at every frame, the effective width of plating may be taken as the frame spacing.

Where cantilevers are fitted at a greater spacing the effective with of planting may approximately be taken as the distance of the respective cross section from the print on which the load is acting, but not greater than the spacing of the cantilevers.

<table>
<thead>
<tr>
<th>$l/b$</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>$\geq 8$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_m/1b$</td>
<td>0</td>
<td>0.36</td>
<td>0.64</td>
<td>0.82</td>
<td>0.91</td>
<td>0.96</td>
<td>0.98</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>$b_{02}/2b$</td>
<td>0</td>
<td>0.20</td>
<td>0.37</td>
<td>0.52</td>
<td>0.65</td>
<td>0.75</td>
<td>0.84</td>
<td>0.89</td>
<td>0.90</td>
</tr>
</tbody>
</table>

**Notice:**
1) $b_m$ is to be applied where girders are loaded by uniformly distributed loads or else by not less than 6 equally spaced single loads.
2) $b_{02}$ is to be applied where girders are loaded by 3 or less single loads.
3) Intermediate values may be obtained by direct interpolation.
4) $l =$ length between zero-points of bending moment curve, i.e. unsupported span in case of simply supported girders and 0.6 x unsupported span in case of constraint of both ends of girder.
5) $b =$ width of plating supported, measured from centre to centre of the adjacent unsupported fields.

2.6 STRUCTURAL DETAILS

2.6.1 Longitudinal members

2.6.1.1 All longitudinal members taken into account for calculating the midship section modulus are to extend over the required length amidships and are to be tapered gradually to the required ship’s ends thicknesses.

2.6.1.2 Abrupt discontinuities of strength of longitudinal members are to be avoided as far as practicable. Where longitudinal members having different scantlings are connected with each other, smooth transitions are to be provided.

2.6.2 Girders and transverses

2.6.2.1 Where transverses and girders fitted in the same plane are connected to each other, major discontinuities of strength are to be avoided. The web depth of the smaller girder is, in general, not to be less than 0.6 of the web depth of the greater one.
2.6.2.2 The taper between face plates with different dimensions is to be gradual. In general the taper shall not exceed 1:3. At intersections the forces acting in the face plates are to be properly transmitted.

2.6.2.3 For transmitting the acting forces the face plates are to be supported at their knuckles. The stiffeners at the knuckles may be omitted if the following condition is complied with:

$$\sigma_a \leq \sigma_p \frac{b_e}{b_f}, \quad [\text{N/mm}^2],$$

where:

- $\sigma_a$ = actual stress in the face plate at the knuckle, in [N/mm$^2$];
- $\sigma_p$ = permissible stress in the face plate, in [N/mm$^2$];
- $b_f$ = breadth of face plate, in [mm];
- $b_e$ = effective breadth of face plate:
  $$b_e = t_w + n_1 (t_f + c (b - t_f)), \quad [\text{mm}];$$
- $t_f$ = face plate thickness, in [mm];
- $b = \frac{1}{n_2} (b_f - t_w) \quad [\text{mm}];$
- $c = \frac{1}{\left(\frac{b - t_f}{R \cdot t_f}\right)^2 - n_2} + \frac{n_3 t_f}{\alpha^2 \cdot R};$
- $\alpha_{max} = 45^\circ$;
- $\alpha$ = knuckle angle, in $[^\circ]$, (see Fig. 2.6.2.3);
- $R$ = radius of rounded face plates, in [mm];
- $n_1$ = 1 for un-symmetrical face plates (face plate at one side only);
- $n_1$ = 2 for symmetrical face plates;
- $n_2$ = 0 for free face plates.
- $n_3$ = 3 if no radial stiffener is fitted
- $n_3$ = 3000 if two or more radial stiffeners are fitted or if one knuckle stiffener is fitted in according to (a) in Fig. 2.6.2.3.
- $n_3 = \left(\frac{d}{t_f} - 8\right)^4$, if one stiffener is fitted in according to (b) in Fig. 2.6.2.3.
- $3 \leq n_3 \leq 3\ 000$
- $d$ = distance of the stiffener from the knuckle, [mm].

Scantlings of stiffeners are:

- thickness: $t_b = \frac{\sigma_d}{\sigma_p} \cdot t_f \cdot 2\sin\alpha$
- height: $h = 1.5 \cdot b$

2.6.2.4 For preventing the face plates from tripping adequately spaced stiffeners or tripping brackets are to be provided. The spacing of these tripping elements is not exceed 12 $b_f$.

2.6.2.5 The webs are to be stiffened to prevent buckling.

2.6.2.6 The location of lightening holes is to be such that the distance from hole edge to face plate is not less than 0.3 x web depth.

2.6.2.7 In way of high shear stresses lightening holes in the webs are to be avoided as far as possible.

2.6.2.8 Knuckles (general)

Flanged structural elements transmitting forces perpendicular to the knuckle, are to be adequately supported at their knuckle, (i.e. the knuckles of the inner bottom are to be located above floors, longitudinal girders or bulkheads). See Fig. 2.6.2.8.

If longitudinal structures, such as longitudinal bulkheads or decks, include a knuckle which is formed by two butt-welded plates, the knuckle is to be supported in the vicinity of the joint rather than at the exact location of the joint. The minimum distance $d$ to the supporting structure is to be at least:

$$d = 25 + \frac{t_f}{2}, \quad \text{but not more than 50 mm, see Fig. 2.6.2.8-2.}$$

On bulk carriers at knuckles between inner bottom and tank side slopes in way of floors the welding cutouts have to be closed by collar plates or insert plates, see Fig. 2.6.2.8-1. In both cases a full penetration weld is required to inner bottom and bottom girder.
2.7 RIGIDITY OF TRANSVERSES AND GIRDERS

The moment of inertia of deck transverses and girders is not to be less than:

\[ I = C \cdot W \cdot l, \quad [\text{cm}^4] \]

- \( C = 4.0 \) if both ends are simply supported;
- \( C = 2.0 \) if one end is constrained;
- \( C = 1.5 \) if both ends are constrained;

\( W \) = section modulus of the structural member considered, in \([\text{cm}^3]\);

\( l \) = unsupported span of the structural member considered, in \([\text{m}]\).

2.8 EVALUATION OF NOTCH STRESSES

The notch stress \( \sigma_k \) evaluated for linear-elastic material behaviour at free plate edges, e.g. at hatch corners openings in decks, walls, girders etc., should, in general, fulfill the following criterion:

\[ \sigma_k \leq f \cdot R_{\text{eff}}, \quad [\text{N/mm}^2] \]

\( f = 1.1 \) for normal strength hull structural steel;
\( f = 0.9 \) for higher strength hull structural steel with \( R_{\text{eff}} = 315 \text{ N/mm}^2 \);
\( f = 0.8 \) for higher strength hull structural steel with \( R_{\text{eff}} = 355 \text{ N/mm}^2 \);
\( f = 0.73 \) for higher strength hull structural steel with \( R_{\text{eff}} = 390 \text{ N/mm}^2 \);

If plate edges are free of notches and corners are rounded-off, a 20% higher notch stress \( \sigma_k \) may be permitted.

A further increase of stresses may be permitted on the basis of a fatigue strength analysis as per Section 16.

2.9 CORROSION ADDITIONS

2.9.1 The scantling requirements of the subsequent Sections imply the following general corrosion additions \( t_k \):

\[ t_k = \begin{cases} 1.5 \text{ mm}, & \text{for } t \leq 10 \text{ mm;} \\ \frac{0.1 \cdot t}{k} + 0.5, & \text{max. } 3.0 \text{ mm, for } t > 10 \text{ mm,} \end{cases} \]

where:

- \( t \) = required rule thickness excluding \( t_k \), in \([\text{mm}]\);
- \( k \) = material factor according to Section 1.4.2.2.

For structural elements in specified areas \( t_k \) is not to be less than given in Table 2.9.2.

<table>
<thead>
<tr>
<th>Area</th>
<th>( t_{\text{min}}, [\text{mm}] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>In ballast tanks where the weather deck forms the tanktop, 1.5 m below tanktop(^1)</td>
<td>2.5</td>
</tr>
<tr>
<td>- In cargo oil tanks where the weather deck forms the tanktop, 1.5 m below tanktop. - Horizontal members in cargo oil and fuel oil tanks. Deck plating below elastically mounted deckhouses.</td>
<td>2.0</td>
</tr>
<tr>
<td>Longitudinal bulkheads of ships assigned to the notation GRAB and exposed to grab operation.</td>
<td>3.0</td>
</tr>
<tr>
<td>2.9.3 For structures in dry spaces such as box girders of container ships and for similar spaces as well as for hatch covers of dry cargo holds the corrosion additions is:</td>
<td>2.5</td>
</tr>
<tr>
<td>( t_k = \frac{0.1 \cdot t}{k}, \text{ max. } 2.5 \text{ mm, but not less than } 1.0 \text{ mm.} )</td>
<td></td>
</tr>
</tbody>
</table>

Corrosion additions for hatch covers and hatch coamings are to be determined in accordance to the Rules, Part 3 – Hull Equipment, 7.10.

---

1) \( t_{\text{min}} = 2.5 \text{ mm for all structures within topside tanks of bulk carriers.} \)
3 DESIGN LOADS

3.1 GENERAL

3.1.1 This Section provides data regarding design loads for determining the scantlings of the hull structural elements by means of the design formulae given in the following Sections or by means of direct calculations. Guidelines for direct calculations of ship structure are given in Annex D.

3.1.2 Definitions

3.1.2.1 Load centre:

a) For plates:
   - vertical stiffening system: 0.5 x stiffener spacing above the lower support of plate field, or lower edge of plate when the thickness changes within the plate field;
   - horizontal stiffening system: midpoint of plate field.

b) For stiffeners and girders:
   - centre of span l.

3.1.2.2 Definition of symbols:

\( v \) = ship’s speed according to Section 1.2.6;
\( \rho_c \) = density of cargo as stowed, [t/m³];
\( \rho \) = density of liquids, [t/m³];
\( \zeta \) = vertical distance of the structure’s load centre above base line, [m];
\( x \) = distance from aft end of length \( L \), in [m];
\( C_b \) = block coefficient according to 1.2.6.1, but is not to be taken less than 0.60;
\( p_o \) = 2.1 \((C_b + 0.7) \cdot C_b \cdot C_f \cdot f \), [kN/m²], basic external load for:
\( C_w \) = \( \frac{L}{25} + 4.1 \), for \( L < 90 \) [m]
\( C_w \) = 10.75 \( \left( \frac{300 - L}{100} \right)^{1.5} \), for \( 90 \leq L \leq 300 \) m
\( C_w \) = 10.75, for \( 300 < L \leq 350 \) m;
\( C_w \) = 10.75 \( \left( \frac{L - 350}{150} \right)^{1.5} \), for \( L > 350 \) m;
\( C_L \) = \( \frac{L}{90} \), for \( L < 90 \) m;
\( C_L \) = 1.0, for \( L \geq 90 \) m;
\( f \) = 1 for shell plating and weather deck;
\( f \) = 0.75 for frames and deck beams;
\( f \) = 0.60 for web frames, stringers and grillage systems.

Note: For restricted service areas these values \( p_o \) may be decreased, as follows:
25% for service range 3
30% for service range 4, 5
40% for service range 6, 7, 8

3.2 EXTERNAL SEA LOADS

3.2.1 Load on weather deck

3.2.1.1 The load on weather decks is to be determined according to the following formula:

\[
p_D = p_o \left( \frac{20 \cdot d}{(10 + z - d) \cdot D} \right) \cdot C_s \cdot f \quad [kN/m^2]
\]

where:
\( C_s \) = factor depending of the longitudinal position according to Table 3.2.1.1.

<table>
<thead>
<tr>
<th>Range</th>
<th>Coefficient ( C_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 \leq \frac{x}{L} &lt; 0.2</td>
<td>1.2 \cdot \frac{x}{L}</td>
</tr>
<tr>
<td>0.2 \leq \frac{x}{L} \leq 0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>0.7 \leq \frac{x}{L} \leq 1.0</td>
<td>1.0 + \frac{C}{3} \left( \frac{x}{L} - 0.7 \right)</td>
</tr>
<tr>
<td>100 m \leq L \leq 250 m</td>
<td>C = 0.15 \cdot L - 10</td>
</tr>
</tbody>
</table>

3.2.1.2 For strength deck which are to be treated as weather decks as well as for forecastle decks the load is not to be less than the greater of the following two values:

\[
p_{D_{max}} = 16 \cdot f \quad [kN/m^2];
\]
or

\[
p_{D_{max}} = 0.7 \cdot p_o \quad [kN/m^2]
\]

\( f \) = according to 3.1.2.2.

3.2.1.3 Where deck cargo is intended to be carried on the weather deck resulting in a load greater than the value determined according to 3.2.1.1, the greater load governs the scantlings.

Where the stowage height of deck cargo is less than 1.0 m, the deck cargo load may require to be increased by the following value:

\[
p_z = 10 \left( 1 - \frac{h}{h_o} \right) \quad [kN/m^2],
\]

where:
\( h_o \) = stowage height of the cargo, [m].

3.2.2 Load on ship’s sides and of bow structures

3.2.2.1 Load on ship’s sides

The external load on the ship’s sides is to be determined according to the following formulae:

a) For elements the load centre of which is located below load waterline:

\[
p_s = 10 \left( \frac{d - z}{d} \right) + p_o \cdot C_F \left( 1 + \frac{z}{d} \right) \quad [kN/m^2];
\]

b) For elements the load centre of which is located above load waterline:

\[
p_s = p_o \cdot C_F \left( \frac{20}{10 + z - d} \right) \quad [kN/m^2];
\]
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\[ CF = \text{factor depending on the longitudinal position according to Table 3.2.2.1;} \]

<table>
<thead>
<tr>
<th>Range</th>
<th>Coefficient ( CF )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 0 \leq \frac{x}{L} &lt; 0.2 )</td>
<td>( 1.0 + \frac{5}{C_b} \left( \frac{0.2 - x}{L} \right) )</td>
</tr>
<tr>
<td>( 0.2 \leq \frac{x}{L} &lt; 0.7 )</td>
<td>1.0</td>
</tr>
<tr>
<td>( 0.7 \leq \frac{x}{L} \leq 1.0 )</td>
<td>( 1.0 + \frac{20}{C_b} \left( \frac{x}{L} - 0.7 \right)^2 )</td>
</tr>
</tbody>
</table>

\( 1) \frac{x}{L} \text{ need not be taken less than 0,1} \\
\( 2) \frac{x}{L} \text{ need not be taken greater than 0,93} \)

### 3.2.2.2 Load on bow structures

The design load for bow structures from forward to 0.1 \( L \) behind F.P. and above the ballast waterline in accordance with the draft \( d_b \) in 3.2.4 is to be determined according to the following formula:

\[ p_e = \frac{c \left( 0.2 \cdot v + 0.6 \cdot \sqrt{L} \right)^2}{[\text{kN/m}^2]} \]

\( L_{\max} = 300 \text{ m.} \)

\( c = 0.8 \text{ in general.} \)

\( \frac{c}{\alpha} \text{ sin} \frac{1}{2} \), for extremely flared sides

\( \text{where the flare angle} \ \alpha \text{ is larger than 40°} \)

The flare angle at the load centre is to be measured in the plane of frame between a vertical line and the tangent to the side shell plating, see Fig. 3.2.2.2.

For unusual bow shapes \( p_e \) can be specially considered.

\( p_e \) must not be smaller than \( p_s \) according to 3.2.2.1.

Aft of 0.1 \( L \) from F.P. up to 0.15 \( L \) from F.P. the pressure between \( p_e \) and \( p_s \) is to be graded steadily.

### 3.2.2.3 Load on stern structure

The design load for stern structures from the aft end to 0.1 \( L \) forward of the aft end of \( L \) and above the smallest design ballast draught at A.P. up to \( d + C_s / 2 \) is to be determined according to the following formula:

\[ p_e = c \cdot a \cdot L, \quad [\text{kN/m}^2] \]

\( c_a = 0.3 \cdot c \geq 0.36 \)

\( c = \text{see 3.2.2.2} \)

\( L_{\max} = 300 \text{ m.} \)

\( p_e \) must not be smaller than \( p_s \) according to 3.2.2.1.

### 3.2.3 Load on the ship’s bottom

The external load \( p_b \) of the ship’s bottom is to be determined according to the following formula:

\[ p_a = 10 \cdot d + p_s \cdot CF, \quad [\text{kN/m}^2], \]

where:

\( CF = \text{see Table 3.2.2.1} \)

### 3.2.4 Design slamming pressure

The design slamming pressure may be determined by the following formulae:

\[ p_{SL} = 162 \sqrt{L} \cdot C_1 \cdot C_2 \cdot C_{SL} \cdot [\text{kN/m}^2], \text{ for } L \leq 150 \ [\text{m}]; \]

\[ p_{SL} = 1984 \left( 1.3 - 0.002 \cdot L \right) \cdot C_1 \cdot C_2 \cdot C_{SL} \cdot [\text{kN/m}^2], \text{ for } L > 150 \ [\text{m}] \]

\( C_1 = 3.6 - 6.5 \frac{L}{d_b}, \quad \left[ \frac{L}{d_b} \right] \)

\( C_2 = \frac{10}{A} \)

\( A = \text{loaded area between the supports of the structure considered, in [m]}; \)

\( C_2 = 1.0, \text{ for plate panels and stiffeners;} \)

\( 0.3 \leq C_2 \leq 1.0 \; \text{generally;} \)

\( C_{SL} = \text{distribution factor, see Figure 3.2.4.} \)

**Figure 3.2.4**

\( C_{SL} = 0, \text{ for } \frac{x}{L} \leq 0.5 \)

\( C_{SL} = \frac{x}{C_3}, \text{ for } 0.5 \leq \frac{x}{L} \leq 0.5 + C_3 \)

\( C_{SL} = 1.0, \text{ for } 0.5 + C_3 \leq \frac{x}{L} \leq 0.65 + C_3 \)
\[ C_{ul} = 0.5 \left[ 1 + \frac{1 - \frac{x}{L}}{0.35 - C_i} \right] \text{ for } \frac{x}{L} > 0.65 + C_i \]

\[
C_s = 0.33 \cdot C_o + \frac{L}{2500}
\]

\[
C_{SL_{max}} = 0.35
\]

*Note*: For restricted service areas these values \( p_{ul} \) may be decreased, as follows:

- 5% for service range 2
- 12.5% for service range 3, 4
- 17% for service range 5, 6
- 20% for service range 7, 8

### 3.2.5 Load on decks of superstructures and deckhouses

#### 3.2.5.1 The load on exposed decks and parts of superstructure and deckhouse decks, which are not to be treated as strength deck, is to be determined as follows:

\[
p_{Dn} = p_o \cdot n \text{ in } [\text{kN/m}^2]
\]

where:

- \( p_o \) = according to 3.2.1.1;
- \( n = 1 - \frac{z - D}{10} \);
- \( n_{min} = 0.5 \);
- \( n = 1.0 \) for the forecastle deck.

For deckhouses the value so determined may be multiplied by the factor:

\[
\left( 0.7 \frac{b'}{B'} + 0.3 \right)
\]

- \( b' \) = breadth of deckhouse;
- \( B' \) = largest breadth of ship at the position considered.

Except for the forecastle deck the minimum load is:

\[
p_{Dmin} = 4 \text{ kN/m}^2.
\]

For exposed wheel house tops the load is not to be taken less than:

\[
p = 2.5 \text{ kN/m}^2.
\]

### 3.3 CARGO LOADS, LOAD ON ACCOMMODATION DECKS

#### 3.3.1 Load on cargo decks

##### 3.3.1.1 The load on cargo decks is to be determined according to the following formula:

\[
p_{c} = p_{c} \cdot (1 + a_{c}) \text{, } [\text{kN/m}^2],
\]

where:

- \( p_{c} \) = static cargo load, in [kN/m²];
- \( p_{c} = 7 \cdot h \) for 'tween decks but not less than 15 kN/m², if no cargo load is given;
- \( h \) = mean 'tween deck height, in [m].

In way of hatch casings the increased height of cargo is to be taken into account.

\[ a_{c} \text{ = acceleration factor as follows:} \]

\[
a_{c} = F \cdot m
\]

\[
F = 0.11 \frac{v}{\sqrt{L}}
\]

\[
m = m_{o} - 5 \left( m_{o} - 1 \right) \frac{x}{L}, \text{ for } 0 < \frac{x}{L} \leq 0.2;
\]

\[
m = 1.0, \text{ for } 0.2 \leq \frac{x}{L} \leq 0.7;
\]

\[
m = 1 + \frac{m_{o} + 1}{0.3} \left[ \frac{x}{L} - 0.7 \right], \text{ for } 0.7 < \frac{x}{L} \leq 1.0;
\]

\[
m_{o} = (1.5 + F);
\]

\[
v \text{ = see 3.1.2.2, } v \text{ is not to be taken less than } \sqrt{L}, [\text{kN}].
\]

##### 3.3.1.2 For timber and coke deck cargo the load on deck is to be determined by the following formula:

\[
p_{c} = 5 \cdot h_{s} (1 + a_{c}), [\text{kN/m}^2],
\]

\[ h_{s} \text{ = stowing height of cargo, in [m].} \]

##### 3.3.1.3 The loads due to single forces \( P_{E} \) (e.g. in case of containers) are to be determined as follows:

\[
P = P_{E} (1 + a_{c}), [\text{kN}]
\]

##### 3.3.1.4 The cargo pressure of bulk cargoes is to be determined by the following formula:

\[
p_{c} = p_{c} (1 + a_{c}), [\text{kN/m}^2],
\]

where:

- \( p_{c} = 9.81 \cdot \rho_{c} \cdot h \cdot n \), [kN/m²], static bulk cargo load;
- \( n = \tan^{2} (45^\circ - \gamma/2) \sin^{2} \gamma + \cos^{2} \gamma \);
- \( \gamma \) = angle of repose of the cargo, in degrees;
- \( \alpha \) = angle, in degrees, between the structural element considered and a horizontal plane;
- \( h \) = distance between upper edge of cargo and the load centre, in [m];
- \( \rho_{c} \) = density of stowed cargo, in [t/m³].

### 3.3.2 Load on inner bottom

#### 3.3.2.1 The inner bottom cargo load is to be determined as follows:

\[
p_{DB} = 9.81 \cdot \frac{G}{V} \cdot h (1 + a_{c}), [\text{kN/m}^2],
\]

where:

- \( G \) = mass of cargo in the hold, [t];
- \( V \) = volume of the hold, in [m³], (hatchways excluded);
- \( h \) = height of the highest point of the cargo above the inner bottom, in [m], assuming hold to be completely filled;
- \( a_{c} \) = see 3.3.1.1.

For calculating \( a_{c} \) the distance between the centre of gravity of the hold and the aft end of the length \( L \) is to be taken.

#### 3.3.2.2 For inner bottom load in case of ore stowed in conical shape, see Section 17.
3.3.3 Loads on accommodation and machinery decks

3.3.3.1 The deck load in accommodation and service spaces is:

\[ p = 3.5 \left( 1 + a_0 \right) \quad [\text{kN/m}^2] \]

3.3.3.2 The deck load of machinery decks is:

\[ p = 8 \left( 1 + a_0 \right) \quad [\text{kN/m}^2] \]

3.3.3.3 Significant single forces are also to be considered, if necessary.

3.4 LOAD ON TANK STRUCTURES

3.4.1 Design pressure for filled tanks

3.4.1.1 The design pressure for service conditions is the greater of the following values:

\[ p_1 = 9.81 \cdot h_1 \cdot \rho \cdot (1+a_0) + 100 \cdot p_s \quad [\text{kN/m}^2] \]

or

\[ p_1 = 9.81 \cdot \rho \cdot h_1 \cdot \cos \varphi + (0.3 \cdot b+y) \cdot \sin \varphi + 100 \cdot p_s \quad [\text{kN/m}^2] \]

where:

- \( h_1 \) = distance of load centre from tank top, [m];
- \( a_0 \) = see 3.3.1.1;
- \( \varphi \) = design heeling angle, [°], for tanks;
- \( \varphi \) = design heeling angle, [°], for holds carrying liquids;
- \( b \) = breadth of tank, [m];
- \( y \) = distance of load centre from the vertical longitudinal central plane of tank, [m];
- \( p_s \) = set pressure of pressure relief valve, [bar], (if a pressure relief valve is fitted);
- \( p_{\text{min}} \) = pressure of pressure relief valve, [bar], during ballast water exchange for both, the sequential method as well as the flow-through method;
- \( mSV \) = metre of head water.

3.4.1.2 The maximum static design pressure is:

\[ p_2 = 9.81 \cdot h_2 \quad [\text{kN/m}^2] \]

\[ h_2 = \text{distance of load centre from top of overflow or from a point 2.5 m above tank top, whichever is the greater. Tank venting pipes of cargo tanks of tankers are not to be regarded as overflow pipes.} \]

For tanks equipped with pressure relief valves and/or for tanks intended to carry liquids of a density greater than 1 t/m³, the head \( h_2 \) is at least to be measured to a level at the following distance \( h_p \) above tank top:

\[ h_p = 2.5 \cdot \rho \cdot mSV \quad [\text{m}], \text{head of water, [m]}, \text{or} \]

\[ h_p = 9.81 \cdot p_s \quad [\text{mSV}], \text{where } p_s > 0.25 \cdot \rho. \]

3.4.2 Design pressure for partially filled tanks

3.4.2.1 For tanks which may be partially filled between 20% and 90% of their height, the design pressure is not to be taken less than given by the following formulae:

- a) For structures located within \( l/4 \) from the bulkheads limiting the free liquid surface in the ship’s longitudinal direction:

\[ p_d = \left[ 4 - \frac{L}{150} \right] b_1 \cdot \rho \cdot n_x + 100 \cdot p_s \quad [\text{kN/m}^2]; \]

- b) For structures located within \( b/4 \) from the bulkheads limiting the free liquid surface in the ship’s transverse direction:

\[ p_d = \left[ 5.5 - \frac{B}{20} \right] b_1 \cdot \rho \cdot n_y + 100 \cdot p_s \quad [\text{kN/m}^2], \]

where:

- \( b_1 \) = distance, in [m], between transverse bulkheads or effective transverse wash bulkheads at the height where the structure is located;
- \( b_1 \) = distance in, [m], between bulkheads or effective longitudinal wash bulkhead at the height where the structure is located;
- \( n_x = 1 - \frac{4}{l} \cdot x_1 \)
- \( n_y = 1 - \frac{4}{b} \cdot y_1 \)
- \( x_1 = \text{distance of structural element from the tank's ends in the ship's longitudinal direction, in [m]}; \)
- \( y_1 = \text{distance of structural element from the tank's sides in the ship's transverse direction, in [m]}. \)

3.4.2.2 For tanks with ratios \( l/L > 0.1 \) or \( b/B > 0.6 \) a direct calculation of the pressure \( p_s \) may be required.

3.5 DESIGN VALUES OF ACCELERATION COMPONENTS

3.5.1 Acceleration components

The following formulae may be taken when calculating the acceleration components owing to ship’s motions:

- Vertical acceleration (vertical to the base line) due to heave and pitch:

\[ a_z = \pm a_0 \sqrt{1 + \left[ 5.3 \cdot \frac{45^2}{L} \right] \left[ \frac{x}{L} - 0.45 \right]^2 + \left[ \frac{0.6}{C_b} \right]^{1.5}} \]

- Transverse acceleration (vertical to the ship’s side) due to sway, yaw and roll including gravity component of roll:
Longitudinal acceleration (in longitudinal direction) due to surge and pitch including gravity component of pitch:

\[ a_x = \pm a_o \sqrt{0.06 + A^2 - 0.25 A} \]

where:

\[ a_x, a_y, a_z = \text{maximum dimensionless accelerations (i.e., relative to the acceleration of gravity g) in the related directions x, y and z.} \]

\[ A = \left[ 0.7 - \frac{L}{1200} + 5 \frac{z-d}{L} \right] \frac{0.6}{C_b}; \]

\[ a_o = \left[ 0.2 \frac{v}{\sqrt{L}} + \frac{3 \cdot C_w \cdot C_L}{L} \right] f; \]

\[ k = 13 \frac{GM}{B}; \]

\[ GM = \text{metacentric height, in [m]}; \]

\[ k_{\text{min}} = 1.0; \]

\[ C_w = \text{wave coefficient, see 3.1.2.2}; \]

\[ C_L = \text{length coefficient, see 3.1.2.2}; \]

\[ f = \text{factor depending on probability level } Q \text{ as outlined in Table 3.5.1}; \]

\[ L = \text{not to be taken less than 100 m.} \]

### Table 3.5.1

<table>
<thead>
<tr>
<th>( Q )</th>
<th>( f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 10^{-8} )</td>
<td>1,000</td>
</tr>
<tr>
<td>( 10^{-7} )</td>
<td>0.875</td>
</tr>
<tr>
<td>( 10^{-6} )</td>
<td>0.750</td>
</tr>
<tr>
<td>( 10^{-5} )</td>
<td>0.625</td>
</tr>
<tr>
<td>( 10^{-4} )</td>
<td>0.500</td>
</tr>
</tbody>
</table>
4 LONGITUDINAL STRENGTH

4.1 GENERAL

4.1.1 These requirements apply only to steel ships of length 65 m and greater in unrestricted service. For ships having one or more of the following characteristics, special additional considerations will be given by the Register.

- ships with proportion $L/B \leq 5$ and $B/D \geq 2.5$;
- ships with length $L \geq 500$ m;
- ships with block coefficient $Cb < 0.6$;
- ships with large deck openings;
- ships with large flare;
- ships intended for carriage of heated cargoes;
- ships of unusual type or design,
- ships with speed greater than: $v = 1.6 \sqrt{L}$ [kn].

For ships other than bulk carriers, this revision of these requirements is to be complied with by ships contracted for construction on or after 1 July 2004.

These requirements do not apply to CSR Bulk Carriers and Oil Tankers or to container ships, except otherwise mentioned, to which Section 4.8 is applicable.

4.1.2 Definitions

$M_s$ = still water bending moment, in [kNm];
$M_{sw}$ = vertical wave bending moment, in [kNm];
$C_v$ = wave coefficient depending on length;
$F_i$ = still water shear force, in [kN];
$F_{sw}$ = vertical wave shear force, in [kN];
$I_{v}$ = moment of inertia of the transversal section, in [cm]$^4$, related to the horizontal axis;
$W$ = section modulus of transversal section around the horizontal axis, in [cm]$^3$;
$S$ = first moment of the sectional area of the longitudinal members, in [cm]$^2$, related to the neutral axis;
$C_b$ = block coefficient;
$v$ = maximum speed of ship, in [kn], at defined shaft revolution and engine power.
$k$ = material factor according to 1.4.2.2
$x$ = distance, in [m], between aft end of length $L$ and the position considered
$H_{ds}$ = vertical extent of HS steel used in deck or bottom, [m].

4.1.3 Explanations

- **Longitudinal members** - parts of hull structure which participate in longitudinal strength and which extend continuously over 0.4 $L$ amidship.
- **Strength deck** - is the deck forming the upper flange of the hull girder. That may be deck of a midship superstructure if it is at amidship and extend in length greater than:
  $$L = 3 \cdot (B/2 + h), \quad [m]$$
  where:
  $h$ = height from uppermost continuous deck to the deck considered, in [mm].
- **Longitudinal bulkhead** - longitudinal bulkhead which extend from bottom to deck and which is effectively connected with shell plating by transversal bulkheads at both ends.
- **Effective shear area of shell or inner shell** - area of entire height.
- **Effective shear area of longitudinal bulkhead** - area of entire height of bulkhead. Where bulkhead is corrugated area of cross section is to be deducted for relation between projected and developed length of corrugation
- **Loading manual** - is a document which describes:
  - The loading conditions on which the design of the ship has been based, including permissible limits of still water bending moment and shear force.
  - The results of the calculations of still water bending moments, shear forces and where applicable, limitations due to torsional and lateral loads.
  - The allowable local loading for hatch covers, decks, double bottom, etc.
- **Loading instrument** - is an instrument, which is either analog or digital, consisting of loading computer (hardware) loading program (software) and by means of which it can be easily and quickly ascertained that, at specified read-out points, the still water bending moments, shear forces, and the still water torsional moments and lateral loads, where applicable, in any load or ballast condition are not exceed the specified permissible values.

An operational manual is always to be provided for the loading instrument.

Loading instrument must be approved and type tested, see also 4.1.4.5.

Single point loading instrument are not acceptable.

The operation manual is also subject to approval.

Type approved hardware may be waived, if redundancy is ensured by a second certified loading instrument.

Loading programs shall be approved and certified, see also 4.1.4.5.

4.1.4 Requirements for loading manuals and loading instruments

4.1.4.1 General, application

- A loading guidance information is a means which enables the master to load and ballast the ship in a safe manner without exceeding the permissible stresses.
- An approved loading manual is to be supplied for all ships except those of Category II with length less than 90 m which the deadweight does not exceed 30% of the displacement at the summer loadline raft.

In addition, an approved loading instrument is to be supplied for all ships at Category I with length of 100 m and above.

- In special cases, e. g. extreme loading conditions or unusual structural configurations, Register may also require an approved
loading instrument for ships of Category I
less than 100 m in length.
- Additional requirements for loading con-
tions, loading manuals and loading instru-
ments for bulk carriers, ore carriers and combi-
nation carriers are given in Section 17.4.

Ship categories for the purpose of this par-
agraph are defined as follows:

Category I ships:
- Ships with large deck openings where com-
bined stresses due to vertical and horizontal
hull girder bending and torsional and lateral
loads have to be considered.
- Ships liable to carry non-homogeneous
loadings, where the cargo and ballast may
be unevenly distributed. Ships less than 120
metres in length, when their design takes
into account uneven distribution of cargo or
ballast, belong to Category II.
- Chemical tankers and gas carriers.

Category II ships:
- Ships with arrangement giving small possi-
bilities for variation in the distribution of
cargo and ballast (e.g. passenger vessels)
and ships on regular and fixed trading pat-
tern where the Loading Manual gives suffi-
cient guidance, and in addition those excep-
tions given under Categories I.

4.1.4.2 Annual and renewal survey

At each Annual and Class Renewal Survey, it is
to be checked that the approved loading guidance information is available on board.

The loading instrument is to be checked for ac-
curacy at regular intervals by the ship’s Master by applying
test loading conditions.

At each Class Renewal Survey this checking is
to be done in the presence of the Surveyor.

4.1.4.3 Conditions of approval of loading manuals

4.1.4.3.1 The approved Loading Manual is to be based on the final data of the ship. The Manual is to include the design
loading and ballast conditions upon which the approval of the hull scantlings is based.

The Loading Manual must be prepared in a
language understood by the users. If this language is not Eng-
lish, a translation into English is to be included.

In case of modifications resulting in changes to
the main data of the ship, a new approved Loading Manual is
to be issued.

Item 4.1.4.3.2 contains, as guidance only, a list of the loading conditions which normally should be included in the Loading Manual.

4.1.4.3.2 The Loading Manual should contain the design
loading and ballast conditions, subdivided into departure and
arrival conditions, and ballast exchange at sea conditions,
where applicable, upon which the approval of the hull scant-
lings is based.

In particular the following loading conditions
should be included:

Cargo ships, container ships, roll-on/roll-off
and refrigerated carriers, ore carriers and bulk carriers:

- Homogeneous loading conditions at maxi-
mum draught.
- Ballast conditions.
- Special loading conditions e.g., container or
light load conditions at less than the maxi-
mum draught, heavy cargo, empty holds or
non-homogeneous cargo conditions, deck
cargo conditions, etc., where applicable.
- Short voyages or harbour conditions, where
applicable.
- Docking conditions afloat.
- Loading and unloading transitory condi-
tions, where applicable.

Oil tankers:
- Homogeneous loading conditions (exclud-
ing dry and clean ballast tanks) and ballast
or part loaded conditions for both departure and
arrival.
- Any specified non-uniform distribution of
loading.
- Mid-voyage conditions relating to tank
cleaning or other operations where these
differ significantly from the ballast condi-
tions.
- Docking conditions afloat.
- Loading and unloading transitory condi-
tions.

Chemical tankers:
- Conditions as specified for oil tankers.
- Conditions for high density or heated cargo
and segregated cargo where these are in-
cluded in the approved cargo list.

Liquefied gas carriers:
- Homogeneous loading conditions for all
approved cargoes for both arrival and de-
parture.
- Ballast conditions for both arrival and de-
parture.
- Cargo conditions where one or more tanks
are empty or partially filled or where more
than one type of cargo having significantly
different densities are carried, for both arri-
val and departure.
- Harbour condition for which an increased
vapour pressure has been approved.
- Docking condition afloat.

Combination carriers:
- Conditions as specified for oil tankers and
cargo ships.

4.1.4.4 Conditions of approval of loading instru-
ments

4.1.4.4.1 The approval of the loading instrument is to in-
clude:

- Verification of type approval, if any,
- Verification that the final ship data have
been used,
- Acceptance of number and position of read-
out points,
- Acceptance of relevant limits for all read-
out points,
- Checking of proper installation and opera-
tion of the instrument on board, in accord-

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ance with agreed test conditions, and that a copy of the approved operation manual is available.

4.1.4.4.2 Paragraph 4.1.4.5 contains information on approval procedures for loading instruments.

4.1.4.4.3 In case of modifications implying changes in the main ship data, the loading instrument is to be modified accordingly and approved.

4.1.4.4.4 The operation manual and the instrument output must be prepared in a language understood by the users. If this language is not English, a translation into English is to be included.

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

4.1.4.5 Approval procedures of loading instruments

4.1.4.5.1 Type test of the loading instrument

The type test requires:

- The instrument has to undergo successful tests in simulated conditions to prove suitability for shipboard operation,
- The type test may be waived if a loading instrument has been tested and certified by an independent and recognised authority, provided the testing program and results are considered satisfactory.

4.1.4.5.2 Certification of the loading program

a) After the successful type test of the hardware, if required, see 4.1.3, the producer of the loading program shall apply at Register for certification.

b) The number and location of read-out points are to be to the satisfaction of the Register. Read-out points are to be usually selected at the positions of the transverse bulkheads or other obvious boundaries. Additional read-out points may be required between bulkheads of long holds/tanks.

c) The Register will specify:

- the maximum permissible still water shear forces, bending moments (limits) at the agreed read-out points - when applicable, the shear force correction factors at the transverse bulkheads,
- the shear force correction factors at the transverse bulkheads,
- when applicable, the maximum permissible torsional moment,
- also when applicable the maximum lateral load.

d) For approval of the loading program the following documents have to be handed in:

- operation manual for the loading program,
- print-outs of the basic ship data like distribution of light ship weight, tank and hold data etc.,
- print-outs of at least 4 test cases,
- diskettes with loading program and stored test cases.

The calculated strength results at the fixed read-out points shall not differ from the results of the test cases by more than 5% related to the approved limits.

4.1.4.5.3 Loading instrument

Final approval of the instrument be granted when the accuracy of the instrument has been checked in the presence of the Surveyor after installation on board ship using the approved test conditions.

If the performance of the loading instrument is found satisfactory during the installation test on board, the certificate issued by the Register and handed over on board will become valid.

4.2 VERTICAL LONGITUDINAL BENDING MOMENTS AND SHEAR FORCES

4.2.1 Still water bending moment and shear force

4.2.1.1 Still water bending moments, $M_s$ [kNm], and still water shear forces, $F_s$ [kN], are to be calculated at each section along the ship length for design cargo and ballast loading conditions as specified in 4.2.1.2.

For these calculations, downward loads are assumed to be taken as positive values, and are to be integrated in the forward direction from the aft end of $L$. The sign conventions of $M_s$ and $F_s$ are as shown in Fig. 4.2.1.1.

![Figure 4.2.1.1](image)

### Figure 4.2.1.1

4.2.1.2 Design loading conditions

In general, the following design cargo and ballast loading conditions, based on amount of bunker, fresh water and stores at departure and arrival, are to be considered for the $M_s$ and $F_s$ calculations. Where the amount and disposition of consumables at any intermediate stage of the voyage are considered more severe, calculations for such intermediate conditions are to be submitted in addition to those for departure and arrival conditions. Also, where any ballasting and/or deballasting is intended during voyage, calculations of the intermediate condition just before and just after ballasting and/or deballasting any ballast tank are to be submitted and where approved included in the loading manual for guidance.

**General cargo ships, roll-on/roll-off and refrigerated cargo carriers, bulk carriers, ore carriers:**

- Homogeneous loading conditions at maximum draught.
Ballast conditions.
Special loading conditions e.g. light load conditions at less than the maximum draught, heavy cargo, empty holds or non-homogeneous cargo conditions, deck cargo conditions, etc., where applicable.

**Oil tankers:**
- Homogeneous loading conditions (excluding dry and clean ballast tanks) and ballast or part loaded conditions.
- Any specified non-uniform distribution of loading.
- Mid-voyage conditions relating to tank cleaning or other operations where these differ significantly from the ballast conditions.

**Chemical tankers:**
- Conditions as specified for oil tankers.
- Conditions for high density or segregated cargo.

**Liquefied gas carriers:**
- Homogeneous loading conditions for all approved cargoes.
- Ballast conditions.
- Cargo conditions where one or more tanks are empty or partially filled or where more than one type of cargo having significantly different densities are carried.

**Combination carriers:**
- Conditions as specified for oil tankers and cargo ships.

### 4.2.1.3 Partially filled ballast tanks in ballast loading conditions

Ballast loading conditions involving partially filled peaks and/or other ballast tanks at departure, arrival or during intermediate conditions are not permitted to be used as design conditions unless:
- design stress limits are satisfied for all filling levels between empty and full and
- for bulk carriers, Section 17.2.2.2, as applicable, is complied with for all filling levels between empty and full.

To demonstrate compliance with all filling levels between empty and full, it will be acceptable if, in each condition at departure, arrival and where required by Section 4.2.1.2 any intermediate condition, the tanks intended to be partially filled are assumed to be:
- empty
- full
- partially filled at intended level

Where multiple tanks are intended to be partially filled, all combinations of empty, full or partially filled at intended level for those tanks are to be investigated. However, for conventional ore carriers with large wing water ballast tanks in cargo area, where empty or full ballast water filling levels of one or maximum two pairs of these tanks lead to the ship’s trim exceeding one of the following conditions, it is sufficient to demonstrate compliance with maximum, minimum and intended partial filling levels of these one or maximum two pairs of ballast tanks such that the ship’s condition does not exceed any of these trim limits. Filling levels of all other wing ballast tanks are to be considered between empty and full. The trim conditions mentioned above are:
- trim by stern of 5% of the ship’s length, or
- trim by bow of 1.5% of ship’s length, or
- any trim that cannot maintain propeller immersion (I/D) not less than 25%, where;

\[ I = \text{the distance from propeller centerline to the waterline} \]
\[ D = \text{propeller diameter (see Fig. 4.2.1.3)} \]

![Figure 4.2.1.3](image)

The maximum and minimum filling levels of the above mentioned pairs of side ballast tanks are to be indicated in the loading manual.

It is recommended that IACS Rec. No. 97 be taken into account when compiling ballast loading conditions.

### 4.2.1.4 Partially filled ballast tanks in cargo loading conditions

In cargo loading conditions, the requirement in 4.2.1.3 applies to the peak tanks only.

### 4.2.1.5 Sequential ballast water exchange

Requirements of 4.2.1.3 and 4.2.1.4 are not applicable to ballast water exchange using the sequential method. However, bending moment and shear force calculations for each deballasting or ballasting stage in the ballast water exchange sequence are to be included in the loading manual or ballast water management plan of any vessel that intends to employ the sequential ballast water exchange method.

### 4.2.2 Wave bending moment

The vertical wave bending moments, \( M_w \) [kNm], at each section along the ship length are given by the following formulae:

\[ M_w = +190MC_wL^2B(C_v+0.7)\cdot10^{-3}, \text{[kNm], hogging condition,} \]

\[ M_w = -110MC_wL^2B(C_v+0.7)\cdot10^{-3}, \text{[kNm], sagging condition,} \]

where:

\[ M = \text{Distribution factor given in Fig. 4.2.2.} \]
\[ C_v = 10.75 - \left[ \frac{300-L}{100} \right]^{1.5}, \text{for } 90 \leq L \leq 300 \]
\[ C_v = 10.75, \text{for } 300 < L \leq 350 \]
\[ C_v = 10.75 - \left[ \frac{L-350}{150} \right]^{1.5}, \text{for } 350 < L \leq 500 \]

\[ C_v = \text{not to be taken less than } 0.6 \]
\[ M = 2.5 \frac{x}{L}, \text{for } \frac{x}{L} < 0.40 \]
\[ M = 1.0, \text{for } 0.4 \leq \frac{x}{L} \leq 0.65 \]

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**PART 2**

**RULES FOR THE CLASSIFICATION OF SHIPS**

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RULES FOR THE CLASSIFICATION OF SHIPS

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Figure 4.2.2

Wave bending moment for ships in limited service conditions may be reduced as follows:
- navigation area 7 and 8 for 40%,
- navigation area 5 and 6 for 30%,
- navigation area 3 and 4 for 25%,
- navigation area 2 for 10%.

Wave bending moment for harbour conditions may be multiplied with coefficient 0.1, and for conditions of the off-shore terminal with 0.5.

4.2.3 Wave shear force

The wave shear forces \( F_w \), at each section along the length of the ship are given by the following formulae:

\[
F_w = \begin{cases} 
30 \cdot F_1 \cdot C_w \cdot L \cdot B \cdot (C_b + 0.7) \cdot 10^{-2} & \text{for positive shear force;} \\
-30 \cdot F_2 \cdot C_w \cdot L \cdot B \cdot (C_b + 0.7) \cdot 10^{-2} & \text{for negative shear force.}
\end{cases}
\]

where:
\[
F_1, F_2 = \text{Distribution factors given in Figs. 4.2.3-1 and 4.2.3-2, see also Table 4.2.3;} \\
C_b = \text{not to be less than 0.6}
\]

Table 4.2.3

<table>
<thead>
<tr>
<th>Range</th>
<th>Positive shear forces</th>
<th>Negative shear forces</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 0 \leq \frac{x}{L} &lt; 0.2 )</td>
<td>( 5 \cdot m \frac{x}{L} )</td>
<td>( 4.6 \frac{x}{L} )</td>
</tr>
<tr>
<td>( 0.2 \leq \frac{x}{L} &lt; 0.3 )</td>
<td>( m )</td>
<td>0.92</td>
</tr>
<tr>
<td>( 0.3 \leq \frac{x}{L} &lt; 0.4 )</td>
<td>( 4 \cdot m - 2.1 + (7 - 10 \cdot m) \cdot \frac{x}{L} )</td>
<td>( 1.58 - 2.2 \frac{x}{L} )</td>
</tr>
<tr>
<td>( 0.4 \leq \frac{x}{L} &lt; 0.6 )</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>( 0.6 \leq \frac{x}{L} &lt; 0.7 )</td>
<td>( 3 \cdot \frac{x}{L} - 1.1 )</td>
<td>( 4.9 - 6 m_1 + (10 \cdot m_1 - 7) \cdot \frac{x}{L} )</td>
</tr>
<tr>
<td>( 0.7 \leq \frac{x}{L} &lt; 0.85 )</td>
<td>1.0</td>
<td>( m_1 )</td>
</tr>
</tbody>
</table>

where:
\[
m = \frac{0.92 \cdot 190 \cdot C_b}{110 \cdot (C_b + 0.7)}; \quad m_1 = \frac{190 \cdot C_b}{110 \cdot (C_b + 0.7)}
\]

The wave shear forces for harbour and offshore terminal conditions may be reduced as stipulated in 4.2.2.

4.3 BENDING STRENGTH

4.3.1 Bending strength amidships

4.3.1.1 General

The deck modulus \( W_d \), is related to the moulded deck line at side (lower edge of deck stringer)

The bottom modulus \( W_b \), is related to the base line (upper edge of keel plate)

4.3.1.2 Members included in calculation of midship section moduli

Continuous trunks and longitudinal hatch coamings are to be included in the longitudinal sectional area provided they are effectively supported by longitudinal bulkheads or deep girders. The deck modulus is then to be calculated by dividing the moment of inertia by the following distance, provided this is greater than the distance to the deck line at side:

\[
W_d' = \frac{1}{Z_g} \cdot 10^2 \text{[cm]}
\]

\[
Z_g' = Z_g \cdot \left( 0.9 + 0.2 \frac{Y}{B} \right) \text{[m]}
\]

where:
\( Z_g \) – distance in from neutral axis to top of continuous strength member (hatch coaming), in [m];
\( Y \) – distance from centre line of the ship to top of continuous strength member in [m];
\( (Y \text{ and } Z_g) \) – are to be measured to the point giving the largest value of \( Z_g' \).

When continuous hatch coamings or other longitudinal continuous members are not above longitudinal bulkheads or similar constructions, Register can accept reduced area of their cross section.
4.3.1.3 Effective sectional area used in calculation

When calculating the midship section modulus within 0.4L amidships the sectional area of all continuous longitudinal strength members is to be taken into account.

Large openings, i.e. openings exceeding 2.5 m in length or 1.2 m in breadth and scallops, where scallop welding is applied, are always to be deducted from the sectional areas used in the section modulus calculation.

Smaller openings (manholes, lightening holes, single scallops in way of seams, etc.) need not be deducted provided that the sum of their breadths or shadow area breadths in one transverse section does not reduce the section modulus at deck or bottom by more than 3% and provided that the height of lightening holes, draining holes and scallops, where scallop in longitudinal girders does not exceed 75 mm.

A deduction-free sum of smaller opening breadths in one transverse section in the bottom or deck area of 0.06 (B - b) ( failures = total breadth of large openings) may be considered equivalent to the above reduction in section modulus at deck or bottom by more than 3% and provided that the height of lightening holes, draining holes and single scallops in longitudinal girders does not exceed 25% of the web depth, for scallops maximum 75 mm.

The shadow area is to be obtained by drawing two tangent lines with an opening angle of 30° (see Fig. 4.3.1.3).

![Figure 4.3.1.3](image)

Longitudinal girders between multi-hatchways will be considered by special calculations.

4.3.2 Section modulus - strength criteria

Hull section modulus, \( W \), calculated in accordance with 4.3.1, is not to be less than the values given by the following formula in way of 0.4L midship for the \( M_s \), given in 4.2.1 and the \( M_u \) given in 4.2.2, respectively:

\[
\frac{[M_s + M_u]}{\sigma} \geq 10^3 \text{ [cm}^3]\]

where:

\[\sigma = \frac{18.5 \sqrt{L}}{k} \text{, for } L < 90 \text{ m and } 0.3 \leq \frac{x}{L} \leq 0.7\]

\[\sigma = \text{permissible bending stress } = 175/k \text{ [N/mm]}, \text{ for } L \geq 90 \text{ m and } 0.3 \leq \frac{x}{L} \leq 0.7;\]

\[\sigma = \left(0.5 + \frac{5}{3} \frac{x}{L}\right) \sigma, \text{ for } \frac{x}{L} < 0.30\]

\[\sigma = \frac{5}{3} \left(1.3 \frac{x}{L}\right) \sigma, \text{ for } \frac{x}{L} > 0.70\]

\[k = 1.0 \text{ for ordinary hull structural steel; }\]

\[k < 1 \text{ for higher tensile steel according to 1.4.2.2}\]

Hull section modulus at 0.4L amidship is not to be less than \( W_{min} \) given in 4.3.4.

4.3.3 Moment of inertia

Moment of inertia of hull section at the midship point is not to be less than:

\[I_{min} = 3 \cdot L/k \cdot W_{min} \text{ [cm}^4]\]

where:

\[C_W = \text{as specified in 4.2.2.}\]

\[W_{min} = \text{section moduli according to 4.3.2 and 4.3.4, which is the greater value.}\]

4.3.4 Minimum midship section modulus

These requirements do not apply to CSR Bulk Carriers and Oil Tankers.

The minimum midship section modulus at deck and keel for ships 90 m ≤ L ≤ 500 m is:

\[W_{min} = C_W \cdot L^2 \cdot B \cdot (C_b + 0.7) \cdot k \text{ [cm}^3]\]

where:

\[L, B, C_b = \text{according to Section 1.2; }\]

\[C_W \geq 0.6; \]

\[k = \text{material factor according to 4.3.2; }\]

\[C_b = \text{as specified in 4.2.2 for new ships; }\]

\[C_b = 0.9 \cdot C_b \text{ for ships in service.}\]

Minimum midship section modulus for ships in limited service conditions may be reduced as follows:

- 5% for navigation area 2
- 15% for navigation area 3
- 20% for navigation area 4,5
- 25% for navigation area 6,7,8

Scantlings of all continuous longitudinal members of hull girder based on the section modulus requirement are to be maintained within 0.4L amidships.

However, in special cases, based on consideration of type of ship, hull form and loading conditions, the scantlings may be gradually reduced towards the end of the 0.4L part, bearing in mind the desire not to inhibit the vessel's loading flexibility.

In ships where part of the longitudinal strength material in the deck or bottom area are forming boundaries of tanks for oil cargoes or ballast water and such tanks are provided with an effective corrosion protection system, certain reductions in the scantlings of these boundaries are allowed.

These reductions, however, should in no case reduce the minimum hull girder section modulus for a new ship by more than 5%.

4.3.5 Extent of high strength steel (HS)

The vertical extent of HS steel used in deck or bottom are determined in according Section 2.2.3 and Fig. 4.3.5-1.

Longitudinal members which are made of HS, are to be extended outside 0.4L amidship to a point where the scantling is equal to those of an identical ship built of normal strength steel over the full length as shown in Fig. 4.3.5-2.
4.3.6 Bending strength outside amidships

4.3.6.1 As a minimum, hull girder bending strength checks are to be carried out at the following locations:
- In way of the forward end of the engine room.
- In way of the forward end of the foremost cargo hold.
- At any locations where there are significant changes in hull cross-section.
- At any locations where there are changes in the framing system.

4.3.6.2 Buckling strength of members contributing to the longitudinal strength and subjected to compressive and shear stresses is to be checked, in particular in regions where changes in the framing system or significant changes in the hull cross-section occur. The buckling evaluation criteria used for this check is given in Section 4.6.

4.3.6.3 Continuity of structure is to be maintained throughout the length of the ship. Where significant changes in structural arrangement occur adequate transitional structure is to be provided.

4.3.6.4 For ships with large deck openings, sections at or near to the aft and forward quarter length positions are to be checked. For such ships with cargo holds aft of the superstructure, deckhouse or engine room, strength checks of sections in way of the aft end of the aft-most holds, and the aft end of the deckhouse or engine room are to be performed.

4.4 SHEARING STRENGTH

4.4.1 Correction of still water shear force curve

4.4.1.1 In case of alternate loading the conventional shear force curve may be corrected according to the direct load transmission by the longitudinal structure at the transverse bulkheads. See also Fig. 4.4.1.

4.4.1.2 The supporting forces of the bottom grillage at the transverse bulkheads may either be determined by direct calculation or by approximation, according to 4.4.1.3.

4.4.1.3 The sum of the supporting forces of the bottom grillage at the aft or forward boundary bulkhead of the hold considered may be determined by the following formulae:

\[
\Delta F_1 = \Delta F_{s1} \cdot \Delta F_{s2} = u \cdot G \cdot v \cdot d_1, \quad [kN]
\]

where:

\[ G = \text{mass of cargo or ballast, in [t], in the hold considered, including any contents of bottom tanks within the flat part of the double bottom; } \]

\[ d_1 = \text{mean draught, in [m], corresponding considered load condition; } \]

\[ u, v = \text{correction coefficients for cargo and buoyancy as follows: } \]

\[
u = \frac{10 \cdot c \cdot l \cdot b \cdot h}{V}
\]

\[
 v = 10 \cdot c \cdot l \cdot b
\]

\[
 c = \frac{B}{2.3 \cdot (b + l)}
\]

\[ l = \text{length of the flat part of the double bottom, in [m]; } \]

\[ b = \text{breadth of the flat part of the double bottom, in [m]; } \]

\[ h = \text{height of the hold, in [m]; } \]

\[ V = \text{volumen of the hold, in [m$^3$]. } \]
4.4.2 Calculation of shear stresses

4.4.2.1 The shear stress distribution may be determined by means of calculation procedures approved by Register. For ships having more than 2 longitudinal bulkheads and for double hull ships, particularly with uneven load distribution over the ship’s cross section, the application of such approved calculation procedures may be required.

4.4.2.2 For ships without longitudinal bulkheads and with two longitudinal bulkheads respectively the shear stress distribution in the side shell and in the longitudinal bulkheads may be determined by the following formula:

\[ \tau = \frac{(F_s + F_w) \cdot S}{I_y \cdot t} \cdot (0.5 - \Phi) \cdot 10^3 \text{ [N/mm}^2]\]

where:

- \( I_s, F_s, F_w \) = according to 4.1.2
- \( S \) = first moment, in [cm]³, about the neutral axis, of the area of the effective longitudinal members between the vertical level at which the shear stress is being determined and the vertical extremity of effective longitudinal members, taken at the section under consideration;
- \( t \) = thickness of side shell or longitudinal bulkhead plating, in [mm], at the section considered;
- \( \Phi = 0 \) for ships without longitudinal bulkhead.

For ships with usual design and form the ratio \( S/I_y \) determined for the midship section may be used for other sections also.

4.4.2.3 Permissible shear stress

The shear stress in the side shell and in the longitudinal bulkheads due to the shear forces \( F_s \) and \( F_w \) are not to exceed 110/\( k \), [N/mm²].

where:

- \( k \) = material factor according to 1.4.2.2

4.4.2.4 Where stringers on transverse bulkheads are supported at longitudinal bulkheads or at the side shell, the supporting forces of these girders are to be considered when determining the shear stresses in longitudinal bulkheads or side shell. The shear stress introduced by the stringer into the longitudinal bulkhead or side shell may be determined by the following formula.

\[ \tau_s = \frac{F_s}{b_{st} \cdot t} \text{ [N/mm}^2]\]

\( F_s \) = supporting force of stringer, in [kN];

\( b_{st} \) = breadth of stringer including end bracket (if any), in [m], at the supporting point.

The additional shear stress is to be added to the shear stress due to longitudinal bending in the following area:

- 0.5 \( m \) on both sides of stringer in the ship’s longitudinal direction;
- 0.25 \( b_s \) above and below the stringer.

4.4.3 Shearing strength for ships without effective longitudinal bulkheads

The thickness of side shell is not to be less than the values given by following formula (for the still water shear forces \( F_s \) given in 4.2.1 and the wave shear forces \( F_w \) given in 4.2.3 respectively):

\[ t = \frac{0.5 \left( F_s + F_w \right) \cdot S}{\tau} \cdot I_y \cdot 10^2 [\text{mm}], \]

where:

- \( \tau \) = permissible shear stress = 110/\( k \) [N/mm²]
- \( k \) = as specified in 4.1.2.

4.4.4 Shearing strength for ships with two effective longitudinal bulkheads

The thickness of side shell and longitudinal bulkheads are not to be less than the values given by the following formulae:

For side shell:

\[ t = \frac{\left[ 0.5 - \Phi \right] \left( F_s + F_w \right) + \Delta F_{sh}}{\tau} \cdot I_y \cdot 10^2, [\text{mm}] \]

for longitudinal bulkheads:

\[ t = \frac{\Phi \left( F_s + F_w \right) + \Delta F_{bl}}{\tau} \cdot I_y \cdot 10^2, [\text{mm}] \]

where:

- \( \Phi, A_s, A_L \) = according to 4.4.2.2
- \( \tau = \frac{110}{k}, [\text{N/mm}^2]; \)
- \( \Delta F_{sh}, \Delta F_{bl} \) = shear force acting upon the side shell plating and longitudinal bulkhead plating, respectively, due to local loads (see 4.4.2.4)

4.5 ADDITIONAL BENDINGMoments

4.5.1 Additional bending moments due to slamming loads in the forebody region

For ships with lengths between 110 m and 180 m, the mean bow flare of which amounts to \( \alpha > 30^\circ \) within the forebody region 0.2 \( L \) aft of \( x/L \approx 1.0 \), the following additional bending moment \( M_{SL} \) due to slamming loads in the forebody region is to be included when determining the total bending moment. The additional bending moment may be determined approximately by the following formula:

\[ M_{SL} = w \cdot L^4 \cdot B \cdot n_1 \cdot n_2 \cdot n_3 \cdot M_1 \cdot 10^5 \text{ [kNm]} \]
4.5.2 Horizontal wave bending moments

The rule horizontal wave bending moments along the length of the ship are given by formula:

\[ M_{WH} = 0.32 \cdot C_w \cdot M \cdot \sqrt{L^3} \cdot d \cdot B \] [kNm]

where:
- \( C_w \) = wave coefficient, see 4.2.2;
- \( M \) = distribution factor, see 4.2.2;
- \( L, B, d \) = according to Section 1.2.3.

4.6 BUCKLING STRENGTH

4.6.1 These requirements apply to plate panels and longitudinals subject to hull girder bending and shear stresses.

4.6.2 Elastic buckling stresses

4.6.2.1 Elastic buckling of plates

4.6.2.1.1 Compression

The ideal elastic buckling stress is given by:

\[ \sigma_E = 0.9 \cdot mE \cdot \left( \frac{b_d}{1000 \cdot b} \right)^2 \] [N/mm²].

- For plating with longitudinal stiffeners (parallel to compressive stress):
  \[ m = \frac{8.4}{\psi + 1.1} \] ,  buckling factor
  \[ O \leq \psi \leq 1 \]

- For plating with transverse stiffeners (perpendicular to compressive stress):
  \[ m = c \left[ 1 + \left( \frac{b}{a} \right)^2 \right]^{\frac{2.1}{\psi + 1.1}} \]  
  \[ O \leq \psi \leq 1 \]

For same load cases of plates the buckling factor \( m \), given in Tables 4.6.2.1-2 and 4.6.2.1-3.

\( E \) = modulus of elasticity of material, N/mm²]
\( E = 2.06 \times 10^5 \) N/mm², for shipbuilding steel;
\( E = 0.69 \times 10^5 \) N/mm², for aluminium alloys;
\( t_b \) = net thickness, in [mm], of plating, considering standard deductions equal to the val-ues given in the Table 4.6.2.1-1;
\( b \) = shorter side of plate panel, in [m], see Fig. 4.6.2.1;
\( a \) = longer side of plate panel, in [m], see Fig. 4.6.2.1;
\( c \) = correction factor;
\( c = 1.0 \) for stiffeners snipe at both ends;
\( c = 1.1 \) when plating stiffened by floors or deep girders;
\( c = 1.21 \) when stiffeners are angles or T-sections;
\( c = 1.10 \) when stiffeners are bulb bars;
\( c = 1.05 \) when stiffeners are flat bars;
\( \psi \) = ratio between smallest and largest compressive \( \sigma_a \) stress when linear variation across panel.
Table 4.6.2.1-1

<table>
<thead>
<tr>
<th>Structure</th>
<th>Standard deduction [mm]</th>
<th>Min-max. [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Compartments carrying dry bulk cargoes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- One side exposure to ballast and/or liquid cargo</td>
<td>0,05 t</td>
<td>0,5 ÷ 1</td>
</tr>
<tr>
<td>- Vertical surfaces and surfaces sloped at an angle greater than 25° to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the horizontal line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- One side exposure to ballast and/or liquid cargo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Horizontal surfaces and surfaces sloped at an angle less than 25° to</td>
<td>0,1 t</td>
<td>2 ÷ 3</td>
</tr>
<tr>
<td>the horizontal line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Two side exposure to ballast and/or liquid cargo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Vertical surfaces and surfaces sloped at an angle greater than 25° to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the horizontal line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Two side exposure to ballast and/or liquid cargo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Horizontal surfaces and surfaces sloped at an angle less than 25° to</td>
<td>0,15 t</td>
<td>2 ÷ 4</td>
</tr>
<tr>
<td>the horizontal line</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 4.6.2.1-2

<table>
<thead>
<tr>
<th>Load case</th>
<th>Buckling factor</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="https://example.com/diagram1.png" alt="Diagram 1" /></td>
<td>( m = \frac{8.4}{\psi + 1.1} )</td>
</tr>
<tr>
<td><img src="https://example.com/diagram2.png" alt="Diagram 2" /></td>
<td>( m = c \left[ 1 + \left( \frac{b}{a} \right)^2 \right]^2 \cdot \frac{2.1}{(\psi + 1.1)} )</td>
</tr>
<tr>
<td><img src="https://example.com/diagram3.png" alt="Diagram 3" /></td>
<td>( m = \frac{1.333 \cdot 0.425 + \left( \frac{b}{a} \right)^2}{\psi + 0.333} )</td>
</tr>
<tr>
<td><img src="https://example.com/diagram4.png" alt="Diagram 4" /></td>
<td>( m = 0.425 \left( \frac{b}{a} \right)^2 \cdot (1.5 - 0.5 \cdot \psi) )</td>
</tr>
<tr>
<td><img src="https://example.com/diagram5.png" alt="Diagram 5" /></td>
<td>( k_t = 5.34 + 4 \cdot \left( \frac{b}{a} \right)^2 )</td>
</tr>
<tr>
<td><img src="https://example.com/diagram6.png" alt="Diagram 6" /></td>
<td>( k_t = \left( 1 - \frac{d_a}{b} \right) \left[ 5.34 + 4 \left( \frac{b}{a} \right)^2 \right] ) for ( (a - d_a) \geq (b - d_b) )</td>
</tr>
<tr>
<td><img src="https://example.com/diagram7.png" alt="Diagram 7" /></td>
<td>( k_t = \left( 1 - \frac{d_a}{b} \right) \left[ 5.34 + 4 \left( \frac{b}{a} \right)^2 \right] ) for ( (a - d_a) &lt; (b - d_b) )</td>
</tr>
<tr>
<td><img src="https://example.com/diagram8.png" alt="Diagram 8" /></td>
<td>( m = 1.28 )</td>
</tr>
<tr>
<td><img src="https://example.com/diagram9.png" alt="Diagram 9" /></td>
<td>( m = 6.97 )</td>
</tr>
<tr>
<td><img src="https://example.com/diagram10.png" alt="Diagram 10" /></td>
<td>( m = 4 + \left[ \frac{4 - \left( \frac{b}{a} \right)}{3} \right]^3 \cdot 2.74 )</td>
</tr>
<tr>
<td><img src="https://example.com/diagram11.png" alt="Diagram 11" /></td>
<td>( m = 6.97 + \left[ \frac{4 - \left( \frac{b}{a} \right)}{3} \right]^3 \cdot 3.1 )</td>
</tr>
</tbody>
</table>
### Table 4.6.2.1-3

Curved plate field $R/t \leq 2500$

<table>
<thead>
<tr>
<th>Load case</th>
<th>Aspect ratio $b/R$</th>
<th>Buckling factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>$b \leq 1.63 \sqrt{\frac{R}{t}}$</td>
<td>$m = \frac{b}{\sqrt{R \cdot t}} + 3 \left(\frac{R \cdot t}{b^0.35}\right)^{0.175}$</td>
</tr>
<tr>
<td></td>
<td>$b &gt; 1.63 \sqrt{\frac{R}{t}}$</td>
<td>$m = 0.3 \frac{b^2}{R^2} + 2.25 \left(\frac{R^2}{b \cdot t}\right)^2$</td>
</tr>
<tr>
<td>2</td>
<td>$b \leq 0.5 \sqrt{\frac{R}{t}}$</td>
<td>$m = 1 + \frac{2}{3} \frac{b^2}{R \cdot t}$</td>
</tr>
<tr>
<td></td>
<td>$b &gt; 0.5 \sqrt{\frac{R}{t}}$</td>
<td>$m = 0.267 \frac{b^2}{R \cdot t} \left[3 - \frac{b}{R} \sqrt{\frac{t}{R}} \right] \geq 0.4 \frac{b^2}{R \cdot t}$</td>
</tr>
<tr>
<td>3</td>
<td>$b \leq \sqrt[3]{\frac{R}{t}}$</td>
<td>$m = \frac{0.6 \cdot b}{R \cdot t} + \sqrt{\frac{R \cdot t}{b}} - 0.3 \frac{R \cdot t}{b^2}$</td>
</tr>
<tr>
<td></td>
<td>$b &gt; \sqrt[3]{\frac{R}{t}}$</td>
<td>$m = 0.3 \frac{b^2}{R^2} + 0.291 \left(\frac{R^2}{b \cdot t}\right)^2$</td>
</tr>
<tr>
<td>4</td>
<td>$b \leq 8.7 \sqrt{\frac{R}{t}}$</td>
<td>$m = k_t \sqrt{3}$</td>
</tr>
<tr>
<td></td>
<td>$b &gt; 8.7 \sqrt{\frac{R}{t}}$</td>
<td>$k_t = \left[28.3 \frac{0.67 \cdot b^3}{R^{15} \cdot t^{15}} \right]^{0.5}$</td>
</tr>
</tbody>
</table>

Explanations for boundary conditions:
- ------ plate edge free
- ---- plate edge simply supported
- --- plate edge clamped
4.6.2.1.2 Shear

The ideal elastic buckling stress is given by:

\[ \sigma_e = 0.9 k_t E \left( \frac{t_p}{1000 \cdot b} \right)^2, \quad [\text{N/mm}^2], \]

where:

\[ k_t = 5.34 + 4 \left( \frac{b}{a} \right)^2; \]

\[ E, \, t, \, h, \, b, \, a \quad \text{see 4.6.2.1.1} \]

For some load cases of plates the buckling factor \( k_t \) is given in Tables 4.6.2.1-2 and 4.6.2.1-3.

4.6.2.2 Elastic buckling of longitudinals

4.6.2.2.1 Stress of longitudinal without rotation of transversal sections.

For the column buckling mode (perpendicular to plane of plating) the ideal elastic buckling stress is given by:

\[ \sigma_e = 0.001 \frac{E L_s}{A t} \cdot [\text{N/mm}^2], \]

where:

\[ A = \text{cross-sectional area, in } [\text{cm}^2], \text{ of longitudinal, including plate flange}; \]

\[ I_s = \text{moment of inertia, in } [\text{cm}^4], \text{ of longitudinal, including plate flange and calculated with thickness as specified in 4.6.2.1.1,} \]

\( l = \text{span, in [m], of longitudinal,} \)

A plate flange equal to the frame spacing may be included.

4.6.2.2.2 Stress of longitudinal with rotation of transversal sections.

The ideal elastic buckling stress for the torsional mode is given by:

\[ \sigma_e = \frac{\pi^2 E I_w}{10^4 I_p l^2} \left( m^2 + \frac{K}{m^2} \right) + 0.385 \frac{E l}{I_p}, \quad [\text{N/mm}^2], \]

where:

\[ K = \frac{C \cdot l^4}{\pi^4 E \cdot I_w} \cdot 10^6; \]

\[ m = \text{number of half waves, given by the following table:} \]

<table>
<thead>
<tr>
<th>O &lt; K &lt; 4</th>
<th>4 &lt; K &lt; 36</th>
<th>36 &lt; K &lt; 144</th>
<th>(m - 1)^2 m^2 &lt; K</th>
<th>m^2 &lt; K</th>
<th>( m^2 ) ( m + 1 )^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

\( I_t = \text{torsional, moment of inertia, in } [\text{cm}^4], \]

\( I_t = \text{of profile without plate flange:} \)

\[ I_t = \frac{h_w t_w^3}{3} \cdot 10^{-4}, \text{ for flat bars (slabs)} \]

\( I_t = \frac{1}{3} h_w t_w^3 + b_f t_f^3 \left( 1 - 0.63 \frac{t_f}{b_f} \right) \cdot 10^{-4}, \text{ for flanged profiles:} \)

\[ I_p = \text{polar moment of inertia, in } [\text{cm}^4], \text{ of profile about connection of stiffener to plate:} \]

\[ I_p = \frac{h_w^3 \cdot t_w^3}{3} \cdot 10^{-4}, \text{ for flat bars:} \]

\[ I_p = \left( \frac{h_w^3 \cdot t_w^3 + h_w^2 \cdot b_f \cdot t_f}{3} \right) \cdot 10^{-4}, \text{ for flanged profiles:} \]

\[ I_w = \text{sectional moment of inertia, in } [\text{cm}^4], \text{ of profile about connection of stiffener to plate:} \]

\[ I_w = \frac{h_w^3 \cdot t_w^3}{36} \cdot 10^{-6} \text{ for flat bars (slabs):} \]

\[ I_w = \frac{t_f \cdot b_f^3 \cdot h_w^2}{12} \cdot 10^{-6}, \text{ for "Tee" profiles} \]

\[ I_w = \frac{b_f^3 h_w^2}{12(b_f + h_w)^2} \left[ t_f \left( b_f^3 + 2b_f h_w + 4h_w^2 \right) + 3w b_f h_w \right] \cdot 10^{-6} \text{ for angles and bulb profiles:} \]

where:

\[ h_w = \text{web height, in } [\text{mm}], \text{ see Fig. 4.6.2.2.2,} \]

\[ t_w = \text{web thickness, in } [\text{mm}], \text{ considering standard deductions as specified in 4.6.2.1.1, see Fig. 4.6.2.2.2,} \]

\[ b_f = \text{flange width, in } [\text{mm}], \text{ see Fig. 4.6.2.2.2,} \]

\[ t_f = \text{flange thickness, in } [\text{mm}], \text{ considering standard deductions as specified in 4.6.2.1.1, see Fig. 4.6.2.2.2,} \]

For bulb profiles the means thickness of the bulb may be used.

\( l = \text{span of profile, in [m],} \)

\( s = \text{spacing of profiles, in [m],} \)

\[ C = \text{spring stiffness exerted by supporting plate panel:} \]

\[ C = \frac{k_p E t_p^3}{3s \left( 1 + \frac{133 k_p h_w t_p}{100 s t_w^3} \right)} \cdot 10^{-3} \]

where:

\[ k_p = 1 - \eta, \text{ not to be taken less than zero;} \]

\[ t_p = \text{plate thickness, in } [\text{mm}], \text{ considering standard deductions as specified in 4.6.2.1.1;} \]

\[ \eta = \frac{\sigma_{uw}}{\sigma_{kp}}; \]

\( \sigma_{uw} \) = calculated compressive stress. For longitudinals, see 4.6.4.1;
\[ \sigma_{\text{ep}} = \text{elastic buckling stress of supporting plate as calculated 4.6.2.1, in [N/mm}]^2]. \]

For flanged profiles, \( k_{f} \) need not be taken less than 0.1.

### 4.6.2.2.3 Web and flange buckling

For web plate of longitudinals the ideal elastic buckling stresses is given by:

\[ \sigma_c = 3.8 \left( \frac{t_w}{b_w} \right), \text{[N/mm}^2] \]

For flanges on angles and T-sections of longitudinals, buckling is taken care of the following requirement:

\[ \frac{b_f}{t_f} \leq 15, \]

where:

- \( b_f \) = flange width, in [mm].
- \( t_f \) = as built flange thickness, in [mm].

### 4.6.3 Critical buckling stresses

#### 4.6.3.1 Compression

The critical buckling stress in compression is determined as follows:

\[ \sigma_c = \sigma_E, \text{if } \sigma_c \leq \frac{\sigma_F}{2} \]

\[ \sigma_c = \sigma_E \left( 1 - \frac{\sigma_F}{4 \sigma_E} \right), \text{if } \sigma_c > \frac{\sigma_F}{2} \]

where:

- \( \sigma_E \) = yield stress of material, in [N/mm]²
- \( \sigma_F \) = 235 [N/mm]² (may be taken for mild steel);\n- \( \sigma_c \) = ideal elastic buckling stress calculated according to 4.6.2.

#### 4.6.3.2 Shear

The critical buckling stress in shear is determined as follows:

\[ \tau_c = \tau_s, \text{if } \tau_c < \frac{\tau_F}{2} \]

\[ \tau_c = \tau_s \left( 1 - \frac{\tau_F}{4 \tau_E} \right), \text{if } \tau_c > \frac{\tau_F}{2} \]

where:

- \( \tau_s = \frac{\sigma_F}{\sqrt{3}} \)
- \( \sigma_F \) = as given in 4.6.3.1;
- \( \tau_c = \) as given in 4.6.2.1.2

### 4.6.4 Working stress

#### 4.6.4.1 Longitudinal compressive stresses

The compressive stresses are given in the following formula:

\[ \sigma_c = \frac{M_s + M_w}{I_n} y \cdot 10^5, \text{[N/mm}^2] \]

but not less than:

\[ \sigma_c \geq \frac{30}{k} \]

where

\[ \sigma_c \] = still water bending moment, [kNm]; as given in 4.2.1;
\[ M_w \] = wave bending moment, [kNm]; as given in 4.2.2;
\[ I_n \] = moment of inertia, in [cm]² of the midship section;
\[ y \] = vertical distance, in [m], from neutral axis to considered point;
\[ k \] = as specified in 4.1.2.

\( M_s \) and \( M_w \) are to be taken as sagging or hogging bending moments, respectively, for members above or below the neutral axis.

Where the ship is always in hogging condition in still water, the sagging bending moment \((M_s + M_w)\) is to be specially considered.

#### 4.6.4.2 Shear stresses

##### 4.6.4.2.1 Ships without effective longitudinal bulkheads

For side shell:

\[ \tau_c = 0.5 \left( \frac{F_s + F_w}{t} \right) S \frac{y}{I_y} \cdot 10^2, \text{[N/mm}^2] \]

where:

- \( F_s, F_w, S \) and \( I_y \) = as specified in 4.1.2;
- \( t \) = as specified in 4.4.3.

##### 4.6.4.2.2 Ships with two effective longitudinal bulkheads

For side shell:

\[ \tau_c = \left( 0.5 - \Phi \right) \left( \frac{F_s + F_w + \Delta F_{sh}}{t} \right) S \frac{y}{I_y} \cdot 10^2, \text{[N/mm}^2] \]

For longitudinal bulkheads:

\[ \tau_c = \left( \Phi \left( \frac{F_s + F_w + \Delta F_{sh}}{t} \right) \right) \cdot 10^2, \text{[N/mm}^2] \]

\( F_s, F_w, \Delta F_{sh}, \Delta F_{sh}, t, S, I_y \) = as specified in 4.4.4.

### 4.6.5 Scantling criteria

#### 4.6.5.1 Buckling Stress

The design buckling stress, \( \sigma_c \), of plate panels and longitudinals (as calculated in 4.6.3.1) is not to be less than:

\[ \sigma_c \geq \beta \sigma_n \]

where:

\[ \beta = 1 \text{ - for plating and for web plating of stiffeners (local buckling)}; \]
\[ \beta = 1.1 \text{ - for stiffeners.} \]

The critical buckling stress \( \sigma_c \), of plate panels (as calculated in 4.6.3.2) is not to be less than:

\[ \tau_c \geq \tau_n \]
4.7 HULL GIRDER ULTIMATE STRENGTH

4.7.1 General

4.7.1.1 Application

The requirements of this section apply to ships with length \( L \) equal to or greater than 90 m.

4.7.1.2 Definitions

The ultimate hull girder vertical bending moment capacity, \( M_{UH} \), is defined as the maximum sagging \( (M_{US}) \) or hogging \( (M_{UH}) \) hull girder vertical bending moment capacity beyond which the hull will collapse. Hull girder inter-frame collapse is defined as the progressive collapse of the critical hull girder transverse section. Longitudinal structural members of the critical hull girder transverse section fail due to buckling and/or yielding under hull girder flexure. Progressive collapse analysis is to be performed according to incremental – iterative method, as described in 4.7.3 of this section.

The ultimate hull girder vertical bending moment capacities in sagging and hogging conditions are defined as the maximum values of the \( M - \kappa \) curve, see Figure 4.7.1, which represents static non-linear relationship between vertical bending moment capacity \( M \) and curvature \( \kappa \) of the considered hull girder transverse section and describes it's progressive collapse behavior.

\[
\kappa = \frac{\theta}{l}, \text{ in [1/m]}
\]

where:

\( \theta = \) relative angle of rotation of the two adjacent hull girder cross-sections at transverse frame position;

\( l = \) transverse frame spacing, in [m], i.e. span of longitudinals.

4.7.1.3 Assumptions

Only vertical bending is considered. The effects of horizontal bending moment, shear force, torsional loading and lateral pressure are neglected.

Throughout the hull girder flexure, it's transverse sections remain plane, infinitely stiff (in their own plane) and perpendicular on elastic line throughout the curvature incrementation process.

Hull girder (isotropic) material is idealized by bilinear (elastic – perfectly plastic) material model.

The ultimate strength is calculated at a hull girder transverse section between two adjacent transverse web frames.

The hull girder transverse section can be divided into a set of decoupled discrete structural elements which act independently while responding on the imposed hull girder flexure.

4.7.2 Criteria

It is to be verified that ultimate hull girder vertical bending moment capacity at any hull girder transverse section is in compliance with the following criteria:

\[
\gamma_s M_s + \gamma_w M_w \leq \frac{M_U}{\gamma_R}
\]

where:

\( \gamma_s = \) partial safety factor for vertical still water bending moment, equal to: \( \gamma_s = 1.0 \);

\( \gamma_w = \) partial safety factor for vertical wave bending moment covering environmental and wave load prediction uncertainties, equal to: \( \gamma_w = 1.2 \);

\( \gamma_R = \) partial safety factor for ultimate hull girder vertical bending moment capacity covering material, geometric and load carrying capacity prediction uncertainties, equal to: \( \gamma_R = 1.1 \).
4.7.3 Incremental – iterative method for hull girder progressive collapse analysis

The $M - \kappa$ curve is obtained by means of an incremental-iterative procedure given in 4.7.3.1 and illustrated by Fig. 4.7.2. $M_U$ represents the peak value of obtained $M - \kappa$ curve.

4.7.3.1 Procedure

4.7.3.1.1 General overview

The vertical bending moment $M$ which acts on the hull girder transverse section due to the imposed curvature $\kappa$ is calculated for each step of the incremental procedure. This imposed curvature corresponds to an angle of rotation of the hull girder transverse section about its effective horizontal neutral axis, which induces an average axial strain $\varepsilon_{xA}$ in each decoupled longitudinal structural element of the considered longitudinal inter-frame segment.

Figure 4.7.2 Flowchart of the incremental – iterative progressive collapse analysis method.

The average longitudinal stress $\sigma_{xA}$ induced in each structural element by the $\varepsilon_{xA}$ is obtained from the set of applicable average stress – average strain ($\sigma_{xA} - \varepsilon_{xA}$) curves of the element, which consider structural behavior of the element in the non-linear elasto-plastic domain. In the sagging condition, elements below the neutral axis are lengthened, while elements above the neutral axis are shortened, and vice-versa in hogging condition. Elements compressed beyond their buckling limit have reduced load-carrying capacity. All relevant failure modes for individual longitudinal structural elements (yielding, plate buckling, torsional stiffener buckling, stiffener web buckling, lateral or global stiffener buckling) are considered in order to identify the critical inter-frame failure mode.

The axial force in each individual element $F_{xA}$ is represented by the product of element's cross-sectional area $A$ (total area of the longitudinal structural element) and $\sigma_{xA}$. Forces of all individual elements are summated to derive the total axial force on the hull girder transverse section. Since the position of the effective neutral axis of the transverse section is not constant throughout the flexure (due to the non-linear response), total axial force might not initially assume the zero value. Total axial force value should be equal to zero since sectional equilibrium implies equality of total compressive and tensile axial forces. This is enforced by iterative repositioning of the effective neutral axis which requires recalculation of $\varepsilon_{xA}, \sigma_{xA}, F_{xA}$ and the total axial force on the hull girder transverse section for each iterative step. Once the correct position of the neutral axis is determined, the correct $\sigma_{xA}$ distribution becomes available.

The curvature for the first step is to be taken as $\Delta \kappa$. Curvature step size $\Delta \kappa$ is to be taken as $\frac{\kappa_F}{300}$.

4.7.3.1.2 Algorithm

Step1: Divide the hull girder transverse section on discrete uncoupled structural elements, as described by 4.7.3.2.

Step2: Derive the $\sigma_{xA} - \varepsilon_{xA}$ curves (load-end shortening curves) for all discrete structural elements, as described by 4.7.3.3.

Step3: Determine the expected maximum considered curvature $\kappa_F$:

$$\kappa_F = \pm 0.003 \frac{M_Y}{EI_y}$$

where:

$M_Y = \text{vertical bending moment given by the linear elastic bending stress equal to yield strength of deck or keel, whichever appears first. To be taken as the greater of } M_{Yd} \text{ and } M_{Yk};$

$M_{Yd} = ZdR_{yy}1000, \text{ in } [\text{kNm}];$

$M_{Yk} = ZkR_{yy}1000, \text{ in } [\text{kNm}];$

$Z_d = \text{section modulus at deck, in } [\text{m}^3];$

$Z_k = \text{section modulus at keel, in } [\text{m}^3];$

$E = \text{Young’s modulus, in } [\text{N/mm}^2];$

$R_{yy} = \text{minimum yield stress, in } [\text{N/mm}^2];$

$I_y = \text{hull girder transverse section moment of inertia, in } [\text{m}^4].$

Curvature step size $\Delta \kappa$ is to be taken as $\kappa_F/300$. The curvature for the first step is to be taken as equal to $\Delta \kappa$.

Step4: For each discrete structural element, calculate the $\varepsilon_{xA} = \kappa(z-z_{NA})$ corresponding to imposed $\kappa$, corresponding
\( \sigma_{\text{fs}} \) (to be taken as the minimum value from all applicable \( \sigma_{\text{fl}} \) - \( \varepsilon_{\text{fl}} \) curves) and resulting \( F_{\text{fl}} = \sigma_{\text{fl}} A \).

**Step5:** Determine the current neutral axis position \( z_{\text{NA}} \) on the basis of longitudinal force equilibrium over the whole transverse section. Hence, adjust \( z_{\text{NA}} \) until \( \Sigma F_z = 0.1 \Sigma \sigma_{\text{fl}} A = 0 \), in [kN].

**Note:** \( \sigma_{\text{fl}} \) is positive for elements under compression and negative for elements under tension. Iteratively repeat procedure from step4 until the change in neutral axis position is less than 0.0001m.

**Step6:** Calculate the \( M \) of the balanced hull girder transverse section corresponding to imposed \( k \), by summing the force contributions of all elements as follows:

\[
M = 0.1 \sum |\sigma_{\text{fl}} A (z-z_{\text{NA}})|, \text{ in [kNm]}
\]

**Step7:** Increase the curvature by \( \Delta k \) and use the current neutral axis position as the initial value for the next curvature increment. Repeat the procedure from step4 until the \( k_f \) is reached. Eventually, the \( M/k_f \) is determined as the peak value of the \( M-k \) curve. If the peak is not reached within the considered interval of curvature, then \( k_f \) is to be increased until the peak is reached.

### 4.7.3.2 Modelling of the hull girder transverse section

Hull girder transverse sections are to be considered as being constituted by the three different kinds of discrete uncoupled structural elements contributing to the hull girder longitudinal ultimate strength: stiffener – plate combinations (longitudinal stiffeners with effective breadth of attached plating; structural behavior described in 4.7.3.3), transversely stiffened plate panels (longitudinally unstiffened plating; structural behavior described in 4.7.3.3) and hard corners (structural behavior described in 4.7.3.3).

Hard corners (HCs) are generally constituted by two or more plates not lying in the same plane. They are considered to be stiff enough to collapse only according to elasto-plastic mode of failure (material yielding), both in compression and tension. Structural areas idealized by hard corner elements are: plating area adjacent to intersecting plates, plating area adjacent to knuckles in the plating with an inclination angle greater than 30 degrees and plating comprising rounded gunwales. It is to be assumed that the hard corner element extends up to \( s \) from the plate intersection for longitudinally stiffened plate, where \( s \) is the stiffener spacing. It is to be assumed that the hard corner extends up to \( 20 \rho \) from the plate intersection for transversely stiffened plate, where \( \rho \) is the plate thickness.

For stiffener – plate combinations (SPCs), the effective breadth of attached plate is equal to the mean spacing of the ordinary stiffener (when the panels on both sides of the stiffener are longitudinally stiffened), or equal to the breadth of the longitudinally stiffened panel (when the panel on one side of the stiffener is longitudinally stiffened and the other panel is transversely stiffened).

For transversely stiffened plates (TSPs), the effective breadth of plate for the load shortening (compression) portion of the \( \sigma_{\text{fl}} - \varepsilon_{\text{fl}} \) curve is to be taken as the full plate breadth, i.e. to the intersection of other plates, not from the end of the hard corner if any. The area on which \( \sigma_{\text{fl}} \) applies is to be taken as the breadth between the hard corners, i.e. excluding the end of the hard corner if any.

![Figure 4.7.3 Illustration of transverse cross section discretization rules](image)

Where the plate members are stiffened by non-continuous longitudinal stiffeners, the non-continuous stiffeners are not modeled as stiffener plate combinations since they do not contribute to the hull girder ultimate strength. They are considered only as dividers of the plating into various elementary plate panels.

#### 4.7.3.3 \( \sigma_{\text{fl}} - \varepsilon_{\text{fl}} \) Curves (Load – end shortening curves)

Discrete structural elements are assumed to fail according to one of the failure modes specified in Table 4.7.3.3. For each element appropriate \( \sigma_{\text{fl}} - \varepsilon_{\text{fl}} \) curve (Table 4.7.3.3) is to be obtained for lengthening and shortening straining regime.

<table>
<thead>
<tr>
<th>Discrete structural element</th>
<th>Applicable mode(s) of failure</th>
<th>( \sigma_{\text{fl}} - \varepsilon_{\text{fl}} ) curve reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lengthened (loaded in uniaxial tension) or shortened (loaded in uniaxial compression) HCs, SPCs and TSPs.</td>
<td>Elasto-plastic failure (yielding).</td>
<td>4.7.3.3.1</td>
</tr>
<tr>
<td>Shortened (loaded in uniaxial compression) SPCs.</td>
<td>Elasto-plastic failure (yielding); Beam column buckling; Torsional buckling; Web local buckling of flanged profiles; Web local buckling of flat bars.</td>
<td>4.7.3.3.2</td>
</tr>
<tr>
<td>Shortened (loaded in uniaxial compression) TSPs.</td>
<td>Elasto-plastic failure (yielding); Plate buckling.</td>
<td>4.7.3.3.3</td>
</tr>
</tbody>
</table>

**Notes:** HC Hard corner; SPC Stiffener-plate combination; TSP transversely stiffened plate.

#### 4.7.3.3.1 Elasto – plastic failure (material yielding)

The equation describing the \( \sigma_{\text{fl}} - \varepsilon_{\text{fl}} \) curve for the elasto-plastic failure of discrete structural elements composing the hull girder transverse section is to be obtained from the following formula, valid for both positive (shortening) and negative (lengthening) strains:

\[
\sigma_{\text{fl}} = \Phi R_{\text{yfA}}
\]
where:

\[ \Phi = \text{edge function, in [-]:} \]

\[ \Phi = \begin{cases} 
-1 & \text{for } \frac{\varepsilon_{ek}}{\varepsilon_{k,a}} < -1 \\
\frac{\varepsilon_{ek}}{\varepsilon_{k,a}} & \text{for } -1 \leq \frac{\varepsilon_{ek}}{\varepsilon_{k,a}} \leq 1 \\
1 & \text{for } \frac{\varepsilon_{ek}}{\varepsilon_{k,a}} > 1 
\end{cases} \]

\[ \varepsilon_{k,a} = \text{yield strain, in [-], of the considered element:} \]

\[ \varepsilon_{k,a} = \frac{R_{eHA}}{E} ; \]

\[ \varepsilon_{xA} = \text{average axial strain, in [-], of the considered element;} \]

\[ R_{eHA} = \text{equivalent minimum yield stress, in [N/mm}^2\text{], of the considered element:} \]

\[ R_{eHA} = \frac{R_{shp} A_p + R_{shs} A_s}{A_p + A_s} ; \]

\[ R_{shp} = \text{minimum yield stress of the plate material, in [N/mm}^2\text{];} \]

\[ R_{shs} = \text{minimum yield stress of the stiffener material, in [N/mm}^2\text{];} \]

\[ A_s = \text{sectional area of the stiffener without attached plating, in [cm}^2\text{];} \]

\[ A_s = A_e + A_f ; \]

\[ A_p = \text{sectional area of the attached plating, in [cm}^2\text{];} \]

\[ A_p = 0.01 b_p t_p ; \]

\[ A_w = \text{sectional area of the stiffener web, in [cm}^2\text{];} \]

\[ A_w = 0.01 b_w h_w ; \]

\[ A_f = \text{sectional area of the stiffener flange, in [cm}^2\text{];} \]

\[ A_f = 0.01 b_f t_f ; \]

\[ b_p = \text{breadth of attached plating, in [mm];} \]

\[ h_w = \text{height of stiffener web, in [mm];} \]

\[ b_f = \text{breadth of stiffener flange, in [mm];} \]

\[ t_p = \text{thickness of attached plating, in thickness of stiffener web, in [mm];} \]

\[ t_w = \text{thickness of stiffener web, in [mm];} \]

\[ t_f = \text{thickness of stiffener flange, in [mm];} \]

4.7.3.3.2 Beam column buckling

The equation describing the shortening portion of the \( \sigma_{eA} - \varepsilon_{eA} \) curve for the beam column buckling of stiffener – plate combinations is to be obtained from the following formula:

\[ \sigma_{eA} = \Phi \sigma_{CE} \frac{A_s + A_e}{A_s + A_p} \]

where:

\[ \sigma_{CE} = \text{critical stress, in [N/mm}^2\text{], corrected for the effect of plasticity according to Johnson – Ostenfeld formula:} \]

\[ \sigma_{CE} = \begin{cases} 
\frac{\sigma_{eA} \varepsilon_{eA}}{E} & \text{for } \sigma_{eA} \leq \frac{R_{shs} \varepsilon_{eA}}{2 \varepsilon_{k,a}} ; \\
\frac{1}{4} \frac{R_{shs} \varepsilon_{eA}}{E} & \text{for } \sigma_{eA} > \frac{R_{shs} \varepsilon_{eA}}{2 \varepsilon_{k,a}} 
\end{cases} \]

\[ \sigma_{eA} = \text{Euler column buckling stress, in [N/mm}^2\text{];} \]

\[ l = \text{span of the stiffener – plate combination, in [m], equal to the spacing between primary supporting members;} \]

\[ l = \text{moment of inertia of the stiffener – plate combination, in [cm}^4\text{], with attached plating of width } b_e ; \]

\[ b_e = \text{effective width of attached plating, in [mm];} \]

\[ b_e = \begin{cases} 
\frac{b_p}{\beta_{ef}} & \text{for } \beta_{ef} > 1 ; \\
\frac{b_p}{\beta_{ef}} & \text{for } \beta_{ef} \leq 1 
\end{cases} \]

\[ \beta_{ef} = \text{effective plate slenderness of the attached plating, in [-]:} \]

\[ \beta_{ef} = \frac{b_p}{t_p \sqrt{\varepsilon_{k,a} E}} ; \]

\[ A_e = \text{sectional area of the stiffener – plate combination, in [cm}^2\text{], with attached plating of width } b_e ; \]

\[ A_e = 0.01 (b_f t_f + h_w t_w + b_e t_e) ; \]

\[ b_e = \text{effective width of attached plating, in [mm];} \]

\[ b_e = \begin{cases} 
\frac{b_p}{\beta_{ef} (2.25 - \frac{1.25}{\beta_{ef}})} & \text{for } \beta_{ef} > 1.25 ; \\
\frac{b_p}{\beta_{ef}} & \text{for } \beta_{ef} \leq 1.25 
\end{cases} \]

4.7.3.3.3 Torsional buckling

The equation describing the shortening portion of the \( \sigma_{eA} - \varepsilon_{eA} \) curve for the flexural – torsional buckling of stiffener – plate combinations is to be obtained from the following formula:
\[ \sigma_{sa} = \Phi \frac{A_s \sigma_{ct} + A_p \sigma_{cp}}{A_s + A_p} \]

where:

\[ \sigma_{ct} = \text{critical stress, in [N/mm}^2\text{], corrected for the effect of plasticity according to Johnson – Ostenfeld formula:} \]

\[\sigma_{ct} = \left\{ \begin{array}{ll}
\frac{E \varepsilon_{ps}}{R_{shta}} & \text{for } \sigma_{ct} \leq \frac{E \varepsilon_{ps}}{2 \varepsilon_{ra}}; \\
\frac{E \varepsilon_{ps}}{4 \sigma_{ct} \varepsilon_{ra}} & \text{for } \sigma_{ct} > \frac{E \varepsilon_{ps}}{2 \varepsilon_{ra}}.
\end{array} \right.\]

\[ \sigma_{ct} = \text{Euler torsional buckling stress, in [N/mm}^2\text{]}:\]

\[\sigma_{ct} = E \left( \frac{\pi^2 I_p}{l_p^4} \Theta + 0.385 l_T \right);\]

\[\Theta = \text{degree of fixation parameter, in [-], defined by following formula:} \]

\[\Theta = 1 + 0.001 \left( \frac{l_p^4}{3 \pi^4 I_p \left( b_p + 4h_p / 3l_p \right)} \right);\]

\[I_p = \text{polar moment of inertia of the stiffener, in [cm}^4\text{], about stiffener root (point where stiffener is joined with the attached plating), defined in Table 4.7.3.3.3;} \]

\[I_T = \text{St. Venant’s moment of inertia of the stiffener, in [cm}^4\text{], defined in Table 4.7.3.3.3;} \]

\[I_T = \text{sectorial moment of inertia of the stiffener, in [cm}^4\text{], about stiffener root (point where stiffener is joined with the attached plating), defined in Table 4.7.3.3.3;} \]

\[\varepsilon_f = \text{distance from the stiffener root (point where stiffener is joined with the attached plating) to the centre of flange, in [mm]}; \]

\[e_f = h_u + \frac{l_u}{2}; \]

\[l_T = \text{torsional buckling length, in [m], to be taken equal to the distance between tripping supports;} \]

\[\sigma_{cp} = \text{buckling stress of the attached plating, in [N/mm}^2\text{]}:\]

\[\sigma_{cp} = \left\{ \begin{array}{ll}
R_{shp} \frac{2.25 \varepsilon_{ps} - 1.25 \varepsilon_{ra}}{\beta \varepsilon_{ps}} & \text{for } \beta > 1.25, \\
R_{shp} \varepsilon_{ps} & \text{for } \beta \leq 1.25.
\end{array} \right.\]

### 4.7.3.3.4 Web local buckling of flanged stiffeners

The equation describing the shortening portion of the \( \sigma_{sa} - \varepsilon_{sa} \) curve for the web local buckling of flanged stiffener - plate combinations is to be obtained from the following formula:

\[\sigma_{sa} = \Phi \frac{b_w l_f R_{shp} + (h_w l_u + A_f) R_{shb}}{A_w + A_f} \]

where:

\[h_w = \text{effective height of web, in [mm]}; \]

\[h_w = \left\{ \begin{array}{ll}
h \left( \frac{2.25 \varepsilon_{ps} - 1.25 \varepsilon_{ra}}{\beta \varepsilon_{ps}} \right) & \text{for } \beta > 1.25, \\
h \left( \frac{\varepsilon_{ps}}{\beta \varepsilon_{ps}} \right) & \text{for } \beta \leq 1.25.
\end{array} \right.\]

\[\beta = \text{web plate slenderness, in [-]}; \]

\[\beta = \frac{h_w}{l_u} \sqrt{\frac{\varepsilon_{ps} R_{shb}}{E}} \]

### 4.7.3.3.5 Web local buckling of flat bar stiffeners

The equation describing the shortening portion of the \( \sigma_{sa} - \varepsilon_{sa} \) curve for the web local buckling of flat bar stiffener – plate combinations is to be obtained from the following formula:

\[\sigma_{sa} = \Phi \frac{A \sigma_{cp} + A \sigma_{cl}}{A_p + A_f} \]

where:

\[\sigma_{cl} = \text{critical stress, in [N/mm}^2\text{], corrected for the effect of plasticity according to Johnson – Ostenfeld formula:} \]

\[\sigma_{ct} = \left\{ \begin{array}{ll}
\frac{E \varepsilon_{ps}}{R_{shta}} & \text{for } \sigma_{ct} \leq \frac{E \varepsilon_{ps}}{2 \varepsilon_{ra}}; \\
\frac{E \varepsilon_{ps}}{4 \sigma_{ct} \varepsilon_{ra}} & \text{for } \sigma_{ct} > \frac{E \varepsilon_{ps}}{2 \varepsilon_{ra}}.
\end{array} \right.\]

\[\sigma_{cl} = \text{local Euler buckling stress, in [N/mm}^2\text{]}:\]

\[\sigma_{cl} = 160000 \left( \frac{l_w}{h_u} \right)^2 \]
4.7.3.3.6 Plate buckling

The equation describing the shortening portion of the $\sigma_{x,x} - e_{z,A}$ curve for the plate buckling of transversely stiffened plates is to be obtained from the following formula:

$$\sigma_{x,x} = \text{MIN} \left[ \frac{\Phi R_{BH}}{L} \left( \frac{b}{\ell} \frac{2.25}{\beta d} - \frac{1.25}{\beta d^2} \right) + 0.1 \left( \frac{2.5}{\beta d^2} \right) \right]$$

4.8 LONGITUDINAL STRENGTH STANDARD FOR CONTAINER SHIPS

4.8.1 General

4.8.1.1 Application

This requirement applies to the following types of steel ships with a length $L$ of 90 m and greater and operated in unrestricted service:

1. Container ships
2. Ships dedicated primarily to carry their load in containers.

This requirement is to be implemented for ships contracted for construction on or after 1 July 2016.

4.8.1.2 Load limitations

The wave induced load requirements apply to monohull displacement ships in unrestricted service and are limited to ships meeting the following criteria:

(i) Length: $90 \leq L \leq 500$ m
(ii) Proportion: $5 \leq L/B \leq 9; \quad 2 \leq B/T \leq 6$
(iii) Block coefficient at scantling draught: $0.55 \leq C_b \leq 0.9$

For ships that do not meet all of the aforementioned criteria, special considerations such as direct calculations of wave induced loads may be required by the Register.

4.8.1.3 Longitudinal extent of strength assessment

The stiffening, yield strength, buckling strength and hull girder ultimate strength assessment are to be carried out in way of $0.2L$ to $0.75L$ with due consideration given to locations where there are significant changes in hull cross section, e.g. changing of framing system and the fore and aft end of the forward bridge block in case of two-island designs.

In addition, strength assessments are to be carried out outside this area. As a minimum assessments are to be carried out at forward end of the foremost cargo hold and the aft end of the aft most cargo hold. Evaluation criteria used for these assessments are determined by these Rules.

4.8.1.2 Symbols and definitions

4.8.1.2.1 Symbols

$L = \text{rule length, in [m], as defined in } 1.2.3.1$
$B = \text{moulded breadth, in [m], see } 1.2.3.2$
$C = \text{wave parameter, see } 4.8.2.3.2$
$d_{sc} = \text{scantling draught, in [m], see } 1.2.3.5$

$C_b = \text{block coefficient at scantling draught, see } 1.2.6.1$
$C_w = \text{waterplane coefficient at scantling draught, to be taken as: } A_w/LB$
$A_w = \text{waterplane area at scantling draught, in } [\text{m}^2]$
$R_{BH} = \text{specified minimum yield stress of the material, in } [\text{N/mm}^2]$.
$k = \text{material factor as defined in } 1.4.2.2 \text{ for higher tensile steels, } k=1.0 \text{ for mild steel having a minimum yield strength equal to } 235 \text{ N/mm}^2$
$E = \text{Young's modulus, in } [\text{N/mm}^2], \text{ to be taken as } E = 2.06 \times 10^5 \text{ N/mm}^2, \text{ for steel}$
$M_S = \text{vertical still water bending moment in seagoing condition, in } [\text{kNm}], \text{ at the cross section under consideration}$
$M_{S\max}, M_{S\min} = \text{permissible maximum and minimum vertical still water bending moments in seagoing condition, in } [\text{kNm}], \text{ at the cross section under consideration, see } 4.8.2.2.2$
$M_W = \text{vertical wave induced bending moment, in } [\text{kNm}], \text{ at the cross section under consideration}$
$F_S = \text{vertical still water shear force in seagoing condition, in } [\text{kN}], \text{ at the cross section under consideration}$
$F_{S\max}, F_{S\min} = \text{permissible maximum and minimum still water vertical shear force in seagoing condition, in } [\text{kN}], \text{ at the cross section under consideration, see } 4.8.2.2.2$
$F_W = \text{vertical wave induced shear force, in } [\text{kN}], \text{ at the cross section under consideration}$
$q_v = \text{shear flow along the cross section under consideration, see } 4.8.2.3.2$
$\delta_{NL-Hog} = \text{non-linear correction factor for hogging, see } 4.8.2.3.2$
$\delta_{NL-Sag} = \text{non-linear correction factor for sagging, see } 4.8.2.3.2$
$f_r = \text{factor related to the operational profile, see } 4.8.2.3.2$
$I_{net} = \text{net thickness, in } [\text{mm}], \text{ see } 4.8.1.3.1$
$t_{res} = \text{reserve thickness, to be taken as } 0.5 \text{ mm}$
$I_{net} = \text{net vertical hull girder moment of inertia at the cross section under consideration, to be determined using net scantlings as defined in } 4.8.1.3.3, \text{ in } [\text{m}^4]$
4.8.1.2.2 Fore end and aft end

The fore end (FE) of the rule length $L$, see Figure 4.8.1.2.2, is the perpendicular to the scantling draught waterline at the forward side of the stem.

The aft end (AE) of the rule length $L$, see Figure 1, is the perpendicular to the scantling draught waterline at a distance $L_{aft}$ of the fore end (FE).

$$z_n = \text{distance from the baseline to the horizontal neutral axis, in [m]}.$$

4.8.1.2.3 Reference coordinate system

The ships geometry, loads and load effects are defined with respect to the following right-hand coordinate system, see Figure 4.8.1.2.3.

- Origin: at the intersection of the longitudinal plane of symmetry of ship, the aft end of $L$ and the baseline.
- X axis: longitudinal axis, positive forwards.
- Y axis: transverse axis, positive towards portside.
- Z axis: vertical axis, positive upwards.

4.8.1.3 Corrosion margin and net thickness

4.8.1.3.1 Net scantling definitions

The strength is to be assessed using the net thickness approach on all scantlings. The net thickness, $t_{net}$, for the plates, webs, and flanges is obtained by subtracting the voluntary addition $t_{vol \_add}$ and the factored corrosion addition $t_c$ from the as built thickness $t_{as \_built}$, as follows:

$$t_{net} = t_{as \_built} - t_{vol \_add} - \alpha \cdot t_c$$

where $\alpha$ is a corrosion addition factor whose values are defined in Table 4.8.1.3.1.

The voluntary addition, if being used, is to be clearly indicated on the drawings.

<table>
<thead>
<tr>
<th>Structural requirement</th>
<th>Property / analysis type</th>
<th>$\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength assessment (4.8.3)</td>
<td>Section properties</td>
<td>0.5</td>
</tr>
<tr>
<td>Buckling strength (4.8.4)</td>
<td>Section properties (stress determination)</td>
<td>0.5</td>
</tr>
<tr>
<td>Hull girder ultimate strength (4.8.5)</td>
<td>Buckling / collapse capacity</td>
<td>0.5</td>
</tr>
</tbody>
</table>

4.8.1.3.2 Determination of corrosion addition

The corrosion addition for each of the two sides of a structural member, $t_{c1}$ or $t_{c2}$, is specified in Table 4.8.1.3.2. The total corrosion addition, $t_c$, in mm, for both sides of the structural member is obtained by the following formula:

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

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

$$t_c = (2 \cdot t_{c1}) + t_{res}$$

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

4.8.1.3.3 Determination of net section properties

The net section modulus, moment of inertia, and shear area properties of a supporting member are to be calculated using the net dimensions of the attached plate, web, and flange, as defined in Figure 4.8.1.3.3. The net cross-sectional area, the moment of inertia about the axis parallel to the attached plate and the associated neutral axis position are to be determined through applying a corrosion magnitude of 0.5 $\alpha t_c$ deducted from the surface of the profile cross-section.
4.8.2 Loads

4.8.2.1 Sign convention for hull girder loads

The sign conventions of vertical bending moments and vertical shear forces at any ship transverse section are as shown in Figure 4.8.2.1, namely:

- the vertical bending moments $M_S$ and $M_W$ are positive when they induce tensile stresses in the strength deck (hogging bending moment) and negative when they induce tensile stresses in the bottom (sagging bending moment).
- the vertical shear forces $F_S$, $F_W$ are positive in the case of downward resulting forces acting aft of the transverse section and upward resulting forces acting forward of the transverse section under consideration.

**Figure 4.8.2.1** Sign conventions of bending moments and shear forces

4.8.2.2 Still water bending moments and shear forces

4.8.2.2.1 General

Still water bending moments, $M_S$ in [kNm], and still water shear forces, $F_S$ in [kN], are to be calculated at each section along the ship length for design loading conditions as specified in 4.8.2.2.2.

4.8.2.2.2 Design loading conditions

In general, the design cargo and ballast loading conditions, based on amount of bunker, fresh water and stores at departure and arrival, are to be considered for the $M_S$ and $F_S$ calculations. Where the amount and disposition of consumables at any intermediate stage of the voyage are considered more severe, calculations for such intermediate conditions are to be submitted in addition to those for departure and arrival conditions. Also, where any ballasting and/or de-ballasting is intended during voyage, calculations of the intermediate condition just before and just after ballasting and/or de-ballasting any ballast tank are to be submitted and where approved included in the loading manual for guidance.

The permissible vertical still water bending moments $M_S^{max}$ and $M_S^{min}$ and the permissible vertical still water shear forces $F_S^{max}$ and $F_S^{min}$ in seagoing conditions at any longitudinal position are to envelop:

- the maximum and minimum still water bending moments and shear forces for the seagoing loading conditions defined in the Loading Manual.
- the maximum and minimum still water bending moments and shear forces specified by the designer

The Loading Manual should include the relevant loading conditions, which envelop the still water hull girder loads for seagoing conditions, including those specified in 4.8.7.

4.8.2.3 Wave loads

4.8.2.3.1 Wave parameter

The wave parameter is defined as follows:

$$ C = 1 - 1.5 \left( 1 - \frac{L}{L_{ref}} \right)^{2.2}, \text{ for } L \leq L_{ref} $$
\( C = 1 - 0.48 \left( \frac{L}{L_{ref}} - 1 \right)^{1.7} \), for \( L > L_{ref} \)

where:

\( L_{ref} \) = reference length, in [m], taken as:
\( L_{ref} = 315 \cdot C_w^{-1.2} \), for the determination of vertical wave bending moments according to 4.8.2.3.2
\( L_{ref} = 330 \cdot C_w^{-1.3} \), for the determination of vertical wave shear forces according to 4.8.2.3.3

### 4.8.2.3.2 Vertical wave bending moments

The distribution of the vertical wave induced bending moments, \( M_W \) in [kNm], along the ship length is given in Figure 4.8.2.3.2-2, where:

\[
M_{W-Hog} = +1.5 f_R L^0 C_W \left( \frac{B}{L} \right)^{0.8} f_{NL-Hog}
\]

\[
M_{W-Sag} = -1.5 f_R L^0 C_W \left( \frac{B}{L} \right)^{0.8} f_{NL-Sag}
\]

where:

\( f_R \) = factor related to the operational profile, to be taken as:
\( f_R = 0.85 \)
\( f_{NL-Hog} \) = non-linear correction for hogging, to be taken as:
\( f_{NL-Hog} = 0.3 \frac{C_B}{C_W} \sqrt{d} \), not to be taken greater than 1.1
\( f_{NL-Sag} \) = non-linear correction for sagging, to be taken as:
\( f_{NL-Sag} = 4.5 \left( 1 + 0.2 f_{Bow} \right) \frac{C_B}{C_W} \sqrt{\frac{C_W}{C_B} L^3} \), not to be taken less than 1.0
\( f_{Bow} \) = bow flare shape coefficient, to be taken as:
\( f_{Bow} = \frac{A_{DK} - A_{WL}}{0.2 L z_f} \)

\( A_{DK} \) = projected area in horizontal plane of uppermost deck, in [m²], including the forecastle deck, if any, extending from 0.8L forward, see Figure 4.8.2.3.2-1. Any other structures, e.g. plated bulwark, are to be excluded.

\( A_{WL} \) = waterplane area, in [m²], at draught \( d \), extending from 0.8L forward

\( z_f \) = vertical distance, in [m], from the waterline at draught \( d \) to the uppermost deck (or forecastle deck), measured at FE (see Figure 4.8.2.3.2-1. Any other structures, e.g. plated bulwark, are to be excluded.
4.8.2.3.3 Vertical wave shear force

The distribution of the vertical wave induced shear forces, \( F_W \) in [kN], along the ship length is given in Figure 4.8.2.3.3, where,

\[
F_{W \text{hog}} = +5.2 f_d L^2 C_W \left( \frac{B}{L} \right)^{0.8} (0.3 + 0.7 f_{\text{NL-hog}})
\]

\[
F_{W \text{seg}} = -5.7 f_d L^2 C_W \left( \frac{B}{L} \right)^{0.8} f_{\text{NL-seg}}
\]

\[
F_{W \text{seg}} = -5.2 f_d L^2 C_W \left( \frac{B}{L} \right)^{0.8} (0.3 + 0.7 f_{\text{NL-seg}})
\]

\[
F_{W \text{seg}} = +5.7 f_d L^2 C_W \left( \frac{B}{L} \right)^{0.8} (0.25 + 0.75 f_{\text{NL-seg}})
\]

\[
F_{W \text{hl}} = +4.0 f_d L^2 C_W \left( \frac{B}{L} \right)^{0.8}
\]

Figure 4.8.2.3.3 Distribution of vertical wave shear force \( F_W \) along the ship length

4.8.2.4 Load cases

For the strength assessment, the maximum hogging and sagging load cases given in Table 4.8.2.4 are to be checked. For each load case the still water condition at each section as defined in 4.8.2.2 is to be combined with the wave condition as defined in 4.8.2.3, refer also to Figure 4.8.2.4.

Table 4.8.2.4 Combination of still water and wave bending moments and shear forces

<table>
<thead>
<tr>
<th>Load case</th>
<th>Bending moment</th>
<th>Shear force</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( M_S )</td>
<td>( M_W )</td>
</tr>
<tr>
<td>Hogging</td>
<td>( M_{\text{Smax}} )</td>
<td>( M_{\text{WH}} )</td>
</tr>
<tr>
<td>Sagging</td>
<td>( M_{\text{Smin}} )</td>
<td>( M_{\text{WS}} )</td>
</tr>
</tbody>
</table>

Figure 4.8.2.4 Load combination to determine the maximum hogging and sagging load cases as given in Table 4.8.2.4

4.8.2.5 Hull girder stress

The hull girder stresses in, [N/mm²], are to be determined at the load calculation point under consideration, for the “hogging” and “sagging” load cases defined in 4.8.2.4 as follows:
Bending stress:

\[ \sigma_{HG} = \frac{\gamma_s M_s + \gamma_w M_w}{I_{net}} (z - z_s) \times 10^{-3} \]

Shear stress:

\[ \tau_{HG} = \frac{\gamma_s F_s + \gamma_w F_w}{I_{net} q_x} \times 10^3 \]

where:

- \( \gamma_s, \gamma_w \) = partial safety factors, to be taken as:
  - \( \gamma_s = 1.0 \)
  - \( \gamma_w = 1.0 \)

4.8.3 Strength assessment

4.8.3.1 General

Continuity of structure is to be maintained throughout the length of the ship. Where significant changes in structural arrangement occur adequate transitional structure is to be provided.

4.8.3.2 Stiffness criterion

The two load cases “hogging” and “sagging” as listed in 4.8.2.4 are to be checked. The net moment of inertia, in [m^4], is not to be less than:

\[ I_{net} \geq 1.55 \left[ \frac{M_s + M_w}{L} \right] \times 10^7 \]

4.8.3.3 Yield strength assessment

4.8.3.3.1 General acceptance criteria

The yield strength assessment is to check, for each of the load cases “hogging” and “sagging” as defined in 4.8.2.4, that the equivalent hull girder stress \( \sigma_{eq} \), in [N/mm^2], is less than the permissible stress \( \sigma_{perm} \), in [N/mm^2], as follows:

\[ \sigma_{eq} < \sigma_{perm} \]

where:

- \( \sigma_{eq} = \sqrt{\sigma_s^2 + 3 \tau^2} \)
- \( \sigma_{perm} = \frac{R_{act}}{\gamma_1 \gamma_2} \)
- \( \gamma_1 = \) partial safety factor for material, to be taken as:
  - \( \gamma_1 = k \frac{R_{act}}{235} \)
  - \( R_{act} \) is to be determined such that it satisfies the equation.
- \( \gamma_2 = \) partial safety factor for load combinations and permissible stress, to be taken as:
  - \( \gamma_2 = 1.24 \), for bending strength assessment according to 4.8.3.3.2.
  - \( \gamma_2 = 1.13 \), for shear stress assessment according to 4.8.3.3.3.

4.8.3.3.2 Bending strength assessment

The assessment of the bending stresses is to be carried out according to 4.8.3.3.1 at the following locations of the cross section:

- at bottom
- at deck
- at top of hatch coaming
- at any point where there is a change of steel yield strength

The following combination of hull girder stress as defined in 4.8.2.5 is to be considered:

\[ \sigma_s = \sigma_{HG} \]

\[ \tau = 0 \]

4.8.3.3.3 Shear strength assessment

The assessment of shear stress is to be carried out according to 4.8.3.3.1 for all structural elements that contribute to the shear strength capability.

The following combination of hull girder stress as defined in 4.8.2.5 is to be considered:

\[ \sigma_s = 0 \]

\[ \tau = \tau_{HG} \]

4.8.4 Buckling strength

4.8.4.1 Application

These requirements apply to plate panels and longitudinal stiffeners subject to hull girder bending and shear stresses.

Definitions of symbols used in the present requirement 4.8.4 are given in 4.8.8.

4.8.4.2 Buckling criteria

The acceptance criterion for the buckling assessment is defined as follows:

\[ \eta_{act} \leq 1 \]

where:

\[ \eta_{act} = \] maximum utilisation factor as defined in 4.8.4.3.

4.8.4.3 Buckling utilisation factor

The utilisation factor, \( \eta_{act} \), is defined as the inverse of the stress multiplication factor at failure \( \gamma_c \), see figure 4.8.4.3.

\[ \eta_{act} = \frac{1}{\gamma_c} \]

Failure limit states are defined in:

- 4.8.8.2 for elementary plate panels,
- 4.8.8.3 for overall stiffened panels,
- 4.8.8.4 for longitudinal stiffeners.

Each failure limit state is defined by an equation, and \( \gamma_c \) is to be determined such that it satisfies the equation.

Figure 4.8.4.3 illustrates how the stress multiplication factor at failure \( \gamma_c \), of a structural member is determined for any combination of longitudinal and shear stress.
where:
\[ \sigma, \tau = \text{applied stress combination for buckling given in 4.8.4.4.1} \]
\[ \sigma_c, \tau = \text{critical buckling stresses to be obtained according to 4.8.8 for the stress combination for buckling } \sigma \text{ and } \tau. \]

Figure 4.8.4.3 Example of failure limit state curve and stress multiplication factor at failure

4.8.4.4 Stress determination

4.8.4.4.1 Stress combinations for buckling assessment

The following two stress combinations are to be considered for each of the load cases “hogging” and “sagging” as defined in 4.8.2.4. The stresses are to be derived at the load calculation points defined in 4.8.4.4.2.

a) Longitudinal stiffening arrangement:

Stress combination 1 with:
\[ \sigma_x = \sigma_{HG} \]
\[ \sigma_y = 0 \]
\[ \tau = 0.7 \tau_{HG} \]

Stress combination 2 with:
\[ \sigma_x = 0.7 \sigma_{HG} \]
\[ \sigma_y = 0 \]
\[ \tau = \tau_{HG} \]

b) Transverse stiffening arrangement:

Stress combination 1 with:
\[ \sigma_z = 0 \]
\[ \sigma_y = \sigma_{HG} \]
\[ \tau = 0.7 \tau_{HG} \]

Stress combination 2 with:
\[ \sigma_z = 0 \]
\[ \sigma_y = 0.7 \sigma_{HG} \]
\[ \tau = \tau_{HG} \]

4.8.4.4.2 Load calculation points

The hull girder stresses for elementary plate panels (EPP) are to be calculated at the load calculation points defined in Table 4.8.4.2.

Table 4.8.4.2 Load calculation points (LCP) coordinates for plate buckling assessment

<table>
<thead>
<tr>
<th>LCP coordinates</th>
<th>Hull girder bending stress</th>
<th>Hull girder shear stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>x coordinate</td>
<td>Mid-length of the EPP</td>
<td>Both upper and lower ends of the EPP (points A1 and A2 in Figure 4.8.4.2)</td>
</tr>
<tr>
<td>y coordinate</td>
<td>Outboard and inboard ends of the EPP (points A1 and A2 in Figure 4.8.4.2)</td>
<td>Mid-point of EPP (point B in Figure 4.8.4.2)</td>
</tr>
<tr>
<td>z coordinate</td>
<td>Corresponding to x and y values</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.8.4.2 LCP for plate buckling – assessment, PSM stands for primary supporting members

The hull girder stresses for longitudinal stiffeners are to be calculated at the following load calculation point:
4.8.5 Hull girder ultimate strength

4.8.5.1 General

The hull girder ultimate strength is to be assessed for ships with length \( L \) equal or greater than 150 m.

The acceptance criteria, given in 4.8.5.4 are applicable to intact ship structures.

The hull girder ultimate bending capacity is to be checked for the load cases "hogging" and "sagging" as defined in 4.8.2.4.

4.8.5.2 Hull girder ultimate bending moments

The vertical hull girder bending moment, \( M \) in hogging and sagging conditions, to be considered in the ultimate strength check is to be taken as:

\[
M = \gamma_s M_s + \gamma_w M_w
\]

where:

\( M_s \) = permissible still water bending moment, in \([\text{kNm}]\), defined in 4.8.2.4

\( M_w \) = vertical wave bending moment, in \([\text{kNm}]\), defined in 4.8.2.4.

\( \gamma_s \) = partial safety factor for the still water bending moment, to be taken as: \( \gamma_s = 1.0 \)

\( \gamma_w \) = partial safety factor for the vertical wave bending moment, to be taken as: \( \gamma_w = 1.2 \)

4.8.5.3 Hull girder ultimate bending capacity

4.8.5.3.1 General

The hull girder ultimate bending moment capacity, \( M_U \) is defined as the maximum bending moment capacity of the hull girder beyond which the hull structure collapses.

4.8.5.3.2 Determination of hull girder ultimate bending moment capacity

The ultimate bending moment capacities of a hull girder transverse section, in hogging and sagging conditions, are defined as the maximum values of the curve of bending moment \( M \) versus the curvature \( \chi \) of the transverse section considered (\( M_{UH} \) for hogging condition and \( M_{US} \) for sagging condition, see Figure 4.8.5.3.2). The curvature \( \chi \) is positive for hogging condition and negative for sagging condition.

\[
M \leq \frac{M_U}{\gamma_M \gamma_{DB}}
\]

where:

\( M \) = vertical bending moment, in \([\text{kNm}]\), to be obtained as specified in 4.8.5.2.

\( M_U \) = hull girder ultimate bending moment capacity, in \([\text{kNm}]\), to be obtained as specified in 4.8.5.3.

\( \gamma_M \) = partial safety factor for the hull girder ultimate bending capacity, covering material, geometric and strength prediction uncertainties, to be taken as: \( \gamma_M = 1.05 \)

\( \gamma_{DB} \) = partial safety factor for the hull girder ultimate bending moment capacity, covering the effect of double bottom bending, to be taken as:

- for hogging condition: \( \gamma_{DB} = 1.15 \)
- for sagging condition: \( \gamma_{DB} = 1.0 \)

For cross sections where the double bottom breadth of the inner bottom is less than that at amidships or where the double bottom structure differs from that at amidships (e.g. engine room sections), the factor \( \gamma_{DB} \) for hogging condition may be reduced based upon agreement with the Register.

4.8.6 Additional requirements for large container ships

4.8.6.1 General

The requirements in 4.8.6.2 and 4.8.6.3 are applicable, in addition to requirements in 4.8.3 to 4.8.5, to container ships with a breadth \( B \) greater than 32.26 m.
4.8.6.2 Yielding and buckling assessment

Yielding and buckling assessments are to be carried out in accordance with these Rules, taking into consideration additional hull girder loads (wave torsion, wave horizontal bending and static cargo torque), as well as local loads. All in-plane stress components (i.e. bi-axial and shear stresses) induced by hull girder loads and local loads are to be considered.

4.8.6.3 Whipping

Hull girder ultimate strength assessment is to take into consideration the whipping contribution to the vertical bending moment according to the Register’s procedures.

4.8.7 Calculation of shear flow

4.8.7.1 General

This requirement describes the procedures of direct calculation of shear flow around a ship’s cross section due to hull girder vertical shear force. The shear flow, \( q_s \), at each location in the cross section, is calculated by considering the cross section is subjected to a unit vertical shear force of 1 N.

The unit shear flow per mm, \( q_v \), in [N/mm], is to be taken as:

\[ q_v = q_D + q_I \]

where:

\[ q_D \] = determinate shear flow, as defined in 4.8.7.2.
\[ q_I \] = indeterminate shear flow which circulates around the closed cells, as defined in 4.8.7.3.

In the calculation of the unit shear flow, \( q_v \), the longitudinal stiffeners are to be taken into account.

4.8.7.2 Determinate shear flow

The determinate shear flow, \( q_D \), in [N/mm], at each location in the cross section is to be obtained from the following line integration:

\[
q_D(s) = -\frac{1}{10^6} l_{y\text{-net}} \int_z (z - z_n) t_{\text{net}} \, ds
\]

where:

\( s \) = coordinate value of running coordinate along the cross section, in [m].
\( l_{y\text{-net}} \) = net moment of inertia of the cross section, in [m^4].
\( t_{\text{net}} \) = net thickness of plating, in [mm].
\( z_n \) = \( z \) coordinate of horizontal neutral axis from baseline, in [m].

It is assumed that the cross section is composed of line segments as shown in Figure 4.8.7.2-1, where each line segment has a constant plate net thickness. The determinate shear flow is obtained by the following equation.

\[
q_{Di} = -\frac{l_{\text{net}}}{2 \cdot 10^6 l_{y\text{-net}}} (z_i + z_n - 2z_n) + q_{Di}
\]

where:

\( q_D, q_v \) = determinate shear flow at node \( k \) and node \( i \) respectively, in [N/mm].
\( \ell \) = length of line segments, in [m].
\( y_k, y_i \) = \( y \) coordinate of the end points \( k \) and \( i \) of line segment, in [m], as defined in Figure 4.8.7.2-1.
\( z_k, z_i \) = \( z \) coordinate of the end points \( k \) and \( i \) of line segment, in [m], as defined in Figure 4.8.7.2-1.

Where the cross section includes closed cells, the closed cells are to be cut with virtual slits, as shown in Figure 4.8.7.2-2 in order to obtain the determinate shear flow. These virtual slits must not be located in walls which form part of another closed cell.

Determinate shear flow at bifurcation points is to be calculated by water flow calculations, or similar, as shown in Figure 4.8.7.2-2.

4.8.7.3 Indeterminate shear flow

The indeterminate shear flow around closed cells of a cross section is considered as a constant value within the same closed cell. The following system of equation for determination of indeterminate shear flows can be developed. In the equations, contour integrations of several parameters around all closed cells are performed.

\[
q_{Ic} = \frac{1}{l_{\text{net}}} \int ds - \sum_{n=1}^{N_c} \left( q_{im} \int_{c_{\text{in}}} \frac{1}{l_{\text{net}}} \, ds \right)
\]

where:

\( q_{Ic} \) = indeterminate shear flow at node \( c \) in closed cell, in [N/mm].
\( q_{im} \) = indeterminate shear flow at node \( m \) in closed cell, in [N/mm].
\( l_{\text{net}} \) = net length of line segment, in [m].
\( c_{\text{in}} \) = internal contour of closed cell.
\[ N_c = \text{number of common walls shared by cell } c \text{ and all other cells.} \]
\[ c\&m = \text{common wall shared by cells } c \text{ and } m \]
\[ q_{01}, q_{0m} = \text{indeterminate shear flow around the closed cell } c \text{ and } m \text{ respectively, in } [\text{N/mm}]. \]

Under the assumption of the assembly of line segments shown in Figure 4.8.7.2-1 and constant plate thickness of each line segment, the above equation can be expressed as follows:

\[ q_{0} = \sum_{j=1}^{N} \left( \frac{\ell}{t_{n,et}} \right) - \sum_{m=1}^{N} \left( q_{0,m} \sum_{j=1}^{N_{m}} \left( \frac{\ell}{t_{n,et}} \right) \right) = \sum_{j=1}^{N} \phi_{j} \]

\[ \phi_{j} = \left[ -\frac{\ell^2}{6 \cdot 10^7 I_{y,net}} (z_{j} + 2 z_{m} - 3 z_{a}) + \frac{\ell}{t_{n,et}} q_{0j} \right] \]

where:
\[ N_c = \text{number of line segments in cell } c. \]
\[ N_m = \text{number of line segments on the common wall shared by cells } c \text{ and } m. \]
\[ q_{0j} = \text{determinate shear flow, in } [\text{N/mm}], \]

The difference in the directions of running co-ordinates specified in 4.8.7.2 and in this section has to be considered.

**Figure 4.8.7.3 Closed cells and common wall**

### 4.8.7.4 Computation of sectional properties

Properties of the cross section are to be obtained by the following formulae where the cross section is assumed as the assembly of line segments:

\[ \ell = \sqrt{(y_{a} - y_{b})^2 + (z_{a} - z_{b})^2} \]
\[ d_{net} = 10^{-3} t_{n,et}; \quad A_{net} = \sum q_{net} \]
\[ s_{y,net} = \frac{d_{net}}{2} (z_{a} + z_{b}); \quad s_{y,net} = \sum s_{y,net} \]
\[ i_{y0,net} = \frac{d_{net}}{3} (z_{a} + z_{b} z_{a} + z_{b}^2) \]
\[ I_{y0,net} = \sum i_{y0,net} \]

where:

\[ a_{net}, A_{net} = \text{area of the line segment and the cross section respectively, in } [\text{m}^2]. \]
\[ s_{y,net}, s_{y,net} = \text{first moment of the line segment and the cross section about the baseline, in } [\text{m}^3]. \]
\[ i_{y0,net}, I_{y0,net} = \text{moment of inertia of the line segment and the cross section about the baseline, in } [\text{m}^4]. \]

The height of horizontal neutral axis, \( z_{n} \), in [m], is to be obtained as follows:

\[ z_{n} = \frac{s_{y,net}}{A_{net}} \]

Inertia moment about the horizontal neutral axis, in [m^4], is to be obtained as follows:

\[ I_{y,net} = I_{y0,net} - z_{n}^2 A_{net} \]

### 4.8.8 Buckling capacity

**Symbols**

- \( x \text{ axis} \) = local axis of a rectangular buckling panel parallel to its long edge.
- \( y \text{ axis} \) = local axis of a rectangular buckling panel perpendicular to its long edge.
- \( \sigma_{x} \) = membrane stress applied in \( x \) direction, in [N/mm^2].
- \( \sigma_{y} \) = membrane stress applied in \( y \) direction, in [N/mm^2].
- \( \tau \) = membrane shear stress applied in \( xy \) plane, in [N/mm^2].
- \( \sigma_{a} \) = axial stress in the stiffener, in [N/mm^2].
- \( \sigma_{b} \) = bending stress in the stiffener, in [N/mm^2].
- \( \sigma_{w} \) = warping stress in the stiffener, in [N/mm^2].
- \( \sigma_{e,x,y,n,T} \) = critical stress, in [N/mm^2], defined in 4.8.8.2.1.1 for plates.
- \( R_{HY,S} \) = specified minimum yield stress of the stiffener, in [N/mm^2].
- \( R_{HY,P} \) = specified minimum yield stress of the plate, in [N/mm^2].
- \( a \) = length of the longer side of the plate panel as shown in Table 4.8.8.2.1.4-2, in [mm].
- \( b \) = length of the shorter side of the plate panel as shown in Table 4.8.8.2.1.4-2, in [mm].
- \( d \) = length of the side parallel to the axis of the cylinder corresponding to the curved plate panel as shown in Table 4.8.8.2.2, in [mm].
- \( \sigma_{e} \) = elastic buckling reference stress, in [N/mm^2] to be taken as:

For the application of plate limit state according to 4.8.8.2.1.2:
\[ \sigma_e = \frac{\pi^2 \cdot E \cdot \left( \frac{t_p}{b} \right)^2}{12(1-\nu^2)} \]

For the application of curved plate panels according to 4.8.8.2.2:

\[ \sigma_e = \frac{\pi^2 \cdot E \cdot \left( \frac{t_p}{d} \right)^2}{12(1-\nu^2)} \]

\[ \nu = \text{Poisson’s ratio to be taken equal to 0.3} \]
\[ t_p = \text{net thickness of plate panel, in [mm].} \]
\[ t_w = \text{net stiffener web thickness, in [mm].} \]
\[ t_f = \text{net flange thickness, in [mm].} \]
\[ b_f = \text{breadth of the stiffener flange, in [mm].} \]
\[ h_w = \text{stiffener web height, in [mm].} \]
\[ e_f = \text{distance from attached plating to centre of flange, in [mm], to be taken as:} \]
\[ e_f = h_w \cdot 0.5 \cdot t_f, \text{ for bulb profile.} \]
\[ e_f = h_w + 0.5 \cdot t_f, \text{ for angle and Tee profiles.} \]
\[ \alpha = \text{aspect ratio of the plate panel, to be taken as} \]
\[ \beta = \frac{1-\psi}{\alpha} \]
\[ \psi = \text{edge stress ratio to be taken as} \]
\[ \psi = \frac{\sigma_2}{\sigma_1} \]
\[ \sigma_1 = \text{maximum stress, in [N/mm}^2\text{].} \]
\[ \sigma_2 = \text{minimum stress, in [N/mm}^2\text{].} \]
\[ R = \text{radius of curved plate panel, in [mm].} \]
\[ \ell = \text{span, in [mm], of stiffener equal to the spacing between primary supporting members} \]
\[ s = \text{spacing of stiffener, in [mm], to be taken as the mean spacing between the stiffeners of the considered stiffened panel.} \]

4.8.8.1 Elementary plate panel (EPP)
4.8.8.1.1 Definition

An elementary plate panel (EPP) is the unstiffened part of the plating between stiffeners and/or primary supporting members.

All the edges of the elementary plate panel are forced to remain straight (but free to move in the in-plane directions) due to the surrounding structure/neighbouring plates (usually longitudinal stiffened panels in deck, bottom and inner-bottom plating, shell and longitudinal bulkheads).

4.8.8.1.2 EPP with different thicknesses

4.8.8.1.2.1 Longitudinally stiffened EPP with different thicknesses

In longitudinal stiffening arrangement, when the plate thickness varies over the width, \( b \), in [mm], of a plate panel, the buckling capacity is calculated on an equivalent plate panel width, having a thickness equal to the smaller plate thickness, \( t_1 \). The width of this equivalent plate panel, \( b_{eq} \), in [mm], is defined by the following formula:

\[ b_{eq} = \ell_1 + \ell_2 \left( \frac{t_1}{t_2} \right)^2 \]

where:

\[ \ell_1 = \text{width of the part of the plate panel with the smaller plate thickness, } t_1, \text{ in [mm], as defined in Figure 4.8.8.1.2.1.} \]
\[ \ell_2 = \text{width of the part of the plate panel with the greater plate thickness, } t_2, \text{ in [mm], as defined in Figure 4.8.8.1.2.1.} \]

4.8.8.1.2.2 Transversally stiffened EPP with different thicknesses

In transverse stiffening arrangement, when an EPP is made of different thicknesses, the buckling check of the plate and stiffeners is to be made for each thickness considered constant on the EPP.

4.8.8.2 Buckling capacity of plates
4.8.8.2.1 Plate panel
4.8.8.2.1.1 Plate limit state

The plate limit state is based on the following interaction formulae:

a) Longitudinal stiffening arrangement:

\[ \left( \frac{\gamma_c \cdot \sigma_x}{\sigma_{tx}} \right)^{\frac{2}{\beta_p^{\gamma_c}}} + \left( \frac{\gamma_c \cdot |\tau|}{\tau_c} \right)^{\frac{2}{\beta_p^{\gamma_c}}} = 1 \]

b) Transverse stiffening arrangement:

\[ \left( \frac{\gamma_c \cdot \sigma_y}{\sigma_{ty}} \right)^{\frac{2}{\beta_p^{\gamma_c}}} + \left( \frac{\gamma_c \cdot |\tau|}{\tau_c} \right)^{\frac{2}{\beta_p^{\gamma_c}}} = 1 \]

where:
σ, σ = applied normal stress to the plate panel, in [N/mm²], as defined in 4.8.4.4, at load calculation points of the considered elementary plate panel.

τ = applied shear stress to the plate panel, in [N/mm²], as defined in 4.8.4.4, at load calculation points of the considered elementary plate panel.

σₜ = ultimate buckling stress, in [N/mm²], in direction parallel to the longer edge of the buckling panel as defined in 4.8.8.2.1.3

σᵧ = ultimate buckling stress, in [N/mm²], in direction parallel to the shorter edge of the buckling panel as defined in 4.8.8.2.1.3

τₑ = ultimate buckling shear stress, in [N/mm²], as defined in 4.8.8.2.1.3

βₑ = plate slenderness parameter taken as:

\[ \betaₑ = \frac{b}{tₑ} \sqrt{\frac{E}{Rₑₑ}} \]

4.8.8.2.1.2 Reference degree of slenderness

The reference degree of slenderness is to be taken as:

\[ \lambda = \frac{Rₑₑ}{Kσₑₑ} \]

where:

K = buckling factor, as defined in Table 4.8.8.2.1.4-2 and Table 4.8.8.2.2.

4.8.8.2.1.3 Ultimate buckling stresses

The ultimate buckling stress of plate panels, in [N/mm²], is to be taken as:

σₑₑ = Cₑₑ Rₑₑₑₑₑ

σᵧᵧ = Cᵧᵧ Rₑₑₑₑₑ

The ultimate buckling stress of plate panels subject to shear, in [N/mm²], is to be taken as:

τₑₑ = Cₑₑ Rₑₑₑₑₑ \sqrt{3}

where:

Cₑₑ, Cᵧᵧ, Cₑₑ = reduction factors, as defined in Table 4.8.8.2.1.4-2

The boundary conditions for plates are to be considered as simply supported (see cases 1, 2 and 15 of Table 4.8.8.2.1.4-1). If the boundary conditions differ significantly from simple support, a more appropriate boundary condition can be applied according to the different cases of Table 4.8.8.2.1.4-2 subject to the agreement of the Register.

4.8.8.2.1.4 Correction factor \( F_{\text{long}} \)

The correction factor \( F_{\text{long}} \) depending on the edge stiffener types on the longer side of the buckling panel is defined in Table 4.8.8.2.1.4-1. An average value of \( F_{\text{long}} \) is to be used for plate panels having different edge stiffeners. For stiffener types other than those mentioned in Table 4.8.8.2.1.4-1, the value of \( c \) is to be agreed by the Register. In such a case, value of \( c \) higher than those mentioned in Table 4.8.8.2.1.4-1 can be used, provided it is verified by buckling strength check of panel using non-linear FE analysis and deemed appropriate by the Register.
### Table 4.8.8.1.4-1 Correction factor $F_{\text{long}}$

<table>
<thead>
<tr>
<th>Structural element types</th>
<th>$F_{\text{long}}$</th>
<th>$c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstiffened panel</td>
<td>1.0</td>
<td>N/A</td>
</tr>
<tr>
<td>Stiffened panel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stiffener not fixed at both ends</td>
<td>1.0</td>
<td>N/A</td>
</tr>
<tr>
<td>Stiffener fixed at both ends</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flat bar (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulb profile</td>
<td>$F_{\text{long}} = c + 1 \quad \text{for} \quad \frac{t_w}{t_p} &gt; 1$</td>
<td>0.10</td>
</tr>
<tr>
<td>Angle profile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T profile</td>
<td>$F_{\text{long}} = \left( \frac{t_w}{t_p} \right)^3 + 1 \quad \text{for} \quad \frac{t_w}{t_p} \leq 1$</td>
<td>0.30</td>
</tr>
<tr>
<td>Girder of high rigidity (e.g. bottom transverse)</td>
<td>1.4</td>
<td>N/A</td>
</tr>
</tbody>
</table>

(1) $t_w$ is the net web thickness, in [mm], without the correction defined in 4.3.5

<table>
<thead>
<tr>
<th>Structural element types</th>
<th>$F_{\text{long}}$</th>
<th>$c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstiffened panel</td>
<td>1.0</td>
<td>N/A</td>
</tr>
<tr>
<td>Stiffened panel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stiffener not fixed at both ends</td>
<td>1.0</td>
<td>N/A</td>
</tr>
<tr>
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<td></td>
<td></td>
</tr>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>T profile</td>
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<td>0.30</td>
</tr>
<tr>
<td>Girder of high rigidity (e.g. bottom transverse)</td>
<td>1.4</td>
<td>N/A</td>
</tr>
</tbody>
</table>

(2) $t_w$ is the net web thickness, in [mm], without the correction defined in 4.8.8.4.3.5
### Table 4.8.8.1.4-2 Buckling factor and reduction factor for plane plate panels

<table>
<thead>
<tr>
<th>Case</th>
<th>Stress ratio $\psi$</th>
<th>Aspect ratio $\alpha$</th>
<th>Buckling factor $K$</th>
<th>Reduction factor $C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$0 &lt; \psi_0 &lt; 1$</td>
<td>$1 &lt; \alpha &lt; 6$</td>
<td>$K = F_{long} \cdot \frac{8.4}{\psi + 1.1}$</td>
<td>$C = 1$ for $\lambda \leq \lambda_c$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$C = e \left( \frac{1}{\lambda} - \frac{0.22}{\lambda^2} \right)$ for $\lambda &gt; \lambda_c$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\psi_0 = \psi_{long} \cdot [7.63 - \psi (6.26 - 10\psi)]$</td>
<td>ere: $c = (1.25 - 0.12\psi) \leq 1.25$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\lambda_0 = \frac{2}{(1 + \sqrt{1 - 0.88/c})}$</td>
<td>$\lambda_c$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$K = F_{long} \cdot [5.975(1 - \psi)^2]$</td>
<td>$\lambda_c$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\lambda_c \leq \frac{1}{3} \left[ \frac{1}{5} - \frac{1}{4}^3 \right]$</td>
</tr>
<tr>
<td>2</td>
<td>$1 \geq \psi$</td>
<td>$\psi &lt; 1$</td>
<td>$K = \frac{2 \left(1 + \frac{1}{\alpha^2} \right)^2}{1 + \psi + \left( \frac{1 - \psi}{100} \right) \frac{2.4}{\alpha^2} + 6.9f_1}$</td>
<td>$C = e \left( \frac{1}{\lambda} - R + F_2 (H - R) \right)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\alpha \leq 6$</td>
<td>where: $c = (1.25 - 0.12\psi) \leq 1.25$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$f_1 = (1 - \psi) (\alpha - 1)$</td>
<td>$R = \lambda (1 - \lambda/c)$ for $\lambda &lt; \lambda_c$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\alpha &gt; 6$</td>
<td>$\lambda_c = 0.5c \left[ 1 + \sqrt{1 - 0.88/c} \right]$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$f_1 = 0.6 \left( 1 - \frac{6\psi}{\alpha} \left[ \frac{\alpha + 14}{\alpha} \right] \right)$</td>
<td>$F = \left[ 1 - \left( \frac{K}{0.91} - 1 \right) \lambda_0^2 \right] c \geq 0$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>but not greater than $14.5 - \frac{0.35}{\alpha^2}$</td>
<td>$\lambda_0^2 = \lambda^2 - 0.5$ for $1 \leq \lambda_0^2 \leq 3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$c_0 = \left[ 1 - \frac{1}{\alpha} \right] \geq 0$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$H = \lambda - \frac{2\lambda}{c(T + \sqrt{T^2 - 4})} \geq R$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$T = \lambda + \frac{14}{15\lambda} + \frac{1}{3}$</td>
</tr>
</tbody>
</table>

**Notes:**
- $F_{long}$ is the long wavelength buckling factor.
- $\lambda = \frac{2(1 + h_1^2)}{h_1^2} + \frac{2(1 + h_2^2)}{h_2^2}$ for $h_1, h_2 \geq 0$.
- $\lambda = \frac{2}{h_1^2} + \frac{2}{h_2^2}$ for $h_1, h_2 < 0$. 
- $f_1 = \left(1 - \frac{h_1^2}{h_2^2}\right)$ for $h_1, h_2 \geq 0$.
- $f_1 = \left(1 - \frac{h_1^2}{h_2^2}\right)$ for $h_1, h_2 < 0$. 
- $\beta = \frac{\lambda}{\lambda_0}$.
### Case 1

**Stress ratio** $\psi$

**Aspect ratio** $\alpha$

**Buckling factor** $K$

**Reduction factor** $C$

For $\alpha > 1.5$:

- $f_1 = \left( \frac{1}{\beta} - 16 \left( 1 - \frac{\alpha}{5} \right) ^4 \right) \left( \frac{1}{\beta} - 1 \right)$
- $f_2 = 3 \beta - 2$
- $f_3 = 0$

For $\alpha \leq 1.5$:

- $f_1 = \left( \frac{1.5}{1-\psi} - 1 \right) \left( \frac{1}{\beta} - 1 \right)$
- $f_2 = \frac{\psi (1 - 16 f_3)}{1 - \alpha}$
- $f_3 = 0$
- $f_4 = (1.5 - \text{Min}(1.5; \alpha))^2$

**Formulae**

\[
K = \frac{5.972}{1-f_3} \\
\text{where:} \\
\begin{align*}
   f_3 &= f_s \left( \frac{f_s}{1.81} + \frac{1 + 3 \psi}{5.24} \right) \\
   f_s &= \frac{9}{16} \left( 1 + \text{Max}(-1; \psi) \right)
\end{align*}
\]

### Case 3

**Stress ratio** $\psi$

**Aspect ratio** $\alpha$

**Buckling factor** $K$

**Reduction factor** $C$

- $\psi < 1.4 \alpha$

- $\psi \geq 1.5$

- $0 \leq \lambda < 1$

$K_s = \frac{4 (0.425 + 1 / \alpha^2)}{3 \psi + 1}$

\[C_s = 1\] for $\lambda \leq 0.7$

\[C_s = \frac{1}{\alpha^2 + 0.51}\] for $\lambda > 0.7$

### Case 4

**Stress ratio** $\psi$

**Aspect ratio** $\alpha$

**Buckling factor** $K$

**Reduction factor** $C$

$K_s = \left( 0.425 + \frac{1}{\alpha^2} \right) \frac{3 - \psi}{2}$

### Case 5

**Stress ratio** $\psi$

**Aspect ratio** $\alpha$

**Buckling factor** $K$

**Reduction factor** $C$

$K_s = 1.28$
<table>
<thead>
<tr>
<th>Case</th>
<th>Stress ratio $\psi$</th>
<th>Aspect ratio $\alpha$</th>
<th>Buckling factor $K$</th>
<th>Reduction factor $C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>$0 \leq \psi \leq 1$</td>
<td>$\alpha \leq 1.64$</td>
<td>[ K_s = \frac{1}{\alpha^2} + 0.56 + 0.13\alpha^2 ]</td>
<td>[ C_s = 1 \text{ for } \lambda \leq 0.7 ] [ C_s = \frac{1}{\alpha^2 + 0.51} \text{ for } \lambda &gt; 0.83 ]</td>
</tr>
<tr>
<td>7</td>
<td>$1 \geq \psi &gt; 0$</td>
<td>$\alpha &gt; 1$</td>
<td>$K_s = 4(0.425 + \alpha^2)\left(\frac{1}{\alpha^2} + \frac{1}{\alpha^2}\right) - 5\psi(1 - 3.42\psi)\frac{1}{\alpha^2}$</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>$1 \geq \psi &gt; 1$</td>
<td>$\alpha &gt; 1$</td>
<td>$K_s = (0.425 + \alpha^2)\left(\frac{3 - \psi}{2\alpha^2}\right)$</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td>$K_s = 6.97$</td>
<td>[ C_s = 1 \text{ for } \lambda \leq 0.83 ] [ C_s = 1.13\left(\frac{1}{\alpha} - \frac{0.22}{\alpha^2}\right) \text{ for } \lambda &gt; 0.83 ]</td>
</tr>
<tr>
<td>Case</td>
<td>Stress ratio $\psi$</td>
<td>Aspect ratio $\alpha$</td>
<td>Buckling factor $K$</td>
<td>Reduction factor $C$</td>
</tr>
<tr>
<td>------</td>
<td>---------------------</td>
<td>---------------------</td>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>10</td>
<td>$\sigma_y$</td>
<td>$\alpha$</td>
<td>$K_y = 4 + \frac{2.07}{\alpha^3} + \frac{0.67}{\alpha^4}$</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>$\alpha \geq 4$</td>
<td>$\alpha &lt; 4$</td>
<td>$K_y = 4 + 2.74 \left(\frac{4-\alpha}{3}\right)^4$</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>$\alpha \geq 4$</td>
<td>$\alpha &lt; 4$</td>
<td>$K_y = K_i$ determined as per case 2</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>$\alpha \geq 4$</td>
<td>$\alpha &lt; 4$</td>
<td>$K_y = 6.97 + 3.1 \left(\frac{4-\alpha}{3}\right)^4$</td>
<td>$C_y = 1$ for $\lambda \leq 0.83$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$C_y = 1.13 \left(\frac{1}{\alpha} - \frac{0.22}{\alpha^2}\right)$ for $\lambda &gt; 0.83$</td>
</tr>
<tr>
<td>14</td>
<td>$\alpha \geq 4$</td>
<td>$\alpha &lt; 4$</td>
<td>$K_y = \frac{6.97 + 3.1 \left(\frac{4-\alpha}{3}\right)^4}{\alpha^2}$</td>
<td>$C_y = 1$ for $\lambda \leq 0.83$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$C_y = 1.13 \left(\frac{1}{\alpha} - \frac{0.22}{\alpha^2}\right)$ for $\lambda &gt; 0.83$</td>
</tr>
<tr>
<td>15</td>
<td>$\alpha \geq 4$</td>
<td>$\alpha &lt; 4$</td>
<td>$K_y = \sqrt{5}(5.34 + \frac{4}{\alpha^2})$</td>
<td>$C_y = 1$ for $\lambda \leq 0.84$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$C_y = \frac{0.84}{\lambda}$ for $\lambda &gt; 0.84$</td>
</tr>
</tbody>
</table>
### Rules for the Classification of Ships

#### Case Stress

<table>
<thead>
<tr>
<th>Case</th>
<th>Stress ratio ( \psi )</th>
<th>Aspect ratio ( \alpha )</th>
<th>Buckling factor ( K )</th>
<th>Reduction factor ( C )</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>-</td>
<td>-</td>
<td>( K = 3 \sqrt{5.34 + Max \left[ \frac{4}{\alpha^2} ; \frac{7.15}{\alpha^2} \right]} )</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>( \tau )</td>
<td>-</td>
<td>( K = K' r ) ( K' = K ) according to case 15. ( r ) = opening reduction factor taken as ( r = (1 - \frac{b}{a})(1 - \frac{d}{b}) ) with ( \frac{d}{a} \leq 0.7 ) and ( \frac{d}{b} \leq 0.7 )</td>
<td>-</td>
</tr>
<tr>
<td>18</td>
<td>( \tau )</td>
<td>-</td>
<td>( K = 3^{0.5} \left( 0.6 + \frac{4}{\alpha^2} \right) )</td>
<td>( C = \begin{cases} 1 &amp; \text{for } \lambda \leq 0.84 \ \frac{0.84}{\lambda} &amp; \text{for } \lambda &gt; 0.84 \end{cases} )</td>
</tr>
<tr>
<td>19</td>
<td>( \tau )</td>
<td>-</td>
<td>( K = 8 )</td>
<td>-</td>
</tr>
</tbody>
</table>

#### Edge boundary conditions:
- - - - - - - - plate edge free.
- - - - - - plate edge simply supported.
- - - - - - - - - plate edge clamped.

#### Notes:
1) Cases listed are general cases. Each stress component \((\sigma_x, \sigma_y)\) is to be understood in local coordinates.

#### 4.8.8.2.2 Curved plate panels

This requirement for curved plate limit state is applicable when \( R/t_p \leq 2500 \). Otherwise, the requirement for plate limit state given in 4.8.8.2.1.1 is applicable.

The curved plate limit state is based on the following interaction formula:

\[
\left( \frac{\gamma_c \cdot \sigma_{ax}}{\sigma_{ax} R_{th}, p} \right)^{1.25} + \left( \frac{\gamma_c \cdot \tau \sqrt{3}}{C \cdot R_{th}, p} \right)^2 = 1
\]

where:
- \( \sigma_{ax} \) = applied axial stress to the cylinder corresponding to the curved plate panel, in \([\text{N/mm}^2]\). In case of tensile axial stresses, \( \sigma_{ax} = 0 \).
The buckling reduction factor \( C_{ax} \) of the curved plate panel, as defined in Table 4.8.8.2.1.4-2.

The stress multiplier factor \( \gamma \) of the curved plate panel needs not be taken less than the stress multiplier factor \( \gamma \) for the expanded plane panel according to 4.8.8.2.1.1.

<table>
<thead>
<tr>
<th>Case</th>
<th>Aspect ratio</th>
<th>Buckling factor ( K )</th>
<th>Reduction factor ( C )</th>
</tr>
</thead>
</table>
| 1    | \( \frac{d}{R} \leq 0.5 \frac{R}{t_p} \) | \( K = 1 + \frac{2}{3} \frac{d^2}{R t_p} \) | For general application: \( C_{ax} = 1 \) for \( \lambda \leq 0.25 \)
|      |              |                          | \( C_{ax} = 1.233 - 0.933 \lambda \) for \( 0.25 < \lambda \leq 1 \)
|      |              |                          | \( C_{ax} = 0.3\lambda^2 \) for \( 1 < \lambda \leq 1.5 \)
| 2    | \( \frac{d}{R} > 0.5 \frac{R}{t_p} \) | \( K = 0.267 \frac{d^2}{R t_p} \left( 3 - \frac{t_p}{R} \right) \geq 0.4 \frac{d^2}{R t_p} \) | \( C_{ax} = 0.65/\lambda^2 \leq 1.0 \)
|      | \( \frac{R}{t_p} \leq 2500 \) | \( K = \sqrt{3} \left( 28.3 + \frac{0.67d^2}{R^1.5t_p^1.5} \right) \) | \( C_{ax} = 1 \) for \( \lambda \leq 0.4 \)
|      | \( \frac{R}{t_p} > 2500 \) | \( K = \sqrt{3} \frac{0.28d^2}{R \sqrt{R t_p}} \) | \( C_{ax} = 1.274 - 0.686 \lambda \) for \( 0.4 < \lambda \leq 1.2 \)
|      |              |                          | \( C_{ax} = 0.65/\lambda^2 \) for \( \lambda > 1.2 \)

**Explanations for boundary conditions:**
- Plate edge simply supported.

### 4.8.8.3 Buckling capacity of overall stiffened panel

The elastic stiffened panel limit state is based on the following interaction formula:

\[
P = \frac{P_c}{C_f} = 1
\]

where \( P_c \) and \( C_f \) are defined in 4.8.8.4.4.3.

### 4.8.8.4 Buckling capacity of longitudinal stiffeners

#### 4.8.8.4.1 Stiffeners limit states

The buckling capacity of longitudinal stiffeners is to be checked for the following limit states:
- Stiffener induced failure (\( SI \)).
- Associated plate induced failure (\( PI \)).

#### 4.8.8.4.2 Lateral pressure

The lateral pressure is to be considered as constant in the buckling strength assessment of longitudinal stiffeners.

### 4.8.8.4.3 Stiffener idealization

#### 4.8.8.4.3.1 Effective length of the stiffener \( \ell_{eff} \)

The effective length of the stiffener \( \ell_{eff} \), in [mm], is to be taken equal to:

\[
\ell_{eff} = \ell \sqrt{\lambda} \text{ for stiffener fixed at both ends.}
\]

\[
\ell_{eff} = 0.75 \ell \text{ for stiffener simply supported at one end and fixed at the other.}
\]

\[
\ell_{eff} = \ell \text{ for stiffener simply supported at both ends.}
\]

#### 4.8.8.4.3.2 Effective width of the attached plating \( b_{eff} \)

The effective width of the attached plating of a stiffener \( b_{eff} \), in [mm], without the shear lag effect is to be taken equal to:

\[
b_{eff} = \frac{C_{s1} b_1 + C_{s2} b_2}{2}
\]

where:

\( C_{s1}, C_{s2} \) = reduction factor defined in Table 4.8.8.4.2 calculated for the EPP1.
and EPP2 on each side of the considered stiffener according to case 1.

\[ b_1, b_2 = \text{width of plate panel on each side of the considered stiffener, in [mm].} \]

4.8.8.4.3 Effective width of attached plating \( b_{eff} \)

The effective width of attached plating of stiffeners, \( b_{eff} \), in [mm], is to be taken as:

\[ b_{eff} = \min(b_{eff1}, \chi_s) \]

where:

\[ \chi_s = \text{effective width coefficient to be taken as:} \]

\[ \chi_s = \min \left[ \frac{1.12}{1 + 1.75\left(\frac{\ell_{eff}}{s}\right)^{0.8}}, 0.407\frac{\ell_{eff}}{s}, \text{for } \frac{\ell_{eff}}{s} \geq 1 \right] \]

\[ \chi_s = 0.407\frac{\ell_{eff}}{s}, \text{for } \frac{\ell_{eff}}{s} < 1 \]

4.8.8.4.4 Net thickness of attached plating \( t_p \)

The net thickness of plate \( t_p \), in [mm], is to be taken as the mean thickness of the two attached plating panels.

4.8.8.4.5 Effective web thickness of flat bar

For accounting the decrease of stiffness due to local lateral deformation, the effective web thickness of flat bar stiffener, in mm, is to be used for the calculation of the net sectional area, \( A_w \), the net section modulus, \( Z \), and the moment of inertia, \( I \), of the stiffener and is taken as:

\[ t_{w,red} = t_w \left(1 - \frac{2\pi^2}{3} \left(\frac{h}{s}\right)^2 \left(1 - \frac{b_{eff1}}{s}\right)\right) \]

4.8.8.4.6 Net section modulus \( Z \) of a stiffener

The net section modulus \( Z \) of a stiffener, in [cm\(^3\)], including effective width of plating \( b_{eff} \) is to be taken equal to:

- the section modulus calculated at the top of stiffener flange for stiffener induced failure (SI).
- the section modulus calculated at the attached plating for plate induced failure (PI).

4.8.8.4.7 Net moment of inertia \( I \) of a stiffener

The net moment of inertia \( I \), in [cm\(^4\)], of a stiffener including effective width of attached plating \( b_{eff} \) is to comply with the following requirement:

\[ I \geq \frac{St_p}{12 \cdot 10^3} \]

4.8.8.4.3.8 Idealisation of bulb profile

Bulb profiles may be considered as equivalent angle profiles. The net dimensions of the equivalent built-up section are to be obtained, in mm, from the following formulae:

\[ h_w = h'_w - \frac{h'_w}{9.2} + 2 \]

\[ b_f = \left(\frac{h'_w}{6.7} - 2\right) \]

\[ t_f = \frac{h'_w}{9.2} - 2 \]

\[ t_w = t'_w \]

where:

\[ h'_w, t'_w = \text{net height and thickness of a bulb section, in [mm], as shown in Figure 4.8.8.4.3.8.} \]

\[ \alpha = \text{coefficient equal to:} \]

\[ \alpha = 1.1 + \frac{(120 - h'_w)^2}{3000}, \text{for } h'_w \leq 120 \]

\[ \alpha = 1.0 \text{ for } h'_w > 120 \]

Figure 4.8.8.4.3.8 Idealisation of bulb stiffener

4.8.8.4.4 Ultimate buckling capacity

4.8.8.4.4.1 Longitudinal stiffener limit state

When \( \sigma_e + \sigma_b + \sigma_t > 0 \), the ultimate buckling capacity for stiffeners is to be checked according to the following interaction formula:

\[ \gamma_{e} \cdot \sigma_e + \sigma_b + \sigma_t = \frac{\pi^2}{2} \]

where:

\[ \sigma_e = \text{effective axial stress, in [N/mm}^2\text{], at mid-span of the stiffener, defined in 4.8.8.4.4.2.} \]

\[ \sigma_b = \text{bending stress in the stiffener, in [N/mm}^2\text{], defined in 4.8.8.4.4.3.} \]

\[ \sigma_t = \text{stress due to torsional deformation, in [N/mm}^2\text{], defined in 4.8.8.4.4.4.} \]
4.8.8.4.2 Effective axial stress

The effective axial stress $\sigma_a$, in [N/mm\(^2\)], at mid-span of the stiffener, acting on the stiffener with its attached plating is to be taken equal to:

$$\sigma_a = \sigma x \cdot \frac{St_p + At}{b_{eff} t_p + A_t}$$

where:

$\sigma x$ = Nominal axial stress, in [N/mm\(^2\)], acting on the stiffener with its attached plating, calculated according to 4.8.4.4.1 a) at load calculation point of the stiffener.

$A_s$ = Net sectional area, in [mm\(^2\)], of the considered stiffener.

4.8.8.4.3 Bending stress

The bending stress in the stiffener $\sigma b$, in [N/mm\(^2\)], is to be taken equal to:

$$\sigma b = \left( \frac{\pi^2 \cdot EI}{P \cdot z} \right)$$

where:

$M_1$ = bending moment, in Nmm, due to the lateral load $P$:

- EMBED Equation.3 for continuous stiffener
- EMBED Equation.3 for sniped stiffener

$P$ = lateral load, in [kN/m\(^2\)], to be taken equal to the static pressure at the load calculation point of the stiffener.

$C_I$ = pressure coefficient:

$C_I = C_{SI}$ for stiffener induced failure (SI).

$C_I = C_{PI}$ for plate induced failure (PI).

$C_{PI} = 1$, if the lateral pressure is applied on the side opposite to the stiffener.

$C_{PI} = 0$, if the lateral pressure is applied on the same side as the stiffener.

$C_{SI} = -1$, if the lateral pressure is applied on the side opposite to the stiffener.

$C_{SI} = 1$, if the lateral pressure is applied on the same side as the stiffener.

$M_0$ = bending moment, in [Nm], due to the lateral deformation $w$ of stiffener:

$$M_0 = F_E \left( \frac{P \cdot w}{c_f - \tau} \right)$$

with $c_f - \tau > 0$

$F_E$ = ideal elastic buckling force of the stiffener, in [N].

$P_f = \text{nominal lateral load, in [N/mm\(^2\)], acting on the stiffener due to stresses $\sigma x$ and $\tau$, in the attached plating in way of the stiffener mid span}:

$$P_f = \frac{E}{s} \left( \frac{\pi^2 \cdot s \cdot x}{l} \right)^2 + \frac{\tau \cdot \pi^2}{s}$$

$\sigma_{pl} = \gamma_c \cdot \frac{s}{s} + \frac{A_s}{s}$, but not less than 0

$\tau = \left( \gamma_c \cdot l \cdot \sqrt{R_{pl-p} \cdot E \left( \frac{m_1}{a^2} + \frac{m_2}{s^2} \right)} \right) \geq 0$

but not less than 0

$m_1, m_2 = \text{coefficients taken equal to:}$

$m_1 = 1.47, m_2 = 0.49$, for $\alpha \geq 2$

$m_1 = 1.96, m_2 = 0.37$, for $\alpha < 2$

$w = \text{deformation of stiffener, in [mm], taken equal to:}$

$$w = w_0 + w_1$$

$w_0 = \text{assumed imperfection, in [mm], taken equal to:}$

$$w = \ell \cdot 10^{-3}$$

in general

$w_0 = -\frac{w_{na}}{2}$

for stiffeners snipped at both ends, considering stiffener induced failure (SI)

$w_0 = \frac{w_{na}}{2}$

for stiffeners snipped at both ends, considering plate induced failure (PI)

$w_{na} = \text{distance, in [mm], from the mid-point of attached plating to the neutral axis of the stiffener calculated with the effective width of the attached plating $b_{eff}$,}$

$w_1 = \text{deformation of stiffener at midpoint of stiffener span due to lateral load $P$, in [mm]. In case of uniformly distributed load, $w_1$ is to be taken as:}$
\[ w_i = C_i \frac{|P|k_i^4}{384EI} \times 10^{-7}, \text{ in general} \]

\[ w_i = C_i \frac{5|P|k_i^4}{384EI} \times 10^{-7}, \text{ for stiffener sniped at both ends} \]

\[ c_f = \text{elastic support provided by the stiffener, in [N/mm]²}, \text{ to be taken equal to:} \]

\[ c_f = F_k \left( \frac{\pi}{\ell} \right)^2 \left( 1 + c_p \right) \]

\[ c_p = \text{coefficient to be taken as:} \]

\[ c_p = \frac{1}{1 + \frac{0.91}{c_{sw}} \left( \frac{12/10^4}{s_p} - 1 \right)} \]

\[ c_{sw} = \text{coefficient to be taken as:} \]

\[ c_{sw} = \left( \frac{\ell}{2s} + \frac{2s}{\ell} \right)^2, \text{ for } \ell \geq 2s \]

\[ c_{sw} = \left( 1 + \left( \frac{\ell}{2s} \right)^2 \right)^2, \text{ for } \ell < 2s \]

4.8.8.4.4 Stress due to torsional deformation \( \sigma_w \)

The stress due to torsional deformation \( \sigma_w \), in [N/mm²], is to be taken equal to:

\[ \sigma_w = E \cdot y_s \left( \frac{t_f + b_n}{2} \right) \Phi_o \left( \frac{\pi}{\ell} \right)^2 \left( 1 - \frac{1}{0.4R_{3h-s}} \right), \]

for stiffener induced failure (SI).

\( \sigma_w = 0, \text{ for plate induced failure (PI).} \)

where:

\[ y_s = \text{distance, in [mm], from centroid of stiffener cross-section to the free edge of stiffener flange, to be taken as:} \]

\[ y_s = \frac{t_f}{2}, \text{ for flat bar.} \]

\[ y_s = b_j - \frac{h_f i^2 + t_i b_j^2}{2A_j}, \text{ for angle and bulb profiles.} \]

\( y_s = \frac{b_j}{2}, \text{ for Tee profile.} \)

\[ \Phi_o = \frac{\ell}{h_w} 10^{-3} \]

\( \sigma_{et} = \text{reference stress for torsional buckling, in [N/mm²]:} \)

\[ \sigma_{et} = \frac{E}{I_p} \left( \frac{\pi^2 l}{\ell^2} + 0.385I_T \right) \]

\( I_p = \text{net polar moment of inertia of the stiffener about point C as shown in Figure 4.8.8.4.4.4, as defined in Table 4.8.8.4.4.4, in [cm}^4]. \)

\( I_T = \text{net St. Venant’s moment of inertia of the stiffener, as defined in Table 4.8.8.4.4.4, in [cm}^4]. \)

\( I_w = \text{net sectional moment of inertia of the stiffener about point C as shown in Figure 4.8.8.4.4.4, as defined in Table 4.8.8.4.4.4, in [cm}^4]. \)

\( \varepsilon = \text{degree of fixation.} \)

\[ \varepsilon = 1 + \frac{\left( \frac{\ell}{\pi} \right)^2 10^{-3}}{\left( \frac{0.75 \cdot s}{t_p} + \frac{c_f - 0.5 \cdot t_f}{t_w} \right)} \]
### Table 4.8.4.4.4 Moments of inertia

<table>
<thead>
<tr>
<th></th>
<th>Flat bars</th>
<th>Bulb, angle and Tee profiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_c$</td>
<td>$h_w^4 t_w^3 / 3 \cdot 10^4$</td>
<td>$A_w (e_f - 0.5 t_f) t_w / 3 + A_f e_f^2 / 10^{-4}$</td>
</tr>
<tr>
<td>$I_t$</td>
<td>$h_w t_w^3 / 3 \cdot 10^4 \left( 1 - 0.63 t_w / h_w \right)$</td>
<td>$\frac{(e_f - 0.5 t_f) t_w^3}{3 \cdot 10^4} \left( 1 - 0.63 t_w / e_f - 0.5 t_f \right)$ + $\frac{b_f t_f^3}{3 \cdot 10^4} \left( 1 - 0.63 t_f / b_f \right)$</td>
</tr>
<tr>
<td>$I_{aw}$</td>
<td>$h_w^2 t_w^3 / 36 \cdot 10^6$</td>
<td>$A_f e_f^2 b_f^3 / 12 \cdot 10^6 \left( A_f + 2.6 A_w / A_f + A_w \right)$, for bulb and angle profiles. $b_f^3 t_f e_f^3 / 12 \cdot 10^6$ for Tee profiles.</td>
</tr>
</tbody>
</table>

$A_w = $ net web area, in $[\text{mm}^2]$.  
$A_f = $ net flange area, in $[\text{mm}^2]$. 

### Figure 4.8.4.4.4 Stiffener cross sections

#### 4.8.9 Hull girder ultimate bending capacity

**Symbols**

- $I_{net} = $ net moment of inertia, in $[\text{m}^4]$, of the hull transverse section around its horizontal neutral axis.
- $Z_{b,net}, Z_{d,net} = $ section moduli, in $[\text{m}^3]$, at bottom and deck, respectively.
- $R_{Hi,S} = $ minimum yield stress, in $[\text{N/mm}^2]$, of the material of the considered stiffener.
- $R_{Hi,P} = $ minimum yield stress, in $[\text{N/mm}^2]$, of the material of the considered plate.
- $A_{s,net} = $ net sectional area, in $[\text{cm}^2]$, of stiffener, without attached plating.
- $A_{p,net} = $ net sectional area, in $[\text{cm}^2]$, of attached plating.

**4.8.9.1 General Assumptions**

The method for calculating the ultimate hull girder capacity is to identify the critical failure modes of all main longitudinal structural elements.
4.8.9.1.2 Structures compressed beyond their buckling limit have reduced load carrying capacity. All relevant failure modes for individual structural elements, such as plate buckling, torsional stiffener buckling, stiffener web buckling, lateral or global stiffener buckling and their interactions, are to be considered in order to identify the weakest inter-frame failure mode.

4.8.9.2 Incremental-iterative method

4.8.9.2.1 Assumptions

In applying the incremental-iterative method, the following assumptions are generally to be made:

- The ultimate strength is calculated at hull transverse sections between two adjacent transverse webs.
- The hull girder transverse section remains plane during each curvature increment.
- The hull material has an elasto-plastic behaviour.
- The hull girder transverse section is divided into a set of elements, see 4.8.9.2.2, which are considered to act independently.

According to the iterative procedure, the bending moment \( M_i \) acting on the transverse section at each curvature value \( \chi \) is obtained by summing the contribution given by the stress \( \sigma \) acting on each element. The stress \( \sigma \) corresponding to the element strain, \( \epsilon \), is to be obtained for each curvature increment from the non-linear load-end shortening curves \( \sigma-\epsilon \) of the element.

These curves are to be calculated, for the failure mechanisms of the element, from the formulae specified in 4.8.9.2.3. The stress \( \sigma \) is selected as the lowest among the values obtained from each of the considered load-end shortening curves \( \sigma-\epsilon \).

The procedure is to be repeated until the value of the imposed curvature reaches the value \( \chi \) in [m⁻¹], in hogging and sagging condition, obtained from the following formula:

\[
X_f = \pm 0.003 \frac{M_y}{EI_{y-net}}
\]

where:

\[
M_y = \text{lesser of the values } M_{Y1} \text{ and } M_{Y2}, \text{ in } [\text{kNm}].
\]

\[
M_{Y1} = 10^3 R_{eh} Z_{b-net}.
\]

\[
M_{Y2} = 10^3 R_{eh} Z_{D-net}.
\]

If the value \( X_f \) is not sufficient to evaluate the peaks of the curve \( M_x \), the procedure is to be repeated until the value of the imposed curvature permits the calculation of the maximum bending moments of the curve.

4.8.9.2.2 Procedure

4.8.9.2.2.1 General

The curve \( M_x \) is to be obtained by means of an incremental-iterative approach, summarised in the flow chart in Figure 1.

In this procedure, the ultimate hull girder bending moment capacity, \( M_U \), is defined as the peak value of the curve with vertical bending moment \( M \) versus the curvature \( \chi \) of the ship cross section as shown in Figure 4.8.9.2.2.1. The curve is to be obtained through an incremental-iterative approach.

Each step of the incremental procedure is represented by the calculation of the bending moment \( M \) which acts on the hull transverse section as the effect of an imposed curvature \( \chi \).

For each step, the value \( \chi \) is to be obtained by summing an increment of curvature, \( \Delta \chi \), to the value relevant to the previous step \( \chi_{i-1} \). This increment of curvature corresponds to an increment of the rotation angle of the hull girder transverse section around its horizontal neutral axis.

This rotation increment induces axial strains \( E \) in each hull structural element, whose value depends on the position of the element. In hogging condition, the structural elements above the neutral axis are lengthened, while the elements below the neutral axis are shortened, and vice-versa in sagging condition.

The stress \( \sigma \) induced in each structural element by the strain \( E \) is to be obtained from the load-end shortening curve \( \sigma-\epsilon \) of the element, which takes into account the behaviour of the element in the non-linear elasto-plastic domain.

The distribution of the stresses induced in all the elements composing the hull transverse section determines, for each step, a variation of the neutral axis position due to the nonlinear \( \sigma-\epsilon \) relationship. The new position of the neutral axis relevant to the step considered is to be obtained by means of an iterative process, imposing the equilibrium among the stresses acting in all the hull elements on the transverse section.

Once the position of the neutral axis is known and the relevant element stress distribution in the section is obtained, the bending moment of the section \( M_i \) around the new position of the neutral axis, which corresponds to the curvature \( \chi \) imposed in the step considered, is to be obtained by summing the contribution given by each element stress.

The main steps of the incremental-iterative approach described above are summarised as follows (see also Figure 4.8.9.2.2.1.1.1):

a) step 1: divide the transverse section of hull into stiffened plate elements.

b) step 2: define stress-strain relationships for all elements as shown in Table 4.8.9.2.3.1.

c) step 3: initialise curvature \( \chi \) and neutral axis for the first incremental step with the value of incremental curvature (i.e. curvature that induces a stress equal to 1% of yield strength in strength deck) as:

\[
X_i = \Delta \chi = 0.01 \frac{R_{eh}}{E} \frac{1}{z_D - z_a}.
\]

where:

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$z_o = z$ coordinate, in [m], of strength deck at side.

$z_n = z$ coordinate, in [m], of horizontal neutral axis of the hull transverse section with respect to the reference coordinate system defined in 4.8.1.2.3

d) step 4: calculate for each element the corresponding strain, $\varepsilon_i = \chi (z_i - z_o)$ and the corresponding stress $\sigma_i$

e) step 5: determine the neutral axis $z_{NA,cur}$ at each incremental step by establishing force equilibrium over the whole transverse section as:

$$\Sigma A_{i,net} \sigma_i = \Sigma A_{j,net} \sigma_j \text{ (i-th element is under compression, j-th element under tension).}$$

f) step 6: calculate the corresponding moment by summing the contributions of all elements as:

$$M_U = \sum \sigma_i A_{i,net} (z_i - z_{NA,cur})$$

g) step 7: compare the moment in the current incremental step with the moment in the previous incremental step. If the slope in $M_2$ relationship is less than a negative fixed value, terminate the process and define the peak value $M_U$. Otherwise, increase the curvature by the amount of $\Delta \chi$ and go to Step 4.
4.8.9.2.2 Modelling of the hull girder cross section

Hull girder transverse sections are to be considered as being constituted by the members contributing to the hull girder ultimate strength.

Snipped stiffeners are also to be modelled, taking account that they do not contribute to the hull girder strength.

The structural members are categorised into a stiffener element, a stiffened plate element or a hard corner element.

The plate panel including web plate of girder or side stringer is idealised into a stiffened plate element, an attached plate of a stiffener element or a hard corner element.

The plate panel is categorised into the following two kinds:
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• longitudinally stiffened panel of which the longer side is in ship’s longitudinal direction, and
• transversely stiffened panel of which the longer side is in the perpendicular direction to ship’s longitudinal direction.

4.8.9.2.2.1 Hard corner element:

Hard corner elements are sturdier elements composing the hull girder transverse section, which collapse mainly according to an elasto-plastic mode of failure (material yielding); they are generally constituted by two plates not lying in the same plane.

The extent of a hard corner element from the point of intersection of the plates is taken equal to $20 t_{net}$ on a transversely stiffened panel and to $0.5 s$ on a longitudinally stiffened panel, see Figure 4.8.9.2.2.2-1.

where:

$t_{net} = \text{net thickness of the plate, in [mm]}.$

$s = \text{spacing of the adjacent longitudinal stiffener, in [m].}$

Bilge, sheer strake-deck stringer elements, girder-deck connections and face plate-web connections on large girders are typical hard corners.

4.8.9.2.2.2 Stiffener element:

The stiffener constitutes a stiffener element together with the attached plate.

The attached plate width is in principle:

• equal to the mean spacing of the stiffener when the panels on both sides of the stiffener are longitudinally stiffened, or
• equal to the width of the longitudinally stiffened panel when the panel on one side of the stiffener is longitudinally stiffened and the other panel is of the transversely stiffened, see Figure 4.8.9.2.2.2-1.

4.8.9.2.2.2.3 Stiffened plate element:

The plate between stiffener elements, between a stiffener element and a hard corner element or between hard corner elements is to be treated as a stiffened plate element, see Figure 4.8.9.2.2.2-1.

The typical examples of modelling of hull girder section are illustrated in Figure 4.8.9.2.2.2-2.

Notwithstanding the foregoing principle, these figures are to be applied to the modelling in the vicinity of upper deck, sheer strake and hatch coaming.

![Figure 4.8.9.2.2.2-1](image)

**Figure 4.8.9.2.2.2-1** Extension of the breadth of the attached plating and hard corner element
in case of the knuckle point as shown in Figure 4.8.9.2.2.2-3, the plating area adjacent to knuckles in the plating with an angle greater than 30 degrees is defined as a hard corner. The extent of one side of the corner is taken equal to 20 $t_{net}$ on transversely framed panels and to 0.5 $s$ on longitudinally framed panels from the knuckle point.

• where the plate members are stiffened by non-continuous longitudinal stiffeners, the non-continuous stiffeners are considered only as dividing a plate into various elementary plate panels.

• where the opening is provided in the stiffened plate element, the openings are to be considered in accordance with the requirements of the Register.

• where attached plating is made of steels having different thicknesses and/or yield stresses, an average thickness and/or average yield stress obtained from the following formula are to be used for the calculation.

\[
I_{net} = \frac{t_{1,net}s_1 + t_{2,net}s_2}{s}
\]

where:

\[
R_{eH,p} = \frac{R_{eH,p1}t_{1,net}s_1 + R_{eH,p2}t_{2,net}s_2}{t_{net}s}
\]

where:

$R_{eH,p1}$, $R_{eH,p2}$, $t_{1,net}$, $t_{2,net}$, $s_1$, $s_2$ and $s$ are shown in Figure 4.8.9.2.2.2-4.

4.8.9.2.3 Load-end shortening curves

4.8.9.2.3.1 Stiffened plate element and stiffener element

Stiffened plate element and stiffener element composing the hull girder transverse sections may collapse following one of the modes of failure specified in Table 4.8.9.2.3.1.

• where the plate members are stiffened by non-continuous longitudinal stiffeners, the stress of the element is to be obtained in accordance with 4.8.9.2.3.2 to 4.8.9.2.3.7, taking into account the non-continuous longitudinal stiffener.

In calculating the total forces for checking the hull girder ultimate strength, the area of non-continuous longitudinal stiffener is to be assumed as zero.

• where the opening is provided in the stiffened plate element, the considered area of the stiffened plate element is to be obtained by deducting the opening area from the plating in calculating the total forces for checking the hull girder ultimate strength.

• for stiffened plate element, the effective width of plate for the load shortening portion of the stress-strain curve is to be taken as full
plate width, i.e. to the intersection of another plate or longitudinal stiffener – neither from the end of the hard corner element nor from the attached plating of stiffener element, if any. In calculating the total forces for checking the hull girder ultimate strength, the area of the stiffened plate element is to be taken between the hard corner element and the stiffener element or between the hard corner elements, as applicable.

<table>
<thead>
<tr>
<th>Element</th>
<th>Mode of failure</th>
<th>Curve</th>
<th>defined in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lengthened stiffened plate element or stiffener element</td>
<td>Elasto-plastic collapse</td>
<td>4.8.9.2.3.2</td>
<td></td>
</tr>
<tr>
<td>Shortened stiffener element</td>
<td>Beam column buckling</td>
<td>4.8.9.2.3.3, 4.8.9.2.3.4, 4.8.9.2.3.5, 4.8.9.2.3.6</td>
<td></td>
</tr>
<tr>
<td>Shortened stiffened plate element</td>
<td>Plate buckling</td>
<td>4.8.9.2.3.7</td>
<td></td>
</tr>
</tbody>
</table>

4.8.9.2.3.2 Elasto-plastic collapse of structural elements (hard corner element)

The equation describing the load-end shortening curve $\sigma \varepsilon$ for the elasto-plastic collapse of structural elements composing the hull girder transverse section is to be obtained from the following formula.

$$\sigma = \Phi R_{elHA}$$

where:

$$R_{elHA} = \text{equivalent minimum yield stress, in } [N/mm^2], \text{ of the considered element, obtained by the following formula:}$$

$$R_{elHA} = \frac{R_{cl,H} A_{p-net} + R_{cl,H} A_{s-net}}{A_{p-net} + A_{s-net}}$$

$$\Phi = \text{edge function, equal to:}$$

$$\Phi = -1, \text{ for } \varepsilon < -1$$

$$\Phi = \varepsilon, \text{ for } -1 \leq \varepsilon \leq 1$$

$$\Phi = 1, \text{ for } \varepsilon > 1$$

$$\varepsilon = \text{relative strain, equal to:}$$

$$\varepsilon = \frac{\varepsilon}{\varepsilon_Y}$$

$$\varepsilon_Y = \text{element strain.}$$

$$\varepsilon_Y = \text{strain at yield stress in the element, equal to:}$$

$$\varepsilon_Y = \frac{\sigma_{el}}{E}$$

4.8.9.2.3.3 Beam column buckling

The positive strain portion of the average stress – average strain curve $\sigma_{CRI} - \varepsilon$ based on beam column buckling of plate-stiffener combinations is described according to the following:

$$\sigma_{CRI} = \phi \sigma_{C1} A_{x-net} + A_{pE-net} \frac{A_{x-net} + A_{p-net}}{A_{x-net} + A_{p-net}}$$

where:

$$\phi = \text{edge function, as defined in 4.8.9.2.3.2.}$$

$$\sigma_{C1} = \text{critical stress, in } [N/mm^2], \text{ of the considered element, obtained by the following formula:}$$

$$\sigma_{C1} = \frac{\sigma_{e1}}{\varepsilon} \text{ for } \sigma_{e1} < -\frac{R_{elHB}}{2}$$

$$\sigma_{e1} = R_{elHB} \left(1 - \frac{R_{elHA}}{4\sigma_{e1}}\right) \text{ for } \sigma_{e1} > -\frac{R_{elHB}}{2}$$

$$R_{elHB} = \text{equivalent minimum yield stress, in } [N/mm^2], \text{ of the considered element, obtained by the following formula:}$$

$$R_{elHB} = \frac{R_{cl,H} A_{pE-net} \ell pE + R_{cl,H} A_{s-net} \ell sE + A_{pE-net} \ell pE + A_{s-net} \ell sE}{A_{pE-net} \ell pE + A_{s-net} \ell sE}$$

$$A_{pE-net} = \text{effective area, in } [cm^2], \text{ equal to:}$$

$$A_{pE-net} = 10b_E I_{E-net}$$

$$\ell pE = \text{distance, in } [mm], \text{ measured from the neutral axis of the stiffener with attached plate of width } b_{E1} \text{ to the bottom of the attached plate}$$

$$\ell sE = \text{distance, in } [mm], \text{ measured from the neutral axis of the stiffener with attached plate of width } b_{E1} \text{ to the top of the stiffener}$$

$$\varepsilon = \text{relative strain, as defined in 2.3.2}$$

$$\sigma_{E1} = \text{Euler column buckling stress, in } [N/mm^2], \text{ equal to:}$$

$$\sigma_{E1} = \pi^2 E I_{E-net} \ell sE^2 A_{E-net}^2 10^{-4}$$

$$I_{E-net} = \text{net moment of inertia of stiffeners, in } [cm^4], \text{ with attached plate of width } b_{E1}$$

$$A_{E-net} = \text{net area, in } [cm^2], \text{ of stiffeners with attached plating of width } b_E$$
\[ b_{EI} = \text{effective width corrected for relative strain, in [m], of the attached plating,} \]
\[ b_{EI} = \frac{s}{\beta_e}, \text{ for } \beta_e > 1.0 \]
\[ b_{EI} = s, \text{ for } \beta_e \leq 1.0 \]
\[ \beta_e = 10^{1/2} \frac{s}{t_{net}} \sqrt{\frac{\epsilon_R_{EI,p}}{E}} \]
\[ A_{pE-net} = \text{net area, in [cm}^2], \text{ of attached plating of width } be \text{, equal to:} \]
\[ A_{pE-net} = 10b_t E_{net} \]
\[ be = \text{effective width, in [m], of the attached plating, equal to:} \]
\[ b_e = \frac{2.25}{\beta_e} - 1.25 \beta_e, \text{ for } \beta_e > 1.25 \]
\[ b_e = s, \text{ for } \beta_e \leq 1.25 \]

4.8.9.2.3.4 Torsional buckling

The load-end shortening curve \( \sigma_{CR2} \) for the flexural-torsional buckling of stiffeners composing the hull girder transverse section is to be obtained according to the following formula:

\[ \sigma_{CR2} = \phi \frac{A_{y-net} \sigma_{C2} + A_{pE-net} \sigma_{CP}}{A_{pE-net}} \]

where:

\[ \phi = \text{edge function, as defined in 4.8.9.2.3.2} \]
\[ \sigma_{C2} = \text{critical stress, in [N/mm}^2], \text{ equal to:} \]
\[ \sigma_{C2} = \frac{\sigma_{E2}}{\epsilon} \text{, for } \sigma_{E2} \leq \frac{R_{EI,s}}{2} \epsilon \]
\[ \sigma_{C2} = R_{EI,s} \left( 1 - \frac{R_{EI,s}}{4 \sigma_{E2}} \epsilon \right), \]

for \( \sigma_{E2} > \frac{R_{EI,s}}{2} \epsilon \)
\[ \epsilon = \text{relative strain, as defined in 4.8.9.2.3.2} \]
\[ \sigma_{E2} = \text{Euler column buckling stress, in [N/mm}^2], \text{ taken as } \sigma_{ET} \text{ defined in 4.8.8.4.4.4} \]
\[ \sigma_{CP} = \text{buckling stress of the attached plating, in [N/mm}^2], \text{ equal to:} \]
\[ \sigma_{CP} = \left( \frac{2.25}{\beta_e} - 1.25 \beta_e \right) R_{EI,s}, \text{ for } \beta_e > 1.25 \]
\[ \sigma_{CP} = R_{EI,s}, \text{ for } \beta_e \leq 1.25 \]

\[ \beta_e = \text{coefficient, as defined in 4.8.9.2.3.3} \]

4.8.9.2.3.5 Web local buckling of stiffeners made of flanged profiles

The load-end shortening curve \( \sigma_{CR3} - \epsilon \) for the web local buckling of flanged stiffeners composing the hull girder transverse section is to be obtained from the following formula:

\[ \sigma_{CR3} = \phi \frac{10^4 b_t E_{net} R_{EI,s} + (h_w t_{w-net} + b_f t_{f-net}) R_{EI,s}}{10^4 s t_{net} + h_w t_{w-net} + b_f t_{f-net}} \]

where:

\[ \phi = \text{edge function, as defined in 4.8.9.2.3.2} \]
\[ b_E = \text{effective width, in m, of the attached plating, as defined in 4.8.9.2.3.3} \]
\[ h_{we} = \text{effective height, in [mm], of the web, equal to:} \]
\[ h_{we} = \frac{2.25}{\beta_e} - 1.25 \beta_e, \text{ for } \beta_e \geq 1.25 \]
\[ h_{we} = h_w, \text{ for } \beta_e < 1.25 \]
\[ \beta_e = \frac{h_w}{s}, \text{ for } \beta_e < 1.25 \]
\[ \epsilon = \text{relative strain, as defined in 4.8.9.2.3.2} \]

4.8.9.2.3.6 Web local buckling of stiffeners made of flat bars

The load-end shortening curve \( \sigma_{CR4} - \epsilon \) for the web local buckling of flat bar stiffeners composing the hull girder transverse section is to be obtained from the following formula:

\[ \sigma_{CR4} = \phi \frac{A_{pE-net} \sigma_{CP} + A_{y-net} \sigma_{C4}}{A_{pE-net} + A_{y-net}} \]

where:

\[ \phi = \text{edge function, as defined in 4.8.9.2.3.2} \]
\[ \sigma_{CP} = \text{buckling stress of the attached plating, in [N/mm}^2], \text{ as defined in 4.8.9.2.3.4} \]
\[ \sigma_{C4} = \text{critical stress, in [N/mm}^2], \text{ equal to:} \]
\[ \sigma_{C4} = \frac{\sigma_{E4}}{\eta}, \text{ for } \sigma_{E4} \leq \frac{R_{EI,s}}{2} \epsilon \]
\[ \sigma_{C4} = R_{EI,s} \left( 1 - \frac{R_{EI,s}}{4 \sigma_{E4}} \epsilon \right), \text{ for} \]
\[ \sigma_{E4} > \frac{R_{EI,s}}{2} \epsilon \]
\[ \sigma_{E4} = \text{local Euler buckling stress, in [N/mm}^2], \text{ equal to:} \]
\[ \sigma_{E4} = 160000 \left( \frac{t_{w-net}}{h_w} \right)^2 \]
ε = relative strain, as defined in 4.8.9.2.3.2.

4.8.9.2.3.7 Plate buckling

The load-end shortening curve ε∥+ε for the buckling of transversely stiffened panels composing the hull girder transverse section is to be obtained from the following formula:

$$\sigma_{crs} = \min \left\{ \Phi \beta \left[ \left( \frac{2.25}{\beta_e} - \frac{1.25}{\beta_e} \right) \frac{1}{2} \right] + 0.1 \left( 1 - \frac{2}{\epsilon} \right) \left( 1 + \frac{1}{\beta_e} \right) \right\}$$

where:

Φ = edge function, as defined in 4.8.9.2.3.2.

β = coefficient as defined in 4.8.9.2.3.3.

s = plate breadth, in [m], taken as the spacing between the stiffeners.

ℓ = longer side of the plate, in [m].

4.8.9.3 Alternative methods

4.8.9.3.1 General

4.8.9.3.1.1 Application of alternative methods is to be agreed by the Register prior to commencement. Documentation of the analysis methodology and detailed comparison of its results are to be submitted for review and acceptance. The use of such methods may require the partial safety factors to be recalibrated.

4.8.9.3.1.2 The bending moment-curvature relationship, \( M_{xx} \), may be established by alternative methods. Such models are to consider all the relevant effects important to the non-linear response with due considerations of:

   a) non-linear geometrical behaviour.
   b) inelastic material behaviour.
   c) geometrical imperfections and residual stresses (geometrical out-of-flatness of plate and stiffeners).
   d) simultaneously acting loads:
      - bi-axial compression.
      - bi-axial tension.
      - shear and lateral pressure.
   e) boundary conditions.
   f) interactions between buckling modes.
   g) interactions between structural elements such as plates, stiffeners, girders, etc.
   h) post-buckling capacity.
   i) overstressed elements on the compression side of hull girder cross section possibly leading to local permanent sets/buckle damages in plating, stiffeners etc. (double bottom effects or similar).

4.8.9.3.2 Non-linear finite element analysis

4.8.9.3.2.1 Advanced non-linear finite element analyses models may be used for the assessment of the hull girder ultimate capacity. Such models are to consider the relevant effects important to the non-linear responses with due consideration of the items listed in 4.8.9.3.1.2.

4.8.9.3.2.2 Particular attention is to be given to modelling the shape and size of geometrical imperfections. It is to be ensured that the shape and size of geometrical imperfections trigger the most critical failure modes.

4.9 FUNCTIONAL REQUIREMENTS ON LOAD CASES FOR STRENGTH ASSESSMENT OF CONTAINER SHIPS BY FINITE ELEMENT ANALYSIS

4.9.1 Application

This requirement applies to container ships and ships dedicated to carry their entire cargo in containers.

4.9.2 Principles

The requirements in this section are functional requirements on load cases to be considered on finite element analysis for the structural strength assessment (yielding and buckling).

The procedure for yielding and buckling assessment are to be in accordance with these Rules. All in-plane stress components (i.e. bi-axial and shear stresses) induced by hull girder loads and local loads as specified in this requirement are to be considered.

All aspects and principles not mentioned explicitly in this requirement are to be applied according to the procedure of the Register.

4.9.3 Definitions

4.9.3.1 Global analysis

A global analysis is a finite element analysis, using a full ship model, for assessing the structural strength of global hull girder structure, cross deck structures and hatch corner radii.

4.9.3.2 Cargo hold analysis

A cargo hold analysis is a finite element analysis for assessing the structural strength of the cargo hold primary structural members (PSM) in the midship region.

4.9.3.3 Primary structural members (PSM)

Primary structural members are members of girder or stringer type which provide the overall structural integrity of the hull envelope and cargo hold boundaries, such as:

   i) double bottom structure (bottom plate, inner bottom plate, girders, floors)
   ii) double side structure (shell plating, inner hull, stringers and web frames)
   iii) bulkhead structure
   iv) deck and cross deck structure
4.9.4 Analysis

4.9.4.1 Global analysis

A global analysis is to be carried out for ships of length 290 m or above. Hull girder loads (including torsional effects) are to be considered in accordance with the procedures of the Register. The following methods may be used for global analysis:

Method 1: analysis where hull girder loads only (vertical bending moment, horizontal bending moment and torsional moment) are directly applied to the full ship finite element model

Method 2: analysis where direct loads transferred from direct load analysis are applied to the full ship finite element model.

4.9.4.2 Cargo hold analysis

Cargo hold analysis is to be carried out for ships of length 150 m or above. Local loads such as sea pressure and container loads as well as hull girder loads are to be considered in accordance with the procedures of the Register.

4.9.5 Load principles

4.9.5.1 Wave environment

The ship is to be considered sailing in the North Atlantic wave environment for yielding and buckling assessments. The corresponding vertical wave bending moments are to be in line with the requirements in section 4.8 and the other hull girder loads are to be taken in accordance with the requirements in section 4 of these Rules. The corresponding local loads are to be taken in accordance with these Rules.

4.9.5.2 Ship operating conditions

Seagoing conditions are to be considered. Harbour conditions and special conditions such as flooded conditions, tank testing conditions may be considered in accordance with these Rules.

4.9.6 Load components

4.9.6.1 Global analysis

The load components to be considered in global analysis are shown in Table 4.9.6.1.

### Table 4.9.6.1 Load components to be considered in global analysis

<table>
<thead>
<tr>
<th>Static load</th>
<th>Dynamic load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method 1: Still water vertical bending moment</td>
<td>Wave-induced vertical bending moment</td>
</tr>
<tr>
<td>Still water torsional moment</td>
<td>Wave-induced horizontal bending moment</td>
</tr>
<tr>
<td>Wave-induced torsional moment</td>
<td></td>
</tr>
</tbody>
</table>

| Method 2: Static sea pressure | Wave-induced sea pressure |
| Static container loads | Dynamic loads for hull structure, containers, ballast and fuel oil |
| Static loads for ballast and fuel oil | |
| Self-weight of hull structure | |

4.9.6.2 Cargo hold analysis

The load components to be considered in cargo hold analysis are defined in Table 4.9.6.2.

### Table 4.9.6.2 Load components to be considered in cargo hold analysis

<table>
<thead>
<tr>
<th>Static load</th>
<th>Dynamic load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull girder loads: Still water vertical bending moment</td>
<td>Wave-induced vertical bending moment</td>
</tr>
<tr>
<td>Local loads: Static sea pressure</td>
<td>Wave-induced sea pressure</td>
</tr>
<tr>
<td>Static container loads</td>
<td>Dynamic loads for hull structure, containers, ballast and fuel oil</td>
</tr>
<tr>
<td>Static loads for ballast and fuel oil</td>
<td></td>
</tr>
<tr>
<td>Self-weight of hull structure</td>
<td></td>
</tr>
</tbody>
</table>

(1) For the minimum set of loading conditions specified in Table 4.9.7.2, all ballast and fuel oil tanks in way of the cargo hold model are to be empty. If additional loading conditions other than those given in Table 4.9.7.2 are considered, ballast and fuel oil loads may be taken into consideration at the discretion of the Register.

4.9.7 Loading conditions

4.9.7.1 Global analysis

Loading conditions to be considered for the global analysis are to be in accordance with the Loading Manual and with these Rules.

4.9.7.2 Cargo hold analysis

The minimum set of loading conditions is specified in Table 4.9.7.2. In addition, loading conditions from the Loading Manual are to be considered in the cargo hold analysis where deemed necessary.
### Table 4.9.7.2  Minimum set of loading conditions for cargo hold analysis

<table>
<thead>
<tr>
<th>Loading condition</th>
<th>Draught condition</th>
<th>Container weight</th>
<th>Ballast and fuel oil tanks</th>
<th>Still water hull girder moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full load condition</td>
<td>Scanling draught</td>
<td>Heavy cargo weight(^{(1)}) (40’ containers)</td>
<td>Empty</td>
<td>Permissible hogging</td>
</tr>
<tr>
<td>Full load condition</td>
<td>Scanling draught</td>
<td>Light cargo weight(^{(2)}) (40’ containers)</td>
<td>Empty</td>
<td>Permissible hogging</td>
</tr>
<tr>
<td>Full load condition</td>
<td>Reduced draught(^{(3)})</td>
<td>Heavy cargo weight(^{(1)}) (20’ containers)</td>
<td>Empty</td>
<td>Permissible sagging (minimum hogging)</td>
</tr>
<tr>
<td>One bay empty condition(^{(4)})</td>
<td>Scanling draught</td>
<td>Heavy cargo weight(^{(1)}) (40’ containers)</td>
<td>Empty</td>
<td>Permissible hogging</td>
</tr>
</tbody>
</table>

(1) Heavy cargo weight of a container unit is to be calculated as the permissible stacking weight divided by the maximum number of tiers planned.

(2) Light cargo weight corresponds to the expected cargo weight when light cargo is loaded in the considered holds.

- Light cargo weight of a container unit in hold is not to be taken more than 55% of its related heavy cargo weight (see (1) above).
- Light cargo weight of a container unit on deck is not to be taken more than 90% of its related heavy cargo weight (see (1) above) or 17 ton, whichever is the lesser.

(3) Reduced draught corresponds to the expected draught amidships when heavy cargo is loaded in the considered holds while lighter cargo is loaded in other holds. Reduced draught is not to be taken more than 90% of scantling draught.

(4) For one bay empty condition, if the cargo hold consists of two or more bays, then each bay is to be considered entirely empty in hold and on deck (other bays full) in turn as separate load cases.

### 4.9.8  Wave conditions

#### 4.9.8.1  Global analysis

Wave conditions presumed to lead to the most severe load combinations due to vertical bending moment, horizontal bending moment, torsional moment (and shear forces) are to be considered.

#### 4.9.8.2  Cargo hold analysis

The following wave conditions are to be considered:

(i) Head sea condition yielding the maximum hogging and sagging vertical bending moments.

(ii) Beam sea condition yielding the maximum roll motion. This condition may be disre-
5 SHELL PLATING

5.1 GENERAL

5.1.1 The application of the design formulae given in 5.2.1.2 to ships of less than 90 m in length may be accepted by the Register when a proof of longitudinal strenght has been carried out.

5.1.2 Definitions

Following definitions are used in this Section:

- \( k \) = material factor according to 1.4.2.2;
- \( p_k \) = load on bottom, in [kN/m²], according to 3.2.3;
- \( p_\theta \) = load on sides, in [kN/m²], according to 3.2.2.1;
- \( p_\sigma \) = design pressure for the bow area, in [kN/m²], according to 3.2.2.2;
- \( p_{sl} \) = design slamming pressure, in [kN/m²], according to 3.2.4;
- \( \sigma_1 \) = maximum hull girder bending stress in [N/mm²] for calculating stress and for fatigue analysis at the considered station is given by the following formula:

\[
\sigma_1 = \frac{M_{L}}{W} + 0.75 \left[ M_{wL} + M_{wD} \right] \cdot 10^{3}, \text{[N/mm²]}
\]

where:

- \( W = W_{sl} \), if \( W_{sl} \) section modulus at deck or bottom, in [cm³];
- \( \tau_1 \) = maximum design shear stress due to longitudinal hull girder bending, in [N/mm²], where the wave shear force may be taken as 0.75 \( F_{sl} \);
- \( \sigma_{dop} \) = permissible design stress in [N/mm²];

\[
\sigma_{dop} = \left[ 0.8 + \frac{L}{450} \right] \frac{230}{k}, \text{[N/mm²]}, \text{for} \ L < 90 \text{ m};
\]

\[
\sigma_{dop} = 230/k, \text{[N/mm²]}, \text{for} \ L \geq 90 \text{ m};
\]

- \( t_k \) = corrosion addition according to Section 2.9.1.

5.2 BOTTOM PLATING

5.2.1 Plating within 0,4 L amidships

5.2.1.1 The thickness of the bottom plating of ships up to 90 m in length is not to be less than:

\[
t_1 = 1.9 \cdot n_1 \cdot s \cdot \sqrt{\frac{P_B \cdot k}{\sigma_1}} + t_k, \text{[mm]}
\]

5.2.1.2 The thickness of the bottom plating for ships of 90 m in length and more is not to be less than the following two values:

\[
t_1 = 18.3 \cdot n_1 \cdot s \cdot \sqrt{\frac{P_B}{\sigma_1}} + t_k, \text{[mm]}
\]

\[
t_2 = 1,21 \cdot s \cdot \sqrt{\frac{P_B \cdot k}{\sigma_1}} + t_k, \text{[mm]}
\]

\[
\sigma_a = \sqrt{\sigma_{dop}^2 - 3 \cdot \sigma_1^2 - 0.89 \cdot \sigma_1}, \text{[N/mm²]};
\]

As a first approximation \( \sigma_a \) may be taken as follows:

\[
\sigma_a = \frac{12.6 \cdot \sqrt{L}}{k}, \text{[N/mm²]}, \text{for} \ L < 90 \text{ m};
\]

\[
\sigma_a = \frac{120}{k}, \text{[N/mm²]}, \text{for} \ L \geq 90 \text{ m};
\]

- \( \sigma_1 = 0; \)
- \( s = \text{stiffener’s spacing, [m], according to 1.2.6.} \)

5.2.2 Critical plate thickness

5.2.2.1 For ships, for which proof of longitudinal strength is carried out, the thickness is not to be less than thickness according to the following formula:

\[
t_{krit} = c_1 \cdot 2.32 \cdot s \cdot \sqrt{\sigma_1} + t_k, \text{[mm]}
\]

where:

- \( c_1 = 0.5, \text{for longitudinal framing}; \)
- \( c_1 = 1,0, \text{for longitudinal framing}; \)
- \( \alpha = \text{aspect ratio of plate panel considered}, \frac{s}{l}; \)
- \( c = \text{according to 4.6.2.1.1}; \)
- \( c = 1.0 \text{for longitudinal framing}; \)
- \( \sigma_1 = \text{according to 5.1.2}; \)
- \( s = \text{stiffener’s spacing according to 1.2.6}; \)
- \( l = \text{larger side of panel, [m]}. \)

5.2.2.2 The values obtained from 5.2.2.1 are to be verified according to Section 4.6. For this purpose the stresses due to hull girder bending and the stresses to local loads of the bottom structure are to be considered.

5.2.3 Bottom plating outside 0,4 L amidships

5.2.3.1 The thickness at the ends for 0,1 L from aft end of the length \( L \) and for 0,05 \( L \) from F.P. respectively is not to be less than the value \( t \) obtained according to 5.2.1.2.

5.2.3.2 The thicknesses are to be gradually tapered from the midship thicknesses to the thicknesses at the ends.

Gradual taper is also to be effectuated between the thicknesses required for strengthening of the bottom forward and the adjacent thicknesses.

5.2.4 Bilge strake

5.2.4.1 The thickness of the bilge strake is to be determined as required for the bottom plating according to 5.2.1. The thickness so determined is to be verified for sufficient buckling strength according to Section 4.6, see Table 4.6.2.1-3, load cases 1a, 1b, 2 and 4.

5.2.4.2 If a higher steel grade than A/AH is required for the bilge strake, the width of the bilge strake is not to be less than:

\[
b = 800 + 5 \cdot L, \text{[mm]}
\]

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5.2.5 Flat plate keel and garboard strake

5.2.5.1 The width of the flat plate keel is not to be less than:
\[ b = 800 + 5L, \text{[mm]} \]
and need not be greater than:
\[ b_{\text{max}} = 1800 \text{ mm}. \]
The thickness of the flat plate keel within 0.7 \( L \) amidships is not to be less than:
\[ t_{\text{sec}} = t + 2.0, \text{[mm]} \]
where:
\[ t = \text{thickness of the adjacent bottom plating, in [mm]} \]
5.2.5.2 Where a bar keel is arranged, the adjacent garboard strake is to have the scantling of a flat plate keel.

5.2.6 Minimum thickness

At no point the thickness of the bottom shell plating is to be less than:
\[ t_{\text{min}} = (1.5 - 0.01 \cdot L) \cdot \sqrt{L / k} \text{[mm]}, \text{for } L < 50 \text{ m} \]
\[ t_{\text{min}} = \sqrt{L / k} \text{[mm]}, \text{for } L \geq 50 \text{ m} \]
or 16.0 mm, whichever is less.

5.3 SIDE SHELL PLATING

5.3.1 Side shell plating within 0.4 \( L \) amidships

5.3.1.1 The thickness of the side shell plating for ships up of 90 m in length is not to be less than:
\[ t_{s1} = 1.9 \cdot n_{1} \cdot s \cdot \sqrt{p_{s} / \sigma_{w}} + t_{u}, \text{[mm]} \]
5.3.1.2 The thickness of the side shell plating for ships of 90 m in length and more is not to be less than the greater of the two following values:
\[ t_{s1} = 18.3 \cdot n_{1} \cdot s \cdot \sqrt{p_{s} / \sigma_{w}} + t_{u}, \text{[mm]} \]
\[ t_{s2} = 12.1 \cdot s \cdot \sqrt{p_{s} / \sigma_{w}} + t_{u}, \text{[mm]} \]
\[ \sigma_{w} = \sqrt{\sigma_{\text{dop}}^{2} - 3r_{L}^{2} \cdot 0.89 \cdot \sigma_{35}} \text{[N/mm}^{2}] \]
As first approximation \( \sigma_{w} \) and \( \sigma_{35} \) may be taken as follows:
\[ \sigma_{35} = 0.76 \cdot \sigma_{w} \]
\[ \sigma_{w} = \text{according to 5.2.1.2} \]
\[ \sigma = \frac{55}{k}, \text{[N/mm}^{2}] \]
5.3.1.3 In way of large shear forces, the shear stresses are to be checked in accordance with 4.4.

5.3.2 Plating outside 0.4 \( L \) amidships

5.3.2.1 The plate thickness at the ends for 0.1 \( L \) from aft end of the length \( L \) and for 0.05 \( L \) from forward perpendicular is not to be less than \( t_{2} \) according to 5.3.1.2.
5.3.2.2 The plate thicknesses may be tapered from 0.4 \( L \) amidship the ends.

5.3.3 Minimum thickness

For the minimum thickness of the side shell plating 5.2.6 applies accordingly.

Above a level \( d + C_{w}/2 \) above base line smaller thicknesses than \( t_{\text{min}} \) may be accepted if the stress level permits such reduction.
\[ C_{w} = \text{according to 4.2.2}. \]

5.3.4 Sheerstrake

5.3.4.1 The width of the sheerstrake is not to be less than:
\[ b = 800 + 5L, \text{[mm]} \]
and need not be greater than:
\[ b_{\text{max}} = 1800 \text{ mm}. \]
5.3.4.2 The thickness of the sheer strake within 0.4 \( L \) amidships, in general, not to be less than the greater of the following values:
\[ t = 0.5 (t_{d} + t_{s}), \text{[mm]}; \]
\[ t = t_{s}, \text{[mm]}; \]
\[ t_{d} = \text{required thickness of strength deck}; \]
\[ t_{s} = \text{required thickness of side shell}. \]
5.3.4.3 Where the connection of the deck stringer with the sheerstrake is rounded, the radius is to be at least 15 times the plate thickness.
5.3.4.4 In ships exceeding 60 m in length, in principle welding is not allowed on the upper edge of the sheerstrake within 0.5 \( L \) amidships.

5.3.5 Buckling strength

For ships for which proof of longitudinal strength is required or carried out proof of buckling strength of the side shell is to be provided in accordance with the requirements of Section 4.6.

5.3.6 Side plating of superstructures

The side plating of effective superstructures is to be determined according to 5.3.

The side plating of non-effective superstructures is to be determined according to Section 13. For the definition of effective and non-effective superstructures see Section 13.

5.3.7 Strengthenings for harbour and tug manoeuvres

5.3.7.1 In those zones of the side shell which may be exposed to concentrated loads due to harbour manoeuvres the plate thickness is not to be less than required by 5.3.7.2. These zones are mainly the plates in way of the ship's fore and aft shoulder and in addition amidships. The exact locations where the tugs shall push are to be defined in the building specification. They are to be identified in the shell expansion plan. The length of the strengthened areas shall not be less than approximately 5 m. The height of the strengthened areas shall extend from about 0.5 m above ballast draught to about 4.0 m above scantling draught. Where the side shell thickness so determined exceeds the thickness required by 5.3.1 – 5.3.4 it is recommended to specially mark these areas.
5.3.7.2 The plate thickness in the strengthened areas is to be determined by the following formula:

\[ t = 0.65 \cdot \sqrt{P_{fl} \cdot k} + t_k , \text{[mm]} \]

where:

\[ P_{fl} = \text{local design impact force, [kN]} \]
\[ D/100, \text{[kN]} \] with a minimum of 200 kN and a maximum of 1 000 kN
\[ D = \text{displacement of the ship, [t].} \]

Any reductions in thickness for restricted service are not permissible.

5.3.7.3 In the strengthened areas the section modulus of side longitudinals is not to be less than:

\[ W = 0.35 \cdot P_{fl} \cdot l \cdot k, \text{[cm}^3\text{]} \]

\[ l = \text{unsupported span of longitudinal, [m].} \]

5.3.7.4 Tween decks, transverse bulkheads, stringer and transverse walls are to be investigated for sufficient buckling strength against loads acting in the ship's transverse direction.

5.4 STRENGTHENING OF BOTTOM FORWARD

5.4.1 Arrangement of floors and girders

5.4.1.1 In case of transverse framing, plate floors are to be fitted at every frame. Where the longitudinal framing system or the longitudinal girder system is adopted the spacing of plate floors may be equal to three transverse frame spaces.

5.4.1.2 In case of transverse framing, the spacing of side girders is not to exceed \( L/250 + 0.9 \text{ (m), up to a maximum of 1.4 m.} \)

5.4.1.3 Spacing stated in 5.4.1.1 and 5.4.1.2 are:

- forward of \( x/L = 0.7, \text{for } L \leq 100 \text{ m} \)
- forward of \( x/L = 0.6 + 0.001 L, \text{for } 100 < L \leq 150 \text{ m} \)
- forward of \( x/L = 0.75, \text{for } L > 150 \text{ m} \)

5.4.2 Bottom plating forward of \( x/L = 0.5 \)

5.4.2.1 The thickness of the bottom plating of the flat part of the ship's bottom up to a height of 0.05 \( d_{min} \) or 0.3 m above base line, whichever is the smaller value, is not to be less than:

\[ t = 0.9 \cdot f_2 \cdot s \cdot \sqrt{P_{sl} \cdot k} + t_k , \text{[mm]} \]

where:

\[ f_2 = \text{see Section 2.1.3;} \]
\[ s = \text{stiffeners spacing, in [m];} \]
\[ P_{sl} = \text{according to Section 3.2.4;} \]
\[ t_k = \text{according to Section 2.9.1.} \]

5.4.2.2 Above 0.05 \( d_{min} \) or 0.3 m above base line the plate thickness may gradually be tapered to the rule thickness determined according to 5.2.

5.4.3 Stiffeners forward of \( x/L = 0.5 \)

5.4.3.1 The section modulus of transverse or longitudinal stiffeners is not to be less than:

\[ W = 0.155 \cdot p_{ul} \cdot s \cdot l^2 \cdot k, \text{[cm}^3\text{]} \]

5.4.3.2 The shear area and the cross sectional area of the welded connection is not to be less than:

\[ A = 0.028 \cdot p_{ul} \cdot s \cdot (l - 0.5 \cdot s) \cdot k, \text{[cm}^2\text{]} \]

5.4.4 Strengthening in way of propellers and propeller prackets

5.4.4.1 In way of propeller bracket and shaft bosssings, the thickness of the shell plating is to be the same as required for 0.4 \( L \) amidships, in way of the struts, the shell plating is to have a strengthened plate of 1.5 times the midship thickness.

5.4.4.2 Where propeller revolution are exceeding 300 rpm (approxim.) particularly in case of that bottoms intercostal carlings are to be fitted above or forward of the propeller in order to reduce the size of the bottom plate panels (see also Section 7.1.1.2.3).

5.5 BILGE KEEL

5.5.1.1 Where bilge keels are provided they are to be continuous over their full length. the bilge keels are to be welded to continuous flat bars which are welded to the shell plating with their flat side.

5.5.1.2 The ends of the bilge keels are to have soft transition zones according to Fig. 5.5.1.2, and they shall terminate above an internal stiffening element.
Any scallops or cut-outs in the bilge keels are to be avoided.

5.6 BULWARK

5.6.1 The thickness of bulwark plating is not to be less than:

\[ t = 0.75 - \frac{L}{1000} \sqrt{L}, \text{ [mm], for } L \leq 100 \text{ m} \]

\[ t = 0.65 \sqrt{L}, \text{ [mm], for } L > 100 \text{ m} \]

where:

\[ p_{\text{min}} = 15 \text{ kN/m}^2; \]

\[ e = \text{spacing of stays, in [m]}; \]

\[ l = \text{length of stay, in [m]}. \]

The stays are to be fitted above deck beams, or other transversal members. Where deck is longitudinally framed, ends of stays have to finish above longitudinal members.

5.6.2 An adequate number of expansion joints is to be provided in the bulwark.

The number of expansion joints for ships exceeding 60 m in length should not be less than:

\[ n = \frac{L}{40}, \text{ but need not be greater than } n = 5. \]

5.6.3 Openings in the bulwarks shall have sufficient distance from the end bulkheads of superstructures. Connection of bulwarks to superstructure sides is to be constructed carefully.

5.7 OPENINGS IN THE SHELL PLATING

5.7.1 General

5.7.1.1 Where openings are cut in the shell plating for windows or side scuttles, hawses, scuppers, sea valves etc., they are to have well rounded corners. If they exceed 500 mm in width in ships up to \( L = 70 \) metres, and 700 mm in ships having a length \( L \) of more than 70 metres, the openings are to be surrounded by framing, a thicker plate or a doubling.

5.7.1.2 Above openings in the sheer strake within 0.4 \( L \) amidships, generally a strengthened plate or a continuous doubling is to be provided compensating the omitted plate sectional area. For shell doors and similar large openings see Rules, Part 3 – Hull Equipment, 7.4. Special strengthening is required in the range of openings at ends of superstructures.

5.7.1.3 The shell plating in way of the hawse pipes is to be reinforced.
5.7.2  Pipe connections at the shell plating

Scupper pipes and valves are to be connected to the shell by weld flanges. Instead of weld flanges short flanged sockets of adequate thickness may be used if they are welded to the shell in an appropriate manner. Reference is made to Rules, Part 3 – Hull equipment, 7.4 and Part 8 – Piping, 1.5.

Construction drawings are to be submitted for approval.
6 DECKS

6.1 STRENGTH DECK

6.1.1 General, definitions

6.1.1.1 The strength deck is:
- the uppermost continuous deck which is forming the upper flange of the hull structure,
- a superstructure deck which extends into 0.4 \( L \) amidships and the length of which exceeds 0.15 \( L \).
- a quarter deck or the deck of a sunk superstructure which extends into 0.4 \( L \) amidships.

6.1.1.2 In way of a superstructure deck which is to be considered as a strength deck, the deck below the superstructure deck is to have the same scantlings as a 2nd deck, and the deck below this deck the same scantlings as a 3rd deck. The thicknesses of a strength deck plating are to be extended into the superstructure for a distance equal to the width of the deck plating abreast the hatchway. For strengthening of the stringer plate in the breaks, see Section 13.

6.1.1.3 If the strength deck is protected by sheathing a smaller corrosion addition \( t_k \) than required by Section 2.9 may be permitted. Where a sheathing other than wood is used, attention is to be paid that the sheathing does not affect the steel. The sheathing is to be effectively fitted to the deck.

6.1.1.4 For ships with a speed \( v = 1.6 \sqrt{L} \), [kn], additional strengthening of the strength deck and the sheerstrake may be required.

6.1.1.5 The following definitions apply throughout this Section:
\[
\begin{align*}
k & = \text{material factor according to 1.4.2.2} \\
p_D & = \text{load according to 3.2.1.1} \\
p_L & = \text{load according to 3.3.1.2} \\
t_k & = \text{corrosion addition according to 2.9.1}
\end{align*}
\]

6.1.2 Connection between strength deck and sheerstrake

6.1.2.1 The welded connection between strength deck and sheerstrake may be effected by fillet welds according to Section 15. Where the plate thickness exceeds approximately 25 mm, a fully welded connection according to Section 15 shall be carried out instead fillet welds.

In special cases a fully welded connections may also be required, where the plate thickness is less than 25 mm.

6.1.2.2 Where the connection of deck stringer to sheerstrake is rounded, the requirements of 5.3.3 are to be observed.

6.1.3 Openings in the strength deck

6.1.3.1 All openings in the strength deck are to have well rounded corners. Circular openings are to be edge-reinforced. The sectional area of the face bar is not to be less than:

\[
A = 0.25 \cdot d_o \cdot t, \, [cm^2]
\]

\( d_o \) = diameter of opening, in [cm],
\( t \) = deck thickness, in [cm].

The distance between the outer edge of opening and the ship's side is not to be less than the opening diameter.

The reinforcing face bar may be dispensed with, where the diameter is less than 300 mm and the smallest distance from another opening is not less than 5 x diameter of the smaller opening.

6.1.3.2 The hatchway corners are to be surrounded by strengthened plates which are to extend over at least one frame spacing fore-and-aft and athwartships. Within 0.5 \( L \) amidships, the thickness of the strengthened plate is to be equal to the deck thickness abreast the hatchway plus the deck thickness between the hatchways. Outside 0.5 \( L \) amidships the thickness of the strengthened plates need not exceed 1.6 times the thickness of the deck plating abreast the hatchway.

6.1.3.3 The hatchway corner radius is not to be less than:

\[
r = n \cdot b \cdot (1 - b/B), \, [m]
\]

where:
\[
\begin{align*}
n & = b/200, \text{ but not lesser than 0.1 and not greater than 0.25;} \\
l & = \text{length of hatchway, in [m];} \\
b & = \text{breadth in [m], of hatchway or total breadth of hatchways in case of more than one hatchway;} \\
B & = \text{need not be taken smaller than 0.4.}
\end{align*}
\]

6.1.3.4 Where the hatchway corners are elliptic or parabolic, strengthening according to 6.1.3.2 is not required. The dimensions of the elliptical and parabolical corners shall be as shown in Fig. 6.1.3.4.

\[
a \geq 2c \]

\( c \) = \( r \) according to 6.1.3.3

Figure 6.1.3.4

Where smaller values are taken for \( a \) and \( c \), reinforced insert plates are required which will be considered in each individual case.

6.1.3.5 For ships with large deck openings the design of the hatch corners will be specially considered on the basis of the stresses due to longitudinal hull girder bending, torsion and transverse loads.

6.1.3.6 At the corners of the engine room casings, strengthenings according to 6.1.3.2 may also be required, depending on the position and the dimensions of the casing.
6.1.4 **Scantlings of strength deck of ships up to 65 m length**

The scantlings of the strength deck for ships, for which proof of longitudinal strength is not required, i.e. in general for ships with length \( L \leq 65 \) [m], the sectional area of the strength deck within 0,4 \( L \) amidships is to be determined such that the requirements for the minimum midship section modulus according to Section 4.3.4 are complied with.

The thickness within 0,4 \( L \) amidships is not to be less than the minimum thickness according to 6.1.7. For the ranges 0,1 \( L \) from ends the requirements of 6.1.7 apply.

6.1.5 **Scantlings of strength deck of ships of more than 65 m in length**

6.1.5.1 **Deck sectional area**

The deck sectional area abreast the hatchways, if any, is to be so determined that the section moduli of the cross sections are in accordance with the requirements of Section 4.3.

6.1.5.2 **Critical plate thickness, buckling strength**

6.1.5.2.1 The critical plate thickness is to be determined according to Section 5.2.2 analogously.

6.1.5.2.2 In regard to buckling strength the requirements of Section 5.2.2 apply analogously.

6.1.5.3 **Deck stringer**

If the thickness of the strength deck plating is less than that of the side shell plating, a stringer plate is to be fitted having the width of the sheerstrake and the thickness of the side shell plating.

6.1.6 **Minimum thickness**

The thickness of deck plating for 0,4 \( L \) amidships outside line of hatchways is not to be less than the greater of the two following values:

\[
\begin{align*}
\tau_{\text{mid}} &= (4,5 + 0,05 L) \cdot \sqrt{k}, \quad \text{[mm]} \\
\tau_{\text{0,1L}} &= 1,21 \cdot s \cdot \sqrt[3]{p_D \cdot k + t_u}, \quad \text{[mm]}
\end{align*}
\]

or

\[
\tau_{\text{0,1L}} = 1,1 \cdot s \cdot \sqrt[3]{p_L \cdot k + t_u}, \quad \text{[mm]}
\]

\[
\tau_{\text{0,1Lmin}} = (5,5 + 0,02 \cdot L) \cdot \sqrt{k}, \quad \text{[mm]}
\]

\( L \) need not be taken greater than 200 m.

6.1.7 **Thickness at ship’s ends and between hatchways**

6.1.7.1 The thickness of strength deck plating for 0,1 \( L \) from the ends and between hatchways is not to be less than:

\[
\begin{align*}
\tau_{\text{0,1L}} &= 1,21 \cdot s \cdot \sqrt[3]{p_D \cdot k + t_u}, \quad \text{[mm]} \\
\tau_{\text{0,1L}} &= 1,1 \cdot s \cdot \sqrt[3]{p_L \cdot k + t_u}, \quad \text{[mm]}
\end{align*}
\]

\[
\tau_{\text{0,1Lmin}} = (5,5 + 0,02 \cdot L) \cdot \sqrt{k}, \quad \text{[mm]}
\]

\( L \) need not be taken greater than 200 m.

6.1.7.2 Between the midship thickness and the end thickness, the thicknesses are to be tapered gradually.

6.1.7.3 The strength of deck structure between hatch openings has to withstand compressive transversely acting loads. Proof of buckling strength is to be provided according to Section 4.6.

6.2 **LOWER DECKS**

6.2.1 **Thickness of decks for cargo loads**

6.2.1.1 The plate thickness of decks loaded with cargo is not to be less than:

\[
t = 1,1 \cdot s \cdot \sqrt[3]{p_L \cdot k + t_u}, \quad \text{[mm]}
\]

but not less than:

\[
\tau_{\text{min}} = (5,5 + 0,02 L) \cdot \sqrt{k}, \quad \text{[mm]}, \text{for the 2}\text{nd deck;}
\]

\[
\tau_{\text{min}} = 6,0 \text{mm}, \text{for other lower decks.}
\]

\( L \) need not be taken greater than 200 mm.

6.2.2 **Thickness of decks for wheel loading**

6.2.2.1 The thickness of deck plating for wheel loading is to be determined by the following formula:

\[
t = c \cdot \sqrt{P \cdot (1+a_t)} \cdot \sqrt{k} + t_u, \quad \text{[mm]}
\]

where:

\[
P = \text{load, in [kN], of one wheel or group of wheels on a plate panel } u \cdot v;
\]

\[
Q = \text{axle load, in [kN].}
\]

For fork lift trucks \( Q \) is generally to be taken as the total weight of the fork lift truck and cargo on it.

\[
n = \text{number of wheels (or group of wheels) per axle;}
\]

\[
a_t = \text{according to 3.3.1.1;}
\]

\[
a_t = 0 - \text{for harbour conditions;}
\]

\[
c = \text{factor according to the following formulae:}
\]

- for \( u/v = 1 \):

\[
c = 1,87 - \frac{a}{A} \left[ 3,4 - 4,4 \frac{a}{A} \right], \quad \text{for } 0 < \frac{a}{A} < 0,3
\]

\[
c = 1,20 - 0,40 \frac{a}{A}, \quad \text{for } 0,3 \leq \frac{a}{A} \leq 1,0
\]

- for \( u/v \geq 2,5 \):

\[
c = 2,00 - \frac{a}{A} \left[ 5,2 - 7,2 \frac{a}{A} \right], \quad \text{for } 0 < \frac{a}{A} < 0,3
\]

\[
c = 1,20 - 0,517 \frac{a}{A}, \quad \text{for } 0,3 \leq \frac{a}{A} \leq 1,0
\]

For intermediate values of \( u/v \) the factor \( c \) is to be obtained by direct interpolation.

\[
a = \text{print area of wheel or group of wheels;}
\]

\[
A = \text{area of plate panel } u \cdot v \text{ according to Fig. 6.2.2.1;}
\]

\[
v = \text{width of smaller side of plate panel;}
\]

\[
u = \text{width of larger side of plate panel;}
\]

\( A \) need not be taken greater than 2,5 \( \cdot v^2 \).

In case of narrowly spaced wheels these may be grouped together to one wheel print area.
8.4 RULES FOR THE CLASSIFICATION OF SHIPS

PART 2

6.2.2.2 Where the wheel print area is not known, it may approximately be determined as follows:

\[ a = \frac{100 \cdot P}{p}, \]  [cm²]

where:

\[ p = \text{specific wheel pressure according to Table 6.2.2.2} \]

Table 6.2.2.2

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Specific wheel pressure ( p ) [bar]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pneumatic tyres</td>
</tr>
<tr>
<td>private cars</td>
<td>2</td>
</tr>
<tr>
<td>trucks</td>
<td>8</td>
</tr>
<tr>
<td>trailer</td>
<td>8</td>
</tr>
<tr>
<td>fork lift trucks</td>
<td>6</td>
</tr>
</tbody>
</table>

6.2.2.3 In deck beams and girders, the stress is not to exceed \( 165/k, [\text{N/mm}^2] \).

6.2.3 Machinery decks and accommodation decks

6.2.3.1 The scantlings of machinery decks and other accommodation decks have to be based on the loads given in Section 3.3.3.

6.2.3.2 The thickness of the plates is not to be less than:

\[ t = 1.1 \cdot \sqrt[p - k + t_k]{\text{[mm]}} \]

\[ t_{\text{min}} = 5 \text{ mm}. \]

6.2.3.3 At the corners of the engine room casings, strengthenings according to 6.1.3 may also be required depending on the position and the dimensions of the casing.

6.3 HELICOPTER DECKS

6.3.1 General

The starting/landing zone is to be dimensioned for the largest helicopter type expected to use the helicopter deck.

Where the conditions of operation are not known, the data in 6.3.2 may be used as a basis.

6.3.2 Load assumptions

6.3.2.1 For helicopter lashed on deck (LH1), with the following vertical forces acting simultaneously:

a) Wheel and/or ski force \( P \) acting at the points resulting from the lashing position and distribution of the wheels and/or supports according to helicopter construction:

\[ P = 0.5 \cdot G (1 + a_v), [\text{kN}], \]

where:

\[ G = \text{maximum permissible take-off weight, in [kN]}; \]
\[ a_v = \text{according to 3.3.1.1}; \]
\[ P = \text{evenly distributed force over the contact area} \]
\[ a = 30 \times 30 \text{ cm for single wheel or according to data supplied by helicopter manufacturers; for dual wheels or skies to be determined individually in accordance with given dimensions.} \]

b) Force due to weight of helicopter deck \( M_{\text{hd}} \) as follows:

\[ M_{\text{hd}} (1 + a_v), [\text{kN}]. \]

c) Evenly distributed load over the entire landing deck determined as follows:

\[ p = 2.0 \text{ kN/m}^2. \]

6.3.2.2 Helicopter lashed on deck (LH2), with the following horizontal and vertical forces acting simultaneously:

a) Forces acting horizontally:

\[ P_{H} = 0.6 (G + M_{\text{hd}}) + W, [\text{kN}], \]

where:

\[ W = \text{wind load, taking into account the lashed helicopter;} \]
\[ \text{wind velocity} \nu_w = 50 \text{ m/s}. \]

b) Forces acting vertically:

\[ P_v = G + M_{\text{hd}}, [\text{kN}]. \]

6.4.3.2.3 Normal landing impact (LH3), with forces acting simultaneously:

a) Wheel and/or ski load \( P \) at two points simultaneously, at an arbitrary point of the helicopter deck (landing zone + safety zone):

\[ P = 0.75 G, [\text{kN}] \]

b) Evenly distributed load for taking into account snow or other environmental loads:

\[ p = 0.5 \text{ kN/m}^2. \]

c) Weight of the helicopter deck

d) Wind load in accordance with the wind velocity admitted for helicopter operation(\( \nu_w \)). Where no data are available, \( \nu_w = 25 \text{ m/s} \) may be used.

6.3.3 Scantlings of structural members

6.3.3.1 Stresses and forces in the supporting structure are to be evaluated by means of direct calculations.

6.3.3.2 Permissible stresses for stiffeners, girders and substructure:
\[ \sigma_p = \frac{235}{k \cdot \nu_s} \text{ N/mm}^2; \]

where

\[ \nu_s = \text{safety factors according to Table 6.3.3.2.} \]

### Table 6.3.3.2

<table>
<thead>
<tr>
<th>Structural element</th>
<th>( \nu_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>stiffeners (beams, deck longitudinals)</td>
<td>1.25, 1.1</td>
</tr>
<tr>
<td>main girders (deck girders)</td>
<td>1.45, 1.45</td>
</tr>
<tr>
<td>load-bearing structure (pillar system)</td>
<td>1.7, 2.0</td>
</tr>
</tbody>
</table>

6.3.3.3 The thickness of the plating is to be determined according to 6.2.2 where the coefficient \( c \) may be reduced by 5%.

6.3.3.4 Proof of sufficient buckling strength is to be carried out in accordance with Section 4.6 for structures subjected to compressive stresses.
7 BOTTOM STRUCTURES

7.1 SINGLE BOTTOM

7.1.1 Floor plates

7.1.1.1 General

Floor plates are to be fitted at every frame. The connection of the frames and floors are to be in accordance with Section 15.

Deep floors, particularly in the after peak, are to be provided with buckling stiffeners.

The floor plates are to be provided with limbers to permit the water to reach the pump suctions.

7.1.1.2 Scantlings

7.1.1.2.1 Floor plates in the cargo hold area

On ships without double bottom or outside any double bottom the scantlings of floor plates fitted between afterpeak bulkhead and collision bulkhead are to be determined according to the following formulae:

a) The section modulus is not to be less than:

\[ W = k_2 \cdot d \cdot s \cdot l^2 \quad [\text{cm}^3], \]

where:

- \( s \) = spacing of plate floors, [m];
- \( l \) = unsupported span, [m], generally measured on upper edge of floor from side shell to side shell;
- \( l_{\text{min}} = 0.7 B \), if the floors are not supported at longitudinal bulkheads;
- \( k_2 = 7.5 \) for spaces which may be empty at full draught, e.g. machinery spaces, storerooms, etc.
- \( k_2 = 4.5 \) elsewhere.

b) The depth of the floor plates is not to be less than:

\[ h = 55 \cdot B - 45 \quad [\text{mm}], \]

but not less than:

\[ h_{\text{min}} = 180 \quad \text{mm}. \]

In ships having rise of floor, at 0.1 \( l \) from the ends of the length \( l \) where possible, the depth of the floor plate webs is not to be less than half the required depth.

In ships having a considerable rise of floor, the depth of the floor plate webs at the beginning of the turn of bilge is not to be less than the depth of the frame.

c) The web thickness is not to be less than:

\[ t = \frac{h}{100} + 3 \quad [\text{mm}] \]

The web sectional area is to be determined according to 7.2.6.2.2. analogously.

7.1.1.2.2 The face plates of the floor plates are to be continuous over the span \( l \). If they are interrupted at the centre keelson, they are to be connected to the centre keelson by means of full penetration welding.

7.1.1.2.3 Floor plates in the peaks

The thickness of the floor plates in the peaks is not to be less than:

\[ t = 0.035L + 5.0 \quad [\text{mm}] \]

The thickness, however, need not be greater than required by 7.2.6.2.1.

The floor plate height in the fore peak is not to be less than:

\[ h = 0.06 \cdot D + 0.7 \quad [\text{m}] \]

The floor plates in the afterpeak are to extend over the stern tube.

7.1.2 Longitudinal girders

7.1.2.1 All single bottom ships are to have a centre girder keelson. Where the breadth measured on top of floors does not exceed 9 m one additional side girder is to be fitted, and two side girders where the breadth exceeds 9 m. Side girders are not required where the breadth does not exceed 6 m.

7.1.2.2 For the spacing of side girders from each other and from the centre girder in way of bottom strengthening forward see Section 5.4.

7.1.2.3 The centre and side girders are to extend as far forward and aft as practicable. They are to be connected to the girders of a non-continuous double bottom or are to be scarped into the double bottom by two frame spacings.

7.1.2.4 Centre girder

The web thickness within 0.7 \( L \) amidships is not to be less than:

\[ t = 0.07L + 5.5 \quad [\text{mm}] \]

The sectional area of the face plate within 0.7 \( L \) amidships is not to be less than:

\[ A_f = 0.7L + 12 \quad [\text{cm}^2] \]

Towards the ends the thickness of the web plate as well as the sectional area of the top plate may be reduced by 10%. Lightening holes are to be avoided.

7.1.2.5 Side girder

The web thickness within 0.7 \( L \) amidships is not to be less than:

\[ t = 0.04L + 5 \quad [\text{mm}] \]

The sectional area of the face plate within 0.7 \( L \) amidships is not to be less than:

\[ A_f = 0.2L + 6 \quad [\text{cm}^2] \]

Towards the ends, the thickness of the web plate and the sectional area of the face plate may be reduced by 10%.

7.2 DOUBLE BOTTOM

7.2.1 General

7.2.1.1 On cargo ships a double bottom is to be fitted extending from the collision bulkhead to the afterpeak bulkhead, as far as this is compatible with service of the ship.

For ships of less than 500 tons gross tonnage and fishing vessels double bottom are not required. For oil tankers see Section 18 and for passenger ships see Section 21.
7.2.1.2 In single hull ships the inner bottom is to be continued out to the ship's side as to protect the bottom to the turn of the bilge. In double hull ships the inner bottom is to be extended to the inner hull.

7.2.1.3 Small wells for hold drainage may be arranged in the double bottom, their depth, however, shall be as small as practicable. A well extending to the outer bottom, may, however, be permitted at the after end of the shaft tunnel.

7.2.1.4 Other wells may be permitted if their arrangement does not reduce the level of protection equivalent to that afforded by a double bottom complying with this Section.

7.2.1.5 In fore-and-aftpeak a double bottom need not to be arranged.

7.2.1.6 If the double bottom is not subdivided by watertight side girders, the centre girder should be watertight at least for 0,5 · L amidships.

7.2.1.7 For bottom strengthening forward, see Section 5.4.

For the double bottom structure of bulk carriers, see Section 17.2.4.

7.2.1.9 Double bottoms in passenger ships and cargo ships other than tankers

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

7.2.1.9.2 Where a double bottom is required to be fitted the inner bottom shall be continued out to the ship's sides in such a manner as to protect the bottom to the turn of the bilge.

Such protection will be deemed satisfactory if the inner bottom is not lower at any part than a plane parallel with the keel line and which is located not less than a vertical distance h measured from the keel line, as calculated by the formula:

\[
h = B/20
\]

However, in no case is the value of h to be less than 760 mm, and need not be taken as more than 2,000 mm.

7.2.1.9.3 Small wells constructed in the double bottom in connection with drainage arrangements of holds, etc., shall not extend downward more than necessary. A well extending to the outer bottom is, however, permitted at the after end of the shaft tunnel.

Other wells (e.g., for lubricating oil under main engines) may be permitted by the Register if satisfied that the arrangements give protection equivalent to that afforded by a double bottom complying with this regulation. In no case shall the vertical distance from the bottom of such a well to a plane coinciding with the keel line be less than 500 mm.

7.2.2 Centre girder

7.2.2.1 Center girder are to be extended as far as possible toward the aft and forward and to be connected with the stem.

Lightening holes in the centre girder are generally permitted only outside 0,75 L amidships. Their depth is not to exceed half the depth of the centre girder and their lengths are not to exceed half the frame spacing.

7.2.2.2 Scantlings

Depth and thickness of the centre girder are determined as follows:

a) The depth of the centre girder is not to be less than:

\[
h_{db} = 350 + 45 \cdot B \quad \text{[mm]}
\]

\[
h_{\text{min}} = 600 \quad \text{[mm]}
\]

where longitudinal wing bulkheads are fitted, the distance between the bulkheads may be taken instead of B, not less than 0,8 · B.

b) The thickness of the centre girder is not to be less than:

\[
t = \frac{h_{db}}{100} \left( \frac{h_{db} + 1,0}{L} \right) \sqrt{k} \quad \text{[mm], for } h_{db} \leq 1200 \text{ mm}
\]

\[
t = \frac{h_{db}}{120} \left( \frac{h_{db} + 3,0}{L} \right) \sqrt{k} \quad \text{[mm], for } h_{db} > 1200 \text{ mm}
\]

where:

\[
h_a = \text{depth of centre girder as built, in } \text{[mm]}, \text{where } h_a \text{ is larger than } h_{db}:
\]

\[
\frac{h_{db}}{h_a} < 1,0
\]

- 0,15 · L at the ends:

\[
t_1 = 0,9 \cdot t
\]

- thickness within 0,7 · L amidships, [mm].

7.2.3 Side girders

7.2.3.1 Arrangement

At least one side girder shall be fitted in the engine room and in way of 0,25 L aft of F.P. In the other parts of the double bottom, one side girder shall be fitted where the horizontal distance between ship's side and centre girder exceeds 4,5 m. Two side girders shall be fitted where the distance exceeds 8 m, and three side girders where it exceeds 10,5 m. The distance of the side girders from each other and from centre girder and ship's side respectively shall not be greater than:

- 1,8 m in the engine room within the breadth of engine seatings,
- 4,5 m where one side girder is fitted in the other parts of double bottom,
- 4,0 m where two side girders are fitted in the other parts of double bottom,
- 3,5 m where three side girders are fitted in the other parts of double bottom.

7.2.3.2 Scantlings

The thickness of the side girders is not to be less than:

\[
t = \frac{h_{db}^2}{120 \cdot h_b} \sqrt{k} \quad \text{[mm],}
\]

\[
h_{db} = \text{depth of the centre girder, in [mm] according to 7.2.2.2.}
\]
7.2.4 Inner bottom

7.2.4.1 The thickness of the inner bottom plating is not to be less than:

\[ t = 1.1 \cdot s \sqrt{p \cdot k} + h \quad [\text{mm}], \]

where:

- \( p = \) design pressure in [\text{kN/m}^2].
- \( p \) is the greater of the following values:
  - \( p_1 = 10 \cdot (d - h_{db}) \)
  - \( p_2 = 10 \cdot h, \) where the inner bottom forms a tank boundary
- \( p_3 = p_{sa} \) according to Section 3.3.2.1;
- \( h = \) distance from top of overflow pipe to inner bottom, in [\text{m}];
- \( h_{db} = \) double bottom height, in [\text{m}].

7.2.4.2 If no ceiling is fitted on the inner bottom, the thickness determined in accordance with 7.2.4.1 for \( p_1 \) or \( p_2 \) is to be increased by 2 mm. This increase is not required for container ships.

7.2.4.3 For strengthening in the range of grabs, see Section 17.

7.2.4.4 For strengthening of inner bottom in machinery spaces, see Section 7.3.

7.2.5 Double bottom tanks

7.2.5.1 Fuel and lubricating oil tanks

7.2.5.1.1 In double bottom tanks, oil fuel may be carried, the flash point of which exceeds 60°C.

7.2.5.1.2 Where practicable, lubricating oil discharge tanks or circulating tanks shall be separated from the shell.

7.2.5.1.3 For the separation of oil fuel tanks from tanks for other liquids, see Section 11.1.4.

7.2.5.1.4 Requirements for air, overflow and sounding pipes, are stated in Rules, Part 8 – Piping, Section 5.

7.2.5.1.5 Where tanks are intended to carry heated liquids thermal stress calculations may be required.

7.2.5.1.6 Manholes for access to oil fuel double bottom tanks situated under cargo oil tanks are not permitted in cargo oil tanks nor in the engine room.

7.2.5.1.7 The thickness of structures is not to be less than the minimum thickness according to Section 11.

7.2.5.2 See chests

7.2.5.2.1 The plate thickness of sea chests is not to be less than:

\[ t = 12 \cdot s \sqrt{p \cdot k} + h \quad [\text{mm}] \]

where:

- \( s = \) spacing of stiffeners, in [\text{m}];
- \( p = \) blow out pressure at the safety valve, in [\text{bar}], but not to be less than 2 bar.

7.2.5.2.2 The section modulus of sea chest stiffeners is not to be less than:

\[ W = 56 \cdot s \cdot p \cdot l^2 \cdot k \quad [\text{cm}^3], \]

where:

- \( l = \) unsupported span of stiffeners, in [\text{m}],
- \( s, p = \) see 7.2.5.2.1.

7.2.5.2.3 The sea-water inlet openings in the shell are to be protected by gratings.

7.2.5.2.4 A cathodic corrosion protection with galvanic anodes made of zinc or aluminium is to be provided in sea chests. For the suitably coated plates a current density of 30 \( \mu \text{A/m}^2 \) is to be provided and for the cooling area a current density of 180 \( \mu \text{A/m}^2 \).

7.2.6 Double bottom, transverse framing system

7.2.6.1 Plate floors

7.2.6.1.1 It is recommended to fit plate floors at every frame in the double bottom if transverse framing is adopted.

7.2.6.1.2 Plate floors are to be fitted at every frame:

- in way of strengthening of the bottom forward according to Section 5.4;
- in the engine room;
- under the boiler bearers;

7.2.6.1.3 Plate floors are to be fitted:

- under bulkheads;
- under corrugated bulkheads.

7.2.6.1.4 For the remaining part of the double bottom, the spacing of plate floors shall not exceed approximately 3 m.

7.2.6.2 Scantlings

7.2.6.2.1 The thickness of plate floors is not to be less than:

\[ t_p = t - 2.0 \sqrt{k} \quad [\text{mm}] \]

\[ t = \text{thickness of centre girder according to 7.2.2.2} \]

\[ t_{p\text{max}} = 16.0 \text{ mm} \]

If the floor depth exceeds the height \( h_{db} \) according to 7.2.2.2., the thickness may be reduced, provided that the buckling strength is considered according to Section 4.6.

7.2.6.2.2 The sectional area of the plate floors is not to be less than:

\[ A_w = f_1 \cdot d \cdot l \cdot s (1 - 2 b_1/l) \cdot k \quad [\text{cm}^2] \]

where:

- \( s = \) spacing of plate floors, in [\text{m}];
- \( l = \) unsupported span of stiffeners, in [\text{m}],
- \( s, p = \) see 7.2.5.2.1.
The brackets are, in general, to be of the same
material as the plate floors, and the thickness is to be 0.75 of the
mean of brackets.

Bracket floors consist of bottom frames at the
shell plating and inner bottom by continuous fillet weld-
ing.

Where plate floors are not required according to
7.2.6.2, the section modulus of bottom and inner bot-
tom frames is to be determined according to 11.2.3.

Bracket floors are to be determined according to 11.2.3.

In way of strengthening of bottom forward ac-
Cording to 5.4, the plate floors are to be connected to the
shell plating and inner bottom by continuous fillet weld-
ing.

7.2.6.3.1 Where plate floors are not required according to
7.2.6.1, bracket floors may be fitted.

Bracket floors consist of bottom frames at the
shell plating and reversed frames at the inner bottom, at-
tached to centre girder, side girders and ship's side bilge by
means of brackets.

The section modulus of bottom and inner bot-
tom frames is not to be less than:

\[ W = e \cdot f_1 \cdot s \cdot l \cdot p \cdot k \] [cm\(^3\)],

where:
- \( p \) = design load, in [kN/m\(^2\)] as follows:
  - for bottom frames
  - for inner bottom frames (the greater value is to be used)
- \( p = p_{os} \) (according to 3.2.3)
- \( p = p_1 \) or \( p_2 \) (according to 3.4.1),
- \( p = 10 \cdot (d - h_d) \),
- \( h_d \) = double bottom height in [m],
- \( e = 0.44 \), if \( p = p_2 \),
- \( e = 0.55 \), if \( p = p_{os} \) or \( p_1 \),
- \( e = 0.70 \), if \( p = p_0 \),
- \( f_1 = 0.60 \) where struts according to
  7.2.6.4.5 are provided at \( l/2 \), otherwise \( f_1 = 1.0 \)
- \( l \) = unsupported span, in [m], disregarding struts, if any.

7.2.6.4 Brackets

The brackets are, in general, to be of the same
thickness as the plate floors, and breadth is to be 0.75 of the
depth of the centre girder. The brackets are to be flanged at
their free edges, where the unsupported span of bottom
frames exceeds 1 m or where the depth of floors exceeds 750
mm.

7.2.6.4.2 As the side girders, bottom frames and inner
bottom frames are to be supported by flat bars having the
same depth as the inner bottom frames.

7.2.6.5 Struts

The cross sectional area of the struts is to be de-
termined according to 9.3.2. The design force is to be taken
as the following value:

\[ P = 0.5 \cdot p \cdot s \cdot l \] [kN],

\( p \) and \( l \) as stated in 7.2.6.3.3.

7.2.7 Double bottom, longitudinal framing system

7.2.7.1 General

Where the longitudinal framing system changes
to the transverse framing system, structural continuity is to be
provided for.

7.2.7.2 Bottom and inner bottom longitudinals

7.2.7.2.1 The scantlings are to be calculated according to
8.2.

7.2.7.2.2 Where bottom and inner bottom longitudinals
are coupled by struts in the centre of their unsupported span \( l \),
their section moduli may be reduced to 60% of the values re-
quired by 8.2.

The scantlings of the struts are to be determined
in accordance with 7.2.6.5.

7.2.7.3 Plate floors

7.2.7.3.1 The floor spacing shall, in general, not exceed 5
times the transverse frame spacing.

7.2.7.3.2 Plate floors are to be fitted under transversal
bulkheads and corrugated bulkheads. Floors are to be fitted at
every frame in the machinery space under the main engine. In
the remaining part of the machinery space, floors are to be
fitted at every alternate frame.

7.2.7.3.3 Regarding floors in way of the strengthening of
the bottom forward, 5.4 is to be observed. For ships intended
for carrying heavy cargo, see Section 17.

7.2.7.3.4 The scantlings of floors are to be determined
according to 7.2.6.2.

7.2.7.3.5 The plate floors are to be stiffened at every lon-
gitudinal by a vertical stiffener having the same scantlings as
the inner bottom longitudinals. The depth of the stiffener
need not exceed 150 mm.

7.2.7.4 Brackets

7.2.7.4.1 Where the ship's sides are framed transversally
frame flanged brackets having a thickness of the floors are to
be fitted between the plate floors at every transverse frame,
extending to the outer longitudinals at the bottom and inner
bottom.

7.2.7.4.2 One bracket is to be fitted at each side of the
centre girder between the plate floors where the plate floors
are spaced not more than 2.5 m apart. Where the floor spac-
ing is greater, two brackets are to be fitted.
7.2.7.5 Longitudinal girder system

7.2.7.5.1 Where longitudinal girders are fitted instead of bottom longitudinals, the spacing of floors may be greater than permitted by 7.3.1, provided that adequate strength of the structure is proved.

7.2.7.5.2 The plate thickness of the longitudinal girders is not to be less than:

\[ t = (5.0 + 0.03 \cdot L) \sqrt{\frac{k}{k}} \] [mm],

but not less than:

\[ t_{\text{min}} = 6.0 \sqrt{\frac{k}{k}} \] [mm]

7.2.7.5.3 The longitudinals girders are to be examined for sufficient safety against buckling according to Section 4.6.

7.2.8 Design loads, permissible stresses for direct calculations

7.2.8.1 Design Loads

\[ p = p_{oa} - p_e \text{ [kN/m}^2\text{]} \text{, for loaded holds} \]

\[ p = p_a \text{ [kN/m}^2\text{]} \text{, for empty holds} \]

where:

\[ p_{oa} = \text{load on inner bottom according to Section 3.3.2, in [kN/m}^2\text{]}, or Section 3.3.1.3, in [kN], (where applicable);} \]

\[ p_e = 10 \cdot d \cdot p_e \cdot C_r \text{, sagging conditions;} \]

\[ p_a = 10 \cdot (10 + p_e) \cdot C_r \text{, hogging conditions;} \]

\[ p_{oa}, C_r = \text{according to 3.2.2.} \]

Where single loads are acting (e.g. loads of containers), such loads are to be used instead of the load \( p_{oa}. \)

7.2.8.2 Permissible stresses

7.2.8.2.1 Equivalent permissible stress, \( \sigma_{ekv} \)

The equivalent stress is not to exceed the following value:

\[ \sigma_{ekv} = \frac{230}{k} \] [N/mm\(^2\)]

\[ \sigma_{ekv} = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \cdot \sigma_y + 3 \cdot \tau^2} \]

where:

\[ \sigma_x = \text{stress in the ship's longitudinal direction;} \]

\[ \sigma_y = \text{stress in the ship's transverse direction;} \]

\[ \sigma_e = \text{design hull girder bending stress, in [N/mm}^2\text{], according to Section 4;} \]

\[ \sigma_b = \text{bending stress, in [N/mm}^2\text{], due to the load } p, \text{ in longitudinal direction, in longitudinal girders;} \]

\[ \sigma_t = 0, \text{for webs of transverse girders;} \]

\[ \sigma_b = \text{bending stress, in [N/mm}^2\text{], due to load } p, \text{ in transverse direction, in transverse girders;} \]

\[ \sigma = 0, \text{for webs of longitudinal girders;} \]

\[ \tau = \text{shear stress in the longitudinal girders or transverse girders due to load } p, \text{ in [N/mm}^2\text{].} \]

For direct calculation of bottom grillage may be used the following stress definitions:

\[ \sigma_e = \sigma + \sigma + 0.3 \cdot \sigma \]

\[ \sigma_b = \sigma + 0.3 \cdot (\sigma_e + \sigma) \]

7.2.8.3 Maximum permissible values of stresses

The stresses \( \sigma, \sigma \) and \( \tau \) are not exceed the following values:

\[ \sigma, \sigma = \frac{150}{k} \] [N/mm\(^2\)]

\[ \tau = \frac{100}{k} \] [N/mm\(^2\)]

7.2.8.4 Buckling strength

The buckling strength of the bottom structures is to be examined according to Section 4.6. For this purpose the design stresses according to Section 4.5.3 and the stresses due to local loads are to be considered.

7.3 BOTTOM STRUCTURE IN WAY OF THE MAIN PROPULSION PLANT

7.3.1 Single bottom

7.3.1.1 The scantlings of floors are to be determined according to 7.1.1.2 for the greatest span measured in the engine room.

7.3.1.2 The web depth of the plate floors in way of the engine foundation should be as large as possible. The depth of plate floors connected to web frames shall be similar to the depth of the longitudinal foundation girders. In way of the crank case, the depth shall not be less than \( 0.5 \cdot h \). The web thickness is not to be less than:

\[ t = \frac{h}{100} + 4 \] [mm],

where:

\[ h = \text{according to 7.1.1.2.1.} \]

7.3.1.3 The thickness of the longitudinal foundation girders is to be determined according to 7.2.3.2.

7.3.1.4 No centre girder need be fitted in way of longitudinal foundation girders. Intercostal docking profiles are to be fitted instead. The sectional area of the docking profiles is not to be less than:

\[ A_w = 10 + 0.2L \] [cm\(^2\)]

7.3.2 Double bottom

7.3.2.1 Lightening holes in way of the engine foundation are to be kept as small as possible with due regard, however, to accessibility. Where necessary, the edges of lightening holes are to be strengthened by means of face bars or the plate panels are to be stiffened.

7.3.2.2 Plate floors

Plate floors are to be fitted at every frame. The floor thickness according to 7.2.6.2.1 is to be increased for percentage as follows:
7.3.2.3 Side girders

7.3.2.3.1 The thickness of side girders under an engine foundation top plate inserted into the inner bottom is to be similar to the thickness of side girders above the inner bottom according to 7.3.3.2.

7.3.2.3.2 Side girders under foundation girders are to be extended into the adjacent spaces and to be connected to the bottom structure. This extension abaft and forward of the engine room bulkheads shall be two to four frame spacings if practicable.

7.3.2.3.3 Between the foundation girders, the thickness of the inner bottom plating required according to 7.2.4.1 is to be increased by 2 mm. The strengthened plate is to be extended beyond the engine seating by three to five frame spacings.

7.3.2.3.4 No centre girder is required in way of the engine seating (see 7.3.1.4).

7.3.3 Engine seating

7.3.3.1 General

The following regulations apply to low speed engines. Seating for medium and high speed engines as well as for turbines will be specially considered.

7.3.3.2 Longitudinal girders

a) The thickness of the longitudinal girders above the inner bottom is not to be less than:

\[ t = \begin{cases} \sqrt{\frac{P}{15}} + 6 \quad [\text{mm}] & \text{for } P < 1500 \text{ kW} \\ \sqrt{\frac{P}{750}} + 14 \quad [\text{mm}] & \text{for } 1500 \leq P \leq 7500 \text{ kW} \\ \sqrt{\frac{P}{1875}} + 20 \quad [\text{mm}] & \text{for } P > 7500 \text{ kW} \end{cases} \]

where:

\[ P = \text{single engine output, [kW].} \]

b) Where two longitudinal girders are fitted on either side of the engine, their thickness may be reduced by 4 mm.

c) The cross sectional area of the top plate is not to be less than:

\[ A = \begin{cases} \frac{P}{15} + 30 \quad [\text{cm}^2] & \text{for } P \leq 750 \text{ kW} \\ \frac{P}{75} + 70 \quad [\text{cm}^2] & \text{for } P > 750 \text{ kW} \end{cases} \]

d) The longitudinal girders of the engine seating are to be supported transversely by means of web frames or wing bulkheads. The scantlings of web frames are to be determined according to Section 8.1.6.

7.4 Docking calculation

7.4.1 General

For ships exceeding 120 m in length, for ships of special design, particularly in the aft body and for ships with a docking load of more than 700 kN/m a special calculation of the docking forces is required. The maximum permissible cargo load to remain onboard during docking and the load distribution are to be specified. The proof of sufficient strength can be performed either by a simplified docking calculation or by a direct docking calculation. The number and arrangement of the keel blocks shall agree with the submitted docking plan. Direct calculations are required for ships with unusual overhangs at the ends or with nohomogeneous distribution of cargo.

7.4.2 Direct docking calculation

If the docking block forces are determined by direct calculation, e.g. by a finite element calculation, considering the stiffness of the ship’s body and the weight distribution, the ship has to be assumed as elastically bedded at the keel blocks. The stiffness of the keel blocks has to be determined including the wood layers.

If a floating dock is used, the stiffness of the floating dock is to be taken into consideration. Transitory docking conditions need also to be considered.

7.4.3 Permissible stresses

The permissible equivalent stress \( \sigma_{ekv} \) is:

\[ \sigma_{ekv} = \frac{R_{eff}}{1,05} \]

7.4.4 Buckling strength

The bottom structures are to be examined according to Section 4.6.
8 FRAMING SYSTEM

8.1 TRANSVERSE FRAMING

8.1.1 General

8.1.1.1 Forward of the collision bulkhead and aft of the afterpeak bulkhead, the frame spacing shall in general not exceed 600 mm.

8.1.1.2 Definitions

\[ S = \text{spacing of web frames, [m]}; \]
\[ s = \text{spacing of frames, in [m]}; \]
\[ l = \text{unsupported span, in [m], according to 2.3.1}; \]
\[ l_{\text{min}} = 2.0 \text{ [m]}; \]
\[ l_{k1}, l_{k2} = \text{length of lower / upper bracket connection at main frames within the length } l \text{ in [m], see Fig. 8.1.2}; \]
\[ p_s = \text{load on ship's sides, in [kN/m]^2}, \text{according to 3.2.2}; \]
\[ p_e = \text{load on bow structures, in [kN/m]^2}, \text{according to 3.2.2.2}; \]
\[ p_L = \text{'tween deck load, in [kN/m]^2}, \text{according to 3.3.1}; \]
\[ p_1 = \text{pressure, in [kN/m]^2}, \text{according to Section 3.4.1}; \]
\[ f = \text{factor for curved frames}; \]
\[ f_{\text{min}} = 0.75; \]
\[ e = \text{max. height of curve, in [m]}. \]

\[ n = 0.55, \text{ for } L \geq 100 \text{ [m]} \]
\[ c = 1.0 \cdot (l_{k1} + 0.45 \cdot l_{k2}) \]
\[ c_{\text{min}} = 0.65; \]

Within the lower bracket connection the section modulus is not to be less than the value obtained for \( c = 1.0 \).

8.1.2 Main frames

8.1.2.1 Scantlings

\[ W = n \cdot c \cdot s \cdot l^2 \cdot p_s \cdot f \cdot k \text{ [cm}^3] \]

where:

\[ n = 0.9 - 0.0035 \cdot L, \text{ for } L < 100 \text{ [m]} \]

8.1.2.2 Frames in tanks

The section modulus of frames in tanks or in hold spaces for ballast water is not to be less than the greater of the following values:

\[ W_1 = n \cdot e \cdot s \cdot l^2 \cdot p_s \cdot f \cdot k \text{ [cm}^3] \]

or

\[ W_2 = \text{according to 11.2.3.1} \]

\[ n, e = \text{see 8.1.2.1.1}. \]

8.1.2.3 End attachment

8.1.2.3.1 The lower bracket attachment to the bottom structure is to be determined according to 2.4.2 on the basis of the main frame section modulus.

8.1.2.3.2 The upper bracket attachment to the deck structure and/or to the 'tween deck frames is to be determined according to 2.4.2 on the basis of the section modulus of the deck beams or 'tween deck frames whichever is the greater.

8.1.2.3.3 Where frames are supported by a longitudinally stiffened deck, the frames fitted between web frames are to be connected to the adjacent longitudinals by brackets. The scantlings of the brackets are to be determined in accordance with 2.4.2 on the basis of the section modulus of the frames.

8.1.3 Tween deck and superstructure frames

8.1.3.1 General

8.1.3.1.1 In ships having a speed exceeding \( v = 1.6 \sqrt{L} \) [kn], the forecastle frames forward of 0.1 \( L \) are to have at least the same scantlings as the frames located between the first and the second deck.

For 'tween deck frames in tanks, the requirements for the section moduli \( W_1 \) and \( W_2 \) according to 8.1.2.2 are to be observed.

8.1.3.2 Scantlings

8.1.3.2.1 The section modulus of the 'tween deck and superstructure frames are not to be less than:
8.1.5.2.1 Forwards of the collision bulkhead, tiers of beams or web frames and stringers are to be fitted in the forepeak. Stringer plates are to be effectively fitted to the collision bulkhead so that the forces can be properly transmitted. As far as practicable and possible, tiers of beams, with stringer plates generally spaced 2.6 m apart, measured vertically, are to be arranged as required under 8.1.5.2.1 as far as practicable with regard to the ship's shape.

Figure 8.1.3.3

8.1.5.2.2 The cross sectional area of each beam is to be determined according to 9.3.2. for a load

\[ P = A \cdot p \]  

where:

- \( A \) = load area of a beam, in [m²];
- \( p \) = \( p_s \) or \( p_f \), whichever is applicable.

8.1.5.2.3 In the afterpeak, tiers of beams, with stringer plates generally spaced 2.6 m apart, measured vertically, are to be arranged as required under 8.1.5.2.1 as far as practicable with regard to the ship's shape.

8.1.5.2.4 Intermittent welding at the stringers in the afterpeak is to be avoided.

8.1.5.2.5 Where peaks are used as tanks, stringer plates are to be flanged or face bars are to be fitted at their inner edges. Stringers are to be effectively fitted to the collision bulkhead so that the forces can be properly transmitted.

8.1.5.2.6 Where perforated decks are fitted instead of tiers of beams, their scantlings are to be determined as for wash bulkheads according to 11.5. the requirements regarding cross sectional area stipulated in 8.1.5.2.2 are, however, to be complied with.

8.1.5.3 Web frames and stringers

8.1.5.3.1 Where web frames and supporting stringers are fitted instead of tiers of beams, their scantlings are to be determined as follows:

- for section modulus:

\[ W = 0.55 \cdot S \cdot f \cdot k \]  

\( p = p_s \) or \( p_f \) whichever is applicable.

- for web sectional area at the supports:

\[ A_w = 0.05 \cdot S \cdot l \cdot p_s \cdot k \]  

where:

- \( l \) = unsupported span, in [m], without consideration of cross ties, if any;
- \( l_1 \) = similar to \( l \), however, considering cross ties, if any;
- \( c \) = coefficient according to the Table 8.1.5.3.1.

<table>
<thead>
<tr>
<th>Number of cross ties</th>
<th>( c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
</tr>
<tr>
<td>≥ 3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

8.1.5.3.2 Vertical transverses are to be interconnected by cross ties the cross sectional area of which is to be determined according to 8.1.5.2.2.

8.1.5.4 Web frames and stringers in 'tween decks and superstructure decks

Where the speed of the ship exceeds \( v = 1.6 \sqrt{L} \), in [kn], or in ships with a considerable bow flare respectively, stringers and transverses according to 8.1.5.3 are to be continuous welding to the shell plating and by a bracket to each frame. The scantlings of the stringer plates are to be determined from the following formulae:

width: \( b = 75 \sqrt{L} \) [mm]

thickness: \( t = 6.0 + L/40 \) [mm].
fitted within 0.1\textit{L} from forward perpendicular in 'tween deck spaces and superstructures.

The spacing of the stringers and transverses shall be less than 2.8 m. A considerable bow flare exists, if the flare angel exceeds 40°, measured in the ship's transverse spaces and superstructures.

shall be less than 2,8 m. A considerable bow flare exists, if generally be fitted at the forward and aft ends of the engine.

The web frames are to be evenly distributed along the length according to 8.1.5.5.1 are to be fitted.

Where proof of safety against tripping is provided tripping brackets may partly or completely be dispensed with.

Where proof of safety against tripping is provided tripping brackets spaced not more than 2,6 m, measured vertically. The arrangement of tripping brackets is shown at Fig. 8.1.5.5.1. Where proof of safety against tripping is provided tripping brackets may partly or completely be dispensed with.

The section modulus of web frames is not to be

The moment of inertia of web frames is not to exceed.

The spacing of the stringers and transverses shall be less than:

The scantlings of the webs are to be calculated as follows:

depth: \( h = 50 \cdot D \text{ [mm]} \)

thickness: \( t = h/(32 + 0,03 h) \text{ [mm]} \)

\( t_{\min} = 8,0 \text{ mm} \)

8.1.5.5 Tripping brackets

8.1.5.5.1 Between the point of greatest breadth of the ship at maximum draft and the collision bulkhead tripping brackets spaced not more than 2,6 m, measured vertically. The arrangement of tripping brackets is shown at Fig. 8.1.5.5.1. Where proof of safety against tripping is provided tripping brackets may partly or completely be dispensed with.

Figure 8.1.5.5.1

8.1.5.5.2 In the same range, in 'tween deck spaces and superstructures of 3 m and more in height, tripping brackets according to 8.1.5.5.1 are to be fitted.

8.1.5.5.3 Where peaks or other spaces forward of the collision bulkhead are intended to be used as tanks, tripping brackets according to 8.1.5.5.1 are to be fitted between tiers of beams or stringers.

8.1.6 Web frames in machinery spaces

8.1.6.1 Arrangement

8.1.6.1.1 In the engine and boiler room, web frames are to be fitted. Generally, they should extend up to the uppermost continuous deck. They are to be spaced not more than 5 times the frame spacing in the engine room.

8.1.6.1.2 For combustion engines, web frames shall generally be fitted at the forward and aft ends of the engine. The web frames are to be evenly distributed along the length of the engine.

8.1.6.1.3 Where combustion engines are fitted aft, stringers spaced 2.6 m apart are to be fitted in the engine room, in alignment with the stringers in the after peak, if any. Otherwise the main frames are to be adequately strengthened. The scantlings of the stringers shall be similar to those of the web frames. At least one stringer is required where the depth up to the lowest deck is less than 4 m.

8.1.6.1.4 For the bottom structure in machinery spaces, see Section 7.3.

8.1.6.2 Scantlings

8.1.6.2.1 The section modulus of web frames is not to be less than:

\[ W = 0,8 \cdot S \cdot I^2 \cdot p_c \cdot k \text{ [cm]} \]

The moment of inertia of web frames is not to be less than:

\[ I = D (4,5 D - 3,75) \cdot c \cdot 10^3 \text{ [cm]}^4 \]

for 3 m ≤ D ≤ 10 m

\[ I = D (7,25 D - 31) \cdot c \cdot 10^2 \text{ [cm]}^4 \]

for D > 10 m

where:

\[ c = 1 + (H_u - 4) \cdot 0,07 \]

\[ H_u = \text{ depth up to the lowest deck, in [m].} \]

8.1.6.2.2 Ships with a depth of less than 3 m are to have web frames with web scantlings not less than 250 x 8 mm and a minimum face sectional area of 12 cm².

8.2 BOTTOM, SIDE-AND DECK LONGITUDINALS, SIDE TRANSVERSES

8.2.1 General

8.2.1.1 Longitudinals shall preferable be continuous through floor plates and transverses. Attachments of their webs to the webs of floor plates and transverses shall be such that the reaction forces of support will be transmitted. The permissible shear stress of 100/k [N/mm²] is not to be exceeded.

8.2.1.2 Where longitudinals abut at transverse bulkheads or webs, brackets are to be fitted. These longitudinals are to be attached to the transverse webs or bulkhead by brackets with the thickness of the stiffeners web thickness, and with a length of weld at the longitudinals equal to 2 x depth of the longitudinals.

8.2.1.3 Where longitudinals are snipped at watertight floors and bulkheads, they are to be attached to the floors by brackets of the thickness of plate floors, and with a length of weld at the longitudinals equal to 2 x depth of the bottom longitudinals.

8.2.1.4 Outside the upper and the lower hull flange, the cross sectional areas stipulated in 8.2.1.2 may be reduced by 20 per cent.

8.2.1.5 For buckling strength of longitudinals see Section 4.6.

8.2.2 Definitions

\( p = \text{ load, in [kN/m²];} \)

\( = p_b \text{ according to 3.2.3 for bottom longitudinals.} \)

\( = p_t \text{ according to 3.2.2 for side longitudinals.} \)

\( = p_b \text{ according to 3.4.1, for longitudinals at decks and at ship's sides, at longitudinal bulkheads and inner bottom in way of tanks.} \)

For bottom longitudinals in way of tanks \( p \) is not to be taken less than:


\[ p_1 = [10 \cdot (d_{sw} - p) \cdot C_r] \text{[kN/m}^2\text{]} \]

For side longitudinals below \( d_{sw} \), \( p \) need not to be taken larger than:

\[ p_1 = \left[ 10 \cdot (d_{sw} - z) - p \cdot C_r \left( 1 + \frac{z}{d_{sw}} \right) \right] \text{[kN/m}^2\text{]} \]

\( = p_c \) according to 3.4.2 for side and deck longitudinals as well as for horizontal stiffeners of longitudinal bulkheads in tanks which may be partially filled;

\( = p_l \) according to 3.2.1 for deck longitudinals of the strength deck;

\( = p_{lb} \) according to 3.3.2 for inner bottom longitudinals, however, not less than the load corresponding to the distance between inner bottom and deepest load waterline;

\( = p_l \) according to 3.3.1 for longitudinals of cargo decks and for inner bottom longitudinals;

\( \sigma_\theta \) = maximum normal stress \( \sigma \) due to longitudinal hull girder bending, in [N/mm]², in the strength deck level at side;

\( \sigma_\theta \) = maximum normal stress \( \sigma \) due to longitudinal hull girder bending, in [N/mm]², in the bottom;

\( \sigma_t \) = according to 4.5.3.

Where \( \sigma_\theta \) and \( \sigma_t \) are not known the following values may be taken:

\( \sigma_\theta = \sigma_{\text{max}} \)

\( \sigma_t = 0.8 \cdot \sigma_{\text{max}} \)

\( z \) = distance, in [m], above base line;

\( m = (m_1^2 + m_2^2) \)

\( m_1 = 1 - \frac{2}{l} \left( \frac{l}{l} \sin^2 \alpha \right) \)

\( l_1 \) = according to Fig. 8.2.2, in [m]

\( \omega \) = according to Fig. 8.2.2, in [°]

\( m_2 = 0.204 \frac{s}{l} \left( 4 - \frac{s}{l} \right)^2 \)

\[ \sigma_{\text{max}} = \sigma \cdot 0.8 + \frac{\sigma_B + \sigma_D}{D} \text{[N/mm}^2\text{]} \]

\( \sigma_{\text{max}} \leq 150/k \text{ [N/mm}^2\text{]} \)

\( \sigma \) = \((0.8 + \frac{L}{450}) \cdot 230/k \text{ [N/mm}^2\text{]} \)

\( \sigma_{\text{max}} = \frac{230}{k} \text{ [N/mm}^2\text{]} \)

For calculation purpose the absolute stress values are to be taken for \( \sigma_\theta \) and \( \sigma_t \).

8.2.3 Scantlings

8.2.3.1 The section modulus and shear area of longitudinals and longitudinal beams of the strength deck is not to be less than:

\[ W_l = 83.3/\sigma_{\text{hyp}} \cdot m \cdot s \cdot l^2 \cdot I \text{[cm}^3\text{]} \]

\[ A_l = (1 - 0.817 \cdot m_2) \cdot 0.05 \cdot s \cdot l \cdot p \cdot k \text{[cm}^2\text{]} \]

The permissible stress \( \sigma_{\text{hyp}} \) is to be determined according to the following formulae:

- below the neutral axis of the respective cross section:

\[ \sigma_{\text{hyp}} = \sigma - \sigma_\theta + \frac{\sigma_B + \sigma_D}{D} \text{[N/mm}^2\text{]} \]

- above the neutral axis of the respective cross section:

\[ \sigma_{\text{hyp}} = \sigma + \sigma_\theta - \frac{\sigma_B + \sigma_D}{D} \text{[N/mm}^2\text{]} \]

\( \sigma_{\text{hyp}} \leq 150/k \text{ [N/mm}^2\text{]} \)

\( \sigma \) = \((0.8 + \frac{L}{450}) \cdot 230/k \text{ [N/mm}^2\text{]} \)

\( \sigma_{\text{max}} = \frac{230}{k} \text{ [N/mm}^2\text{]} \)

For calculation purpose the absolute stress values are to be taken for \( \sigma_\theta \) and \( \sigma_t \).

8.2.3.2 In tanks, the section modulus is not to be less than \( W_2 \) according to 8.2.1.3.

8.2.3.3 For determining the section modulus of longitudinals located adjacent to a bilge strake which is not stiffened longitudinally, the width.

\[ \frac{R}{3} + \frac{s}{2} \]

for \( R \) see Fig. 8.2.3.3

is to be inserted, in lieu of \( s \), into the formula as per 8.2.3.1.

For safety against tripping, the spacing of transverses is to be less than 12 x width of the longitudinal face. Otherwise, an additional bracket is to be fitted at half transverse’s spacing.

Figure 8.2.2

\[ \frac{R}{3} + \frac{s}{2} \]

Figure 8.2.3.3

8.2.3.4 Where the scantlings of longitudinals are determined by strength calculations, the total equivalent stress comprising local bending and shear stresses and normal stresses due to longitudinal hull girder bending is not to exceed the total stress value \( \sigma \) as defined in 8.2.3.1.
8.2.4 Side transverses

8.2.4.1 The section modulus of side transverses supporting side longitudinals is not to be less than:

\[ W = 0.55 \cdot S \cdot l \cdot p \cdot k \quad [\text{cm}^3] \]

Minimum cross sectional area of the web:

\[ A_w = 0.05 \cdot S \cdot l \cdot p \cdot k \quad [\text{cm}^2] \]

8.2.4.2 Where the side transverses are designed on the basis of strength calculations the following stresses are not to be exceeded:

\[ \sigma_b = 150/k \quad [\text{N/mm}^2] \]
\[ \tau = 100/k \quad [\text{N/mm}^2] \]
\[ \sigma_{ekv} = \sqrt{\sigma_b^2 + 3\tau^2} \leq 180/k \quad [\text{N/mm}^2] \]

8.2.4.3 In tanks, the section modulus and the cross sectional area are to be in accordance with 11.2.3, \( W_2 \) and \( A_{w2} \) respectively.

8.2.4.4 The webs of side transverses in those areas, where concentrated loads due to ship manoeuvres at terminals may be expected, are to be examined for sufficient buckling strength according to 4.6. The force induced by a fender into the web frame may approximately be determined by the following formula:

\[ P_g = \frac{\Delta \cdot v^2}{2 \cdot f} \quad [\text{kN}] \]

where:

\( \Delta = \) displacement of the ship, in [t];
\( \Delta_{\text{max}} = 100,000 \) t
\( f = \) displacement of fender, in [m], guidance values for \( f \) are given in Table 8.2.4.4-1
\( v = \) manoeuvring speed of the ship, in [m/s], guidance values are given in Table 8.2.4.4.

<table>
<thead>
<tr>
<th>( \Delta ) [t]</th>
<th>( f ) [m]</th>
<th>( v ) [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \leq 1000 )</td>
<td>0.25</td>
<td>0.2</td>
</tr>
<tr>
<td>( &gt; 1000 ) ( \leq 10000 )</td>
<td>0.22 + 2.8 ( \cdot \Delta \cdot 10^{-5} )</td>
<td>0.21 - 1.1 ( \Delta \cdot 10^{-5} )</td>
</tr>
<tr>
<td>( &gt; 10000 )</td>
<td>0.5</td>
<td>0.10</td>
</tr>
</tbody>
</table>

8.2.4.5 The compressive stress in the web of the transverse due to the action of the force \( P_g \) may be determined by the following formula:

\[ \sigma_D = \frac{P_g \cdot 10^3}{h \cdot t_w} \quad [\text{N/mm}^2] \]

where:

\( h = \) vertical length of application of the force \( P_g \); if \( h \) is not known, \( h = 300 \) mm may be used as a guidance value;
\( t_w = \) web thickness, in [mm].
9 SUPPORTING DECK STRUCTURES

9.1 GENERAL

9.1.1 Definitions

\( k \) = material factor (according to 1.4.2.2.);
\( l \) = unsupported span, in [m], (according to Section 2.3.);
\( b \) = width of deck supported, in [m];
\( p \) = deck load \( p_{\text{a}}, p_{\text{b}}, \) or \( p_{\text{c}} \) in [kN/m²] (according to 3.2.1, 3.2.5 and 3.3.1.);
\( f \) = 0.55;
\( f \) = 0.75 for beams, girder and transverses which are simply supported on one or both ends;
\( P_{\text{p}} \) = pillar load;
\( P_{\text{n}} \) = \( p \cdot A + P_{\text{p}} \) [kN];
\( A \) = load area for one pillar, in [m²];
\( P_{\text{g}} \) = load from pillars located above the pillar considered, in [kN];
\( \lambda_{\text{n}} \) = degree of slenderness of the pillar;
\( \lambda_{\text{s}} \) = \( l_{\text{u}}/d_{\text{u}} \);
\( l_{\text{u}} \) = length of the pillar, in [cm];
\( i_{\text{s}} \) = radius of gyration of the pillar;
\( i_{\text{p}} \) = \( \sqrt{I_{\text{p}}/A_{\text{p}}} \) [cm];
\( I_{\text{p}} \) = moment of inertia of the pillar, in [cm²];
\( A_{\text{u}} \) = sectional area of the pillar, in [cm²];
\( i_{\text{p}} \) = 0.25 \( \cdot d_{\text{p}} \) for solid pillars of circular cross section;
\( i_{\text{w}} \) = 0.25 \( \sqrt{d_{\text{w}}^2 + d_{\text{w}}^2} \) for tubular pillars;
\( d_{\text{p}} \) = pillar diameter in [cm];
\( d_{\text{w}} \) = outside diameter of pillar, in [cm];
\( d_{\text{i}} \) = inside diameter of pillar, in [cm];
\( m_{2} \) = factor according to Section 8.2.2.

9.1.2 Permissible stresses

Where the scantlings of girders not forming part of the longitudinal hull structure, or of transverses, deck beams, etc. are determined by means of strength calculations the following stresses are not to be exceeded:

\[ \sigma_{0} = 150 \text{kN/mm}^2 \]
\[ \tau = 100 \text{kN/mm}^2 \]
\[ \sigma_{t} = \sqrt{\sigma^2 + 3 \tau^2} = 180 \text{kN/mm}^2 \]

9.1.3 Buckling strength

The buckling strength of the deck structures is to be examined according to Section 4.6. For this purpose to design stresses according to Section 4.5.3 and the stresses due to local loads are to be considered.

9.2 DECK BEAMS, LONGITUDINALS AND GIRDERS

9.2.1 Transverse deck beams and deck longitudinals

The section modulus and shear area of transverse deck beams and of deck longitudinals not contributing to the longitudinal strength are to be determined by the following formula:

\[ W_{\text{d}} = f \cdot s \cdot p \cdot l^2 \cdot k \text{ [cm}^3\text{]} \]
\[ A_{\text{d}} = (1 - 0.817 \cdot m_{2}) \cdot 0.05 \cdot s \cdot l \cdot p \cdot k \text{ [cm}^2\text{]} \]

9.2.2 Deck longitudinals in way of the upper and lower hull flange

9.2.2.1 The section modulus of deck longitudinals contributing to the longitudinal strength is to be calculated according to 8.2.3.

9.2.3 Attachment

9.2.3.1 Transverse deck beams are to be connected to the frames by brackets according to 2.4.2.

9.2.3.2 Deck beams crossing longitudinal walls and girders may be attached to the stiffeners of longitudinal walls and the webs of girders respectively by welding without brackets.

9.2.3.3 Where deck beams are to be attached to hatchway coamings and girders of considerable rigidity brackets are to be provided.

9.2.3.4 Within 0.6 \( L \) amidships, the arm lengths of the beam brackets in single deck ships are to be increased by 20%.

9.2.3.5 For the connection of deck longitudinals to transverses and bulkheads, see also Section 8.2.3.

9.2.4 Girders and transverses

9.2.4.1 The section modulus \( W \) is not to be less than:

\[ W = f \cdot b \cdot l^2 \cdot p \cdot k \text{ [cm}^3\text{]} \]

9.2.4.2 The shear area \( A_{\text{w}} \) is not to be less than:

\[ A_{\text{w}} = 0.05 \cdot p \cdot b \cdot l \cdot k \text{ [cm}^2\text{]} \]

9.2.4.3 The depth of girders is not to be less than 1/25 of the unsupported span. The web depth of girders scalloped for continuous deck beams is to be at least 1.5 times the depth of the deck beams.

Scantlings of girders of tank decks are to be determined according to Section 11.2.3.

9.2.4.4 End attachments of girders at bulkheads are to be so dimensioned that the bending moments and shear forces can be transferred. Bulkhead stiffeners under girders are to be sufficiently dimensioned to support the girders.

9.2.4.5 Face plates are to be stiffened by tripping brackets according to 2.6.2.4. At girders of symmetrical sec-
9.2.4.6 Where a girder does not have the same section modulus throughout all girder fields, the greater scantlings are to be maintained above the supports and are to be reduced gradually to the smaller scantlings.

9.2.4.7 For girders forming part of the longitudinal hull structure and for hatchway girders see Section 9.5.

9.2.5 Supporting structure of windlasses and chain stoppers

9.2.5.1 For the supporting structure under windlasses and chain stoppers, the following permissible stresses are to be observed:

\[ \sigma_b = \frac{200}{k} [N/mm^2] \]
\[ \tau = \frac{120}{k} [N/mm^2] \]
\[ \sigma_{ekv} = \sqrt{\sigma^2 + 3\tau^2} = \frac{220}{k} [N/mm^2] \]

9.2.5.2 The acting forces are to be calculated for 80% and 45% respectively of the rated breaking load of the chain cable, i.e.:
- for chain stoppers 80%;
- for windlasses 80%, where chain stoppers are not fitted;
- for windlasses 45%, where chain stoppers are fitted.

9.3 PILLARS

9.3.1 General

9.3.1.1 Structural members at heads and heels of pillars as well as substructures are to be constructed according to the forces they are subjected to. The connection is to be so dimensioned that at least 1 cm² cross sectional area is available for 10 kN of load.

Where pillars are affected by tension loads doublings are not permitted.

9.3.1.2 Pillar in tanks are to be checked for tension. Tubular pillars are not permitted in tanks for flammable liquids.

9.3.1.3 For structural elements of the pillars' transverse section, sufficient buckling strength according to Section 4.6. has to be verified. The wall thickness of tubular pillars which may be expected to be damaged during loading and unloading operations is not to be less than:

\[ t_a = 4.5 + 0.015 \cdot d_{tu} \text{ [mm]}, \text{ for } d_{tu} \leq 300 \text{ mm} \]
\[ t_a = 0.03 \cdot d_{tu} \text{ [mm]}, \text{ for } d_{tu} > 300 \text{ mm} \]

where:
\[ d_{tu} = \text{outside diameter of tubular pillar, in [mm]} \]

9.3.1.4 Pillars also loaded by bending moments have to be specially considered.

9.3.2 Scantlings

The sectional area of pillars is not to be less than:

\[ A_s = 10 \cdot P_u / \sigma \text{ [cm}^2\text{]} \]

where:
\[ \sigma = \text{permissible compressive stress according to Table 9.3.2, in [N/mm}^2\text{]}. \]

Table 9.3.2-1

<table>
<thead>
<tr>
<th>Degree of slenderness (( \lambda_u ))</th>
<th>Pillars within accommodation</th>
<th>Elsewhere</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \leq 100 )</td>
<td>140 - 0.0067 ( \cdot \lambda_u )</td>
<td>117 - 0.0056 ( \cdot \lambda_u )</td>
</tr>
<tr>
<td>( &gt; 100 )</td>
<td>7.3 ( \cdot 10^5 \lambda_u^3 )</td>
<td>6.1 ( \cdot 10^5 \lambda_u^3 )</td>
</tr>
</tbody>
</table>

9.4 CANTILEVERS

9.4.1 General

9.4.1.1 Cantilevers for supporting girders, hatchway coamings, engine casings and unsupported parts of decks are to be connected to transverses, web frames, reinforced main frames, or walls in order to withstand the bending moment arising from the load \( P \).

9.4.1.2 Face plates are to be secured against tilting by tripping brackets fitted to the webs at suitable distances (see also Section 2.6.2).

9.4.2 Permissible stresses

9.4.2.1 When determining the cantilever scantlings, the following permissible stresses are to be observed:

a) Where single cantilevers are fitted at greater distances:
\[ \sigma_b = 125/k [N/mm^2] \]
\[ \tau = 80/k [N/mm^2] \]
\[ \sigma_{ekv} = \sqrt{\sigma^2 + 3\tau^2} = 180/k [N/mm^2] \]

b) Where several cantilevers are fitted at smaller distances (e.g. at every frame):
\[ \sigma_b = 150/k [N/mm^2] \]
\[ \tau = 80/k [N/mm^2] \]

\[ \sigma_{ekv} = \sqrt{\sigma^2 + 3\tau^2} = 180/k [N/mm^2] \]

The stresses in web frames are not exceed the values specified above.

9.5 HATCHWAY GIRDER AND GIRDER FORMING PART OF THE LONGITUDINAL HULL STRUCTURE

9.5.1 The scantlings of longitudinal and transverse hatchway girders are to be determined on the basis of strength calculations. The calculations are to be based upon the deck loads according to Sec. 3.2 and 3.3.

9.5.2 The hatchway girders are to be so dimensioned that the stress values given in Table 9.5.2 will not be exceeded.
Table 9.5.2

<table>
<thead>
<tr>
<th>Longitudinal coaming and girders of the strength deck</th>
<th>All other hatchway girders</th>
</tr>
</thead>
<tbody>
<tr>
<td>upper and lower flanges</td>
<td>150/k [N/mm²]</td>
</tr>
<tr>
<td>deck level</td>
<td>70/k [N/mm²]</td>
</tr>
</tbody>
</table>

9.5.2.3 For continuous longitudinal coamings the combined stress resulting from longitudinal hull girder bending and local bending of the longitudinal coaming is not to exceed the following value:

\[ \sigma + \sigma_l \leq 200/k \ [N/mm^2] \]

where:

\( \sigma_l \) = local bending stress in the ship's longitudinal direction (permissible stress values are given in Table 9.5.2);

\( \sigma_e \) = design longitudinal hull girder bending stress according to 4.5.3;

9.5.2.4 The equivalent stress is not to exceed the following value:

\[ \sigma_{ekv} = \begin{cases} 0.8 + \frac{L}{450} \cdot \frac{230}{k} \ [N/mm^2], & \text{for } L < 90 \text{ m} \\ 230/k \ [N/mm^2], & \text{for } L \geq 90 \text{ m} \end{cases} \]

\[ \sigma_{ekv} = \sqrt{\left(\sigma_x + \sigma_y + \tau \right)^2}, \]

where:

\( \sigma_x \) = local bending stress in the ship's longitudinal direction;

\( \sigma_y \) = stress in the ship's transverse direction;

\( \tau \) = shear stress;

\( \tau_{net} = 90/k \ [N/mm^2] \)

The individual stresses \( \sigma \) and \( \sigma_l \) are not to exceed 150/k [N/mm²].

9.5.2.5 The requirements regarding buckling strength according to Section 9.1.3 are to be observed.
10 WATERTIGHT BULKHEADS

10.1 GENERAL

10.1.1 Watertight subdivision

10.1.1.1 All ships are to have a collision bulkhead, a stern tube bulkhead and one watertight bulkhead at each end of the engine room. In ships with machinery aft, the stern tube bulkhead may substitute the aft engine room bulkhead.

10.1.1.2 Number and location of transverse bulkheads fitted in addition to those specified in 10.1.1.1 are to be determined as to ensure sufficient transverse strength of the hull.

10.1.1.3 For ships without longitudinal bulkheads in the cargo hold the number of watertight transverse bulkheads should, in general, not be less than given in Table 10.1.1.3.

<table>
<thead>
<tr>
<th>L [m]</th>
<th>Arrangement of machinery space</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 65</td>
<td>aft</td>
</tr>
<tr>
<td>65 &lt; L ≤ 85</td>
<td>4</td>
</tr>
<tr>
<td>85 &lt; L ≤ 105</td>
<td>4</td>
</tr>
<tr>
<td>105 &lt; L ≤ 125</td>
<td>5</td>
</tr>
<tr>
<td>125 &lt; L ≤ 145</td>
<td>6</td>
</tr>
<tr>
<td>145 &lt; L ≤ 165</td>
<td>7</td>
</tr>
<tr>
<td>165 &lt; L ≤ 185</td>
<td>8</td>
</tr>
<tr>
<td>L &gt; 185</td>
<td>to be specially considered</td>
</tr>
</tbody>
</table>

10.1.1.4 One or more of the watertight bulkheads may be dispensed with where the transverse strength of the ship is adequate.

10.1.1.5 The number of watertight bulkheads of ships for which the floatability in the damaged condition is required will be determined on the basis of the damage stability calculation.

10.1.1.6 Each watertight subdivision bulkhead, whether transverse or longitudinal, shall be constructed having scantlings and arrangements capable of preventing the passage of water in any direction under the head of water likely to occur in intact and damaged conditions. In the damaged condition, the head of water is to be considered in the worst situation at equilibrium, including intermediate stages of flooding.

In all cases, watertight subdivision bulkheads shall be capable of supporting at least the pressure due to a head of water up to the bulkhead deck.

10.1.1.7 Steps and recesses in watertight bulkheads shall be as strong as the bulkhead at the place where each occurs.

10.1.1.8 For openings in watertight subdivision bulkheads and their closing appliances see the Rules, Part 3 - Hull equipment, Section 7.12.

10.1.1.9 For initial testing of watertight bulkheads see Section 11.6.

10.1.2 Arrangement of watertight bulkheads

10.1.2.1 Collision bulkhead

10.1.2.1.1 Cargo ships with \( L \leq 200 \text{ m} \) are to have the collision bulkhead situated not less than 0,05 \( L_c \) from the forward perpendicular. Cargo ships with \( L > 200 \text{ m} \) are to have the collision bulkhead fitted at least 10 m from the forward perpendicular, see Fig. 10.1.2.1.3.

10.1.2.1.2 All cargo ships are to have the collision bulkhead located not more than 0,08 \( L_c \) from the forward perpendicular. Greater distances may be approved by the Register in special cases.

10.1.2.1.3 In the case of ships having any part of the underwater body extending forward of the forward perpendicular, e.g. a bulbous bow, the required distances specified in 10.1.2.1.1 and 10.1.2.1.2 may be measured from a reference point located at a distance \( x \), as shown on Fig. 10.1.2.1.3, forward of the forward perpendicular which is to be the lesser of:

\[
\begin{align*}
    x &= \frac{a}{2} \\
    x &= 0,015 L_c \\
    x &= 3,0 \text{ m}
\end{align*}
\]

![Figure 10.1.2.1.3](image)

where:

\( L_c \) = length of ship according to Regulation 3 of ICLL, 1966;

\( H_c \) = depth of ship according to Regulation 3 of ICLL, 1966.

For passenger ships see Section 21.

10.1.2.1.4 The collision bulkhead is to extend watertight up to the freeboard deck. Steps or recesses may be permitted provided they are within the limit prescribed in 10.1.2.1.1, 10.1.2.1.2 and 10.1.2.1.3.

10.1.2.1.5 In ships having continuous or long superstructures, the collision bulkhead is to extend to the first deck above the freeboard deck. The extension need not be fitted directly in line with the bulkhead below, provided the requirements of 10.1.2.1.1, 10.1.2.1.2 and 10.1.2.1.3 with the exception as per 10.1.2.1.6 are fulfilled and the scantlings of the part of the freeboard deck which forms the step or recess
are not less than required for a collision bulkhead. Openings with weathertight closing appliances may be fitted above the freeboard deck in the collision bulkhead and in the aforementioned step and recess.

The number of openings in the extension of the collision bulkhead above the freeboard deck shall be restricted to the minimum compatible with the design and normal operation of the ship. All such openings shall be capable of being closed weathertight.

10.1.2.1.6 Where bow doors are fitted and a sloping loading ramp forms part of the extension of the collision bulkhead above the bulkhead/deck the ramp shall be weathertight over its complete length. In cargo ships the part of the ramp which is more than 2.3 m above the bulkhead deck may extend forward of the limit specified in 10.1.2.1.1, 10.1.2.1.2 and 10.1.2.1.3. Ramps not meeting the above requirements shall be disregarded as an extension of the collision bulkhead.

10.1.2.1.7 No doors, manholes, access openings, or ventilation ducts are permitted in the collision bulkhead below the freeboard deck and above the double bottom.

Where on cargo ships pipes are piercing the collision bulkhead below the freeboard deck, screw down valves are to be fitted directly at the collision bulkhead.

Where such valves are fitted within the forecastle they are to be operable from above the freeboard deck.

Where a readily accessible space which is not a hold space is located directly adjacent to the forecastle (e.g. a bow-thruster space), the screw down valves may be fitted within this space directly at the collision bulkhead and need not be operable from a remote position.

10.1.2.2 Stern tube bulkhead

All ships are to have a stern tube bulkhead which is, in general, to be so arranged that the stern tube and the rudder trunk are enclosed in a watertight compartment. The stern tube bulkhead is to extend to the freeboard deck or to a watertight platform situated above the load waterline.

In cargo ships a stern tube enclosed in a water-tight space of moderate volume, such as an aft peak tank, where the inboard end of the stern tube extends through the aft peak/engine room watertight bulkhead into the engine room is considered to be an acceptable solution satisfying the requirement of Chapter II-1, Regulation 12.10 of SOLAS 1974, as amended, provided the inboard end of the stern tube is effectively sealed at the aft peak/engine room bulkhead by means of an approved watertight/oiltight gland system. See also IACS UI SC93.

10.1.2.3 Remaining watertight bulkheads

10.1.2.3.1 The remaining watertight bulkheads are, in general, depending on the ship type, to extend to the freeboard deck. Wherever practicable, they are to be situated in one frame plane, otherwise those portions of decks situated between part of transverse bulkheads are to be watertight.

10.1.2.3.2 Bulkheads shall be fitted separating the machinery space from cargo and passenger spaces forward and aft and made watertight up to the freeboard/bulkhead deck. In passenger ships an afterpeak bulkhead shall also be fitted and made watertight up to the bulkhead deck. The afterpeak bulkhead may, however, be stepped below the bulkhead deck, provided the degree of safety of the ship as regards subdivision is not thereby diminished.

10.2 SCANTLINGS

10.2.1 General

10.2.1.1 Where holds are intended to be filled with ballast water, their bulkheads are to comply with the requirements of Section 11.

10.2.1.2 Bulkheads of holds intended to be used for carrying dry cargo in bulk with a density \( \rho > 1.0 \) are to comply with the requirements of Section 17, as far as their strength is concerned.

10.2.1.3 Definitions

\[
\begin{align*}
C_p, C_t &= \text{coefficients according to Table 10.2.1.3;}

k &= \frac{235}{R_{cH}};

R_{cH} &= \text{minimum nominal upper yield point, in [N/mm²], according to 1.4.2.2.}
\end{align*}
\]

<table>
<thead>
<tr>
<th>Coefficient ( C_p ) and ( C_t )</th>
<th>Collision bulkhead</th>
<th>Other bulkheads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plating</td>
<td>( C_p )</td>
<td>( C_t )</td>
</tr>
<tr>
<td>Stiffeners and correugated bulkhead elements</td>
<td>( C_p ) in case of constraint of both ends</td>
<td>0.33 ( k )</td>
</tr>
<tr>
<td></td>
<td>( C_t ) in case of simple support of one end and constraint at the other end</td>
<td>0.45 ( k )</td>
</tr>
<tr>
<td></td>
<td>( C_t ) both ends simply supported</td>
<td>0.66 ( k )</td>
</tr>
</tbody>
</table>

10.2.1.4 Special requirements for bulk carriers are given in Section 17.

10.2.2 Bulkhead plating

10.2.2.1 The thickness of the bulkhead plating is not to be less than:

\[
t = C_p \cdot s \sqrt{\rho + \mu} \quad [\text{mm}],
\]

but not less than:

\[
I_{\text{min}} = 6,0 \sqrt{t} \quad [\text{mm}]
\]

10.2.2.2 In small ships, the thickness of the bulkhead plating need not exceed the thickness of the shell plating for a frame spacing corresponding to the stiffener spacing.
10.2.2.3 The stern tube bulkhead is to be provided with a strengthened plate in way of the stern tube.

10.2.3 Stiffeners

10.2.3.1 The section modulus of bulkhead stiffeners is not to be less than:

\[ W = C_s \cdot s \cdot l^2 \cdot p \, [\text{cm}^3] \]

10.2.3.2 In horizontal part of bulkheads, the stiffeners are also to comply with the rules for deck beams according to 9.2.1.

10.2.3.3 The scantlings of the brackets are to be determined in dependence of the section modulus of the stiffeners according to Section 2.4.2. If the length of the stiffener is 3.5 m and over, the brackets are to extend to the next beam or the next floor.

10.2.3.4 Unbracketed bulkhead stiffeners are to be connected to the decks by welding. The length of welds is to be at least 0.6 x depth of the section.

10.2.3.5 Bulkhead stiffeners which cut in way of watertight doors are to be supported by carlings or stiffeners.

10.2.4 Corrugated bulkheads

10.2.4.1 The plate thickness of corrugated bulkheads is not to be less than required according to 10.2.2.1. For the spacing s, the greater one of the values b or c, in [m], according to 10.2.4.3 is to be taken.

10.2.4.2 The section modulus of a corrugated bulkhead element is to be determined according to 10.2.3.1. For the spacing s, the width of an element a, in [m], according to 10.2.4.3 is to be taken.

10.2.4.3 The actual section modulus of a corrugated bulkhead element is to be assessed according to the following formula:

\[ W = t \cdot h \cdot \left( b + \frac{c}{3} \right) \, [\text{cm}^3] \]

where:

- \( a \) = width of element, in [cm];
- \( b \) = breadth of face plate, in [cm];
- \( c \) = breadth of web plate, in [cm];
- \( h \) = distance between face plates, in [cm];
- \( t \) = plate thickness, in [cm];
- \( \alpha \geq 45^\circ \)

See Fig. 10.2.4.3

10.3 SHAFT TUNNELS

10.3.1 General

10.3.1.1 Where one or more compartments are situated between stern tube bulkhead and engine room, a watertight shaft tunnels is to be arranged. The size of the shaft tunnels is to be adequate for service and maintenance purposes.

10.3.1.2 The access opening between engine room and shaft tunnel is to be closed by a watertight sliding door. For extremely short shaft tunnels watertight doors between tunnel and engine room may be dispensed with, subject to special approval by the Register.

10.3.1.3 Tunnel ventilators and the emergency exit are to be constructed watertight up to the freeboard deck.

10.3.2 Scantlings

10.3.2.1 The plating of the shaft tunnel is to be dimensioned as for a bulkhead according to 10.2.2.1.

10.3.2.2 The plating of the round part of tunnel tops may be 10 per cent less in thickness.

10.3.2.3 The section modulus of shaft tunnel stiffeners is to be determined according to 10.2.3.1.

10.3.2.4 Shaft tunnels in tanks are to comply with the requirements of Section 11.

10.3.2.5 Horizontal parts of the tunnel are to be treated as horizontal parts of bulkheads and as cargo deck respectively.

10.3.2.6 The tunnel is to be suitably strengthened under pillars.

10.3.2.6 Special requirements for bulk carriers are given in Section 17.
11 TANK STRUCTURES

11.1 GENERAL

11.1.1 Subdivision of tanks

11.1.1.1 In tanks extending over the full breadth of the ship intended to be used for partial filling, at least one longitudinal bulkhead is to be fitted, which may be a swash bulkhead.

11.1.1.2 Where the forepeak is intended to be used as tank, at least one complete or partial longitudinal swash bulkhead is to be fitted, if the tank breadth exceeds 0.5 \( B \) or 6 m, whichever is the greater.

When the afterpeak is intended to be used as tank, at least one complete or partial longitudinal swash bulkhead is to be fitted. The largest breadth of the liquid surface should not exceed 0.3 \( B \) in the aft peak.

11.1.1.3 Peak tanks exceeding 0.06 \( L \) or 6 m in length, whichever is greater, shall be provided with a transverse swash bulkhead.

11.1.2 Air, overflow and sounding pipes

Each tank is to be fitted with air pipes, overflow pipes and sounding pipes. See also Rules, Part 8 - Piping, Section 5.

11.1.3 Forepeak tank

Oil is not to be carried in a forepeak tank or a tank forward of the collision bulkhead.

11.1.4 Separation of oil fuel tanks from tanks for other liquids

11.1.4.1 Oil fuel tanks are to be separated from tanks for lubricating oil, hydraulic oil, vegetable oil, feedwater, condensate water and potable water by cofferdams.

11.1.4.2 Fuel oil tanks adjacent to lubricating oil circulation tanks are not permitted.

11.1.5 Tanks for heated liquids

11.1.5.1 Where heated liquids are intended to be carried in tanks, a calculation of thermal stresses is required, if the carriage temperature of the liquid exceeds the following values:

\[ T = 65 \degree C \text{ in case of longitudinal framing}, \]
\[ T = 80 \degree C \text{ in case of transverse framing}. \]

The calculations are to be carried out for both temperatures, the actual carriage temperature and the limit temperature \( T \) according to 11.1.5.

The calculations are to give the resultant stresses in the hull structure based on a sea water temperature of 0 \( \degree C \) and an air temperature of 5 \( \degree C \).

Constructional measures and/or strengthening will be required on the basis of the results of the calculation for both temperatures.

11.1.6 Cross references

11.1.6.1 Where a tank bulkhead forms part of a watertight bulkhead, its strength is not to be less than required by Section 10.

11.1.6.2 For oil fuel tanks, see also Rules, Part 8 - Piping, Section 8. For tanks in the double bottom, see Section 7.2.

11.1.6.3 For cargo oil tanks, see Section 18.

11.1.6.4 For dry cargo holds which are also intended to be used as ballast water tanks, see 11.3.2.

11.1.6.5 For testing of tanks, see 11.6.

11.1.6.6 For corrosion protection and cathodic protection see Rules, Part 1 - General requirements, Chapter 5 and Part 24 - Non-metallic materials, Section 4.

11.1.7 Minimum thickness

11.1.7.1 The thickness of all structures in tanks is not to be less than the following minimum value:

\[ t_{\text{min}} = 5.5 + 0.02 \cdot L \text{ [mm]} \]

11.1.7.2 For fuel oil, lubrication oil and freshwater tanks \( t_{\text{min}} \) need not be taken greater than 7.5 mm.

11.1.7.3 For ballast tanks of dry cargo ships \( t_{\text{min}} \) need not be taken greater than 9.0 mm.

11.1.7.4 For oil tanker, see Section 18.1.8.

11.2 SCANTLINGS

11.2.1 Definitions

\( k \) = material factor according to 1.4.2.2;
\( s \) = spacing of stiffeners or load width, in [m];
\( l \) = unsupported span, in [m], according to Section 2.3.1;
\( p \) = load \( p_1 \) or \( p_2 \), in [kN/m²], according to Section 3.4 (the greater load to be taken);
\( p_2 \) = load, in [kN/m²], according to 3.4;
\( \tau \) = corrosion addition, in [mm], according to 2.9.1;
\( h \) = filling height of tank, in [m];
\( l_t \) = tank length, in [m];
\( b_t \) = tank breadth, in [m];
\[
\sigma_a = \sqrt{\frac{235}{k} - 3 \cdot \frac{\tau}{l_t} - 0.89 \cdot \sigma_L [N/mm^2]}
\]
\( \alpha, \pi \) = design hull girder bending or shear stress respectively, in [N/mm²], within the plate field considered as defined in Section 4.5.3;
\( C \) = 1.0, for transverse stiffening;
\( C \) = 0.83, for longitudinal stiffening.

11.2.2 Plating

11.2.2.1 The plate thickness is not to be less than:
t₁ = 1.1·s·\sqrt{p·k + t₀} \text{[mm]},

t₂ = 0.9·s·\sqrt{p_2·k + t₀} \text{[mm]},

11.2.2.2 The thickness of tank boundaries (including deck and inner bottom) carrying also normal and shear stresses due to longitudinal hull girder bending is not to be less than:

t = 16.8·C·s·\sqrt{\frac{p}{\sigma_{ts}}} + t₀ \text{[mm]}

11.2.2.3 The buckling strength of longitudinal and transverse bulkheads exposed to compressive stresses is to be carried out according to Section 4.6, for longitudinal bulkheads the design stresses according to 4.5.3 and the stresses due to local are to be considered.

11.2.3 Stiffeners and girders

11.2.3.1 Stiffeners and girders, which are not considered as longitudinal strength members

11.2.3.1.1 The section modulus of stiffeners and girders constrained at their ends, which are not considered as longitudinal strength members, is not to be less than:

\frac{W}{t} = 0.55 \cdot s \cdot l^2 \cdot p \cdot k \text{[cm]}

\frac{W_2}{t} = 0.44 \cdot s \cdot l^2 \cdot p_2 \cdot k \text{[cm]}

Where one or both ends are simply supported, the section moduli are to be increased by 50 per cent. The cross sectional area of the girder webs is not to be less than:

A_{w1} = 0.05 \cdot s \cdot l \cdot p \cdot k \text{[cm]}

A_{w2} = 0.04 \cdot s \cdot l \cdot p_2 \cdot k \text{[cm]}

A_{w2} is to be increased by 50 per cent at the position of constraint for a length of 0.1·l.

The buckling strength of the webs is to be examined according to Section 4.6.

11.2.3.1.2 Where the scantlings of stiffeners and girders, which are not considered as longitudinal strength members, the following permissible stress values apply:

- if subjected to load \( p \):
  \( \sigma_k = 150/k \text{[N/mm}] \)
  \( \tau = 100/k \text{[N/mm}] \)
  \( \sigma_{tk} = \sqrt{\sigma_{pk}^2 + 3\tau^2} = 180/k \text{[N/mm]} \)

- if subjected to load \( p_2 \):
  \( \sigma_k = 180/k \text{[N/mm]} \)
  \( \tau = 120/k \text{[N/mm]} \)
  \( \sigma_{tk} = \sqrt{\sigma_{pk}^2 + 3\tau^2} = 200/k \text{[N/mm]} \)

11.2.3.2 Stiffeners and girders, which are to be considered as longitudinal strength members

11.2.3.2.1 The section moduli and shear areas of horizontal stiffeners and girders, which are to be considered as longitudinal strength members, are to be determined according to 8.2.3 as for longitudinals. In this case for girders supporting transverse stiffeners the factors \( m = 1 \) and \( m_2 = 0 \) are to be used.

11.2.3.2.2 The scantlings of beams and girders of tank decks are also to comply with the requirements of Section 9.

11.2.3.2.3 For frames in tanks, see 8.1.2.2.

11.2.3.2.4 The stiffeners of tank bulkheads are to be attached at their ends by brackets according to Section 2.4.2. The scantlings of the brackets are to be determined according to the section modulus of the stiffeners. Brackets must be fitted where the length of the stiffeners exceeds 2 m.

The brackets of stiffeners are to extend to the next beam, the next floor, the next frame, or are to be otherwise supported at their ends.

11.2.3.2.5 Regarding buckling strength of girders the requirements of 11.2.2.3 are to be observed.

11.2.3.2.5 Where stringers of transverse bulkheads are supported at longitudinal bulkheads or at the side shell, the supporting forces of these stringers are to be considered when determining the shear stress in the longitudinal bulkheads. Likewise, where vertical girders of transverse bulkheads are supported at deck or inner bottom, the supporting forces of these vertical girders are to be considered when determining the shear stresses in the deck or inner bottom respectively.

The shear stress introduced by the stringer into the longitudinal bulkhead or side shell may be determined by the following formula:

\( \tau_{so} = \frac{P_{so}}{2·b_{so}·t} \text{[N/mm]} \)

where:

\( P_{so} \) = supporting force of stringer or vertical girder, in [kN];

\( b_{so} \) = breadth of stringer or depth of vertical girder including end bracket (if any) at the supporting point, in [m];

\( t \) = see 11.2.2.1.

The additional shear stress \( \sigma_o \) is to be added to the shear stress \( \tau_{so} \) due to longitudinal bending according to Section 4.5.3 in the following area:

- 0.5 m on both sides of the stringer in the ship's longitudinal direction
- 0.25 \cdot b_{so} above and below the stringer

Thereby the following requirement shall be satisfied:

\( \frac{110}{k} \geq \tau_{so} = \frac{P_{so}}{2·b_{so}·t} + \tau_{L} \)

11.2.4 Corrugated bulkheads

11.2.4.1 The plate thicknesses of corrugated bulkheads as well as the required section moduli of corrugated bulkhead elements are to be determined according to 11.2.2 and 11.2.3, proceeding analogously to Section 10.2.4.

The minimum plate thickness is to be in accordance with 11.1.7 or as follows:

- if subjected to load \( p_1 \):
  \( t_{min} = \frac{b}{905} \sqrt{\sigma_{pk} + t₀} \text{[mm]} \)

- if subjected to load \( p_2 \):
\[ t_{\text{min}} = \frac{b}{960} \sqrt{\sigma_D + t_k} \text{ [mm]} \]

where:
- \( \sigma_D \) = compressive stress, [N/mm\(^2\)];
- \( b \) = breadth of face plate strip, in [mm], see Fig. 10.2.4.3.

11.2.4.2 For the end attachment Section 2.4 is to be observed.

11.3 TANKS WITH LARGE LENGTHS OR BREADTHS

11.3.1 General

Tanks with lengths \( l_t > 0.1 \cdot L \) or breadths \( b_t > 0.6 \cdot B \) (e.g. hold spaces for ballast water) which are intended to be partially filled, are to be investigated to avoid resonance between the liquid motion and motion of the ship.

If necessary, critical tank filling ratios are to be avoided. The ship's periods of pitch and roll motion as well as the natural periods of the liquid in the tank may be determined by the following formulae:
- natural period of liquid in tank:
  \[ T_{l,b} = 1.132 \frac{e_t}{f} \text{ [s]} \]
  where:
  - \( f = \tanh (\pi \cdot h/e) \) hyperbolic function;
  - period of pitch motion
  \[ T_p = 1.8 \frac{L}{g} \text{ [s]} \]
  - period of roll motion
  \[ T_r = \frac{C_r \cdot B}{GM} \text{ [s]} \]
  where:
  - \( C_r = 0.78 \) in general;
  - \( C_r = 0.70 \) for tankers in ballast;
  - \( GM = 0.07 \cdot B \) in general;
  - \( GM = 0.12 \cdot B \) for tankers and bulk carriers;
  - \( e_t \) = characteristic tank dimension \( l_t \) or \( b_t \), in [m].

11.3.2 Hold spaces for ballast water

In addition to the requirements specified under 11.3.1 for hold spaces of dry cargo ships and bulk carriers, which are intended to be filled with ballast water, the following is to be observed:
- Adequate venting of the hold spaces and of the hatchway trunks is to be provided.
- For frames also Section 8.1.2.2 is to be observed.
- For hold spaces only permitted to be completely filled, a relevant notice will be entered into the Certificate.

11.4 DETACHED TANKS

11.4.1 General

11.4.1.1 Detached tanks are to be adequately secured against forces due to the ship's motions.

11.4.1.2 Detached oil fuel tanks are not to be installed in cargo holds. Where such an arrangement cannot be avoided, provision is to be made to ensure that the cargo cannot be damaged by leakage oil.

11.4.1.3 Fittings and pipings on detached tanks are to be protected by battens, and gutterways are to be fitted on the outside of tanks for draining any leakage oil.

11.4.2 Scantlings

11.4.2.1 The thickness of plating of detached tanks is to be determined according to 11.2.2.1 using the formula for \( t_1 \) and the pressure \( p \) as defined in 11.4.2.2.

11.4.2.2 The section modulus of stiffeners of detached tanks is not to be less than:
\[ W = C_1 \cdot s \cdot \frac{l^2}{p} \cdot k \text{ [cm}^3]\]

where:
- \( C_1 = 0.36 \) if stiffeners are constrained at both ends;
- \( C_1 = 0.54 \) if one or both ends are simply supported;
- \( p = 9.81 \cdot h \text{ [kN/m}^2\]};
- \( h = \text{head measured from the load centre of plate panel or stiffener respectively to the top of overflow}; \) the height of overflow is not to be taken less than 2.5 m.

11.4.2.3 For minimum thickness the requirements of 11.1.7 apply in general.

11.5 SWASH BULKHEADS

11.5.1 The total area of perforation is not to be less than 5% and are not to exceed 10% of the total bulkhead area.

11.5.2 The plate thickness is, in general, to be equal to the minimum thickness according to 11.1.7. Strengthenings may be required for load bearing structural parts. The free lower edge of a wash bulkhead is to be adequately stiffened.

11.5.3 The section modulus of the stiffeners and girders is not to be less than \( W_1 \) as per 11.2.3.1, however, the load \( p_d \) according to 3.4.2 is to be taken in lieu of \( p \).

11.5.4 For swash bulkheads in oil tankers see also Section 18.4.
11.6 TESTING PROCEDURES OF WATERTIGHT COMPARTMENTS

11.6.1 Application

Revision of this Section is to be complied with in respect of the testing of watertight compartments in accordance with notes 1, 2, 3 and 4.

11.6.2 General

11.6.2.1 The testing procedures of watertight compartments are to be carried out in accordance with Section 11.7, the “Procedures for testing tanks and tight boundaries for SOLAS ships” (including CSR BC & OT), and Section 11.8, “Procedures for testing tanks and tight boundaries for non-SOLAS ships and SOLAS exempt/equivalent ships”.

11.6.2.2 Testing procedures of watertight compartments for SOLAS ships (including CSR BC & OT) are to be carried out in accordance with Section 11.7, unless:

a) the shipyard provides documentary evidence of the shipowner’s agreement to a request to the Flag Administration for an exemption from the application of SOLAS Chapter II-1, Regulation 11, or for an equivalency agreeing that the content of Section 11.8 is equivalent to SOLAS Chapter II-1, Regulation 11; and

b) the above mentioned exemption / equivalency has been granted by the responsible Flag Administration.

11.6.2.3 Testing procedures of watertight compartments are to be carried out in accordance with Section 11.8 for non-SOLAS ships, and those SOLAS ships (including CSR BC & OT) for which:

a) the shipyard provides documentary evidence of the shipowner’s agreement to a request to the Flag Administration for an exemption from the application of SOLAS Chapter II-1, Regulation 11, or for an equivalency agreeing that the content of Section 11.8 is equivalent to SOLAS Chapter II-1, Regulation 11; and

b) the above-mentioned exemption / equivalency has been granted by the responsible Flag Administration.

Notes:

1. Revision of the Rules, Part 2.- Hull, 2013 or IACS UR S14, Rev.4 is to be applied to ships contracted for construction on or after 1 July 2013.

2. Revision of the Rules, Part 2.- Hull, 2015 or IACS UR S14, Rev.5 is to be applied to ships contracted for construction on or after 1 January 2016.

3. Revision of these Rules, Part 2.- Hull, 2018 or IACS UR S14, Rev.6 is to be applied to ships contracted for construction on or after 1 January 2018.

4. The “contracted for construction” date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date
11.7 PROCEDURES FOR TESTING TANKS AND TIGHT BOUNDARIES (SOLAS SHIPS)

11.7.1 General

11.7.1.1 These test procedures are to confirm the watertightness of tanks and watertight boundaries and the structural adequacy of tanks which consist of the watertight subdivisions of ships. These procedures may also be applied to verify the weathertightness of structures and shipboard outfitting. The tightness of all tanks and watertight boundaries of ships during new construction and those relevant to major conversions or major repairs is to be confirmed by these test procedures prior to the delivery of the ship.

11.7.1.2 Testing procedures of watertight compartments for SOLAS ships (including CSR BC & OT) are to be carried out in accordance with this Section, unless:

1. the shipyard provides documentary evidence of the shipowner’s agreement to a request to the Flag Administration for an exemption from the application of SOLAS Chapter II-1, Regulation 11, or for an equivalency agreeing that the content of Section 11.7 is equivalent to SOLAS Chapter II-1, Regulation 11; and

2. the above-mentioned exemption / equivalency has been granted by the responsible Flag Administration.

11.7.2 Application

11.7.2.1 All gravity tanks and other boundaries required to be watertight or weathertight are to be tested in accordance with this Procedure and proven to be tight and structurally adequate as follows:

1. gravity tanks for their tightness and structural adequacy,

2. watertight boundaries other than tank boundaries for their watertightness, and

3. weathertight boundaries for their weathertightness.

11.7.2.2 The testing of cargo containment systems of liquefied gas carriers is to be in accordance with standards deemed appropriate by the Register.

11.7.2.3 Testing of structures not listed in Table 11.7.1 or 11.7.2 is to be specially considered.

11.7.3 Test types and definitions

11.7.3.1 The following two types of test are specified in this requirement:

Structural test: A test to verify the structural adequacy of tank construction. This may be a hydrostatic test or, where the situation warrants, a hydropneumatic test.

Leak test: A test to verify the tightness of a boundary. Unless a specific test is indicated, this may be a hydrostatic/hydropneumatic test or an air test. A hose test may be considered an acceptable form of leak test for certain boundaries, as indicated by footnote 3 of Table 11.7.1.

11.7.3.2 The definition of each test type is as follows:

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrostatic test</td>
<td>A test wherein a space is filled with a liquid to a specified head.</td>
</tr>
<tr>
<td>Hydrostatic test (Leak and structural)</td>
<td>A test combining a hydrostatic test and an air test, wherein a space is partially filled with a liquid and pressurized with air.</td>
</tr>
<tr>
<td>Hose test</td>
<td>A test to verify the tightness of a joint by a jet of water with the joint visible from the opposite side.</td>
</tr>
<tr>
<td>Hose test (Leak)</td>
<td>A test to verify tightness by means of air pressure differential and leak indicating solution. It includes tank air tests and joint air tests, such as a compressed air fillet weld test and vacuum box tests.</td>
</tr>
<tr>
<td>Air Tests</td>
<td>A test to verify the tightness of a boundary by visual inspection. It includes tank air tests and joint air tests.</td>
</tr>
<tr>
<td>Air Tests (Leak)</td>
<td>A test to verify tightness by means of air pressure differential and leak indicating solution. It includes tank air tests and joint air tests.</td>
</tr>
<tr>
<td>Compressed air fillet weld test</td>
<td>An air test of a fillet welded tee joint wherein leak indicating solution is applied on fillet welds.</td>
</tr>
<tr>
<td>Compressed air fillet weld test (Leak)</td>
<td>An air test of a fillet welded tee joint wherein leak indicating solution is applied on fillet welds.</td>
</tr>
<tr>
<td>Vacuum box test</td>
<td>A box over a joint with leak indicating solution applied on the welds. A vacuum is created inside the box to detect any leaks.</td>
</tr>
<tr>
<td>Ultrasonic test</td>
<td>A test to verify the tightness of the sealing of closing devices such as hatch covers by means of ultrasonic detection techniques.</td>
</tr>
<tr>
<td>Penetration test</td>
<td>A test to verify that no visual dye penetrant indications of potential continuous leakages exist in the boundaries of a compartment by means of low surface tension liquids (i.e. dye penetrant test).</td>
</tr>
</tbody>
</table>

11.7.4 Test procedures

11.7.4.1 General

Tests are to be carried out in the presence of a Surveyor at a stage sufficiently close to the completion of work with all hatches, doors, windows, etc. installed and all penetrations including pipe connections fitted, and before any ceiling and cement work is applied over the joints. Specific test requirements are given in 11.7.4.4 and Table 11.7.1. For

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1) Watertight subdivision means the main transverse and longitudinal subdivisions of the ship required to satisfy the subdivision requirements of SOLAS Chapter II-1.

2) Major repair means a repair affecting structural integrity.

3) Gravity tank means a tank that is subject to vapour pressure nor greater than 70 kPa.
the timing of the application of coating and the provision of safe access to joints, see 11.7.4.5, 11.7.4.6 and Table 11.7.3.

### 11.7.4.2 Structural test procedures

#### 11.7.4.2.1 Type and time of test

Where a structural test is specified in Table 11.7.1 or Table 11.7.2, a hydrostatic test in accordance with 11.7.4.4.1 will be acceptable. Where practical limitations (strength of building berth, light density of liquid, etc.) prevent the performance of a hydrostatic test, a hydropneumatic test in accordance with 11.7.4.4.2 may be accepted instead.

A hydrostatic test or hydropneumatic test for the confirmation of structural adequacy may be carried out while the vessel is afloat, provided the results of a leak test are confirmed to be satisfactory before the vessel is afloat.

#### 11.7.4.2.2 Testing schedule for new construction or major structural conversion

11.7.4.2.2.1 Tanks which are intended to hold liquids, and which form part of the watertight subdivision of the ship\(^1\), shall be tested for tightness and structural strength as indicated in Table 11.7.1 and Table 11.7.2.

11.7.4.2.2.2 The tank boundaries are to be tested from at least one side. The tanks for structural test are to be selected so that all representative structural members are tested for the expected tension and compression.

11.7.4.2.2.3 The watertight boundaries of spaces other than tanks for structural testing may be exempted, provided that the water-tightness of boundaries of exempted spaces is verified by leak tests and inspections. Structural testing may not be exempted and the requirements for structural testing of tanks in 11.7.4.2.2.1 to 11.7.4.2.2.2 shall apply, for ballast holds, chain lockers and a representative cargo hold if intended for in-port ballasting.

11.7.4.2.2.4 Tanks which do not form part of the watertight subdivision of the ship\(^1\), may be exempted from structural testing provided that the water-tightness of boundaries of exempted spaces is verified by leak tests and inspections.

#### 11.7.4.3 Leak test procedures

For the leak test specified in Table 11.7.1, tank air tests, compressed air fillet weld tests, vacuum box tests in accordance with 11.7.4.4.4 through 11.7.4.4.6, or their combination will be acceptable. Hydrostatic or hydropneumatic tests may also be accepted as leak tests provided that 11.7.4.5, 11.7.4.6 and 11.7.4.7 are complied with. Hose tests will also be acceptable for such locations as specified in Table 11.7.1, footnote 3, in accordance with 11.7.4.4.3.

The application of the leak test for each type of welded joint is specified in Table 11.7.3.

Air test of joints may be carried out in the block stage provided that all work on the block that may affect the tightness of a joint is completed before the test. See also 11.7.4.5.1 for the application of final coatings and 11.7.4.6 for the safe access to joints and the summary in Table 11.7.3.

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\(^1\) Watertight subdivision means the main transverse and longitudinal subdivisions of the ship required to satisfy the subdivision requirements of SOLAS Chapter II-1.
11.7.4.4.5 Compressed air fillet weld test

In this air test, compressed air is injected from one end of a fillet welded joint and the pressure verified at the other end of the joint by a pressure gauge. Pressure gauges are to be arranged so that an air pressure of at least 0.15 \(10^5\) Pa can be verified at each end of all passages within the portion being tested.

Note: Where a leak test is required for fabrication involving partial penetration welds, a compressed air test is also to be applied in the same manner as to fillet weld where the root face is large, i.e. 6-8 mm.

11.7.4.4.6 Vacuum box test

A box (vacuum testing box) with air connections, gauges and an inspection window is placed over the joint with a leak indicating solution applied to the weld cap vicinity. The air within the box is removed by an ejector to create a vacuum of 0.20·10\(^5\) – 0.26·10\(^5\) Pa inside the box.

11.7.4.4.7 Ultrasonic test

An ultrasonic echo transmitter is to be arranged inside of a compartment and a receiver is to be arranged on the outside. The watertight/weather tight boundaries of the compartment are scanned with the receiver in order to detect an ultrasonic leak indication. A location where sound is detectable by the receiver indicates leakage in the sealing of the compartment.

11.7.4.4.8 Penetration test

A test of butt welds or other weld joints uses the application of a low surface tension liquid at one side of a compartment boundary or structural arrangement. If no liquid is detected on the opposite sides of the boundaries after the expiration of a defined period of time, this indicates tightness of the boundaries. In certain cases, a developer solution may be painted or sprayed on the other side of the weld to aid leak detection.

11.7.4.4.9 Other test

Other methods of testing may be considered by the Register upon submission of full particulars prior to the commencement of testing.

11.7.4.5 Application of coating

11.7.4.5.1 Final coating

For butt joints welded by an automatic process, the final coating may be applied any time before the completion of a leak test of spaces bounded by the joints, provided that the welds have been carefully inspected visually to the satisfaction of the Surveyor.

Surveyors reserve the right to require a leak test prior to the application of final coating over automatic erection butt welds.

For all other joints, the final coating is to be applied after the completion of the leak test of the joint. See also Table 11.7.3.

11.7.4.5.2 Temporary coating

Any temporary coating which may conceal defects or leaks is to be applied at the time as specified for the final coating (see 11.7.4.5.1). This requirement does not apply to shop primer.

11.7.4.6 Safe access to joints

For leak tests, a safe access to all joints under examination is to be provided. See also Table 11.7.3.

11.7.4.7 Hydrostatic or hydropneumatic tightness test

In cases where the hydrostatic or hydropneumatic tests are applied instead of a specific leak test, examined boundaries must be dew-free, otherwise small leaks are not visible.
### Table 11.7.1 Test requirements for tanks and boundaries

<table>
<thead>
<tr>
<th>Tank or boundary to be tested</th>
<th>Test type</th>
<th>Test head or pressure</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Double bottom tanks</td>
<td>Leak and structural</td>
<td>The greater of - top of the overflow, - to 2.4 m above top of tank, or - to bulkhead deck</td>
<td>including pump room double bottom and bunker tank protection double hull required by MARPOL, Annex I</td>
</tr>
<tr>
<td>2 Double bottom voids</td>
<td>Leak</td>
<td>See 11.7.4.4.4 through 11.7.4.4.6, as applicable</td>
<td></td>
</tr>
<tr>
<td>3 Double side tanks</td>
<td>Leak and structural</td>
<td>The greater of - top of the overflow, - to 2.4 m above top of tank, or - to bulkhead deck</td>
<td></td>
</tr>
<tr>
<td>4 Double side voids</td>
<td>Leak</td>
<td>See 11.7.4.4.4 through 11.7.4.4.6, as applicable</td>
<td></td>
</tr>
<tr>
<td>5 Deep tanks other than those listed elsewhere in this table</td>
<td>Leak and structural</td>
<td>The greater of - top of the overflow, or - to 2.4 m above top of tank</td>
<td></td>
</tr>
<tr>
<td>6 Cargo oil tanks</td>
<td>Leak and Structural</td>
<td>The greater of - top of the overflow, - to 2.4 m above top of tank, or - to top of tank plus setting of any pressure relief valve</td>
<td></td>
</tr>
<tr>
<td>7 Ballast hold of bulk carriers</td>
<td>Leak and structural</td>
<td>Top of cargo hatch coaming</td>
<td></td>
</tr>
<tr>
<td>8 Peak tanks</td>
<td>Leak and structural</td>
<td>The greater of - top of the overflow, or - to 2.4 m above top of tank</td>
<td>After peak to be tested after installation of stern tube</td>
</tr>
<tr>
<td>9 .1 Fore peak spaces with equipment</td>
<td>Leak</td>
<td>See 11.7.4.4.3 through 11.7.4.4.6, as applicable</td>
<td></td>
</tr>
<tr>
<td>9 .2 Fore peak voids</td>
<td>Leak</td>
<td>See 11.7.4.4.4 through 11.7.4.4.6, as applicable</td>
<td></td>
</tr>
<tr>
<td>9 .3 Aft peak spaces with equipment</td>
<td>Leak</td>
<td>See 11.7.4.4.3 through 11.7.4.4.6, as applicable</td>
<td></td>
</tr>
<tr>
<td>10 Cofferdams</td>
<td>Leak</td>
<td>See 11.7.4.4.4 through 11.7.4.4.6, as applicable</td>
<td></td>
</tr>
<tr>
<td>11 .1 Watertight bulkheads</td>
<td>Leak</td>
<td>See 11.7.4.4.3 through 11.7.4.4.6, as applicable</td>
<td></td>
</tr>
<tr>
<td>11 .2 Superstructure end bulkheads</td>
<td>Leak</td>
<td>See 11.7.4.4.3 through 11.7.4.4.6, as applicable</td>
<td></td>
</tr>
<tr>
<td>12 Watertight doors below freeboard or bulkhead deck</td>
<td>Leak</td>
<td>See 11.7.4.4.3 through 11.7.4.4.6, as applicable</td>
<td></td>
</tr>
<tr>
<td>13 Double plate rudder blades</td>
<td>Leak</td>
<td>See 11.7.4.4.4 through 11.7.4.4.6, as applicable</td>
<td></td>
</tr>
<tr>
<td>14 Shaft tunnels clear of deep tanks</td>
<td>Leak</td>
<td>See 11.7.4.4.3 through 11.7.4.4.6, as applicable</td>
<td></td>
</tr>
<tr>
<td>15 Shell doors</td>
<td>Leak</td>
<td>See 11.7.4.4.3 through 11.7.4.4.6, as applicable</td>
<td></td>
</tr>
<tr>
<td>16 Weathertight hatch covers and closing appliances</td>
<td>Leak</td>
<td>See 11.7.4.4.3 through 11.7.4.4.6, as applicable</td>
<td>Hatch covers closed by tarpaulins and battens excluded</td>
</tr>
<tr>
<td>17 Dual purpose tanks/dry cargo hatch covers</td>
<td>Leak</td>
<td>See 11.7.4.4.3 through 11.7.4.4.6, as applicable</td>
<td>In addition to structural test in item 6 or 7</td>
</tr>
<tr>
<td>18 Chain lockers</td>
<td>Leak and structural</td>
<td>Top of chain pipe</td>
<td></td>
</tr>
<tr>
<td>19 L.O. sump. tanks and other similar tanks/spaces under main engines</td>
<td>Leak</td>
<td>See 11.7.4.4.3 through 11.7.4.4.6, as applicable</td>
<td></td>
</tr>
<tr>
<td>20 Ballast ducts</td>
<td>Leak and structural</td>
<td>The greater of - ballast pump maximum pressure, or - setting of any pressure relief valve</td>
<td></td>
</tr>
</tbody>
</table>
21 Fuel oil tanks  Leak and structural\(^1\)  The greater of  
- top of the overflow,  
- to 2.4m above top of tank\(^2\), or  
- to top of tank\(^2\) plus setting of any pressure relief valve, or  
- to bulkhead deck

Notes:

1. Refer to section 11.7.4.2.2.
2. The top of a tank is the deck forming the top of the tank excluding any hatchways.
3. *Hose Test* may also be considered as a medium of the test. See 11.7.3.2.
4. Including tanks arranged in accordance with the provisions of SOLAS regulation II-1/9-4.
5. Including duct keels and dry compartments arranged in accordance with the provisions of SOLAS regulation II-1/11.2 and II-1/9.4 respectively, and/or oil fuel tank protection and pump room bottom protection arranged in accordance with the provisions of MARPOL Annex I, Chapter 3, Part A Regulation 12A and Chapter 4, Part A, Regulation 22 respectively.
6. Where water tightness of watertight door has not been confirmed by prototype test, testing by filling watertight spaces with water is to be carried out. See SOLAS regulation II-1/16.2 and MSC/Circ.1176.
7. As an alternative to the hose testing, other testing methods listed in 11.7.4.4.7 through 11.7.4.4.9 may be applicable subject to adequacy of such testing methods being verified. See SOLAS regulation II-1/11.1. For watertight bulkheads (item 11.1) alternatives to the hose testing may only be used where a hose test is not practicable.
8. A “Leak and structural test”. see 11.7.4.2.2 is to be carried out for a representative cargo hold if intended for in-port ballasting. The filling level requirement for testing cargo holds intended for in-port ballasting is to be the maximum loading that will occur in-port as indicated in the loading manual.
9. Where L.O. sump tanks and other similar spaces under main engines intended to hold liquid form part of the watertight subdivision of the ship, they are to be tested as per the requirements of Item 5, Deep tanks other than those listed elsewhere in this table.

<table>
<thead>
<tr>
<th>Type of ship/tank</th>
<th>Structures to be tested</th>
<th>Type of test</th>
<th>Test head or pressure</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Liquefied gas carriers</td>
<td>Integral tanks</td>
<td>Leak and structural</td>
<td>Refer to UR G1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hull structure supporting membrane or semi-membrane tanks</td>
<td>Refer to UR G1</td>
<td>Refer to UR G1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Independent tanks type A</td>
<td>Refer to UR G1</td>
<td>Refer to UR G1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Independent tanks type B</td>
<td>Refer to UR G1</td>
<td>Refer to UR G1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Independent tanks type C</td>
<td>Refer to UR G2</td>
<td>Refer to UR G2</td>
<td></td>
</tr>
</tbody>
</table>
| 2 Edible liquid tanks     | Independent tanks       | Leak and structural\(^1\) | The greater of  
- top of the overflow, or  
- to 0.9m above top of tank\(^2\)  | Where a cargo tank is designed for the carriage of cargoes with specific gravities larger than 1.0, an appropriate additional head is to be considered |
| 3 Chemical carriers       | Integral or independent cargo tanks | Leak and structural\(^1\) | The greater of  
- to 2.4m above top of tank\(^2\), or  
- to top of tank\(^2\) plus setting of any pressure relief valve  |         |

Note:

1. Refer to section 11.7.4.2.2.
2. Top of tank is deck forming the top of the tank excluding any hatchways.
Table 11.7.3 Application of leak test, coating and provision of safe access for type of welded joints

<table>
<thead>
<tr>
<th>Type of welded joints</th>
<th>Leak test</th>
<th>Coating(^1)</th>
<th>After leak test but before structural test</th>
<th>Safe Access(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before leak test</td>
<td>structural test</td>
<td>Structural test</td>
</tr>
<tr>
<td>Butt</td>
<td>Automatic</td>
<td>Not required</td>
<td>Allowed(^3)</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Manual or</td>
<td>Required</td>
<td>Not allowed</td>
<td>Allowed</td>
</tr>
<tr>
<td></td>
<td>semi-automatic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fillet</td>
<td>Boundary including penetrations</td>
<td>Required</td>
<td>Not allowed</td>
<td>Allowed</td>
</tr>
</tbody>
</table>

Notes:
1. Coating refers to internal (tank/hold coating), where applied, and external (shell/deck) painting. It does not refer to shop primer.
2. Temporary means of access for verification of the leak test.
3. The condition applies provided that the welds have been carefully inspected visually to the satisfaction of the Register's surveyor.
4. Flux Core Arc Welding (FCAW) semiautomatic butt welds need not be tested provided that careful visual inspections show continuous uniform weld profile shape, free from repairs, and the results of NDE testing show no significant defects.

11.8 PROCEDURES FOR TESTING TANKS AND TIGHT BOUNDARIES (NON-SOLAS SHIPS AND SOLAS EXEMPTION/EQUIVALENT SHIPS)

11.8.1 General

11.8.1.1 These test procedures are to confirm the watertightness of tanks and watertight boundaries and the structural adequacy of tanks which consist of the watertight subdivisions\(^1\) of ships. These procedures may also be applied to verify the watertightness of structures and shipboard outfitting. The tightness of all tanks and watertight boundaries of ships during new construction and those relevant to major conversions or major repairs\(^2\) is to be confirmed by these test procedures prior to the delivery of the ship.

11.8.1.2 Testing procedures of watertight compartments are to be carried out in accordance with this Section for non-SOLAS ships and those SOLAS ships (including CSR BC & OT) for which:

a) the shipyard provides documentary evidence of the shipowner’s agreement to a request to the Flag Administration for an exemption from the application of SOLAS Chapter II-1, Regulation 11, or for an equivalency agreeing that the content of this Section is equivalent to SOLAS Chapter II-1, Regulation 11; and

b) the above-mentioned exemption / equivalency has been granted by the responsible Flag Administration.

1) Watertight subdivision means the main transverse and longitudinal subdivisions of the ship required to satisfy the subdivision requirements of SOLAS Chapter II-1.
2) Major repair means a repair affecting structural integrity.

11.8.2 Application

11.8.2.1 Testing procedures are to be carried out in accordance with the requirements of Section 11.7 in association with the following alternative procedures for 11.7.4.2.2 of 11.7 “Testing schedule for new construction or major structural conversion” and alternative test requirements for 11.7, Table 11.7.1.

11.8.2.2 The tank boundaries are to be tested from at least one side. The tanks for structural test are to be selected so that all representative structural members are tested for the expected tension and compression.

11.8.2.3 Structural tests are to be carried out for at least one tank of a group of tanks having structural similarity (i.e. same design conditions, alike structural configurations with only minor localised differences determined to be acceptable by the attending Register's surveyor) on each vessel provided all other tanks are tested for leaks by an air test. The acceptance of leak testing using an air test instead of a structural test does not apply to cargo space boundaries adjacent to other compartments in tankers and combination carriers or to the boundaries of tanks for segregated cargoes or pollutant cargoes in other types of ships.

11.8.2.4 Additional tanks may require structural testing if found necessary after the structural testing of the first tank.

11.8.2.5 Where the structural adequacy of the tanks of a vessel were verified by the structural testing required in 11.7, Table 11.7.1, subsequent vessels in the series (i.e. sister ships built from the same plans at the same shipyard) may be exempted from structural testing of tanks, provided that:

1. water-tightness of boundaries of all tanks is verified by leak tests and thorough inspections are carried out.
2. structural testing is carried out for at least one tank of each type among all tanks of each sister vessel.
3. additional tanks may require structural testing if found necessary after the structural testing of the first tank or if deemed necessary by the attending Register’s surveyor.

For cargo space boundaries adjacent to other compartments in tankers and combination carriers or boundaries of tanks for segregated cargoes or pollutant cargoes in other types of ships, the provisions of paragraph 11.8.2.3 shall apply in lieu of paragraph 11.8.2.5.2.

11.8.2.6 Sister ships built (i.e. keel laid) two years or more after the delivery of the last ship of the series, may be tested in accordance with 11.8.2.5 at the discretion of the Register, provided that:

1. general workmanship has been maintained (i.e. there has been no discontinuity of shipbuilding or significant changes in the construction methodology or technology at the yard, shipyard personnel are appropriately qualified and demonstrate an adequate level of workmanship as determined by the Register) and:

2. an NDT plan is implemented and evaluated by the Register for the tanks not subject to structural tests. Shipbuilding quality standards for the hull structure during new construction are to be reviewed and agreed during the kick-off meeting. Structural fabrication is to be carried out in accordance with IACS Recommendation 47, “Shipbuilding and Repair Quality Standard”, or a recognised fabrication standard which has been accepted by the Register prior to the commencement of fabrication/construction. The work is to be carried out in accordance with the Rules and under survey of the Register.

11.9 CONSTRUCTION AND INITIAL TESTS OF WATERTIGHT DECKS, TRUNKS, ETC.

11.9.1 Watertight decks, trunks, tunnels, duct keels and ventilators shall be of the same strength as watertight bulkheads at corresponding levels. The means used for making them watertight, and the arrangements adopted for closing openings in them, shall be to the satisfaction of the Register. Watertight ventilators and trunks shall be carried at least up to the bulkhead deck in passenger ships and up to the freeboard deck in cargo ships.

11.9.2 Where a ventilation trunk passing through a structure penetrates the bulkhead deck, the trunk shall be capable of withstanding the water pressure that may be present within the trunk, after having taken into account the maximum heel angle allowable during intermediate stages of flooding, in accordance with requirements of the Rules, Part 5 – Subdivision, 2.7.

11.9.3 Where all or part of the penetration of the bulkhead deck is on the main ro-ro deck, the trunk shall be capable of withstanding impact pressure due to internal water motions (sloshing) of water trapped on the ro-ro deck.

11.9.4 After completion, a hose or flooding test shall be applied to watertight decks and a hose test to watertight trunks, tunnels and ventilators.
12 STEM AND STERNFRAME

12.1 DEFINITIONS

12.1.1 Definitions stated in this section are as follows:

- \( p_e \) = design pressure, in \([\text{kN/m}^2]\), according to 3.2.2.2;
- \( R_{eH} \) = minimum nominal upper yield point, in \([\text{N/mm}^2]\), according to 1.4.2.1;
- \( k \) = material factor according to 1.4.2.2, for cast steel, see Rules, Part 25 - Metallic materials, 3.12;
- \( C_R \) = rudder force, in \([\text{N}]\), according to Rules, Part 3 - Hull equipment, 2.3;
- \( B_1 \) = support force, in \([\text{N}]\), according to Rules, Part 3 - Hull equipment, 2.4;
- \( t_k \) = corrosion addition according to 2.9.1.

12.2 STEM

12.2.1 Bar stem

12.2.1.1 The cross sectional area of a bar stem below the load waterline is not to be less than:

\[ A_s = 1.25 \cdot L \text{ [cm}^2] \]

12.2.1.2 Starting from the load waterline, the sectional area of the bar stem may be reduced towards the upper end to 0.75 \( A_s \).

12.2.2 Plate stem

12.2.2.1 The thickness of welded plate stem is not to be less than:

\[ t = (0.6 + 0.4 \cdot S_B) \cdot (0.08 \cdot L + 6) \cdot \sqrt{k} \text{ [mm]} \]

\[ t_{\text{max}} = 25 \cdot \sqrt{k} \text{ [mm]} \]

where:

- \( S_B \) = spacing, in [m], between horizontal stringers, breasthooks/diaphragm, or equivalent horizontal stiffening members.

12.2.2.2 Starting from 600 mm above the load waterline up to \( d + C_w \), the thickness may gradually be reduced to 0.8 \( t \).

12.2.2.3 Plate stems and bulbous bows are to be stiffened by diaphragm plates and/or cant frames.

12.2.2.4 Where the spacing of the diaphragm plates is reduced to 0.5 m the thickness of the plate stem may be reduced by 20%.

12.2.2.5 The plate thickness of a bulbous bow shall in general not be less than required according to 12.2.2.1.

12.2.2.6 The scantlings of the stiffening is to be done according to Section 8.

12.3 STERNFRAME

12.3.1 General

12.3.1.1 Propeller post and rudder post are to be led into the hull in their upper parts and connected to it in a suitable and efficient manner. In way of the rudder post the shell is to be strengthened according to 5.4.3. Due regard is to be paid to the design of the aft body, rudder and propeller well in order to minimize the forces excited by the propeller.

12.3.1.2 The following value is recommended for the propeller clearance from shell (sternframe) related to 0.9 \( R \) (see Fig. 12.3.1.2-1):

\[ d_{1,9} \geq 0.004 \cdot n \cdot d_p^2 \cdot \left[ \frac{1 - \sin (0.75 \gamma)}{\Delta} \right] \cdot \left( 0.5 + \frac{Z_B}{X_F} \right) \text{ [m]} \]

where:

- \( R \) = propeller radius, in [m];
- \( v \) = ship's speed, in [kn];
- \( n \) = number of propeller revolutions [\text{min}^{-1}];
- \( \Delta \) = maximum displacement of ship, in [t];
- \( d_p \) = propeller diameter in [m];
- \( \gamma \) = skew angle of the propeller, in [\text{o}], see Fig. 12.3.1.2-2;
- \( Z_B \) = height of wheelhouse deck above weather deck, in [m], see Fig. 12.3.1.2-1;
- \( X_F \) = distance of deckhouse front bulkhead from aft edge of stern, in [m], see Fig. 12.3.1.2-1.

Figure 12.3.1.2-1
12.3.1.3  For single screw ships, the lower part of the sternframe is to be extended forward by at least 3 times the frame spacing from fore edge of the boss, for all other ships by 2 times the frame spacing from after edge of the sternframe (rudder post).

12.3.1.4  The stern tube is to be surrounded by the floor plates and connected with welding.

12.3.1.5  The plate thickness of sterns of welded construction for twin screw vessels is not to be less than:

\[ t = (0.07L + 5.0) \cdot \sqrt{k} \text{ [mm]} \]

\[ t_{\text{max}} = 22.0 \sqrt{k} \text{ [mm]} \]

12.3.2  Propeller post

12.3.2.1  The scantlings of rectangular, solid propeller posts are to be determined according to the following formulae:

\[ l = 1.4L + 90 \text{ [mm]} \]
\[ b = 1.6L + 15 \text{ [mm]} \]

Where other sections than rectangular ones are used, their section modulus is not to be less than that resulting from rectangular section.

12.3.2.2  The scantlings of propeller posts of welded construction are to be determined according to the following formulae:

\[ l = 50 \sqrt{L} \text{ [mm]} \]
\[ b = 36 \sqrt{L} \text{ [mm]} \]
\[ t = 2.4 \cdot \sqrt{L \cdot k} \text{ [mm]} \]

for \( l, b \) and \( t \) see Fig. 12.3.2.2.

Figure 12.3.2.2

12.3.2.3  Where the cross sectional configuration is deviating from Fig. 12.3.2.2 and for cast steel propeller posts the section modulus of the cross section related to the longitudinal axis is not to be less than:

\[ W_s = 1.2 \cdot L^{1.5} \cdot k \text{ [cm}^3]\]

12.3.2.4  The wall thickness of the boss in the propeller post in its finished condition is to be not less:

\[ t_w = 0.1d_v + 56 \text{ [mm]} \]
\[ t_{wmin} = 0.6 \cdot b \text{ [mm]} \]

where:
\[ d_v = \text{diameter of tail propeller shaft (see Fig. 12.3.2.4)} \]

12.3.3  Rudder post

12.3.3.1  The section modulus of the rudder post related to longitudinal axis of the ship is not to be less than:

\[ W = C_R \cdot l \cdot k \cdot 10^{-3} \text{ [cm}^3]\]

where:
\[ l = \text{unsupported span of the rudder post, in [m]} \]

Strength calculations for the rudder post, taking into account the flexibility of the sole piece, may be required, by the Register, due to its low rigidity in y-direction.

The bending stress is not to exceed:
\[ \sigma_b = 85, \text{ [N/mm}^2\]
12.3.4 Sole pieces

12.3.4.1 The section modulus of the sole piece around the vertical z-axis is not to be less than:
\[ W_z = \frac{M_y \cdot k}{80} \quad [\text{cm}^3] \]

12.3.4.2 The section modulus of the sole piece around the transverse y-axis is not to be less than:
\[ W_y = \frac{W_z}{2} \quad [\text{cm}^3] \]

12.3.4.3 The sectional area is not to be less than:
\[ A_s = \frac{B_1 \cdot 48 \cdot k}{150} \quad [\text{mm}^2] \]

12.3.4.4 Equivalent stress

At no section within the length \( \ell_{50} \) is the equivalent stress to exceed 115/k N/mm\(^2\). The equivalent stress is to be determined by the following formula:
\[ \sigma_{ekv} = \sqrt{\sigma_b^2 + 3\left(\tau^2 + \tau_T^2\right)} \quad [\text{N/mm}^2] \]

where:
- \( \sigma_b = \frac{M_b}{W_e(x)} \quad [\text{N/mm}^2] \)
- \( \tau = \frac{B_1}{A_h} \quad [\text{N/mm}^2] \)
- \( M_b = \) bending moment at the section considered, in [Nm];
- \( B_1 = \) supporting force in the pintle bearing, in [N], (normally \( B_1 = Ck/2 \))
- \( \ell_{50} = \) see Fig. 12.3.4.1
- \( A_h = \) effective shear area of the rudder horn in y-direction, in [mm\(^2\)].
- \( \tau_T = \frac{M_T \cdot 10^3}{2 \cdot A_T \cdot t_h} \quad [\text{N/mm}^2] \)
- \( M_T = \) torsional moment as given in the Rules, Part 3 – Hull Equipment, Section 2, in [Nm];
- \( A_T = \) area in the horizontal section enclosed by the rudder horn, in [mm\(^2\)];
- \( t_h = \) plate thickness of rudder horn, [mm].
- \( k = \) material factor as given in the Rules, Part 3 – Hull Equipment, Section 2.

Figure 12.3.4.1 Sole piece

12.3.5 Rudder horn

12.3.5.1 When the connection between the rudder horn and the hull structure is designed as a curved transition into the hull plating, special consideration is to be given to the effectiveness of the rudder horn plate in bending and to the stresses in the transverse web plates.

The bending moments and shear forces are to be determined by a direct calculation or in line with the guidelines given in the Rules, Part 3 – Hull Equipment, Section 2 for semi spade rudder with one elastic support and semi spade rudder with 2-conjugate elastic support respectively.

12.3.5.2 The section modulus of the rudder horn around the horizontal x-axis is not to be less than:
\[ W_x = \frac{M_y \cdot k}{67} \quad [\text{cm}^3] \]

12.3.5.3 The shear stress due is not to be larger than:
\[ \tau = \frac{48}{k} \quad [\text{N/mm}^2] \]

where:
- \( k = \) material factor as given in the Rules, Part 3 – Hull Equipment, Section 2.

12.3.5.4 The equivalent stress

At no section within the height of the rudder horn is the equivalent stress to exceed 120/k N/mm\(^2\). The equivalent stress is to be determined by the following formula:
\[ \sigma_{ekv} = \sqrt{\sigma_b^2 + 3\left(\tau^2 + \tau_T^2\right)} \quad [\text{N/mm}^2] \]

where:
- \( \sigma_b = \frac{M_b}{W_e(x)} \quad [\text{N/mm}^2] \)
- \( \tau = \frac{B_1}{A_h} \quad [\text{N/mm}^2] \)
- \( M_b = \) supporting force in the pintle bearing, in [N], (normally \( B_1 = Ck/2 \))
- \( A_h = \) effective shear area of the rudder horn in y-direction, in [mm\(^2\)].
12.3.5.5 Rudder horn plating

The thickness of the rudder horn side plating is not to be less than:

\[ t_{\text{min}} = 2.4 \cdot \sqrt{L \cdot k}, \quad [\text{mm}] \]

where:

- \( L = \) rule length as defined in 1.2.3.1.
- \( k = \) material factor as given in the Rules, Part 3 – Hull Equipment, Section 2.

12.3.5.6 Welding and connection to hull structure

12.3.5.6.1 The rudder horn plating is to be effectively connected to the aft ship structure, e.g. by connecting the plating to side shell and transverse/longitudinal girders, in order to achieve a proper transmission of forces, see Fig. 12.3.5.6.1.

Brackets or stringer are to be fitted internally in horn, in line with outside shell plate, as shown in Fig. 12.3.5.6.1.

12.3.6.1.2 The steel used for the rudder trunk is to be of weldable quality, with a carbon content not exceeding 0.23% on ladle analysis and a carbon equivalent \( C_{\text{EQ}} \) not exceeding 0.41%.

Plating materials for rudder trunks are in general not to be of lower grades than corresponding to class II as defined in 1.4.2.

12.3.6.1.3 The weld at the connection between the rudder trunk and the shell or the bottom of the skeg is to be full penetration.

12.3.6.1.4 The fillet shoulder radius \( r \), in [mm] (see Fig. 12.3.6.1.4) is to be as large as practicable and to comply with the following formulae:

\[ r = \begin{cases} 0.1d_c, & \text{without being less than} \ 60 \text{ mm}, \text{ when } \sigma \geq 40 / k, [\text{N/mm}^2] \ [r = 30 \text{ mm}, \text{ when } \sigma < 40 / k [\text{N/mm}^2] } \end{cases} \]

where:

- \( d_c = \) rudder stock diameter as defined in the Rules, Part 3 – Hull Equipment, Section 2.
- \( \sigma = \) bending stress in the rudder trunk, in \([\text{N/mm}^2]\).
- \( k = \) material factor as given in the Rules, Part 3 – Hull Equipment, Section 2.

12.3.6.1.5 Rudder trunks comprising of materials other than steel are to be specially considered by the Register.

12.3.6.2 Scantlings

12.3.6.2.1 The scantlings of the trunk are to be such that:

- the equivalent stress due to bending and shear does not exceed 0.35 \( R_m \),
- the bending stress on welded rudder trunk is to be in compliance with the following formula:

\[ \sigma \leq 80 / k, [\text{N/mm}^2] \]

with:

- \( \sigma = \) bending stress in the rudder trunk, as defined in 12.3.6.1;
\[ k = \text{material factor for the rudder trunk as given in the Rules, Part 3 – Hull Equipment, Section 2, not to be taken less than 0.7;} \]

\[ R_{eH} = \text{specified minimum yield stress, in } [\text{N/mm}^2] \text{, of the material used.} \]

12.3.6.2.2 For calculation of bending stress, the span to be considered is the distance between the mid-height of the lower rudder stock bearing and the point where the trunk is clamped into the shell or the bottom of the skeg.

### 12.4 PROPELLER SHAFT BRACKETS

12.4.1 The strut axes are to intersect in the axis of the propeller shaft as far as practicable. The struts are to be extended through the shell plating and are to be attached in an efficient manner to the frames and plate floors respectively. The construction in way of the shell is to be carried out with special care.

In case of welded connection, the struts are to have a weld flange or a thickened part or are to be connected with the shell plating in another suitable manner. For strengthening of the shell in way of struts and shaft bossings, see Section 5.4.4

The requirements of Section 15.2.4.3 are to be observed.

12.4.2 The scantlings of solid struts are to be determined as outlined below depending on shaft diameter \( d \):

- thickness \( 0.44 \, d \)
- cross-sectional area \( 0.44 \, d^2 \)
- length of boss see Rules, Part 7 - Machinery installation, Section 2.6
- wall thickness of boss \( 0.25 \, d \).

12.4.3 Propeller brackets of welded construction and shaft bossings are to have the same strength as solid ones according 12.4.2.

### 12.5 BOW AND Stern THRUST UNIT STRUCTURE

12.5.1 Unit wall structure

12.5.1.1 The wall thickness of the unit is, in general, to be in accordance with the manufacturer's practice, but is to be not less than either the thickness of the surrounding shell plating plus 10 per cent or 15 mm, whichever is greater.

12.5.2 Framing

12.5.2.1 The unit is to be to the same standard as the surrounding shell plating.

The unit is to be adequately supported and stiffened.
13 SUPERSTRUCTURES AND DECKHOUSES

13.1 GENERAL

13.1.1 Explanation

13.1.1.1 For definitions of superstructure and deckhouse see 1.2.5.

13.1.1.2 A long deckhouse is a deckhouse the length of which within 0.4 \( L \) amidships exceeds 0.2 \( L \) or 12 m. The strength of a long deckhouse is to be specially considered.

13.1.1.3 Superstructures extending into the range of 0.4 \( L \) amidships and the length of which exceeds 0.15 \( L \) are defined as effective superstructures. Their side plating is to be treated as shell plating and their deck as strength deck.

All superstructures being located beyond 0.4 \( L \) amidships or having a length of less than 0.15 \( L \) or less than 12 m are, for the purpose of this Section, considered as non-effective superstructures.

13.1.1.4 For deckhouses of aluminium, see 1.4.4. For the use of non-magnetic material in way of the wheel house, the requirements of the national Administration concerned are to be observed.

13.1.2 Definitions

Throughout this Section the following definitions apply:

\[ k = \text{material factor according to 1.4.2.2}. \]
\[ p_D = \text{load according to 3.2.1.1}. \]
\[ p_s = \text{load according to 3.2.2.1}. \]
\[ p_e = \text{load according to 3.2.2.2}. \]
\[ p_{DA} = \text{load according to 3.2.5}. \]
\[ p_L = \text{load according to 3.3.1.1}. \]
\[ t_k = \text{corrosion addition according to 2.9.1}. \]

13.1.3 Strengthenings at the ends of superstructures

13.1.3.1 At the ends of superstructures one or both end bulkheads of which are located within 0.4 \( L \) amidships, the thickness of the shear strake, the strength deck in a breadth of 0.1 \( B \) from the shell, as well as the thickness of the superstructure side plating are to be strengthened as specified in Table 13.1.3.1. The strengthenings are to be extend over a region from 4 frame spacings abaft the end bulkhead to 4 frame spacings forward of the end bulkheads.

<table>
<thead>
<tr>
<th>Type of superstructure</th>
<th>Strengthening, in [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strength deck</td>
</tr>
<tr>
<td>Effective, according to 13.1.1.3</td>
<td>30</td>
</tr>
<tr>
<td>Non-effective</td>
<td>20</td>
</tr>
</tbody>
</table>

13.1.4 Transverse structure of superstructures and deckhouses

The transverse structure of superstructures and deckhouses is to be sufficiently dimensioned by a suitable arrangement of end bulkheads, web frames, steel walls of cabins and casings, or by other measures.

13.1.5 Openings in closed superstructures and deckhouses

For openings in closed superstructures and deckhouses see Rules, Part 3 - Hull equipment, 7.5.

13.2 SIDE PLATING AND DECKS OF NON-EFFECTIVE SUPERSTRUCTURES

13.2.1 Side plating

13.2.1.1 The thickness of the side plating is not to be less than the greater of the following values:

\[ t = 1,21 \cdot s \cdot \sqrt{p \cdot k} + t_k \] [mm],

or

\[ t = 0,8 \cdot t_{\text{min}} \] [mm],

where:

\[ p = p_D \text{ or } p_s \text{ as the case may be} \]
\[ t_{\text{min}} = \text{according to Section 5.2.6}. \]

13.2.2 Deck plating

13.2.2.1 The thickness of deck plating is not to be less than the greater of the following values:

\[ t = 1,21 \cdot s \cdot \sqrt{p \cdot k} + t_k \] [mm];

\[ t = (5,5 + 0,02 L) \cdot \sqrt{k} \] [mm],

where:

\[ p = p_{DA} \text{ or } p_L, \text{ (the greater value is to be taken)} \]
\[ L \text{ - need not be taken greater than 200 m}. \]

13.2.2.2 Where additional superstructure are arranged on non-effective superstructures located on the strength deck, the thickness required by 13.2.2.1 may be reduced by 10%.

13.2.2.3 Where plated decks are protected by sheathing, the thickness of the deck plating according to 13.2.2.1 and 13.2.2.2 may be reduced by \( t_k \), however, it is not to be less than 5 mm.

Attention is to be paid that the sheathing does not affect the steel. The sheathing is to be effectively fitted to the deck.
13.2.3 Deck beams, supporting deck structure and frames

13.2.3.1 The scantlings of the deck beams and the supporting deck structure are to be determined in accordance with Section 9.2.

13.2.3.2 The scantlings of superstructure frames are given in Section 8.1.3.

13.3 SUPERSTRUCTURE END BULKHEADS AND DECKHOUSE WALLS

13.3.1 General

The following requirements apply to bulkheads forming the only protection for openings as per Regulation 18 of LLC 1966 and for accommodations. These requirements define minimum scantlings based upon local lateral loads and it may be required that they be increased in individual cases.

These requirements do not apply to CSR Bulk Carriers.

13.3.2 Definitions

The design load for determining the scantlings is:

\[ p_A = n \cdot c \cdot (b \cdot f - z) \quad [\text{kN/m}^2] \]

where:

\[ n = 20 + \frac{L}{12} \] for the lowest tier of unprotected fronts. The lowest tier is normally that tier which is directly situated above the uppermost continuous deck to which the rule depth is to be measured;

\[ n = 10 + \frac{L}{12} \] for 2nd tier unprotected fronts;

\[ n = 5 + \frac{L}{15} \] for 3rd tier of sides and protected fronts;

\[ n = 7 + \frac{L}{100} - 8 \cdot \frac{x}{L} \] for aft ends abaft amidship;

\[ n = 5 + \frac{L}{100} - 4 \cdot \frac{x}{L} \] for aft ends forward of amidship.

\( L \) need not be taken greater than 300 m.

\[ b = 1,0 + \left[ \frac{x}{L} - 0,45 \right]^2 \left( \frac{C_b + 0,2}{C_b + 0,2} \right), \text{ for } \frac{x}{L} < 0,45; \]

\[ b = 1,0 + 1,5 \left( \frac{C_b + 0,2}{C_b + 0,2} \right)^2, \text{ for } \frac{x}{L} \geq 0,45; \]

\( 0,60 \leq C_b \leq 0,8 \), when determining scantlings of aft ends forward of amidships, \( C_b \) need not be taken less than 0,8.

\( x \) = distance, in [m], between the bulkhead considered and aft end of the length \( L \).

When determining sides of a deckhouse, the deckhouse is to be subdivided into parts of approximately equal length, not exceeding 0,15 \( L \) each, and \( x \) is to be taken as the distance between aft end of the length \( L \) and the centre of each part considered.

\[ f = 0,1 \cdot \frac{L}{300} \cdot \left( 1 - \frac{L}{150} \right)^2, \text{ for } L \leq 150 \text{ m}; \]

\[ f = 0,1 \cdot \frac{L}{300}, \text{ for } 150 \text{ m} \leq L \leq 300 \text{ m}; \]

\[ f = 11,0, \text{ for } L > 300 \text{ m}; \]

\( z \) = vertical distance, in [m], from the summer load line to the midpoint of stiffener span, or to the middle of the plate field.

\( c = 0,3 + 0,7 \frac{b'}{B'}; \)

\( b' = \text{breadth of deckhouse at the position considered, in [m]}; \)

\( B' = \text{actual maximum breadth of ship on the exposed weather deck at the position considered, in [m]}. \)

\( b/B' \) is not to be taken less than 0,25.

For exposed parts of machinery casings, \( c \) is not to be taken less than 1,0.

The design load \( p_A \) is not to be taken less than the minimum values given in Table 13.3.2.

<table>
<thead>
<tr>
<th>( L ) [m]</th>
<th>( p_A \text{min} ) [kN/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 50</td>
<td>30 ( \leq 15 )</td>
</tr>
<tr>
<td>&gt; 50 ≤ 250</td>
<td>25 + ( \frac{L}{10} )</td>
</tr>
<tr>
<td>&gt; 250</td>
<td>50 25</td>
</tr>
</tbody>
</table>

13.3.3 Scantlings

13.3.3.1 Stiffeners

The section modulus of the stiffeners is to be determined according to the following formula:

\[ W = 0,35 \cdot s \cdot f^2 \cdot p_A \cdot k \quad [\text{cm}^3]\]

where:

\( W = \text{stiffener modulus, in [cm³]}; \)

\( l = \text{unsupported span, in [m]}; l \) is to be taken as the superstructure height or deckhouse height respectively, however, not less than 2,0 m;

\( s = \text{spacing of stiffeners, in [m]}. \)

These requirements assume the webs of lower tier stiffeners to be efficiently welded to the decks. Scantlings for other types of end connections may be specially considered.

The section modulus of house side stiffeners need not be greater than that of side frames on the deck situated directly below; taking account of spacings and unsupported span \( l \).
13.3.3.2 Plate thickness

The thickness of the plating is to be determined according to the following formula:

\[ t = 0.95 \cdot s \cdot \sqrt{P_A} \cdot k + t_k \] [mm]

but not less than:

\[ t_{\text{min}} = \left( 5.0 + \frac{L}{100} \right) \cdot \sqrt{k} \], for the lowest tier;

\[ t_{\text{min}} = \left( 4.0 + \frac{L}{100} \right) \cdot \sqrt{k} \], for the upper tiers,

however, not less than 5.0 mm.

where:

- \( s \) and \( p_A \) are as defined above.
- When determining \( p_A \), \( z \) is to be measured to the middle of the plate field.

13.4 DECKS OF SHORT DECKHOUSES

13.4.1 Plating

The thickness of deck plating exposed to weather but not protected by sheathing is not to be less than:

\[ t = 8 \cdot s \cdot \sqrt{k} + t_k \] [mm]

For decks exposed to weather protected by sheathing and for decks within deckhouses the thickness may be reduced by \( n \).

In no case the thickness is to be less than the minimum thickness of 5.0 mm.

13.4.2 Deck beams

The deck beams and the supporting deck structure are to be determined according to Section 9.
14 STRENGTHENING FOR NAVIGATION IN ICE

This Section has been removed to the Rules, Part 29 - Rules for classification of Polar Class ships and Ice Class ships.
15 WELDED JOINTS

15.1 GENERAL

15.1.1 Information contained in manufacturing documents

15.1.1.1 The shapes and dimensions of welds and, where proof by calculation is supplied, the requirements applicable to welded joints (the weld quality grade, detail category, are to be stated in drawings and other manufacturing documents (part lists, welding and inspection schedules). In special cases, e.g. where special materials are concerned, the documents shall also state the welding method, the welding consumables used, heat input and control, the weld build-up and any post-weld treatment which may be required.

15.1.1.2 Symbols and signs used to identify welded joints are to be explained if they depart from the symbols and definitions contained in the relevant standards. Where the weld preparation conforms both to normal shipbuilding practice and to these Rules and recognized standards, where applicable, no special description is needed.

15.1.2 Materials, weldability

15.1.2.1 Only base materials of proven weldability may be used for welded structures (in accordance with Section 1.4).

15.1.2.2 For ordinary hull structural steels grades A, B, D and E which have been tested by the Register, weldability is considered to have been proven. No measures beyond those laid down in these welding rules need therefore be taken.

15.1.2.3 Higher tensile hull structural steels grade AH, DH and EH which have been approved by the Register and provided their handling is in accordance with normal shipbuilding practice, may be considered to be proven.

15.1.2.4 High tensile (quenched and tempered) fine grain structural steels, low temperature steels, stainless and other (alloyed) structural steels require special approval by the Register. Proof of weldability of the respective steel is to be presented in connection with the welding procedure and welding consumables.

15.1.2.5 Aluminium alloys require testing by the Register. Proof of their weldability must be presented in connection with the welding procedure and welding consumables.

15.1.3 Manufacture and testing

15.1.3.1 The manufacture of welded structural components may only be carried out in workshops or plants that have been approved. The requirements that have to be observed in connection with the fabrication of welded joints are laid in the Rules, Part 26 - Welding.

15.1.3.2 For details concerning the type, scope and manner of testing, see Rules, Part 26 - Welding, Section 2. Where proof of fatigue strength is required, in addition the requirements of Section 16 apply.

15.2 DESIGN

15.2.1 General design principles

15.2.1.1 During the design stage welded joints are to be planned such as to be accessible during fabrication, to be located in the best possible position for welding and to permit the proper welding sequence to be followed.

15.2.1.2 Both the welded joints and the sequence of welding involved are to be so planned as to enable residual welding stresses to be kept to a minimum in order that no excessive deformation occurs.

15.2.2 Design details

15.2.2.1 Stress flow, transitions

15.2.2.1.1 All welded joints on primary supporting members shall be designed to provide as smooth a stress profile as possible with no major internal or external notches, no discontinuities in rigidity and no obstructions to strains.

15.2.2.1.2 Butt joints in long or extensive continuous structures such as bilge keels, fenders, slop coamings, etc. attached to primary structural members are therefore to be welded over their entire cross-section.

15.2.2.1.3 Wherever possible, joints in girders and sections are not to be located in areas of high bending stress. Joints at the knuckle of flanges are to be avoided.

15.2.2.1.4 The transition between differing component dimensions are to be smooth and gradual. Where the depth of web of girders or sections differs, the flanges or bulbs are to be bevelled and the web split and expanded or pressed together to equalize the depths of the members. The length of the transition are to be at least equal twice the difference in depth.

15.2.2.1.5 Where the plate thickness differs at joints perpendicularly to the direction of the main stress, differences in thickness greater than 3 mm must be accommodated by beveling the proud edge in the manner shown in Fig. 15.2.2.1.5 at a ratio of at least 1:3 or according to the notch category. Differences in thickness of 3 mm or less may be accommodated within the weld.

15.2.2.1.6 For the welding on of plates or other relatively thin-walled elements, steel castings and forgings should be appropriately tapered or provided with integrally cast or forged welding flanges, (in accordance with Fig. 15.2.2.1.6).
15.2.2.1.7 For the connection of shaft brackets to the boss and shell plating, see 15.2.4.3 and Section 12.4. For the connection of horizontal coupling flanges to the rudder body, see 15.2.4.4. For the thickened rudder stock collar required with build-up welds and for the connection of the coupling flange, see 15.2.2.5. The joint between the rudder stock and the coupling flange must be welded over the entire cross-section.

15.2.2.2 Minimum spacing between welds

The local clustering of welds and short distances between welds are to be avoided. Adjacent butt welds are to be separated from each other by a distance of at least

\[ 50 \text{ mm} + 4 \times \text{plate thickness} \]

Fillet welds are to be separated from each other and from butt welds by a distance of at least

\[ 30 \text{ mm} + 2 \times \text{plate thickness} \]

The width of replaced or inserted plates (strips) should, however, be at least 300 mm or ten times the plate thickness (whichever is the greater).

15.2.2.3 Welding cut-outs

15.2.2.3.1 Welding cut-outs for the execution of butt or fillet welds following the positioning of transverse members should be rounded minimum radius 25 mm or twice the plate thickness (whichever is the greater) and are to be shaped to provide a switch transition are the adjoining surface as shown in Fig. 15.2.2.3.1.

15.2.2.3.2 Where the welds are completed prior to the positioning of the crossing members, no welding cut-outs are needed. Any weld reinforcements present are to be machined off prior to the location of the crossing members or these members are to have suitable cut-outs.

15.2.2.4 Local reinforcements, doubling plates

15.2.2.4.1 Where platings are subjected locally to increased stresses, thicker plates are to be used wherever possible in preference to doubling plates.

15.2.2.4.2 Where doublings are not to be avoided, the thickness of the doubling plates are not exceed twice the plating thickness. Doubling plates whose width is greater than approximately 30 times their thickness are to be plug welded to the underlying plating at intervals not exceeding 30 times the thickness of the doubling plate.

15.2.2.4.3 Along their edges, doubling plates are to be continuously fillet welded with a throat thickness \( a \) of 0.3 \( b \) the doubling plate thickness. At the ends of doubling plates, the throat thickness \( a \) at the end faces are to be increased to 0.5 \( b \) the doubling plate thickness but is not exceed the plating thickness (see Fig. 15.2.2.4.3).

15.2.2.4.4 Doubling plates are not permitted in tanks for flammable liquids.

15.2.2.4.5 Where proof of fatigue strength is required (see Section 16), the configuration of the end of the doubling plate must conform to the selected detail category.

15.2.2.5 Build-up welds on rudderstock and pintles

15.2.2.5.1 Wear resistance and/or corrosion resistant build-up welds on the bearing surfaces of rudderstocks, pintles etc. are to be applied to a thickened collar exceeding by at least 20 mm the diameter of the adjoining part of the shaft.

15.2.2.5.2 Where a thickened collar is impossible for design reasons, the build-up weld may be applied to the smooth shaft provided that relief-turning in accordance with 15.2.2.5.3 is possible.

15.2.2.5.3 After welding, the transition areas between the welded and non-welded portions of the shaft shall be relief-turned with large radii, as shown in Fig. 15.2.2.5.3, to remove geometrical and metallurgical "notches".

15.2.3 Weld shapes and dimensions

15.2.3.1 Butt joints

15.2.3.1.1 Depending on the plate thickness, the welding method and the welding position, butt joints shall be of the square, V or X shape conforming to the relevant standards.
Where other weld shapes are applied, these are to be specially described in the drawings.

**15.2.3.1.2** As a matter of principle, the rear sides of butt joints shall be grooved and welded with at least one capping pass.

**15.2.3.1.3** Where the aforementioned conditions cannot be met, e.g. where the welds are accessible from one side only, the joints shall be executed as lesser bevelled welds with an open root and an attached or an integrally machined or cast, permanent weld pool support as shown in Fig. 15.2.3.1.3.

**Figure 15.2.3.1.3**

**15.2.3.2 Corner, T and double-T joints**

**15.2.3.2.1** Corner, T and double-T joints are to be made as single or double-bevel welds with a minimum root face (welds with full root penetration) and adequate air gap, as shown in Fig. 15.2.3.2.1, and with grooving of the root and copping from the opposite sides.

The effective weld thickness are to be assumed as the thickness of the abutting plate.

**Figure 15.2.3.2.1**

**15.2.3.2.2** Corner, T and double-T joints with a defined incomplete root penetration, are to be made as single or double-bevel welds, as described in 15.2.3.2.1, with a back-up weld but without grooving of the root, as shown in Fig. 15.2.3.2.2.

**Figure 15.2.3.2.2**

The effective weld thickness may be assumed as the thickness of the abutting plate minus $f$, where $f$ is to be assigned a value of $0.2 \ t$ subject to a maximum of 3 mm.

**15.2.3.2.3** Corner, T and double-T joints with both an unwelded root face $c$ and a defined incomplete root penetration $f$ are to be made in accordance with Fig. 15.2.3.2.3.

**Figure 15.2.3.2.3**

The effective weld thickness is to be assumed as the thickness of the abutting plate $t$ minus $(c + f)$. For $f$, see Fig. 15.2.3.2.2.

**15.2.3.2.4** Corner, T and double-T joints which are accessible from one side only may be made in accordance with Fig. 15.2.3.2.4 in a manner analogous to the butt joints referred to in 15.2.3.1.3.

**Figure 15.2.3.2.4**

The effective weld thickness shall be determined by analogy with 15.2.3.1.3 or 15.2.3.2.2, as appropriate. Wherever possible, these joints should not be used where proof of fatigue strength is required (see Section 16).

**15.2.3.2.5** Where corner joints are flush, the weld shapes shall be as shown in Fig. 15.2.3.2.5.

**Figure 15.2.3.2.5**

**15.2.3.3 Fillet weld connections**

**15.2.3.3.1** In principle fillet welds are to be of the double fillet weld type. Exceptions to this rule as in the case of closed box girders and mainly shear stresses parallel to the
weld, are subject to the Register for approval in each individual case. The throat thickness \( a \) of the weld (the height of the inscribed isosceles triangle) is to be determined in accordance with Table 15.2.3.3.1. The leg length of a fillet weld is to be not less than 1.4 times the throat thickness \( a \).

15.2.3.3.2 The throat thickness of fillet welds is not exceed 0.7 times the lesser thickness of the parts to be connected (generally the web thickness). The minimum throat thickness is defined by the expression:

\[
\begin{align*}
a_{\min} &= \sqrt{\frac{t_1 + t_2}{3}} \quad [\text{mm}], \\
&\text{but not less than 3 mm,}
\end{align*}
\]

where:

\( t_1 = \text{lesser plate thickness, [mm]}, \)
\( t_2 = \text{greater plate thickness, [mm]} \).

15.2.3.3.3 Intermittent fillet welds may be located opposite one another (chain intermittent welds, possibly with scallops) or may be staggered (see Fig. 15.2.3.3.3). In water and cargo tanks, in the bottom area of fuel oil tanks and of spaces where condensed or sprayed water may accumulate only continuous or intermittent fillet welds with scallops are to be used.

\[ a_i = 1.1 \cdot a \cdot \left[ \frac{b}{l} \right] \quad [\text{mm}], \]

where:

\( a = \text{required fillet weld throat thickness, in [mm], for a continuous weld according to Table 15.2.3.3.1}; \)
\( b = \text{distance between weld's midpoints, in [mm], } = e + l; \)
\( e = \text{interval between the welds in [mm]}; \)
\( l = \text{length of fillet weld, in [mm]}. \)

The pitch ratio \( b/l \) are not to be exceed 5. The maximum unwelded length are not to be exceed 25 times the lesser thickness of the parts to be welded. The length of scallops are, however, not to be exceed 150 mm.

15.2.3.3.5 Lap joints are to be avoided wherever possible and are not to be used for heavily loaded components. In the case of components subject to low loads lap joints may be accepted provided that, wherever possible, they are oriented parallel to the direction of the main stress. The width of the lap is to be \( 1.5 \cdot t + 15 \) [mm] (\( t = \text{thickness of the thiner plate} \)).

The fillet weld must be continuous on both sides and must meet at the ends.

15.2.3.3.6 In the case of plug welding, the distance between the holes and the length of the holes may be determined by analogy with the pitch \( b \) and the fillet weld length \( l \) in the intermittent welds covered by 15.2.3.3.3. The fillet weld throat thickness \( a \) may be determined in accordance with 15.2.3.3.4. The with of the holes is to be equal to at least twice the thickness of the plate and are not to be less than 15 mm. The ends of the holes are to be semi-circular. Wherever possible only the necessary fillet welds are to be welded, while the remaining void is packed with a suitable filler.

15.2.4 Welded joints of particular components

15.2.4.1 Welds at the ends of girders and stiffeners

15.2.4.1.1 The web at the end of intermittently welded girders or stiffeners is to be continuously welded to the plating or the flange plate, as applicable, over a distance at least equal to the depth \( h \) of the girder subject to a maximum of 300 [mm], as shown in Fig. 15.2.4.1.1.

15.2.4.2 Joints between section ends and plates

15.2.4.2.1 Welded joints connecting section ends and plates may be made in the same plane or lapped, see Fig. 15.2.4.2.1.
15.2.4.2 Where the joint between the plate and the section end overlaps, the fillet weld must be continuous on both sides and must meet at the ends. The fillet weld throat thickness is not to be less than the minimum specified in 15.2.3.3.2.

15.2.4.3 Welded shaft bracket joints

15.2.4.3.1 Strut barrel and struts are to be connected to each other and to the shell plating in the manner shown in Fig. 15.2.4.3.1.

Explanations:
\[ t = \text{plating thickness in accordance with Section 5.4.4, in [mm];} \]
\[ t_1 = \text{plating thickness at connecting place;} \]
\[ t' = \frac{t}{3} + 5 \text{ [mm], for } t < 50 \text{ [mm];} \]
\[ t' = 3 \sqrt{t_f} \text{ [mm], for } t_f \geq 50 \text{ mm.} \]

15.2.4.4 Rudder coupling flanges

15.2.4.4.1 Unless forged or cast steel flanges with integrally forged or cast welding flanges are used, horizontal rudder coupling flanges are to be joined to the rudder body by plates of graduated thickness and full penetration single or double-bevel welds as shown in Fig. 15.2.4.4.1.
<table>
<thead>
<tr>
<th>Structural parts to be connected</th>
<th>Basic thickness of fillet welds $a/t_o$,(^1) for double continuous fillet welds</th>
<th>Intermittent fillet welds permissible$^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bottom structures:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse and longitudinal girders to each other</td>
<td>0.35</td>
<td>yes</td>
</tr>
<tr>
<td>to shell and inner bottom</td>
<td>0.20</td>
<td>yes</td>
</tr>
<tr>
<td>Centre girder to flat keel and inner bottom</td>
<td>0.40</td>
<td>–</td>
</tr>
<tr>
<td>Transverse and longitudinal girders and stiffeners in way of bottom strengthening forward</td>
<td>0.30</td>
<td>–</td>
</tr>
<tr>
<td>Transverse and longitudinal girders in machinery space</td>
<td>0.30</td>
<td>–</td>
</tr>
<tr>
<td>Inner bottom to shell</td>
<td>0.40</td>
<td>–</td>
</tr>
<tr>
<td><strong>Machinery foundation:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal and transverse girders to each other and to the shell</td>
<td>0.40</td>
<td>–</td>
</tr>
<tr>
<td>- to inner bottom and face plates</td>
<td>0.40</td>
<td>–</td>
</tr>
<tr>
<td>- to top plates $\text{^{\text{0.50}\text{\textsuperscript{\textsuperscript{3)}}}}$</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>- in way of foundation bolts $\text{^{\text{0.70}\text{\textsuperscript{\textsuperscript{3)}}}}$</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>- to brackets and stiffeners</td>
<td>0.30</td>
<td>–</td>
</tr>
<tr>
<td>Longitudinal girders of thrust bearing to inner bottom</td>
<td>0.40</td>
<td>–</td>
</tr>
<tr>
<td><strong>Decks:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>to shell (general);</td>
<td>0.40</td>
<td>–</td>
</tr>
<tr>
<td>Deck stringer to sheer strake (see also Chapter 6.1.2)</td>
<td>0.50</td>
<td>–</td>
</tr>
<tr>
<td><strong>Frames, stiffeners, beams etc.:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>general</td>
<td>0.15</td>
<td>yes</td>
</tr>
<tr>
<td>in peak tanks</td>
<td>0.30</td>
<td>yes</td>
</tr>
<tr>
<td>bilge keel to shell</td>
<td>0.15</td>
<td>–</td>
</tr>
<tr>
<td><strong>Transverses, longitudinal and transverse girders:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>general</td>
<td>0.15</td>
<td>yes</td>
</tr>
<tr>
<td>within 0.15 of span from supports</td>
<td>0.25</td>
<td>–</td>
</tr>
<tr>
<td>cantilevers</td>
<td>0.40</td>
<td>–</td>
</tr>
<tr>
<td>pillars to decks</td>
<td>0.40</td>
<td>–</td>
</tr>
<tr>
<td><strong>Bulkheads, tank boundaries, walls of superstructures and deckhouses:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>to decks, shell and walls</td>
<td>0.40</td>
<td>–</td>
</tr>
<tr>
<td><strong>Hatch coamings:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>to deck</td>
<td>0.40</td>
<td>–</td>
</tr>
<tr>
<td>to longitudinal stiffeners</td>
<td>0.30</td>
<td>–</td>
</tr>
<tr>
<td><strong>Hatch covers:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>general</td>
<td>0.15</td>
<td>–</td>
</tr>
<tr>
<td>watertight or oiltight fillet welds</td>
<td>0.30</td>
<td>–</td>
</tr>
<tr>
<td><strong>Rudder:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>plating to webs</td>
<td>0.25</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Stem:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>plating to webs</td>
<td>0.25</td>
<td>yes</td>
</tr>
</tbody>
</table>

**Notes:**

1) $t_o=$Thickness of the thinner plate;
2) See 15.2.3.3;
3) For plates thickness exceeding 15 mm single or double bevel butt joints to be applied, with V or X edge preparation.
16  FATIGUE STRENGTH

16.1  GENERAL

16.1.1  Definitions

\[ \Delta \sigma = \text{applied stress range } (\sigma_{\text{max}} - \sigma_{\text{min}}), \text{ in } [\text{N/mm}^2] \],

see also Fig. 16.1.1

\[ \sigma_{\text{max}} = \text{maximum upper stress of a stress cycle in } [\text{N/mm}^2] \]

\[ \sigma_{\text{min}} = \text{maximum upper stress of a stress cycle in } [\text{N/mm}^2] \]

\[ \Delta \sigma_{\text{max}} = \text{applied peak stress range within a stress range spectrum in } [\text{N/mm}^2] \]

\[ \sigma_{\text{m}} = \text{mean stress } (\sigma_{\text{max}}/2 + \sigma_{\text{min}}/2), \text{ in } [\text{N/mm}^2] \]

\[ \Delta \sigma_{\text{p}} = \text{permissible stress range in } [\text{N/mm}^2] \]

\[ \sigma_{\text{n}} = \text{nominal stress in } [\text{N/mm}^2] \]

\[ \sigma_{\text{s}} = \text{structural (or hot-spot) stress in } [\text{N/mm}^2] \]

\[ \sigma_{\text{k}} = \text{notch stress in } [\text{N/mm}^2] \]

\[ n = \text{number of applied stress cycles} \]

\[ N = \text{number of endured stress cycles according to S-N curve (=} \text{endured stress cycles under constant amplitude loading)} \]

\[ \Delta \sigma_{R} = \text{fatigue strength reference value of S-N curve at } 2 \cdot 10^{6} \text{ cycles of stress range in } [\text{N/mm}^2] \]

\[ f_{m} = \text{correction factor for material effect} \]

\[ f_{R} = \text{correction factor for mean stress effect} \]

\[ f_{w} = \text{correction factor for weld shape effect} \]

\[ f_{i} = \text{correction factor for importance of structural element} \]

\[ f_{s} = \text{additional correction factor for structural stress analysis} \]

\[ f_{n} = \text{factor considering stress spectrum and number of cycles for calculation of permissible stress range} \]

\[ \Delta \sigma_{R_{c}} = \text{corrected fatigue strength reference value of S-N curve at 2 stress cycles, in } [\text{N/mm}^2] \]

\[ D = \text{cumulative damage ratio.} \]

\[ m, m_{\text{n}} = \text{see 16.2.3.1.2} \]

---

16.1.2  Scope

16.1.2.1  A fatigue strength analysis is to be performed for structures which are predominantly subjected to cyclic loads. The notched details i.e. the welded joints as well as notches at free plate edges are to be considered individually. The fatigue strength assessment is to be carried out either on the basis of a permissible peak stress range for standard stress spectra (see 16.2.2.1) or on the basis of a cumulative damage ratio (see 16.2.2.2).

16.1.2.2  No fatigue strength analysis is required if the peak stress range due to dynamic loads in the seaway (stress spectrum A according to 16.1.2.4) and/or due to changing draft or loading conditions, respectively, fulfills the following conditions:

- peak stress range only due to seaway-induced dynamic loads:

\[ \Delta \sigma_{\text{max}} \leq 2.5 \Delta \sigma_{R} \]

- sum of the peak stress ranges due to seaway-induced dynamic loads and due to changes of draught or loading condition, respectively:

\[ \Delta \sigma_{\text{max}} \leq 4.0 \Delta \sigma_{R} \]

Note:

For welded structures of detail category 80 or higher a fatigue strength analysis is required only in case of extraordinary high dynamic stresses.

16.1.2.3  The requirements are applicable to constructions made of ordinary and higher-tensile hull structural steels according to Section 1.4. Other materials such as cast steel and aluminium alloys can be treated in an analogous manner by using appropriate design S-N curves.

16.1.2.4  The stress ranges which are to be expected during the service life of the ship or structural component, respectively, may be described by a stress range spectrum (long-term distribution of stress range). Fig. 16.1.2.4 shows three standard stress range spectra A, B and C, which differ from each other in regard to the distribution of stress range as a function of the number of load cycles.

---

**Figure 16.1.1**

**Figure 16.1.2.4**
### Table 16.1.2.4

<table>
<thead>
<tr>
<th>Load</th>
<th>Maximum load</th>
<th>Minimum load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical longitudinal bending moments (Section 4.2)</td>
<td>$M_S + 0.75 \cdot M_o + M_{st}$</td>
<td>$M_S - (0.75 \cdot M_o + M_{st})$</td>
</tr>
<tr>
<td>Influence off horizontal wave bending moments (Section 4.5)</td>
<td>$M_S + 0.5 \cdot M_o + M_{stl}$</td>
<td>$M_S - (0.5 \cdot M_o + M_{stl})$</td>
</tr>
<tr>
<td>Loads on weather decks(^1)) (Section 3.2.1)</td>
<td>$p_D$</td>
<td>0</td>
</tr>
<tr>
<td>Loads on ship’s sides(^1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- below TVL</td>
<td>$10 (d - z) + p_o \cdot c_F \left(1 + \frac{z}{d}\right)$</td>
<td>$10 (d - z) - p_o \cdot c_F, \left(1 + \frac{z}{d}\right), \text{ but }\geq 0$</td>
</tr>
<tr>
<td>- above TVL</td>
<td>$p_o \cdot c_F \cdot \frac{20}{10 + z - d}$</td>
<td>0</td>
</tr>
<tr>
<td>Loads on ship’s bottom(^1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Section 3.2.3)</td>
<td>$10 d + p_o \cdot c_F$</td>
<td>$10 d - p_o \cdot c_F$</td>
</tr>
<tr>
<td>Liquid pressure in completely filled tanks (Section 3.4.1)</td>
<td>$9.81 \cdot h_c \cdot p_1 (1 + z) + 100 \cdot p_1 \cdot c_F \left(1 + \frac{z}{d}\right)$</td>
<td>$9.81 \cdot h_c \cdot p_1 (1 - z) + 100 \cdot p_1$</td>
</tr>
<tr>
<td>Loads due to cargo</td>
<td>$9.81 \cdot p_1 \cdot (0.3 \cdot b + y) \cdot \sin \phi + 100 \cdot p_1$</td>
<td>$9.81 \cdot p_1 \cdot (0.3 \cdot b - y) \cdot \sin \phi + 100 \cdot p_1$, \text{ but }\geq 100 \cdot p_1^1$</td>
</tr>
<tr>
<td>(Section 3.3.11 and 3.5.1)</td>
<td>$p_o (1 + z) $</td>
<td>$p_o (1 - z)$</td>
</tr>
<tr>
<td></td>
<td>$p_o \cdot a_o \cdot 0.7$</td>
<td>$- p_o \cdot a_o \cdot 0.7$</td>
</tr>
<tr>
<td></td>
<td>$p_o \cdot a_o \cdot 0.7$</td>
<td>$- p_o \cdot a_o \cdot 0.7$</td>
</tr>
</tbody>
</table>

\(^1\) With $f=1.0$ in general for all structural components

---

A: straight-line spectrum (typical stress range spectrum of seaway-induced stress ranges),
B: parabolic spectrum (approximated normal distribution of stress range $\Delta \sigma$),
C: rectangular spectrum (constant stress range within the whole spectrum; typical spectrum of engine- or propeller-excited stress ranges).

In case of only seaway-induced stresses, normally the stress range spectrum $A$ is to be assumed with a number of cycles $n_{max} = 7.5 \cdot 10^7$ to be assumed.

For design lifetime of 30 years the number of cycles $n_{max} = 7.5 \cdot 10^7$ is to be assumed.

The maximum and minimum stresses result from the maximum and minimum relevant seaway-induced load effects. The different load-effects are, in general, to be superimposed conservatively. Table 16.1.2.4 shows examples for the individual loads which have to be considered in normal cases.

**16.1.2.5** Additional stress cycles resulting from changing mean stresses, e.g. due to changing loading conditions or draught, need generally not be considered as long as the seaway-included stress ranges are determined for the loading condition being most critical with respect to fatigue strength and the maximum change in mean stress is less than the maximum seaway-induced stress range.

**16.1.2.6** The fatigue strength analysis is, depending on the detail considered, based on one of the following types of stress:

- For notches of free plate edges the notch stress $\sigma_n$, determined for linear-elastic material behaviour (see Section 2.8) is relevant, which can normally be calculated from a nominal stress $\sigma$, and a theoretical stress concentration factor $K_t$. Values for $K_t$ are given in Fig. 16.1.2.6-1 and 16.1.2.6-2 for different types of cut-outs. The fatigue strength is determined by the detail category (or $\Delta \sigma$) according to Table 16.2.1.1, type 29 and 30.
- For welded joints the fatigue strength analysis is normally based on the nominal stress $\sigma$, at the structural detail considered and on an appropriate detail classification as given in Table 16.2.1.1, which defines the detail category (or $\Delta \sigma$).
- For those welded joints, for which the detail classification is not possible or additional stresses occur, which are not or not adequately considered by the detail classification, the fatigue strength analysis may be performed on the basis of the structural stress $\sigma$, in accordance with 16.3.

![Figure 16.1.2.6-1](image)
16.1.3 Quality requirements (fabrication tolerances)

16.1.3.1 The detail classification of the different welded joints as given in Table 16.2.1.1 is based on the assumption that the fabrication of the structural detail or welded joint, respectively, corresponds in regard to external defects at least to the Production Standard of the Shipbuilding Industry. Equivalent Standards may be accepted by Register.

16.1.3.2 Relevant information have to be included in the manufacturing document for fabrication. If it is not possible to comply with the tolerances given in the standards, this has to be accounted for when designing the structural details or welded joints, respectively. In special cases an improved manufacture as stated in 16.1.3.1 may be required, e.g. stricter tolerances or improved weld shapes, see also 16.2.3.2.4.

16.2 FATIGUE STRENGTH ANALYSIS

16.2.1 Definition of nominal stress and detail classification for welded joints

16.2.1.1 Corresponding to their notch effect, welded joints are normally classified into detail categories considering particulars in geometry and fabrication, including subsequent quality control, and definition of nominal stress. Table 16.2.1.1 shows the detail classification based on recommendation of the International Institute of Welding (IIW) giving the detail category number (or $\Delta \sigma$).

16.2.1.2 Details which are not contained in Table 16.2.1.1 may be classified on the basis of local stresses in accordance with 16.3.

16.2.1.3 Regarding the definition of nominal stress, the arrows in Table 16.2.1.1 indicate the location and direction of the stress for which the stress range is to be calculated. The potential crack location is also shown in Table 16.2.1.1. Depending on this crack location, the nominal stress range has to be determined by using either the cross sectional area of the parent metal or the weld throat thickness, respectively. Bending stresses in plate and shell structures have to be incorporated into the nominal stress, taking the nominal bending stress acting at the location of crack initiation.

Additional stress concentrations which are not characteristic of the detail category itself, e.g. due to cut-outs in the neighbourhood of the detail, have also to be incorporated into the nominal stress.

16.2.1.4 In the case of combined normal and shear stress the relevant stress range may be taken as the range of the principal stress at the potential crack location which acts approximately perpendicular to the crack front as shown in Table 16.2.1.1.

16.2.1.5 Where solely shear stresses are acting the largest principal stress $\sigma_1 = \tau$ may be used in combination with the relevant detail category.

16.2.2 Permissible stress range for standard stress range spectra or calculation of the cumulative damage ratio

16.2.2.1 For standard stress range spectra according to Fig. 16.1.2.4, the permissible peak stress range can be calculated as follows:

$$\Delta \sigma_p = f_n \cdot \Delta \sigma_{RC}$$

$\Delta \sigma_{RC} = \text{detail category or fatigue strength reference value, respectively, corrected according to 16.2.3.2.}$

$f_n = \text{factor as given in Table 16.2.2.1}$

The peak stress range of the spectrum must not exceed the permissible value, i.e.

$$\Delta \sigma_{max} \leq \Delta \sigma_p$$

16.2.2.2 If the fatigue strength analysis is based on the calculation of the cumulative damage ratio, the stress range spectrum expected during the envisaged service life is to be established (see 16.1.2.4) and the cumulative damage ratio $D$ is to be calculated as follows:

$$D = \sum_{i=1}^{I} \left( n_i / N_i \right)$$

$I = \text{total number of blocks of the stress range spectrum for summation (normally } I \geq 20)$

$n_i = \text{number of stress cycles in block } i$

$N_i = \text{number of endured stress cycles determined from the corrected design S-N curve (see 16.2.3) taking } \Delta \sigma = \Delta \sigma_i$

$\Delta \sigma = \text{stress range of block } i$.

To achieve an acceptable high fatigue life, the cumulative damage ratio should not exceed $D = 1$.

If the expected stress range spectrum can be superimposed by two or more standard stress spectra according to 16.1.2.4 the partial damage ratios $D_i$ due to the individual stress range spectra can be derived from Table 16.2.2.1. In this case a linear relationship between number of load cycles and cumulative damage ratio may be assumed.
The numbers of load cycles given in Table 16.2.2.1 apply for a cumulative damage ratio of $D = 1$.

### Table 16.2.1.1
Catalogue of Details

<table>
<thead>
<tr>
<th>Type No.</th>
<th>Joint configuration showing mode of fatigue cracking and stresses considered</th>
<th>Description of joint</th>
<th>Detail category $\Delta \sigma_R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image1" alt="Image" /> Transverse butt weld ground flush to plate, 100 % NTD (Non-Destructive Testing)</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td><img src="image2" alt="Image" /> Transverse butt weld made in shop in flat position, max. weld reinforcement 1 mm + 0.1 x weld width, smooth transitions, NTD</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td><img src="image3" alt="Image" /> Transverse butt weld not satisfying conditions for joint type No. 2, NDT</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td><img src="image4" alt="Image" /> Transverse butt weld on backing strip or three-plate connection with unloaded branch Butt weld, welded on ceramic backing, root crack</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td><img src="image5" alt="Image" /> Transverse butt welds between plates of different widths or thickness, NDT - as for joint type No. 2, slope 1:5 - as for joint type No. 2, slope 1:3 - as for joint type No. 2, slope 1:2 - as for joint type No. 3, slope 1:5 - as for joint type No. 3, slope 1:3 - as for joint type No. 3, slope 1:2 For the third sketched case the slope results from the ratio of the difference in plate thicknesses to the breadth of the welded seam. Additional bending stress due to thickness change to be considered, see also 16.2.1.3.</td>
<td>90, 80, 80, 71, 71, 63</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td><img src="image6" alt="Image" /> Transverse butt welds welded from one side without backing bar full penetration root controlled by NDT not NDT For tubular profiles $\Delta \sigma_R$ may be lifted to the next higher detail category</td>
<td>71, 36</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td><img src="image7" alt="Image" /> Partial penetration butt weld, the stress is to be related to the weld throat sectional area, weld overfill not to be taken into account</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td><img src="image8" alt="Image" /> Continuous automatic longitudinal fully penetrated K-butt weld without stop/start positions (based on stress range in flange adjacent to weld)</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td><img src="image9" alt="Image" /> Continuous automatic longitudinal fillet weld without stop/start positions (based on stress range in flange adjacent to weld)</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Type No.</td>
<td>Joint configuration showing mode of fatigue cracking and stresses considered</td>
<td>Description of joint</td>
<td>Detail category $\Delta \sigma$</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------------------------------------------------</td>
<td>----------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>10</td>
<td>Continous manual longitudinal fillet or butt weld (based on stress range in flange adjacent to weld)</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Intermittent longitudinal fillet weld (based on stress range in flange at weld ends) In presence of shear $\tau$ in the web, the detail category has to be reduced by the factor $(1 - \Delta \tau / \Delta \sigma)$, but not below 36.</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Longitudinal butt weld, fillet weld or intermittent fillet weld with cut outs (based on stress range in flange at weld ends) If cut out is higher than 40% of web height or in presence of shear In presence of shear $\tau$ in the web, the detail category has to be reduced by the factor $(1 - \Delta \tau / \Delta \sigma)$, but not below 36. Note: For $\Omega$ shaped scallops, an assessment based on local stresses is recommended.</td>
<td>71 63</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Longitudinal gusset welded on beam flange, bulb or plate: $l \leq 50$ mm $50$ mm $&lt; l \leq 150$ mm $150$ mm $&lt; l \leq 300$ mm $l &gt; 300$ mm For $t_2 \leq 0,5$ $t_1$, $\Delta \sigma$ may be increased by one category, but not over 80; not valid for bulb profiles. When welding close to edges of plates or profiles (distance less than 10 mm) and/or the structural element is subjected to bending, $\Delta \sigma$ is to be decreased by one category.</td>
<td>80 71 63 56</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Gusset with smooth transition (sinped end or radius) welded on beam flange, bulb or plate; $c \leq 2$ $r$, max. 25 mm $r \geq 0,5$ $h$ $r &lt; 0,5$ $h$ or $\phi \leq 20^\circ$ $\phi &gt; 20^\circ$ see joint type 13 For $t_2 \leq 0,5$ $t_1$, $\Delta \sigma$ may be increased by one category; not valid for bulb profiles. When welding close to edges of plates or profiles (distance less than 10 mm), $\Delta \sigma$ is to be decreased by one category.</td>
<td>71 63</td>
<td></td>
</tr>
</tbody>
</table>
Table 16.2.1.1 - continued

<table>
<thead>
<tr>
<th>Type No.</th>
<th>Joint configuration showing mode of fatigue cracking and stresses considered</th>
<th>Description of joint</th>
<th>Detail category $\Delta \sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Longitudinal flat side gusset welded on plate or beam flange edge: $l \leq 50$ mm, $50 \text{ mm} &lt; l \leq 150 \text{ mm}$, $150 \text{ mm} &lt; l \leq 300 \text{ mm}$, $l &gt; 300$ mm. For $t_2 \leq 0.7 t_1$, $\Delta \sigma_R$ may be increased by one category, but not over 56. If the plate or beam flange is subjected to in-plane bending, $\Delta \sigma_R$ has to be decreased by one category.</td>
<td>56 50 45 40</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Gusset with smooth transition (sniped end or radius) welded on beam flange, bulb or plate: $c \leq 2 t_2$, max. 25 mm $r \geq 0.5 h$, $r &lt; 0.5 h$, or $\phi \leq 20^\circ$ $\phi &gt; 20^\circ$, see joint type 15. For $t_2 \leq 0.7 t_1$, $\Delta \sigma_R$ may be increased by one category.</td>
<td>50 45</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Transverse stiffener with fillet welds (applicable for short and long stiffeners)</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Non-load-carrying shear connector.</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Full penetration weld at the connection between a hollow section (e.g. pillar) and a plate, for tubular section, for rectangular hollow section. For $t \leq 8 \text{ mm}$, $\Delta \sigma_R$ has to be decreased by one category.</td>
<td>56 50</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Fillet weld at the connection between a hollow section (e.g. pillar) and a plate, for tubular section, for rectangular hollow section. The stress is to be related to the weld sectional area. For $t \leq 8 \text{ mm}$, $\Delta \sigma_R$ has to be decreased by one category.</td>
<td>45 40</td>
<td></td>
</tr>
<tr>
<td>Type No.</td>
<td>Joint configuration showing mode of fatigue cracking and stresses considered</td>
<td>Description of joint</td>
<td>Detail category ( \Delta \sigma )</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------------------------------------------------------</td>
<td>----------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>21</td>
<td><img src="https://example.com/image1.png" alt="Image" /></td>
<td>Cruciform or tee-joint K-butt welds with full penetration or with defined incomplete root penetration according to Fig. 15.2.3.2.2</td>
<td>71 80</td>
</tr>
<tr>
<td>22</td>
<td><img src="https://example.com/image2.png" alt="Image" /></td>
<td>Cruciform or tee-joint with transverse fillet welds, toe failure (root failure particularly for throat thickness ( a &lt; 0,7 \cdot t ), see joint type. 23)</td>
<td>63 71</td>
</tr>
<tr>
<td>23</td>
<td><img src="https://example.com/image3.png" alt="Image" /></td>
<td>Welded metal in transverse load-carrying fillet welds at cruciform or tee-joint, root failure (based on stress range in weld throat), see also joint type No. 22 ( a \geq t/3 ) ( a &lt; t/3 )</td>
<td>36 40</td>
</tr>
<tr>
<td>24</td>
<td><img src="https://example.com/image4.png" alt="Image" /></td>
<td>End of long doubling plate on beam, welded ends (based on stress range in flange at weld toe) ( t_o \leq 0,8 \cdot t ) ( 0,8 \cdot t &lt; t_o \leq 1,5 \cdot t ) ( t_o &gt; 1,5 \cdot t )</td>
<td>56 50 45</td>
</tr>
<tr>
<td>25</td>
<td><img src="https://example.com/image5.png" alt="Image" /></td>
<td>The following features increase ( \Delta \sigma ) by one category accordingly: – reinforced ends according to Sect. 15, Fig. 15.2.2.4.3 – weld toe angle ( \alpha \leq 30 , ^\circ ) – length of doubling ( \alpha \leq 300 , \text{mm} ) For length of doubling ( \leq 150 , \text{mm} ), ( \Delta \sigma ) may be increased by two categories.</td>
<td>56 56 50</td>
</tr>
<tr>
<td>26</td>
<td><img src="https://example.com/image6.png" alt="Image" /></td>
<td>Fillet welded non-load-carrying lap joint welded to longitudinal stressed element. – flat bar – to bulb section or flat bar – for angle section For ( l &gt; 150 , \text{mm} ), ( \Delta \sigma ) has to be decreased by one category, while for ( l \leq 50 , \text{mm} ) ( \Delta \sigma ) may be increased by one category. If the component is subjected to bending, ( \Delta \sigma ) has to be reduced by one category.</td>
<td>56 56 50</td>
</tr>
<tr>
<td>26</td>
<td><img src="https://example.com/image7.png" alt="Image" /></td>
<td>Fillet welded lap joint with smooth transition (sniped end with ( \varphi \leq 20^\circ ) or radius), welded to longitudinally stressed element. – flat bar – for bulb section or flat bar – to angle section ( c \leq 2 \cdot t ), max. 25 mm</td>
<td>56 56 50</td>
</tr>
</tbody>
</table>
### Table 16.2.1.1 - continued

<table>
<thead>
<tr>
<th>Type No.</th>
<th>Joint configuration showing mode of fatigue cracking and stresses considered</th>
<th>Description of joint</th>
<th>Detail category $\Delta \sigma$</th>
</tr>
</thead>
</table>
| 27       | Continuous butt or fillet weld connecting a pipe penetrating through a plate  | $d \leq 50 \text{ mm}$  
$d > 50 \text{ mm}$  
**Remark:**  
*For large diameters and assessment based on local stress is recommended.* | 71  
63 |
| 28       | Rolled or extruded plates and sections as well as seamless pipes, no surface or rolling defects | 160  
($m_o = 5$) |
| 29       | Plate edge not sheared or machine-cut by any thermal process with surface free of cracks and notches, corners broken or rounded. Stress increase due to geometry of cut-outs to be considered. | 140  
($m_o = 4$) |
| 30       | Plate edge not meeting the requirements of type 29, but free from cracks and sever notches.  
Machine cut or sheared edge:  
Manually thermally cut  
Stress increase due to geometry of cut-outs to be considered. | 125  
($m_o = 3,5$)  
100  
($m_o = 3,5$) |
| 31       | Joint at stiffened knuckle of a flange, to be assessed according to type 21, 22 or 23, depending on the type of joint. The stress in the stiffener at the knuckle can normally be calculated as follows:  
$\sigma = \sigma_a \frac{t_f}{t_b} 2 \sin \alpha$  
For Type No. 22:  
– cruciform joint  
– cruciform joint  
For Type No. 23 | 63  
71  
36 |
| 32       | Unstiffened flange to web joint, to be assessed according to type 21, 22 or 23, depending on the type of joint. The stress in the web is calculated using the force $F_g$ in the flange as follows:  
$\sigma = \frac{F_g}{r-t}$  
For Type No. 21:  
– cruciform joint  
– cruciform joint | 71  
80 |
### Table 16.2.2.1

Factor $f_n$ for the determination of the permissible stress range for standard stress range spectra

<table>
<thead>
<tr>
<th>Stress range spectrum</th>
<th>Welded Joints $(m_o = 3)$</th>
<th>Plating Edges type 28 $(m_o = 5)$</th>
<th>Plating Edges type 29 $(m_o = 4)$</th>
<th>Plating Edges type 30 $(m_o = 3.5)$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n_{max}$</td>
<td>$n_{max}$</td>
<td>$n_{max}$</td>
<td>$n_{max}$</td>
</tr>
<tr>
<td>A</td>
<td>$10^5$</td>
<td>$10^5$</td>
<td>$5 \cdot 10^5$</td>
<td>$10^5$</td>
</tr>
<tr>
<td>B</td>
<td>$(9.2)$</td>
<td>$1.76$</td>
<td></td>
<td>$(9.5)$</td>
</tr>
<tr>
<td>C</td>
<td>$(12.6)$</td>
<td>$2.71$</td>
<td>$0.465$</td>
<td>$(0.737)_{1}^1$</td>
</tr>
</tbody>
</table>

$^1 f_n$ for non-corrosive environment, see also 16.2.3.1.4.
The values given in parentheses may be applied for interpolation.
For interpolation between any pair of values ($n_{max1}$, $f_{n1}$) and ($n_{max2}$, $f_{n2}$), for following formula may be applied in the case of stress spectrum A or B:

$$
\log f_n = \log f_{n1} + \log \left( \frac{n_{max2}}{n_{max1}} \right)
$$

For the stress spectrum C intermediate values may be calculated according to 16.2.3.1.2 by taking $N = n_{max}$ and $f_n = \Delta \sigma / \Delta \sigma_R$.

### 16.2.3 Design S-N curves

#### 16.2.3.1 Description of the design S-N curves

**16.2.3.1.1** The design S-N curves for the calculation of the cumulative damage ratio according to 16.2.2.2 are shown in Fig. 16.2.3.1.1-1 for welded joints and in Fig. 16.2.3.1.1-2 for notches at free plate edges. The S-N curves represent the lower limit of the scatter band of 95% of all test results available (corresponding to 97.5% survival probability) considering further detrimental effects in large structures.

To account for different influence factors, the design S-N curves have to be corrected according to 16.2.3.2.

**16.2.3.1.2** The S-N curves represent sectionwise linear relationships between log ($\Delta \sigma$) and log ($N$):

![Figure 16.2.3.1.1-1](image-url)
log (N) = 6.6987 + m \cdot Q

Q = \frac{\log (\Delta \sigma_R / \Delta \sigma)}{0.39794 / m_o}

m = \text{inverse slope of S-N curve}

m_o = \text{inverse slope in the range } N \leq 5 \cdot 10^6

m_o = 3 \text{ for welded joints}

m_o = 3.5 \div 5 \text{ for free plate edges (see Fig. 16.2.3.1.1-2)}

The S-N curve for detail category 160 forms the upper limit also for free plate edges with detail categories 100 - 140 in the range of low stress cycles, see Fig. 16.2.3.1.1-2.

16.2.3.1.3 For structures subjected to variable stress ranges, the S-N curves shown by the solid lines in Fig. 16.2.3.1.1-1 and Fig. 16.2.3.1.1-2 have to be applied (S-N curves of type "M"), i.e.

- \( m = m_o \), \( Q \leq 0 \)
- \( m = 2 \cdot m_o - 1 \), \( Q > 0 \)

16.2.3.1.4 For stress ranges of constant magnitude (stress range spectrum C) in non-corrosive environment the stress range given at \( N = 5 \cdot 10^6 \) cycles may be taken as fatigue limit (S-N curves of type "O" in Fig. 16.2.3.1.1-1 and 16.2.3.1.1-2) thus:

- \( m = m_o \), \( Q \leq 0 \)
- \( m = \infty \), \( Q > 0 \)

16.2.3.2 Correction of the reference value of the design S-N curve

16.2.3.2.1 A correction of the reference value of the S-N curve (or detail category) is required to account for additional influence factors on fatigue strength as follows:

\[ \Delta \sigma_{Rc} = f_m \cdot f_R \cdot f_w \cdot f_i \cdot \Delta \sigma_{R} \]

\( f_m, f_R, f_w, f_i \) defined in 16.2.3.2.2-16.2.3.2.5.

In order to account for the plate thickness effect, application of an additional reduction factor may be required by Register, for welded connections oriented transversely to the direction of applied stress with larger plate thicknesses.

For the description of the corrected design S-N curve, the formulae given in 16.2.3.1.2 may be used by replacing \( \Delta \sigma_R \) by \( \Delta \sigma_{Rc} \).

16.2.3.2.2 Material effect (\( f_m \))

For welded joints it is generally assumed that the fatigue strength is independent of steel strength, i.e.:

\( f_m = 1.0 \)

For free plate edges the effect of the material's yield point is accounted for as follows:

\( f_m = 1 + \frac{R_{eff} - 235}{1200} \)

\( R_{eff} = \text{minimum nominal upper yield point of the steel [N/mm}^2\text{]}\).

16.2.3.2.3 Effect of mean stress (\( f_R \))

The correction factor is calculated as follows:

- \( f_R = 1.0 \) in the range of tensile pulsating stresses

\[ \sigma_m \geq \frac{\Delta \sigma_{max}}{2} \]

- \( f_R = 1 + c \left( 1 - \frac{2 \cdot \sigma_m}{\Delta \sigma_{max}} \right) \)

in the range of alternating stresses

\[ \frac{\Delta \sigma_{max}}{2} \leq \sigma_m \leq \frac{\Delta \sigma_{max}}{2} \]

- \( f_R = 1 + 2 \cdot c \)

in the range of compressive pulsating stresses

\[ \sigma_m \leq -\frac{\Delta \sigma_{max}}{2} \]
c = 0 for welded joints subjected to constant stress cycles (stress range spectrum C)
= 0,15 for welded joints subjected to variable stress cycles (corresponding to stress range spectrum A or B)
= 0,3 for free plate edges.

16.2.3.2.4 Effect of weld shape \( (f_w) \)

In normal cases:
\( f_w = 1,0. \)

For butt welds ground flush either the corresponding detail category has to be chosen, e.g. type 1 in Table 16.2.1.1 or a weld shape factor
\( f_w = 1,25 \)

may be applied.

For endings of stiffeners or brackets, e.g. type 14 or 16 in Table 16.2.1.1, which have a full penetration weld and are completely ground flush to achieve a notch-free transition, the following factor applies:
\( f_w = 1,4. \)

The assessment of a local post-weld treatment of the weld surface and the weld toe, e.g. by grinding or applying an improved weld profile, has to be agreed on in each case.

16.2.3.2.5 Influence of importance of structural element \( (f_i) \)

In general the following applies:
\( f_i = 1,0. \)

For secondary structural elements failure of which may cause failure of larger structural areas, the correction factor \( f_i \) is to be taken as:
\( f_i = 0,9. \)

For notches at plate edges in general the following correction factor is to be taken which takes into account the radius of rounding:
\( f_i = 0,9 + 5/r \leq 1,0. \)
\( r = \) notch radius in [mm]; for elliptical roundings the mean value of the two main half axes may be taken.

16.3 FATIGUE STRENGTH ANALYSIS FOR WELDED JOINTS BASED ON LOCAL STRESSES

16.3.1 Alternatively to the procedure described in the preceding paragraphs, the fatigue strength analysis for welded joints may be performed on the basis of local stresses. For common plate and shell structures in ships the assessment based on the so-called structural (or hot-spot) stress \( \sigma_s \) is normally sufficient.

The structural stress is defined as the stress being extrapolated to the weld toe excluding the local stress concentration in the local vicinity of the weld, see Fig. 16.3.1.

For the fatigue strength analysis based on structural stress, the S-N curves shown in Fig. 16.2.3.1.1-1 apply with the following reference values:
\( \Delta \sigma_R = 100 \) for K-butt welds with fillet welded ends, e.g. type 21 in Table 16.2.1.1, and for fillet welds which carry no load or only part of the load of the attached plate, e.g. type 17 in Table 16.2.1.1.
\( \Delta \sigma_R = 90 \) for fillet welds, which carry the total load of the attached plate, e.g. type 22 in Table 16.2.1.1.

For butt welds the values given for types 1 to 4 in Table 16.2.1.1 apply. In special cases, where e.g. the structural stresses are obtained by non-linear extrapolation to the weld toe and where they contain a high bending portion, increased reference values of up to 15% can be allowed.

16.3.3 The reference value \( \Delta \sigma_c \) of the corrected S-N curve is to be determined according to 16.2.3.2, taking into account the following additional correction factor which describes further influencing parameters such as e.g. predeformations:
\( f_s = 0,71 \) for cruciform joints (corresponding to types 21 and 22 in Table 16.2.1.1)
\( f_s = 0,8 \) for transverse stiffeners or tee-joints (corresponding to type 17 and 21 - 22 in Table 16.2.1.1)
\( f_s = 1,0 \) in all other cases.

The permissible stress range or cumulative damage ratio, respectively, has to be determined according to 16.2.2.

16.3.4 In addition to the assessment of the structural stress at the weld toe, the fatigue strength with regard to root failure has to be considered by analogous application of the respective detail category, e.g. type 23 of Table 16.2.1.1. In this case the relevant stress is the stress in the weld throat caused by the axial stress in the plate perpendicular to the weld.
17 STRENGTHENINGS FOR HEAVY CARGO, BULK CARRIERS, ORE CARRIERS

17.1 STRENGTHENINGS FOR HEAVY CARGO

17.1.1 General

17.1.1.1 For ships, occasionally or regularly carrying heavy cargo, such as iron, ore, phosphate etc., and not intended to get the notation "Bulk carrier-ESP" or "O re carrier" strengthenings according to the following regulations are recommended.

17.1.1.2 Ships complying with these requirements will get the following notation affixed to their character of classification HCS, see Rules, Part 1 – General requirements Chapter 1, 4.2.

17.1.1.3 It is recommended to provide adequate strengthening or protection of structural elements within the working range of grabs.

17.1.2 Double bottom

17.1.2.1 Where longitudinal framing is adopted for the double bottom, the spacing of plate floors are, in general, not to be greater than the height of the double bottom. The scantlings of the inner bottom longitudinals are to be determined for the load of the cargo according to Section 8.2.

For the longitudinal girder system, see Section 7.2.7.5.

17.1.2.2 Where transverse framing is adopted for the double bottom, plate floors according to Section 7.2.6 are to be fitted at every frame in way of the cargo holds.

17.1.2.3 For strengthening of inner bottom, deep tank tops etc. in way of grabs, see 17.2.4.3.

17.1.3 Longitudinal strength

The longitudinal strength of the ship must comply with the requirements of Section 4 irrespective of the ship's length.

17.2 BULK CARRIERS

17.2.1 General

17.2.1.1 Bulk carriers built in accordance with the following requirements will get affixed the notation Bulk Carrier. Entries HME will be made into the certificate as to whether specified cargo holds may be empty in case of alternating loading. See the Rules, Part 1 – General requirements, Chapter 1 – General information, 4.2.

Additional indications of the types of cargo for which the ship is strengthened may be entered into the certificate.

For harmonised notations and corresponding design loading conditions for bulk carriers see 17.4.6.

17.2.1.2 Bulk carrier is considered in this section a Single Side Skin Bulk Carrier when one or more cargo holds are bound by the side shell only or by two watertight boundaries, one of which is the side shell, which are less than 1000 mm apart. The distance between the watertight boundaries is to be measured perpendicular to the side shell.

When the distance is 1000 mm or above in cargo length area, such a ship is considered a Double Side Skin Bulk Carrier.

See also the Rules, Part 1 – General requirements, Chapter 1 – General requirements, 4.2.

17.2.1.3 For bulk carriers carrying also oil in bulk see the Rules, Part 1 – General requirements, Chapter 1 – General information, 4.2.

17.2.1.4 The scantlings of the bottom construction are to be determined on the basis of direct calculations according to Section 7.2.8.

17.2.1.5 Bulk carriers described in 17.2.1.2 that are contracted for construction on or after 1 January 2003 are to comply with requirements for detection of water ingress into cargo holds, ballast tanks and dry spaces forward of the collision bulkhead by the time of delivery. For these requirements and means of water ingress detection, see Annex A, A.4.

17.2.1.6 Bulk carriers described in 17.2.1.2 that are contracted for construction on or after 1 January 2003 are to comply with requirements for draining and pumping ballast tanks and dry spaces forward of the collision bulkhead by the time of delivery. For these requirements and means of water ingress detection, see Annex A, A.4.

17.2.1.7 The requirements of Sections 1 to 16 apply to bulk carriers unless otherwise mentioned in this Section. Paragraph 17.1.1.3 is also to be observed.

17.2.1.8 For hull structural design of bulk carriers of 90 m in length or greater, contracted for construction on or after 1 April 2006 and in accordance with the definition in 17.2.1.9, the IACS Common Structural Rules for Bulk Carriers shall apply.

17.2.1.9 Bulk carrier according to the IACS Common Structural Rules means a ship which is constructed generally with single deck, double bottom, top-side tanks and hopper side tanks in cargo spaces, with single or double side skin construction in cargo length area and is intended primarily to carry dry cargo in bulk. Typical midship sections are given in Fig. 17.2.1.9.

17.2.1.10 Bulk carriers of 150 m in length and upwards of single-side skin construction, designed to carry solid bulk cargoes having a density of 1,000 kg/m³ and above, constructed on or after 1 July 1999, shall have sufficient strength to withstand flooding of any one cargo hold to the water level...
outside the ship in that flooded condition in all loading and ballast conditions, taking also into account dynamic effects resulting from the presence of water in the hold, and taking into account the recommendations adopted by the Organization.*

17.2.1.11 Bulk carriers of 150 m in length and upwards of double-side skin construction, in which any part of longitudinal bulkhead is located within B/5 or 11.5 m, whichever is less, inboard from the ship’s side at right angle to the centre-line at the assigned summer load line, designed to carry bulk cargoes having a density of 1,000 kg/m\(^3\) and above, constructed on or after 1 July 2006, shall comply with the structural strength provisions in 17.2.1.10.

17.2.1.12 For application of the requirements in 17.2.1.10 and 17.2.1.11 (SOLAS XII/5), see IACS UI SC 207.

17.2.1.13 For application of SOLAS XII/6.5.1 in terms of protection of cargo holds from loading/discharge equipment, see IACS UI SC 208.

17.2.1.14 For application of SOLAS XII/6.5.3 and SLS.14/Circ.250 in terms of redundancy of stiffening structural members for vessels not designed according to CSR for Bulk Carriers, see IACS UI SC 209.

17.2.1.15 For application of the requirements relating to definition of double-side skin (regulation XII/1.4) and structural and other requirements for bulk carriers in areas with double-side skin construction (regulation XII/6.2, see IACS UI SC 210.

* Refer to resolution 3, Recommendation on compliance with SOLAS regulation XII/s, adopted by the 1997 SOLAS Conference.

17.2.2 Longitudinal strength

17.2.2.1 Unless otherwise mentioned in this Section the requirements of Section 4 apply.

17.2.2.2 Longitudinal strength of hull girder in flooded condition for non-CSR bulk carriers

17.2.2.2.1 General

This requirement is to be applied to non-CSR bulk carriers of 150 m in length and upwards, intending to carry solid bulk cargoes having a density of 1.0 t/m\(^3\) or above, and with,

a) Single side skin construction, or

b) Double side skin construction in which any part of longitudinal bulkhead is located within B/5 or 11.5 m, whichever is less, inboard from the ship’s side at right angle to the centre-line at the assigned summer load line.

This requirement is to be complied with in respect of the flooding of any cargo hold of bulk carriers with notation BC-A or BC-B, as defined in Section 17.4.6.

Such ships are to have their hull girder strength checked for specified flooded conditions, in each of the cargo and ballast loading conditions defined in 4.2.1.2 to 4.2.1.4 and in every other condition considered in the intact longitudinal strength calculations, including those according to Section 17.4, except that harbour conditions, docking condition afloat, loading and unloading transitory conditions in port and loading conditions encountered during ballast water exchange need not be considered.

This requirement does not apply to CSR bulk carriers.

17.2.2.2.2 Flooding conditions

17.2.2.2.2.1 Floodable holds

Each cargo hold is to be considered individually flooded up to the equilibrium waterline. This application is to be applied to self-unloading bulk carriers (SUBC) where the unloading system maintains the watertightness during seagoing operations. In SUBCs with unloading systems that do not maintain watertightness, the longitudinal strength in the flooded conditions are to be considered using the extent to which the flooding may occur.

17.2.2.2.2.2 Loads

The still water loads in flooded conditions are to be calculated for the above cargo and ballast loading conditions.

The wave loads in the flooded conditions are assumed to be equal to 80% of those given in Section 4.

17.2.2.2.2.3 Flooding criteria

To calculate the weight of ingressed water, the following assumptions are to be made:

a) The permeability of empty cargo spaces and volume left in loaded cargo spaces above any cargo is to be taken as 0.95.

b) Appropriate permeabilities and bulk densities are to be used for any cargo carried. For iron ore, a minimum permeability of 0.3 with a corresponding bulk density of 3.0 t/m\(^3\) is to be used. For cement, a minimum permeability of 0.3 with a corresponding bulk density of 1.3 t/m\(^3\) is to be used. In this respect, "permeability" for solid bulk cargo means the ratio of the floodable volume between the particles, granules or any larger pieces of the cargo, to the gross volume of the bulk cargo.

For packed cargo conditions (such as steel mill products), the actual density of the cargo should be used with a permeability of zero.

17.2.2.2.4 Strength assessment

The actual hull girder bending stress \(\sigma_{fl}\) at any location is given by:

\[
\sigma_{fl} = \frac{M_{sf} + 0.8 \cdot M_{w}}{W_{z}} \cdot 10^{3}, \text{[N/mm}^2\text{]}.
\]

where:

\(M_{sf}\) = still water bending moment, in [kNm], in the flooded conditions for the section under consideration;

\(M_{w}\) = wave bending moment, in [kNm], as given in Section 4.2.2 for the section under consideration;

\(W_{z}\) = section modulus, in [cm\(^3\)], for the corresponding location in the hull girder.

The sheer strength of the side shell and the inner hull (longitudinal bulkhead) if any, at any location of the ship, is to be checked according to the requirements specified in Section 4.4 in which \(F_{s}\) and \(F_{w}\) are to be replaced respectively by \(F_{3sf}\) and \(F_{3w}\), where:

\(F_{3sf}\) = still water sheer force, in [kN], in the flooded conditions for the section under consideration
\[ F_{\text{WT}} = 0.8 F_w \]
\[ F_w = \text{wave shear force, in [kN], as given in Section 4.2.3 for the section under consideration.} \]

17.2.2.5 Strength criteria
The damaged structure is assumed to remain fully effective in resisting the applied loading. Permissible stress and axial stress buckling strength are to be in accordance with Section 4.

17.2.3 Definitions
\[ k = \text{material factor according to 1.4.2.2;} \]
\[ t_k = \text{corrosion addition according to 2.9.1;} \]
\[ P_{\text{FB}} = \text{bulk cargo pressure as defined in Section 3.3.1.4.} \]

17.2.4 Scantlings of bottom structure
17.2.4.1 General
The scantlings of double bottom structures in way of the cargo holds are to be determined by means of direct calculations according to Section 7.2.8.

17.2.4.2 Floors under corrugated bulkheads
Plate floors are to be fitted under the face plate strips of corrugated bulkheads. A sufficient connection of the corrugated bulkhead elements to the double bottom structure is to be ensured. Under the inner bottom, scallops in the above mentioned plate floors are to be restricted to those required for crossing welds. The plate floors as well as the face plate strips are to be welded to the inner bottom according to the stresses to be transferred. In general, single bevel T-joints or double bevel T-joints are to be used. In general, full or partial penetration welding is to be used, see also 17.2.9.4.4.1.

17.2.4.3 Inner bottom and tank side slopes
17.2.4.3.1 The thickness of the inner bottom plating is to be determined according to Section 7.2.4.
When determining the load on inner bottom \( p_{\text{DB}} \), a cargo density of not less than 1 t/m\(^3\) is to be used.
For determining scantlings of tank side slopes the load \( p_{\text{DB}} \) is not to be taken less than the load which results from an angle of heel of 20\(^\circ\).

17.2.4.3.2 Where grabs are intended to be used, it is recommended to increase the plate thickness by 5 mm above the thickness required in Section 7.2.4.1, or to protect the plating by ceiling or armament in an equivalent manner.

17.2.4.3.3 Sufficient continuity of strength is to be provided for the structure of the bottom wing tanks and the adjacent longitudinal structure.

17.2.4.4 Evaluation of allowable hold loading for non-CSR bulk carriers considering hold flooding
17.2.4.4.1 General
This requirement is to be applied to non-CSR bulk carriers of 150 m in length and upwards, intending to carry solid bulk cargoes having a density of 1.0 t/m\(^3\) or above, and with,
\begin{itemize}
  \item [a)] Single side skin construction, or
  \item [b)] Double side skin construction in which any part of longitudinal bulkhead is located within B/5 or 11.5 m, whichever is less, inboard from the ship’s side at right angle to the centreline at the assigned summer load line.
\end{itemize}
The loading in each hold is not to exceed the allowable hold loading in flooded condition, calculated as per 17.2.4.4.5, using the loads given in 17.2.4.4.2 and 17.2.4.4.3 and the shear capacity of the double bottom given in 17.2.4.4.4.
In no case is the allowable hold loading, considering flooding, to be taken greater than the design hold loading in intact condition.
These requirements do not apply to CSR Bulk Carriers.

17.2.4.4.2 Loads - general
The loads to be considered as acting on the double bottom are those given by the external sea pressures and the combination of the cargo loads with those induced by the flooding of the hold which the double bottom belongs to.
The most severe combinations of cargo induced loads and flooding loads are to be used, depending on the loading conditions included in the loading manual:
\begin{itemize}
  \item homogeneous loading conditions;
  \item non homogeneous loading conditions;
  \item packed cargo condition (such as steel will products).
\end{itemize}
For each loading condition, the maximum bulk cargo density to be carried is to be considered in calculating the allowable hold loading limit.

17.2.4.4.3 Inner bottom flooding head
The flooding head \( h_f \) (see Figure 17.2.4.4.3) is the distance, in [m], measured vertically with the ship in the upright position, from the inner bottom to a level located at a distance \( d_f \), in m, from the baseline equal to:
\begin{itemize}
  \item [a)] in general:
    \begin{itemize}
      \item \( D \), for the foremost hold
      \item \( 0.9 D \), for the other holds
    \end{itemize}
  \item [b)] for ships less than 50,000 tonnes deadweight with Type B freeboard:
    \begin{itemize}
      \item \( 0.95 D \), for the foremost hold
      \item \( 0.85D \), for the other holds
    \end{itemize}
\end{itemize}
\( D \) being the distance, in [m], from the baseline to the freeboard deck at side amidship (see Figure 17.2.4.4.3)

![Figure 17.2.4.4.3](image)

\( V = \text{Volume of cargo} \)

17.2.4.4.4 Shear capacity of the double bottom
The shear capacity \( C \) of the double bottom is defined as the sum of the shear strength at each end of:
\begin{itemize}
  \item all floors adjacent to both hoppers, less one half of the strength of the two floors adjacent to
each stool, or transverse bulkhead if no stool is fitted (see Figure 17.2.4.4.4).
- all double bottom girders adjacent to both stools, or transverse bulkheads if no stool is fitted.

Where in the end holds, girders or floors run out and are not directly attached to the boundary stool or hopper girder, their strength is to be evaluated for the one end only.

The floors and girders to be considered are those inside the hold boundaries formed by the hoppers and stools (or transverse bulkheads if no stool is fitted). The hopper side girders and the floors directly below the connection of the bulkhead stools (or transverse bulkheads if no stool is fitted) to the inner bottom are not to be included.

When the geometry and/or the structural arrangement of the double bottom are such to make the above assumptions inadequate, the shear capacity $C$ of double bottom is to be calculated according to the Register's criteria.

In calculating the shear strength, the net thickness of floors and girders is to be used. The net thickness $t_{net}$ in [mm], is given by:

$$ t_{net} = t - 2.5 $$

where:

$t$ = thickness, in [mm], of floors and girders.

When in the hold, girders or floors run out and are not directly attached to the boundary stool or hopper girder, their strength is to be evaluated for the one end only.

The floors and girders to be considered are those inside the hold boundaries formed by the hoppers and stools (or transverse bulkheads if no stool is fitted). The hopper side girders and the floors directly below the connection of the bulkhead stools (or transverse bulkheads if no stool is fitted) to the inner bottom are not to be included.

When the geometry and/or the structural arrangement of the double bottom are such to make the above assumptions inadequate, the shear capacity $C$ of double bottom is to be calculated according to the Register's criteria.

In calculating the shear strength, the net thickness of floors and girders is to be used. The net thickness $t_{net}$ in [mm], is given by:

$$ t_{net} = t - 2.5 $$

where:

$t$ = thickness, in [mm], of floors and girders.

The floors and girders to be considered are those inside the hold boundaries formed by the hoppers and stools (or transverse bulkheads if no stool is fitted). The hopper side girders and the floors directly below the connection of the bulkhead stools (or transverse bulkheads if no stool is fitted) to the inner bottom are not to be included.

When the geometry and/or the structural arrangement of the double bottom are such to make the above assumptions inadequate, the shear capacity $C$ of double bottom is to be calculated according to the Register's criteria.

In calculating the shear strength, the net thickness of floors and girders is to be used. The net thickness $t_{net}$ in [mm], is given by:

$$ t_{net} = t - 2.5 $$

where:

$t$ = thickness, in [mm], of floors and girders.

The floors and girders to be considered are those inside the hold boundaries formed by the hoppers and stools (or transverse bulkheads if no stool is fitted). The hopper side girders and the floors directly below the connection of the bulkhead stools (or transverse bulkheads if no stool is fitted) to the inner bottom are not to be included.

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where:

$t$ = thickness, in [mm], of floors and girders.

The floors and girders to be considered are those inside the hold boundaries formed by the hoppers and stools (or transverse bulkheads if no stool is fitted). The hopper side girders and the floors directly below the connection of the bulkhead stools (or transverse bulkheads if no stool is fitted) to the inner bottom are not to be included.

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where:

$t$ = thickness, in [mm], of floors and girders.

The floors and girders to be considered are those inside the hold boundaries formed by the hoppers and stools (or transverse bulkheads if no stool is fitted). The hopper side girders and the floors directly below the connection of the bulkhead stools (or transverse bulkheads if no stool is fitted) to the inner bottom are not to be included.

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where:

$t$ = thickness, in [mm], of floors and girders.

The floors and girders to be considered are those inside the hold boundaries formed by the hoppers and stools (or transverse bulkheads if no stool is fitted). The hopper side girders and the floors directly below the connection of the bulkhead stools (or transverse bulkheads if no stool is fitted) to the inner bottom are not to be included.

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$$ t_{net} = t - 2.5 $$

where:

$t$ = thickness, in [mm], of floors and girders.

The floors and girders to be considered are those inside the hold boundaries formed by the hoppers and stools (or transverse bulkheads if no stool is fitted). The hopper side girders and the floors directly below the connection of the bulkhead stools (or transverse bulkheads if no stool is fitted) to the inner bottom are not to be included.
17.2.4.4.6 Floor shear strength

The floor shear strength in way of the floor panel adjacent to hoppers $S_n$, in [kN], and the floor shear strength in way of the openings in the outmost bay (i.e. that bay which is closer to hopper) $S_o$, in [kN], are given by the following expressions:

$$S_n = 10^{-3} \cdot A_f \cdot \frac{\tau_o}{\eta_1}$$
$$S_o = 10^{-3} \cdot A_{f,k} \cdot \frac{\tau_o}{\eta_2}$$

where:

$A_f$ = sectional area, in [mm$^2$], of the floor panel adjacent to hoppers

$A_{f,k}$ = net sectional area, in [mm$^2$], of the floor panels in way of the openings in the outmost bay (i.e. that bay which is closer to hopper)

$\tau_o$ = allowable shear stress, in [N/mm$^2$], to be taken equal to the lesser of

$$\frac{162 \cdot \sigma_f^{0.6}}{(s/\eta_s)^{0.8}} \quad \text{and} \quad \frac{\sigma_f}{\sqrt{3}}$$

For floors adjacent to the stools or transverse bulkheads, as identified in 17.2.4.4.4 $\tau_o$ may be taken

$$\sigma_f = \text{minimum upper yield stress, in [N/mm$^2$], of the material}$$

$s$ = spacing of stiffening members, in [mm], of panel under consideration

$\eta_1$ = 1.10

$\eta_2$ = 1.20

$\eta_s$ may be reduced down to 1.10 where appropriate reinforcements are fitted to the Register's satisfaction

17.2.4.4.7 Girder shear strength

The girder shear strength in way of the girder panel adjacent to stools (or transverse bulkheads, if no stool is fitted) $S_{g1}$, in [kN], and the girder shear strength in way of the largest opening in the outmost bay (i.e. that bay which is closer to stool, or transverse bulkhead, if no stool is fitted) $S_{g2}$, in [kN], are given by

$$S_{g1} = 10^{-3} \cdot A_g \cdot \frac{\tau_o}{\eta_1}$$
$$S_{g2} = 10^{-3} \cdot A_{g,k} \cdot \frac{\tau_o}{\eta_2}$$

where:

$A_g$ = minimum sectional area, in [mm$^2$], of the girder panel adjacent to stools (or transverse bulkheads, if no stool is fitted)

$A_{g,k}$ = net sectional area, in [mm$^2$], of the girder panel in way of the largest opening in the outmost bay (i.e. that bay which is closer to stool, or transverse bulkhead, if no stool is fitted)

$\tau_o$ = allowable shear stress, in [N/mm$^2$], as given in 17.2.2.4.4.6

$\eta_1$ = 1.10

$\eta_2$ = 1.15

$\eta_s$ may be reduced down to 1.10 where appropriate reinforcements are fitted to the Register's satisfaction

17.2.5 Side structures in single side skin bulk carriers

17.2.5.1 These requirements apply to side structures of cargo holds bounded by the side shell only of bulk carriers constructed with single deck, topside tanks and hopper tanks in cargo spaces intended primarily to carry dry cargo in bulk.

These requirements do not apply to CSR Bulk Carriers.

17.2.5.2 The scantlings of side hold frames immediately adjacent to the collision bulkhead are to be increased in order to prevent excessive imposed deformation on the shell plating. As an alternative, supporting structures are to be fitted which maintain the continuity of forepeak stringers within the foremost hold.

17.2.5.3 The thickness of frame webs within the cargo area is not to be less than $w_{min}$, in [mm], given by:

$$w_{min} = C \cdot (7.0 + 0.03 \cdot \frac{L}{200})$$

where $C$ = 1.15 for the frame webs in way of the foremost hold;

$C$ = 1.0 for the frame webs in way of other holds.

The section modulus $SM$ of the frame and bracket or integral bracket, and associated shell plating, at the locations shown in Figure 17.2.5.4-1, is not to be less than twice the section modulus $SM$ required for the frame mid-span area.

The dimensions of the lower and upper brackets are not to be less than those shown in Figure 17.2.5.4-2.

Structural continuity with the upper and lower end connections of side frames is to be ensured within topsides and hopper tanks by connecting brackets as shown in Figure 17.2.5.4-3. The brackets are to be stiffened against buckling according to the Register's criteria.

The section moduli of the side longitudinals and sloping bulkhead longitudinals which support the connecting brackets are to be determined according to the Register's criteria with the span taken between transverses. Other arrangements may be adopted at the Register's discretion.
17.2.5.5 Frames are to be fabricated symmetrical sections with integral upper and lower brackets and are to be arranged with soft toes (see Fig. 17.2.5.4-3).

The side frame flange is to be curved (not knuckled) at the connection with the end brackets. The radius of curvature is not to be less than $r$, in [mm], given by:

$$r = 0.4 \times \frac{b_f^2}{t_f}$$

where $b_f$ and $t_f$ are the flange width and thickness of the brackets, respectively, in [mm]. The end of the flange is to be sniped.

In ships less than 190 m in length, mild steel frames may be asymmetric and fitted with separate brackets. The face plate or flange of the bracket is to be sniped at both ends. Brackets are to be arranged with soft toes.

The web depth to thickness ratio of frames is not to exceed the following values:

- $60 \cdot k^{0.5}$ for symmetrically flanged frames
- $50 \cdot k^{0.5}$ for asymmetrically flanged frames

where $k = 1.0$ for ordinary hull structural steel and $k < 1$ for higher tensile steel according to 1.4.2.2.

The outstanding flange $b_1$ shown in Fig. 17.2.5.4-1 is not to exceed $10 \cdot k^{0.5}$ times the flange thickness.
In way of the foremost hold, side frames of asymmetrical section are to be fitted with tripping brackets at every two frames, as shown in Figure 17.2.5.6:

- 0.44 $t$ in zone "a"
- 0.4 $t$ in zone "b"

where $t$ is the thinner of the two connected members.

The thickness of side shell plating located between hopper and upper wing tanks is not to be less than $t_{p,\min}$ in [mm], given by:

$$t_{p,\min} = \sqrt{L} \quad [\text{mm}]$$

The plate thickness of the topside tanks is to be determined according to Section 11.

Where the transverse stiffening system is applied for the longitudinal walls of the topside tanks and for the shell plating in way of the topside tanks, the stiffeners of the longitudinal walls are to be designed according to Section 11, the transverse frames at the shell according to Section 8.1.3.

The buckling strength of top side tank structures is examined in accordance with Section 4.6.

Sufficient continuity of strength is to be provided for between the structure of the topside tanks and the adjacent longitudinal structure.

Transverses in the wing tanks are to be determined according to Section 11.2.3 for the load resulting from the head of water or for the cargo load.

The greater load is to be considered. The scantlings of the transverses in the lower wing tanks are also to be examined for the loads according to 17.2.4.3.1.

The scantlings of the hatchway coaming plates are to be determined such as to ensure efficient protection against mechanical damage by grabs. The coaming plates are to have a minimum thickness at 15 mm.

The longitudinal hatchway coamings are to be extended in a suitable manner beyond the hatchway corners.

The scantlings of cargo hold bulkheads are to be determined on the basis of the requirements for tank structures according to Section 11.2, where the load $p_{Lh}$ is to be used for the load $p$.

The scantlings are not to be less than those required for watertight bulkheads according to Section 10. The plate thickness is in no case to be taken less than 9.0 mm.

The scantlings of the cargo hold bulkheads are to be verified by direct calculations.

Evaluation of scantlings of corrugated transverse watertight bulkheads in non-CSR bulk carriers considering hold flooding

This requirement is to be applied to non-CSR bulk carriers of 150 m in length and upwards, intending to carry solid bulk cargoes having a density of 1.0 t/m$^3$ or above, with vertically corrugated transverse watertight bulkheads, and with,

a) Single side skin construction, or
b) Double side skin construction in which any part of longitudinal bulkhead is located within B/5 or 11.5 m, whichever is less, inboard from the ship’s side at right angle to the centreline at the assigned summer load line.

The net thickness $t_{net}$ is the thickness obtained by applying the strength criteria given in 17.2.9.4.4.

The required thickness is obtained by adding the corrosion addition $t_k$, given in 17.2.9.4.6, to the net thickness $t_{net}$.

In this requirement, homogeneous loading condition means a loading condition in which the ratio between the highest and the lowest filling ratio, evaluated for each hold, does not exceed 1.20, to be corrected for different cargo densities.

These requirements do not apply to CSR Bulk Carriers.

The loads to be considered as acting on the bulkheads are those given by the combination of the cargo loads with those induced by the flooding of one hold adjacent to the bulkhead under examination. In any case, the pressure due to the flooding water alone is to be considered.

This application is to be applied to self-unloading bulk carriers (SUBC) where the unloading system maintains the watertightness during seagoing operations. In SUBCs with unloading systems that do not maintain watertightness, the combination loads acting on the
bulkheads in the flooded conditions are to be considered using the extent to which the flooding may occur.

The most severe combinations of cargo induced loads and flooding loads are to be used for the check of the scantlings of each bulkhead, depending on the loading conditions included in the loading manual:
- homogeneous loading conditions;
- non homogeneous loading conditions;
considering the individual flooding of both loaded and empty holds.

The specified design load limits for the cargo holds are to be represented by loading conditions defined by the designer in the loading manual.

Non homogeneous part loading conditions associated with multiport loading and unloading operations for homogeneous loading conditions need not to be considered according to these requirements. Holds carrying packed cargoes are to be considered as empty holds for this application.

Unless the ship is intended to carry, in non homogeneous conditions, only iron ore or cargo having bulk density equal or greater than 1,78 t/m$^3$, the maximum mass of cargo which may be carried in the hold is also to be considered to fill that hold up to the upper deck level at center line.

### 17.2.9.4.2.2 Bulkhead corrugation flooding head

The flooding head $h_f$ (see Fig. 17.2.9.4.2.2) is the distance, in [m], measured vertically with the ship in the upright position, from the calculation point to a level located at a distance $d_f$, in [m], from the baseline equal to:

a) in general:
- $D$, for the foremost transverse corrugated bulkhead (bulkhead between cargo holds Nos. 1 and 2)
- $0.9 \cdot D$, for the other bulkheads

Where the ship is to carry cargoes having bulk density less than 1.78 t/m$^3$ in non homogeneous loading conditions, the following values can be assumed:
- $0.95 \cdot D$, for the foremost transverse corrugated bulkhead
- $0.85 \cdot D$, for the other bulkheads

b) for ships less than 50,000 t deadweight with Type B freeboard:
- $0.95 \cdot D$, for the foremost transverse corrugated bulkhead
- $0.85 \cdot D$, for the other bulkheads

Where the ship is to carry cargoes having bulk density less than 1.78 t/m$^3$ in non homogeneous loading conditions, the following values can be assumed:
- $0.9 \cdot D$, for the foremost transverse corrugated bulkhead
- $0.8 \cdot D$, for the other bulkheads

$D$ being the distance, in [m], from the baseline to the freeboard deck at side amidship (see Fig. 17.2.9.4.2.2)

### 17.2.9.4.2.3 Pressure in the non-flooded bulk cargo loaded holds

At each point of the bulkhead, the pressure $p_c$, in [kN/m$^2$], is given by:

$$p_c = \rho_c \cdot g \cdot h_1 \cdot \tan^2 \gamma$$

where:
- $\rho_c$ = bulk cargo density, in [t/m$^3$]
- $g$ = 9.81 m/s$^2$, gravity acceleration
- $h_1$ = vertical distance, in [m], from the calculation point to horizontal plane corresponding to the volume of the cargo (see Fig. 17.2.9.4.2.2), located at a distance $d_1$, in [m], from the baseline.
- $\gamma = 45^\circ - (\varphi/2)$
- $\varphi$ = angle of repose of the cargo, in degrees, that may generally be taken as $35^\circ$ for iron ore and $25^\circ$ for cement

The force $F_c$, in [kN], acting on a corrugation is given by:

$$F_c = \rho_c \cdot g \cdot s_1 \cdot \frac{(d_1 - h_{DB} - h_{LS})^2}{2} \cdot \tan^2 \gamma$$

where:
- $\rho_c \cdot g \cdot s_1$ = as given above
- $s_1$ = spacing of corrugations, in [m] (see Fig. 17.2.9.4.2.3)
- $h_{LS}$ = mean height of the lower stool, in [m], from the inner bottom,
- $h_{DB}$ = height of the double bottom, in [m]

### 17.2.9.4.2.4 Pressure in the flooded holds

a) Bulk cargo holds

Two cases are to be considered, depending on the values of $d_1$ and $d_i$.  

$S = \max \{a, c\}$

1) $d_i \geq d_1$
At each point of the bulkhead located at a distance between $d_1$ and $d_f$ from the baseline, the pressure $p_{cf}$, in [kN/m$^2$], is given by:

$$ p_{cf} = \rho \cdot g \cdot h_f $$

where:

$\rho$ = sea water density, in [t/m$^3$];

$g$ = as given in 17.2.9.4.2.3;

$h_f$ = flooding head as defined in 17.2.9.4.2.2.

At each point of the bulkhead located at a distance lower than $d_1$ from the baseline, the pressure $p_{cf}$, in [kN/m$^2$], is given by:

$$ p_{cf} = \rho \cdot g \cdot h_f + [\rho_f - \rho \cdot (1 - \text{perm})] \cdot g \cdot h_1 \cdot \tan^2 \gamma $$

where:

$p_{cf}$ = as given above;

$p_{cf}, g, h_1$ = as given in 17.2.9.4.2.3;

$\text{perm}$ = permeability of cargo, to be taken as $0.3$ for ore (corresponding bulk cargo density for iron ore may generally be taken as $3.0$ t/m$^3$, coal cargoes and for cement (corresponding bulk cargo density for cement may generally be taken as $1.3$ t/m$^3$).

The force $F_{cf}$, in [kN], acting on a corrugation is given by:

$$ F_{cf} = s_1 \left[ \rho \cdot g \cdot \frac{(d_f - d_1)^2}{2} + \rho \cdot g \cdot (d_1 - d_f) \cdot h_{LS} \right] $$

where:

$\rho$ = as given above;

$s_1, g, d_f, h_{DB}, h_{LS}$ = as given in 17.2.9.4.2.3;

$d_f$ = as given in 17.2.9.4.2.2;

$(p_{cf}, \gamma)$ = pressure, in [kN/m$^2$], at the lower end of the corrugation.

2) $d_f < d_1$

At each point of the bulkhead located at a distance between $d_f$ and $d_1$ from the baseline, the pressure $p_{cf}$, in [kN/m$^2$], is given by:

$$ p_{cf} = \rho \cdot g \cdot h_1 \cdot \tan^2 \gamma $$

where:

$p_{cf}, g, h_1$ = as given in 17.2.9.4.2.3

At each point of the bulkhead located at a distance lower than $d_1$ from the baseline, the pressure $p_{cf}$, in [kN/m$^2$], is given by:

$$ p_{cf} = \rho \cdot g \cdot h_f + [\rho_f - \rho \cdot (1 - \text{perm})] \cdot g \cdot h_1 \cdot \tan^2 \gamma $$

where:

$\rho, h_1, \text{perm}$ = as given in 1) above;

$p_{cf}, g, \gamma$ = as given in 17.2.9.4.2.3.

The force $F_{cf}$, in [kN], acting on a corrugation is given by:

$$ F_{cf} = s_1 \left[ \rho \cdot g \cdot \frac{(d_f - d_1)^2}{2} \cdot \tan^2 \gamma + \rho \cdot g \cdot (d_1 - d_f) \cdot h_{LS} + (p_{cf})_{\gamma} \cdot \frac{(d_f - h_{DB} - h_{LS})}{2} \right] $$

where:

$s_1, \rho, g, d_1, y, h_{DB}, h_{LS}$ = as given in 17.2.9.4.2.3;

$d_f$ = as given in 17.2.9.4.2.2;

$(p_{cf})_{\gamma}$ = pressure, in [kN/m$^2$], at the lower end of the corrugation.

b) Empty holds and pressure due to flooding water alone

At each point of the bulkhead, the hydrostatic pressure $p_f$ induced by the flooding head $h_f$ is to be considered.

The force $F_f$, in [kN], acting on a corrugation is given by:

$$ F_f = s_1 \cdot \rho \cdot g \cdot \frac{(d_f - h_{DB} - h_{LS})^2}{2} $$

where:

$s_1, g, h_{DB}, h_{LS}$ = as given in 17.2.9.4.2.3;

$\rho$ = as given in 17.2.9.4.2.4.1;

$d_f$ = as given in 17.2.9.4.2.2.

17.2.9.4.2.5 Resultant pressure and force

a) Homogeneous loading conditions

At each point of the bulkhead structures, the resultant pressure $p$, in [kN/m$^2$], to be considered for the scantlings of the bulkhead is given by:

$$ p = p_{cf} - 0.8 \cdot p_f $$

The resultant force $F$, in [kN], acting on a corrugation is given by:

$$ F = F_{cf} \cdot 0.8 \cdot F $$

b) Non homogeneous loading conditions

At each point of the bulkhead structures, the resultant pressure $p$, in [kN/m$^2$], to be considered for the scantlings of the bulkhead is given by:

$$ p = p_{cf} $$

The resultant force $F$, in [kN], acting on a corrugation is given by:

$$ F = F_{cf} $$

17.2.9.4.3 Bending moment and shear force in the bulkhead corrugations

The bending moment $M$ and the shear force $Q$ in the bulkhead corrugations are obtained using the formulae given in 17.2.9.4.3.1 and 17.2.9.4.3.2. The $M$ and $Q$ values are to be used for the checks in 17.2.9.4.4.5

17.2.9.4.3.1 Bending moment

The design bending moment $M$, in [kN/m], for the bulkhead corrugations is given by:

$$ M = \frac{F \cdot l}{8} $$

where:

$F$ = resultant force, in [kN], as given in 17.2.9.4.2.5;

$l$ = span of the corrugation, in [m], to be taken according to Fig. 17.2.9.4.3.1.

17.2.9.4.3.2 Shear force

The shear force $Q$, in [kN], at the lower end of the bulkhead corrugations is given by:

$$ Q = 0.8 \cdot F $$

where:

$F$ = as given in 17.2.9.4.2.5.
The thicknesses of the middle part of corrugations as considered in the application of 17.2.9.4.4.2 and 17.2.9.4.4.4 are to be maintained to a distance from the deck (if no upper stool is fitted) or the bottom of the upper stool not greater than 0.3 · 1.

The section modulus of the corrugation in the remaining upper part of the bulkhead is not to be less than 75% of that required for the middle part, corrected for different yield stresses.

(a) Lower stool
The height of the lower stool is generally to be not less than 3 times the depth of the corrugations. The thickness and material of the stool top plate is not to be less than those required for the bulkhead plating above. The thickness and material of the upper portion of vertical or sloping stool side plating within the depth equal to the corrugation flange width from the stool top is not to be less than the required flange plate thickness and material to meet the bulkhead stiffness requirement at lower end of corrugation. The thickness of the stool side plating and the section modulus of the stool side stiffeners is not to be less than those required by the Register on the basis of the load model in 17.2.9.4.2. The ends of stool side vertical stiffeners are to be attached to brackets at the upper and lower ends of the stool. The distance from the edge of the stool top plate to the surface of the corrugation flange is to be in accordance with Fig. 17.2.9.4.4.1. The stool bottom is to be installed in line with double bottom floors and is to have a width not less than 2.5 times the mean depth of the corrugation. The stool is to be fitted with diaphragms in line with the longitudinal double bottom girders for effective support of the corrugated bulkhead. Scallops in the brackets and diaphragms in way of the connections to the stool top plate are to be avoided.

Where corrugations are cut at the bottom stool, corrugated bulkhead plating is to be connected to the stool top plate by full penetration welds. The stool side plating is to be connected to the stool top plate and the inner bottom plating by either full penetration or deep penetration welds (see Figure 17.2.9.4.4.1-1). The supporting floors are to be connected to the inner bottom by either full penetration or deep penetration welds (see Figure 17.2.9.4.4.1-1).
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PART 2

Figure 17.2.9.4.4.1 - Permitted distance, \( d \), from edge of stool top plate to surface of corrugation flange

\[ t_f = \text{as-built flange thickness} \]

Root face (f): 3 mm to \( T/3 \) mm
Groove Angle (\( \alpha \)): 40˚ to 60˚

Figure 17.2.9.4.4.1-1

b) Upper stool
The upper stool, where fitted, is to have a height generally between 2 and 3 times the depth of corrugations. Rectangular stools are to have a height generally equal to 2 times the depth of corrugations, measured from the deck level and at hatch side girder. The upper stool is to be properly supported by girders or deep brackets between the adjacent hatch-end beams.

The width of the stool bottom plate is generally to be the same as that of the lower stool top plate. The stool top of non-rectangular stools is to have a width not less than 2 times the depth of corrugations. The thickness and material of the stool bottom plate are to be the same as those of the bulkhead plating below. The thickness of the lower portion of stool side plating is not to be less than 80% of that required for the upper part of the bulkhead plating where the same material is used. The thickness of the stool side plating and the section modulus of the stool side stiffeners is not to be less than those required by the Register on the basis of the load model in 17.2.9.4.2.

The ends of stool side stiffeners are to be attached to brackets at upper and lower end of the stool. Diaphragms are to be fitted inside the stool in line with and effectively attached to longitudinal deck girders extending to the hatch end coaming girders for effective support of the corrugated bulkhead. Scallops in the brackets and diaphragms in way of the connection to the stool bottom plate are to be avoided.

(c) Alignment
At deck, if no stool is fitted, two transverse reinforced beams are to be fitted in line with the corrugation flanges. At bottom, if no stool is fitted, the corrugation flanges are to be in line with the supporting floors. Corrugated bulkhead plating is to be connected to the inner bottom plating by full penetration welds. The plating of supporting floors is to be connected to the inner bottom by either full penetration or deep penetration welds (see Figure 17.2.9.4.4.1-1). The thickness and material properties of the supporting floors are to be at least equal to those provided for the cor-
ruggation flanges. Moreover, the cut-outs for connections of the inner bottom longitudinals to double bottom floors are to be closed by collar plates. The supporting floors are to be connected to each other by suitably designed shear plates, as deemed appropriate by the Register.

Stool side plating is to align with the corrugation flanges and stool side vertical stiffeners and their brackets in lower stool are to align with the inner bottom longitudinals to provide appropriate load transmission between these stiffening members. Stool side plating is not to be knuckled anywhere between the inner bottom plating and the stool top.

17.2.9.4.4.2 Bending capacity and shear stress

The bending capacity is to comply with the following relationship:

\[
10^3 \cdot \frac{M}{0.5 \cdot Z_{le} \cdot \sigma_{a,le} + Z_m \cdot \sigma_{a,m}} \leq 0.95
\]

where:

- \( M \) = bending moment, in [kNm], as given in 17.2.9.4.3.1;
- \( Z_{le} \) = section modulus, in [cm³], at the lower end of corrugations, to be calculated according to 17.2.9.4.4.3;
- \( Z_m \) = section modulus, in [cm³], at the mid-span of corrugations, to be calculated according to 17.2.9.4.4.4;
- \( \sigma_{a,le} \) = allowable stress, in [N/mm²], as given in 17.2.9.4.4.5, for the lower end of corrugations;
- \( \sigma_{a,m} \) = allowable stress, in [N/mm²], as given in 17.2.9.4.4.5, for the mid-span of corrugations.

In no case \( Z_0 \) is to be taken greater than the lesser of 1,15 \( \cdot Z_{le} \) and 1,15 \( \cdot Z_m \) for calculation of the bending capacity \( Z_\beta \) being defined below.

In case shedsder plates are fitted which:

- are not knuckled;
- are welded to the corrugations and the top of the lower stool by one side penetration welds or equivalent;
- are fitted with a minimum slope of 45° and their lower edge is in line with the stool side plating;
- have thicknesses not less than 75% of that provided by the corrugation flange;
- and material properties at least equal to those provided by the flanges.

or gusset plates are fitted which:

- are in combination with shedder plates having thickness, material properties and welded connection in accordance with the above requirements;
- have a height not less than half of the flange width;
- are fitted in line with the stool side plating;
- are generally welded to the top of the lower stool by full penetration welds, and to the corrugations and shedder plates by one side penetration welds or equivalent.

- have thickness and material properties at least equal to those provided for the flanges.

The section modulus \( Z_\alpha \), in [cm³], is to be taken not larger than the value \( Z_\alpha' \), in [cm³], given by:

\[
Z_\alpha' = Z_\alpha + 10^3 \cdot \frac{Q \cdot h_s - 0.5 \cdot h_s^2 \cdot s_1 \cdot P_s}{\sigma_{a}}
\]

where:

- \( Z_\alpha \) = section modulus, in [cm³], of the corrugations calculated, according to 17.2.9.4.4.4, in way of the upper end of shedder or gusset plates, as applicable;
- \( Q \) = shear force, in [kN], as given in 17.2.9.4.3.2;
- \( h_s \) = height, in [m], of shedders or gusset plates, as applicable (see Fig. 17.2.9.4.4.3-1 and 17.2.9.4.4.3-2);
- \( s_1 \) = as given in 17.2.9.4.2.3;
- \( P_s \) = resultant pressure, in [kN/m²], as defined in 17.2.9.4.2.5, calculated in way of the middle of the shedders or gusset plates, as applicable;
- \( \sigma_{a} \) = allowable stress, in [N/mm²], as given in 17.2.9.4.4.5.

Stresses \( \tau \) are obtained by dividing the shear force \( Q \) by the shear area. The shear area is to be reduced in order to account for possible non-perpendicularity between the corrugation webs and flanges. In general, the reduced shear area may be obtained by multiplying the web sectional area by \( \sin \phi \), \( \phi \) being the angle between the web and the flange.

When calculating the section modulus and the shear area, the net plate thicknesses are to be used.

The section modulus of corrugations are to be calculated on the basis of the following requirements given in 17.2.9.4.4.3 and 17.2.9.4.4.4

17.2.9.4.4.3 Section modulus at the lower end of corrugations

The section modulus is to be calculated with the compression flange having an effective flange width \( b_{ef} \), not larger than as given in 17.2.9.4.4.6.

If the corrugation webs are not supported by local brackets below the stool top (or below the inner bottom) in the lower part, the section modulus of the corrugations is to be calculated considering the corrugation webs 30% effective.

a) Provided that effective shedder plates, as defined in 17.2.9.4.4.2, are fitted (see Fig. 17.2.9.4.4.3-1) when calculating the section modulus of corrugations at the lower end (cross-section ⊙ in Fig. 17.2.9.4.4.3-1), the area of flange plates, in [cm²], may be increased by:

\[
\left(2.5 \cdot a \cdot \sqrt{t_f \cdot t_{sh}}\right)
\]

(Not to be taken greater than 2.5 \( \cdot a \cdot b \)) where:

- \( a \) = width, in [m], of the corrugation flange (see Fig. 17.2.9.4.2.3);
- \( t_{sh} \) = net shedder plate thickness, in [mm];
- \( t_f \) = net flange thickness, in [mm];

b) Provided that effective gusset plates, as defined in 17.2.9.4.4.2, are fitted (see Fig.
17.2.9.4.4.3-2) when calculating the section modulus of corrugations at the lower end (cross-section ① in Fig. 17.2.9.4.4.3-2), the area of flange plates, in [cm²], may be increased by \((7 \cdot h_g \cdot t_f)\) where:

\[ h_g = \text{height of gusset plate in [m], see Fig. 17.2.9.4.4.3-2, not to be taken greater than} \]

\[ \left( \frac{10}{7} \cdot s_{gu} \right) \]

\[ s_{gu} = \text{width of the gusset plates, in [m];} \]

\[ t_f = \text{net flange thickness, in [mm], based on the as built condition.} \]

c) If the corrugation webs are welded to a sloping stool top plate, the section modulus of the corrugations may be calculated considering the corrugation webs full effective. In case effective gusset plates are fitted, when calculating the section modulus of corrugations the area of flange plates may be increased as specified in b) above. No credit can be given to shedder plates only.

For angles less than 45° the effectiveness of the web may be obtained by linear interpolation between 30% for 0° and 100% for 45°.

---

**Figure 17.2.9.4.4.3-1**

**Symmetric shedder plates**

![Symmetric shedder plates diagram](image1)

**Asymmetric shedder plates**

![Asymmetric shedder plates diagram](image2)

**Figure 17.2.9.4.4.3-2**

**Symmetric gusset/shedder plates**

![Symmetric gusset/shedder plates diagram](image3)

**Asymmetric gusset/shedder plates**

![Asymmetric gusset/shedder plates diagram](image4)
17.2.9.4.4 Section modulus of corrugations at cross-sections other than the lower end

The section modulus is to be calculated with the corrugation webs considered effective and the compression flange having an effective flange width, \(b_f\), not larger than as given in 17.2.9.4.4.6.1.

17.2.9.4.5 Allowable stress check

The normal and shear stresses \(\sigma\) and \(\tau\) are not to exceed the allowable values \(\sigma_0\) and \(\tau_0\), in [N/mm²], given by:

\[
\sigma_0 = \sigma_F \quad \text{and} \quad \tau_0 = 0.5 \sigma_F
\]

\(\sigma_F = \) minimum upper yield stress, in [N/mm²], of the material.

17.2.9.4.6 Effective compression flange width and shear buckling check

a) Effective width of the compression flange of corrugations

The effective width \(b_f\), in [m], of the corrugation flange is given by:

\[
b_f = C_c \cdot a
\]

\[
C_c = \frac{2.25}{\beta} \cdot \frac{1.25}{\beta^2}, \quad \text{for } \beta > 1.25
\]

\[
C_c = 1.0, \quad \text{for } \beta \leq 1.25
\]

\[
\beta = 10^3 \cdot \frac{a}{t_f} \sqrt{\frac{\sigma_F}{E}}
\]

where:

\(t_f = \) net flange thickness, in [mm];

\(\sigma_F = \) minimum upper yield stress, in [N/mm²], of the material;

\(E = \) modulus of elasticity of the material, in [N/mm²], to be assumed equal to 2.06 \cdot 10^5 for steel.

b) Shear

The buckling check is to be performed for the web plates at the corrugation ends.

The shear stress \(\tau\) is not to exceed the critical value \(\tau_c\), in [N/mm²], obtained by the following formulae:

\[
\tau_c = \tau_F, \quad \text{when } \tau_0 \leq \frac{\tau_F}{2}
\]

\[
\tau = \tau_F \left(1 - \frac{\tau_F}{2 \tau_E}ight), \quad \text{when } \tau_0 > \frac{\tau_F}{2}
\]

where:

\[
\tau_F = \frac{\sigma_F}{\sqrt{3}}
\]

\(\tau_F = \) minimum upper yield stress, in [N/mm²], of the material;

\[
\tau_0 = 0.09 \cdot k_c \cdot E \cdot \left(\frac{t}{(1000 \cdot c)}\right)^2, \quad \text{in N/mm²}
\]

\(k_c, E, t\) and \(c\) are given by:

\(k_c = 6.34; \quad E = \) modulus of elasticity of material as given in 17.2.9.4.4.6.1.

\(t = \) net thickness, in [mm], of corrugation web;

\(c = \) width, in [m], of corrugation web (see Fig. 17.2.9.4.2.3).

17.2.9.4.7 Local net plate thickness

The bulkhead local net plate thickness \(t\), in [mm], is given by:

\[
t = 14.9 \cdot s_w \cdot \sqrt[3]{\frac{1.05 \cdot p}{\sigma_F}}
\]

where:

\(s_w = \) plate width, in [m], to be taken equal to the width of the corrugation flange or web, whichever is the greater (see Fig. 17.2.9.4.2.3);

\(p = \) resultant pressure, in [kN/m²], as defined in 17.2.9.4.2.5, at the bottom of each strake of plating; in all cases, the net thickness of the lowest strake is to be determined using the resultant pressure at the top of the lower stool, or at the inner bottom, if no lower stool is fitted or at the top of sheds, if shedder or gusset/shedder plates are fitted;

\(\sigma_F = \) minimum upper yield stress, in [N/mm²], of the material.

For built-up corrugation bulkheads, when the thicknesses of the flange and web are different, the net thickness of the narrower plating is to be not less than \(t_n\) in [mm], given by:

\[
t_n = 14.9 \cdot s_w \cdot \sqrt[3]{\frac{1.05 \cdot p}{\sigma_F}}
\]

\(s_w\) being the width, in [m], of the narrower plating.

The net thickness of the wider plating, in [mm], is not to be taken less than the maximum of the following

\[
t_n = 14.9 \cdot s_w \cdot \sqrt[3]{\frac{1.05 \cdot p}{\sigma_F}}
\]

and

\[
t_n = \sqrt[3]{\frac{440 \cdot s_w^2 \cdot 1.05 \cdot p}{\sigma_F \cdot t_{np}^2}}
\]

where \(t_{np}\) ≤ actual net thickness of the narrower plating and not to be greater than

\[
14.9 \cdot s_w \cdot \sqrt[3]{\frac{1.05 \cdot p}{\sigma_F}}
\]

17.2.9.4.5 Local details

As applicable, the design of local details is to comply with the Register’s requirements for the purpose of transferring the corrugated bulkhead forces and moments to the boundary structures, in particular to the double bottom and cross-deck structures.

In particular, the thickness and stiffening of effective gusset and shedder plates, as defined in 17.2.9.4.4.3 is to comply with the Register’s requirements, on the basis of the load model in 17.2.9.4.2.

Unless otherwise stated, weld connections and materials are to be dimensioned and selected in accordance with the Register’s requirements.
17.2.9.4.6 Corrosion addition and steel renewal

The corrosion addition is to be taken equal to 3.5 mm.

Steel renewal is required where the gauged thickness is less than \( t_{\text{net}} + 0.5 \) [mm]

Where the gauged thickness is within the range \( t_{\text{net}} + 0.5 \) [mm] and \( t_{\text{net}} + 1.0 \) [mm], coating (applied in accordance with the coating manufacturer’s requirements) or annual gauging may be adopted as an alternative to steel renewal.

17.2.9.4.7 Above vertically corrugated bulkheads, transverse girders with double webs are to be fitted below the deck, to form the upper edge of the corrugated bulkheads. They are to have the following scantlings:

- web thickness = thickness of the upper plate strake of the bulkhead
- depth of web = \( B/22 \)
- face plate = 1.5 times the thickness of the upper (thickness) plate strake of the bulkhead.

17.2.9.4.8 Vertically corrugated transverse cargo hold bulkheads are to have a plane stiffened strip of plating at the ship’s sides. The width of this strip of plating is to be 0.15 \( D \) where the length of the cargo hold is 20 m. Where the length of the cargo hold is greater/smaller, the width of the strip of plating is to be increased/reduced proportionally.

17.2.10 Requirements for the fitting of a forecastle for bulk carriers, ore carriers and combination carriers

17.2.10.1 Application

These requirements apply to all bulk carriers, ore carriers and combination carriers, as defined in the Rules, Part 1 – General requirements, Chapter 1 – General information, 4.2.

Such ships are to be fitted with a closed forecastle on the freeboard deck.

The required dimensions of the forecastle are defined in Section 17.2.10.2.

The structural arrangements and scantlings of the forecastle are to comply with these Rules.

These requirements do not apply to CSR Bulk Carriers.

17.2.10.2 Dimension

The forecastle is to be located on the freeboard deck with its aft bulkhead fitted in way or aft of the forward bulkhead of the foremost hold, as shown in Figure 17.2.10.2.

However, if this requirement hinders hatch cover operation, the aft bulkhead of the forecastle may be fitted forward of the forward bulkhead of the foremost cargo hold provided the forecastle length is not less than 7% of ship length abaft the forward perpendicular where the ship length and forward perpendicular are defined in Regulation 3 of ICLL, 1966.

The forecastle height \( H_F \) above the main deck is to be not less than:

\[ H_F \geq \begin{cases} \text{the standard height of a superstructure as specified in the Regulation 33 of ICLL, 1966, or,} \\ .2 \ H_c + 0.5 \text{ m, where } H_c \text{ is the height of the forward transverse hatch coaming of cargo hold No. 1, whichever is the greater.} \end{cases} \]

All points of the aft edge of the forecastle deck are to be located at a distance \( l_F \):

\[ l_F \leq 5\sqrt{H_F - H_C} \]

from the hatch coaming plate in order to apply the reduced loading to the No. 1 forward transverse hatch coaming and No. 1 hatch cover in applying Section 7.10.8.4.1 and Section 7.10.8.5.2, respectively, of the Rules, Part 3-Hull Equipment.

A breakwater is not to be fitted on the forecastle deck with the purpose of protecting the hatch coaming or hatch covers. If fitted for other purposes, it is to be located such that its upper edge at centre line is not less than \( H_B/\tan20^\circ \) forward of the aft edge of the forecastle deck, where \( H_B \) is the height of the breakwater above the forecastle (see Figure 17.2.10.2).

![Figure 17.2.10.2](image)

17.3 ORE CARRIERS

17.3.1 General

17.3.1.1 Ore carriers are generally single-deck vessels with the machinery aft and two continuous longitudinal bulkheads with the ore cargo holds fitted between them.

Ships built in accordance with the following requirements will get affixed the notation “Ore carrier”. Entries HME will be made into the Certificate as to whether specified cargo holds may be empty in case of alternating loading. Additional indications of the types of cargo for which the ship is strengthened may be entered into the Certificate.

17.3.1.2 For ships subject to the provisions of this paragraph the requirements of 17.2.9 are applicable unless otherwise mentioned in this sub-section.

17.3.1.3 For ore carriers carrying also oil in bulk also Section 18 applies.

17.3.2 Double bottom

17.3.2.1 For achieving good stability criteria in the loaded condition the double bottom between the longitudinal bulkheads should be as high as possible.
17.3.2.2 The strength of the double bottom structure is to comply with the requirements given in 17.2.4.

17.3.3 Transverse and longitudinal bulkheads

17.3.3.1 The spacing of transverse bulkheads in the side tanks which are to be used as ballast tanks is to be determined according to Section 18, as for tankers. The spacing of transverse bulkheads in way of the cargo hold is to be determined according to Section 10.

17.3.3.2 The scantlings of cargo hold bulkheads exposed to the load of the ore cargo are to be determined according to 17.2.9. The scantlings of the side longitudinal bulkheads are to be at least equal to those required for tankers.

17.4 LOADING INFORMATION FOR BULK CARRIERS, ORE CARRIERS AND COMBINATION CARRIERS

17.4.1 Application

Bulk Carriers, Ore Carriers and Combination Carriers of 150 m length and above, are to be provided with an approved Loading Manual and approved computer-based Loading Instrument, in accordance with 17.4.2, 17.4.3 and 17.4.4.

For loading and unloading sequences, see 17.4.5. These requirements do not apply to CSR Bulk Carriers.

17.4.2 Definitions

17.4.2.1 Loading manual

Loading Manual is a document which describes:

a) the loading conditions on which the design of the ship has been based, including permissible limits of still water bending moments and shear forces;

b) the results of the calculations of still water bending moments, shear forces and where applicable, limitations due to torsional loads;

c) for bulk carriers, envelope results and permissible limits of still water bending moments and shear forces in the hold flooded condition according to Section 17.2.2.2 as applicable;

d) the cargo hold(s) or combination of cargo holds that might be empty at full draught. If no cargo hold is allowed to be empty at full draught, this is to be clearly stated in the Loading Manual;

e) maximum allowable and minimum required mass of cargo and double bottom contents of each hold as a function of the draught at mid-hold position;

f) maximum allowable and minimum required mass of cargo and double bottom contents of any two adjacent holds as a function of the mean draught in way of these holds. This mean draught may be calculated by averaging the draught of the two mid-hold positions;

g) maximum allowable tank top loading together with specification of the nature of the cargo for cargoes other than bulk cargoes;

h) maximum allowable load on deck and hatch covers. If the vessel is not approved to carry load on deck or hatch covers, this is to be clearly stated in the Loading Manual;

i) the maximum rate of ballast change together with the advice that a load plan is to be agreed with the terminal on the basis of the achievable rates of change of ballast.

17.4.2.2 Loading instrument

A loading instrument is an approved digital system as defined in Section 4.1.3. In addition to the requirements in Section 4.1.4, it shall ascertain as applicable that:

a) the mass of cargo and double bottom contents in way of each hold as a function of the draught at mid-hold position;

b) the mass of cargo and double bottom contents of any two adjacent holds as a function of the mean draught in way of these holds;

c) the still water bending moment and shear forces in the hold flooded conditions according to Section 17.2.2.2; are within permissible values.

17.4.3 Conditions of approval of loading manuals

In addition to the requirements given in Section 4.1.4.3, the following conditions, subdivided into departure and arrival conditions as appropriate, are to be included in the Loading Manual:

a) alternate light and heavy cargo loading conditions at maximum draught, where applicable;

b) homogeneous light and heavy cargo loading conditions at maximum draught;

c) ballast conditions. For vessels having ballast holds adjacent to topside wing, hopper and double bottom tanks, it shall be strengthwise acceptable that the ballast holds are filled when the topside wing, hopper and double bottom tanks are empty;

d) short voyage conditions where the vessel is to be loaded to maximum draught but with limited amount of bunkers;

e) multiple port loading/unloading conditions;

f) deck cargo conditions, where applicable;

g) typical loading sequences where the vessel is loaded from commencement of cargo loading to reaching full deadweight capacity, for homogeneous conditions, relevant part load conditions and alternate conditions where applicable. Typical unloading sequences for these conditions shall also be included. The typical loading/unloading sequences shall also be developed paying due atten-
tion to loading rate and the deballasting capability.

h) typical sequences for change of ballast at sea, where applicable.

17.4.4 Conditions of approval of loading instruments

The loading instrument is subject to approval. In addition to the requirements given in Section 4.1.4.4, the approval is to include as applicable:

a) acceptance of hull girder bending moment limits for all read-out points
b) acceptance of hull girder shear force limits for all read-out points
c) acceptance of limits for mass of cargo and double bottom contents of each hold as a function of draught
d) acceptance of limits for mass of cargo and double bottom contents in any two adjacent holds as a function of draught.

17.4.5 Guidance for loading/unloading sequences

17.4.5.1 Item 17.4.1 requires that Bulk Carriers, Ore Carriers and Combination Carriers of 150 m length and above are to be provided with an approved loading manual with typical loading sequences where the ship is loaded from commencement of cargo loading to reaching full deadweight capacity, for homogeneous conditions, relevant part loaded conditions and alternate conditions where applicable. The typical unloading sequences shall be developed paying due attention to the loading rate, the deballasting capacity and the applicable strength limitations.

17.4.5.2 The shipbuilder will be required to prepare and submit for approval typical loading and unloading sequences.

17.4.5.3 The typical loading sequences as relevant should include:

- alternate light and heavy cargo load condition,
- homogeneous light and heavy cargo load condition,
- short voyage condition where the ship is loaded to maximum draught but with limited bunkers
- multiple port loading / unloading condition,
- deck cargo condition,
- block loading.

17.4.5.4 The loading / unloading sequences may be port specific or typical.

17.4.5.5 The sequence is to be built up step by step from commencement of cargo loading to reaching full deadweight capacity. Each time the loading equipment changes position to a new hold defines a step. Each step is to be documented and submitted to the Register. In addition to longitudinal strength, the local strength of each hold is to be considered.

17.4.5.6 For each loading condition a summary of all steps is to be included. This summary is to highlight the essential information for each step such as:

- How much cargo is filled in each hold during the different steps,
- How much ballast is discharged from each ballast tank during the different steps,
- The maximum still water bending moment and shear at the end of each step,
- The ship’s trim and draught at the end of each step.

17.4.5.7 It is recommended that IACS Rec. 83 be taken into account when compiling the typical loading and unloading sequences described in Section 17.4.5.

17.4.6 Harmonised notations and corresponding design loading conditions for bulk carriers

17.4.6.1 Application

17.4.6.1.1 This requirement is applicable to "Bulk Carrier" as defined in the Rules for classification of ships, Chapter 4.2.5.5, having length \( L \) as defined in Section 1.2.3.1 of 150 m or above and contracted for new construction on or after 1 July 2003. The consideration of the following requirements is recommended for ships having a length \( L < 150 \) m.

17.4.6.1.2 The loading conditions listed under Section 17.4.6.3 are to be used for the checking of rules criteria regarding longitudinal strength (see Section 4 and Section 17.2.2), local strength, capacity and disposition of ballast tanks and stability. The loading conditions listed under 17.4.6.4 are to be used for the checking of rule criteria regarding local strength.

17.4.6.1.3 For the purpose of applying the conditions given in this requirement, maximum draught is to be taken as moulded summer load line draught.

17.4.6.1 Harmonized notations and annotations

Bulk Carriers are to be assigned one of the following notations:

- BC-A: for bulk carriers designed to carry dry bulk cargoes of cargo density 1.0 tonne/m\(^3\) and above with specified holds empty at maximum draught in addition to BC-B conditions.
- BC-B: for bulk carriers designed to carry dry bulk cargoes of cargo density of 1.0 tonne/m\(^3\) and above with all cargo holds loaded in addition to BC-C conditions.
- BC-C: for bulk carriers designed to carry dry bulk cargoes of cargo density less than 1.0 tonne/m\(^3\).

The following additional notations and annotations are to be provided giving further detailed description of limitations to be observed during operation as a consequence of the design loading condition applied during the design in the following cases:

1. additional notations;
   {\text{maximum cargo density (in tonne/m}^3\text{)}}
   for notations BC-A and BC-B if the maximum cargo density is less than 3.0 tonnes/m\(^3\);
   \{\text{no MP}\}
   for all notations when the vessel has not been designed for loading and unloading in multiple ports in accordance with the conditions specified in Section 17.4.6.4.4.3.
2. annotations;
   \{\text{allowed combination of specified empty holds}\}
   for notation BC-A.
17.4.6.2 Design loading conditions (general)

17.4.6.3.1 BC-C

Homogeneous cargo loaded condition where the cargo density corresponds to all cargo holds, including hatchways, being 100% full at maximum draught with all ballast tanks empty.

17.4.6.3.2 BC-B

As required for BC-C, plus:

Homogeneous cargo loaded condition with cargo density 3.0 tonnes/m³, and the same filling rate (cargo mass/hold cubic capacity) in all cargo holds at maximum draught with all ballast tanks empty.

In cases where the cargo density applied for this design loading condition is less than 3.0 tonnes/m³, the maximum density of the cargo that the vessel is allowed to carry is to be indicated with the additional notation \( \text{maximum cargo density } x.y \text{ tonnes/m}^3 \).

17.4.6.3.3 BC-A

As required for BC-B, plus:

At least one cargo loaded condition with specified holds empty, with cargo density 3.0 tonnes/m³, and the same filling rate (cargo mass/hold cubic capacity) in all loaded cargo holds at maximum draught with all ballast tanks empty.

The combination of specified empty holds shall be indicated with the annotation \{holds a, b, . . . . may be empty, with maximum cargo density x.y tonnes/m³\}.

17.4.6.3.4 Ballast conditions (applicable to all notations)

17.4.6.3.4.1 Ballast tank capacity and disposition

All bulk carriers are to have ballast tanks of sufficient capacity and so disposed to at least fulfill the following requirements.

17.4.6.3.4.1a) Normal ballast condition

Normal ballast condition for the purpose of this requirement is a ballast (no cargo) condition where:

1. the ballast tanks may be full, partially full or empty. Where partially full option is exercised, the conditions in the last paragraph of Section 4.2.1.2 are to be complied with,
2. at least one cargo hold adapted for carriage of water ballast at sea, where required or provided, is to be full,
3. the propeller immersion I/D is to be at least 60% where
   \[ I = \text{the distance from propeller centerline to the waterline} \]
   \[ D = \text{propeller diameter, and} \]
4. the trim is to be by the stern and is not to exceed 0.015L, where L is the length between perpendiculars of the ship,
5. the moulded forward draught in the heavy ballast condition is not to be less than the smaller of 0.03L or 8 m.

17.4.6.3.4.2 Strength requirements

All bulk carriers are to meet the following strength requirements:

17.4.6.3.4.2 a) Normal ballast condition

1. the structures of bottom forward are to be strengthened in accordance with the Section 5.4 against slamming for the condition of Section 17.4.6.3.4.1a) at the lightest forward draught,
2. the longitudinal strength requirements are to be met for the condition of Section 17.4.6.3.4.1a), and
3. in addition, the longitudinal strength requirements are to be met with all ballast tanks 100% full.

17.4.6.3.4.2 b) Heavy ballast condition

1. the longitudinal strength requirements are to be met for the condition of Section 17.4.6.3.4.1b),
2. in addition to the conditions in 1., the longitudinal strength requirements are to be met under a condition with all ballast tanks 100% full and one cargo hold adapted and designated for the carriage of water ballast at sea, where provided, 100 % full, and
3. where more than one hold is adapted and designated for the carriage of water ballast at sea, it will not be required that two or more holds be assumed 100% full simultaneously in the longitudinal strength assessment, unless such conditions are expected in the heavy ballast condition. Unless each hold is individually investigated, the designated heavy ballast hold and any/all restrictions for the use of other ballast hold(s) are to be indicated in the loading manual.

17.4.6.3.5 Departure and arrival conditions

Unless otherwise specified, each of the design loading conditions defined in Section 17.4.6.3.1 to Section 17.4.6.3.4 is to be investigated for the arrival and departure conditions as defined below.

Departure condition: with bunker tanks not less than 95 % full and other consumables 100 %. 
17.4.6.4 Design loading conditions (for local strength)

17.4.6.4.1 Definitions

The maximum allowable or minimum required cargo mass in a cargo hold, or in two adjacent loaded holds, is related to the net load on the double bottom. The net load on the double bottom is a function of draft, cargo mass in the cargo hold, as well as the mass of fuel oil and ballast water contained in double bottom tanks.

The following definitions apply:

- $M_{H}$: the actual cargo mass in a cargo hold corresponding to a homogeneously loaded condition at maximum draught.
- $M_{H\text{max}}$: the cargo mass in a cargo hold corresponding to cargo with virtual density (homogeneous mass/hold cubic capacity, minimum 1.0 tonne/m$^3$) filled to the top of the hatch coaming. $M_{H\text{max}}$ is in no case to be less than $M_{H}$.
- $M_{H\text{HD}}$: the maximum cargo mass allowed to be carried in a cargo hold according to design loading condition(s), with specified holds empty at maximum draft.

17.4.6.4.2 General conditions applicable for all notations

17.4.6.4.2.1 Any cargo hold is to be capable of carrying $M_{\text{HL}}$ with fuel oil tanks in double bottom in way of the cargo hold, if any, being 100% full and ballast water tanks in the double bottom in way of the cargo hold being empty, at maximum draught.

17.4.6.4.2.2 Any cargo hold is to be capable of carrying minimum 50% of $M_{H}$ with all double bottom tanks in way of the cargo hold being empty, at maximum draught.

17.4.6.4.2.3 Any cargo hold is to be capable of being empty, with all double bottom tanks in way of the cargo hold being empty, at the deepest ballast draught.

17.4.6.4.3 Condition applicable for all notations, except when notation (no MP) is assigned

17.4.6.4.3.1 Any cargo hold is to be capable of carrying $M_{\text{HL}}$ with fuel oil tanks in double bottom in way of the cargo hold, if any, being 100% full and ballast water tanks in the double bottom in way of the cargo hold being empty, at 67% of maximum draught.

17.4.6.4.3.2 Any cargo hold is to be capable of being empty with all double bottom tanks in way of the cargo hold being empty, at 83% of maximum draught.

17.4.6.4.3.3 Any two adjacent cargo holds are to be capable of carrying $M_{\text{HL}}$ with fuel oil tanks in double bottom in way of the cargo hold, if any, being 100% full and ballast water tanks in the double bottom in way of the cargo hold being empty, at 67% of the maximum draught. This requirement to the mass of cargo and fuel oil in double bottom tanks in way of the cargo hold applies also to the condition where the adjacent hold is filled with ballast, if applicable.

17.4.6.4.3.4 Any two adjacent cargo holds are to be capable of being empty, with all double bottom tanks in way of the cargo hold being empty, at 75% of maximum draught.

17.4.6.4.4 Additional conditions applicable for BC-A notation only

17.4.6.4.4.1 Cargo holds, which are intended to be empty at maximum draught, are to be capable of being empty with all double bottom tanks in way of the cargo hold also being empty.

17.4.6.4.4.2 Cargo holds, which are intended to be loaded with high density cargo, are to be capable of carrying $M_{H}$ plus 10% of $M_{H}$, with fuel oil tanks in the double bottom in way of the cargo hold, if any, being 100% full and ballast water tanks in the double bottom being empty in way of the cargo hold, at maximum draught.

In operation the maximum allowable cargo mass shall be limited to $M_{\text{HL}}$.

17.4.6.4.4.3 Any two adjacent cargo holds which according to a design loading condition may be loaded with the next holds being empty, are to be capable of carrying 10% of $M_{H}$ in each hold in addition to the maximum cargo load according to that design loading condition, with fuel oil tanks in the double bottom in way of the cargo hold, if any, being 100% full and ballast water tanks in the double bottom in way of the cargo hold being empty, at maximum draught.

In operation the maximum allowable mass shall be limited to the maximum cargo load according to the design loading conditions.

17.4.6.4.5 Additional conditions applicable for ballast hold(s) only

17.4.6.4.5.1 Cargo holds, which are designed as ballast water holds, are to be capable of being 100% full of ballast water including hatchways, with all double bottom tanks in way of the cargo hold being 100% full, at any heavy ballast draught. For ballast holds adjacent to topside wing, hopper and double bottom tanks, it shall be strengthwise acceptable that the ballast holds are filled when the topside wing, hopper and double bottom tanks are empty.

17.4.6.4.6 Additional conditions applicable during loading and unloading in harbour only

17.4.6.4.6.1 Any single cargo hold is to be capable of holding the maximum allowable sea-going mass at 67% of maximum draught, in harbour condition.

17.4.6.4.6.2 Any two adjacent cargo holds are to be capable of carrying $M_{\text{HL}}$ with fuel oil tanks in the double bottom in way of the cargo hold, if any, being 100% full and ballast water anks in he double bottom in way of the cargo hold being empty, at 67% of maximum draught, in harbour condition.

17.4.6.4.6.3 A reduced draught during loading and unloading in harbour, the maximum allowable mass in a cargo hold may be increased by 15% of the maximum mass allowed at the maximum draught in sea-going condition, but shall not exceed the mass allowed at maximum draught in the sea-going condition. The minimum required mass may be reduced by the same amount.

17.4.6.4.7 Hold mass curves

Based on the design loading criteria for local strength, as given in Section 17.4.6.4.2 to Section 17.4.6.4.6 (except Section 17.4.6.4.1) above, hold mass curves are to be included in the loading manual and the loading instrument, showing maximum allowable and minimum required mass as a function of draught, in sea-going condition as well as during loading and unloading in harbour.
At other draughts than those specified in the design loading conditions above, the maximum allowable and minimum required mass is to be adjusted for the change in buoyancy acting on the bottom. Change in buoyancy is to be calculated using water plane area at each draught.

Hold mass curves for each single hold, as well as for any two adjacent holds, are to be included.
18 OIL TANKERS

18.1 GENERAL

18.1.1 Scope, definitions

18.1.1.1 The following regulations apply to oil tankers which are intended to carry oil in bulk having a flashpoint not exceeding 60°C and whose Reid vapour pressure is below that of atmospheric pressure and other liquid products having a similar fire hazard. Unless specially mentioned in this Section the regulations of Sections 1-16 apply.

18.1.1.2 For definitions concerning the application of requirements as considered in items 18.1.2, 18.1.3, 18.1.4, 18.1.5 and 18.1.6, see Annex I of MARPOL 73/78.

18.1.1.3 For the purpose of this Section "oil" means petroleum in any form including crude oil, refined products, sludge or oil refuse.

18.1.1.4 For the purpose of this Section "crude oil" means any liquid hydrocarbon mixture occurring naturally in the earth whether or not treated to render it suitable for transportation and includes:
   a) crude oil from which certain distillate fractions may have been removed;
   b) crude oil to which certain distillate fractions may have been added.

18.1.1.5 Products which are permitted to be carried in tankers, are stated in the Rules, Part 17 – Fire protection, Annex 1.

18.1.1.6 For hull structures of double hull oil tankers of 150 m in length or greater, contracted for construction on or after 1st April 2006, IACS Common Structural Rules for Double Hull Oil Tankers shall apply.

18.1.2 Segregated ballast tanks

18.1.2.1 Every new crude oil tanker (see 18.1.1.2) of 20,000 tons deadweight and above and every new product carrier (see 18.1.1.2) of 30,000 tons deadweight and above shall be provided with segregated ballast tanks.

18.1.2.2 The capacity of the segregated ballast tanks shall be so determined that the ship may operate safely on ballast voyages without recourse to the use of cargo tanks for water ballast except as provided for in paragraph 18.1.2.3 or 18.1.2.4. In all cases, however, the capacity of segregated ballast tanks shall be at least such that, in any ballast condition at any part of the voyage, including the conditions consisting of lightweight plus segregated ballast only, the ship’s draughts and trim can meet each of the following requirements:
   .1 the moulded draught amidships \((d_{m})\) in metres (without taking into account any ship’s deformation) shall not be less than:
     \[ d_{m} = 2.0 + 0.02 L \] 
     \((L\text{- length, see 1.2.3.1})\)
   .2 the draughts at the forward and after perpendiculars shall correspond to those determined by the draught amidships \((d_{m})\) as specified in formula 18.1.2.2.1, in association with the trim by the stern of not greater than 0.015\(L\); and
   .3 in any case the draught at the after perpendicular shall not be less than that which is necessary to obtain full immersion of the propeller(s).

18.1.2.3 In no case shall ballast water be carried in cargo tanks, except:
   .1 on those rare voyage when weather conditions are so severe that, in the opinion of the master, it is necessary to carry additional ballast water in cargo tanks for the safety of the ship; and
   .2 in exceptional cases where the particular character of the operation of an oil tanker renders it necessary to carry ballast water in excess of the quantity required under paragraph 18.1.2.2, provided that such operation of the oil tanker falls under the category of exceptional cases as established by the Organization.
   Such additional ballast water shall be processed and discharged in compliance with Regulation 34 of Annex I of MARPOL 73/78 and an entry shall be made in the Oil Record Book, Part II.

18.1.2.4 In the case of new crude oil tankers, the additional ballast permitted in 18.1.2.3 shall be carried in cargo tanks only if such tanks have been crude oil washed in accordance with Regulation 35 of Annex I of MARPOL 73/78 before departure from an oil unloading port or terminal.

18.1.2.5 Three formulations are set forth as guidance concerning minimum draught requirements for segregated ballast tanks below 150 metres in length.
   .1 Formulation A
     .1 mean draught (m) = 0.200 + 0.032 \(L\)
     .2 maximum trim = (0.024 - 0.6x10^{-5} \(L\)) \(L\)
   The ballast conditions represent sailing condition in weather up to and including Beaufort 5.
   .2 Formulation B
     .1 minimum draught at bow (m) = 0.700 + 0.0170 \(L\)
     .2 minimum draught at stern (m) = 2.300 + 0.030L
     or
     .3 minimum mean draught (m) = 1.550 + 0.022L
     .4 maximum trim = 1.600 + 0.013L
   These formulae are based on a Sea 6 (International Sea Scale).
   .3 Formulation C
     .1 minimum draught aft (m) = 2.000 + 0.0275L
     .2 minimum draught forward (m) = 0.5000 + 0.0225L
   These expressions provide for certain increased draughts to aid in the prevention of propeller emergence and slamming in higher length ships.

18.1.2.6 Any oil tanker which is not required to be provided with segregated ballast tanks in accordance with paragraphs 18.1.2.1 may, however be qualified as a segregated bal-
last tanker, provided that it complies with the requirements of paragraphs 18.1.2.2 and 18.1.2.3 or 18.1.2.5 as appropriate.

18.1.2.7 Oil tankers of 70,000 tonnes deadweight and above delivered after 31 December 1979, as defined in Regulation 1.28.2 of Annex I of MARPOL 73/78, shall be provided with segregated ballast tanks and shall comply with paragraphs 18.1.2.2, 18.1.2.3 and 18.1.2.4 or paragraph 18.1.2.5 as appropriate.

18.1.2.8 For separation of oil fuel tanks from other tanks, see Section 11.1.4.

18.1.3 Protective location of segregated ballast spaces

18.1.3.1 In every new crude oil tanker of 20,000 tons deadweight and above and every new product carrier of 30,000 tons deadweight and above, the segregated ballast tanks required to provide the capacity to comply with the requirements of 18.1.2.2 which are located within the cargo tank length, shall be arranged in accordance with the requirements of 18.1.3.2 to 18.1.3.8 to provide a measure of protection against oil outflow in the event of grounding or collision.

18.1.3.2 Segregated ballast tanks and spaces other than oil tanks within the cargo tank length \( L_c \) shall be so arranged as to comply with the following requirement:

\[
\sum PA_s + \sum PA_o \geq J \cdot L_c \cdot (B + 2D)
\]

where:

- \( PA_s \) = the side shell area in square metres for each segregated ballast tank or space other than an oil tank based on projected moulded dimensions,
- \( PA_o \) = the bottom shell area in square metres for each such tank or space based on projected moulded dimensions,
- \( L_c \) = length in metres between the forward and after extremities of the cargo tanks,
- \( B \) = maximum breadth of the ship in metres as defined in 1.2.3.2,
- \( D \) = moulded depth in metres measured vertically from the top of the keel to the top of the freeboard deck beam at side amidships. In ships having rounded gunwales, the moulded depth shall be measured to the point of intersection of the moulded lines of the deck and side shell plating, the lines extending as though the gunwale were of angular design,
- \( J \) = 0.45 for oil tankers of 20,000 tons deadweight, 0.30 for oil tankers of 200,000 tons deadweight and above, subject to the provisions of 18.1.3.3.

For intermediate values of deadweight the value of \( J \) shall be determined by linear interpolation.

18.1.3.3 For tankers of 200,000 tons deadweight and above the value of \( J \) may be reduced as follows:

\[
J_{reduced} = 0.3 - \left( \alpha - \frac{O_e + O_s}{4O_s} \right)
\] or 0.2 whichever is greater.

where:

\[
\alpha = 0.25 \text{ for oil tankers of 200,000 tons deadweight},
\]

\[
\alpha = 0.40 \text{ for oil tankers of 300,000 tons deadweight},
\]

\[
\alpha = 0.50 \text{ for oil tankers of 420,000 tons deadweight and above}.
\]

For intermediate values of deadweight the value of "\( \alpha \)" shall be determined by linear interpolation.

\[
O_e[m^3] = \text{the hypothetical outflow of oil in the case of side damage (see Regulation 25 of Annex I of MARPOL 73/78)}
\]

\[
O_s[m^3] = \text{the hypothetical outflow of oil in the case of bottom damage (see Regulation 25 of Annex I of MARPOL 73/78)}
\]

\[
O_o[m^3] = \text{the allowable oil outflow (see Regulation 26 of Annex I of MARPOL 73/78).}
\]

18.1.3.4 In the determination of \( PA_s \) and \( PA_o \) for segregated ballast tanks and spaces other than oil tanks the following shall apply:

1. the minimum \( w \) (m) width of each wing tank or space either of which extends for the full depth of the ship's side or from the deck to the top of the double bottom shall be not less than 2 metres. The width shall be measured inboard from the ship's side at right angles to the centreline. Where a lesser width is provided the wing tank or space shall not be taken into account when calculating the protecting area \( PA_s \), e.i. \( PA_s = 0 \).

2. the minimum vertical depth \( h \) (m) of each double bottom tank or space shall be \( B/15 \) or 2 metres, whichever is the lesser. Where a lesser depth is provided the bottom tank or space shall not be taken into account when calculating the protecting area \( PA_o \), e.i. \( PA_o = 0 \).

3. the minimum with \( w \) and depth \( h \) of wing tanks and double bottom tanks shall be measured clear of the bilge area and, in the case of minimum width, shall be measured clear of any rounded gunwale area.

18.1.3.5 The measurement of the 2 metres minimum width of wing tanks and the measurement of the minimum vertical depth of double bottom tanks of 2 metres or \( B/15 \) in respect of tanks at the ends of the ship where no identifiable bilge area exists should be interpreted as given hereunder. No difficulty exists in the measurement of the tanks in the parallel middle body of the ship where the bilge area is clearly identified. The regulation does not explain how the measurements should be taken.

18.1.3.6 The minimum width of wing tanks should be measured at a height of \( D/5 \) above the base line providing a reasonable level above which the 2 metres width of collision protection should apply, under the assumption that in all cases \( D/5 \) is above the upper turn of bilge amidships (see Figure 18.1.3.1). The minimum height of double bottom tanks should be measured at a vertical plane measured \( D/5 \) inboard from the intersection of the shell with a horizontal line \( D/5 \) above the base line (see figure 18.1.3.2).
18.1.3.7 The $PA_c$ value for a wing tank which does not have a minimum width of 2 metres throughout its length would be zero; no credit should be given for that part of the tank in which the minimum width is in excess of 2 metres. No credit should be given in the assessment of $PA_c$ to any double bottom tank, part of which does not meet the minimum depth requirements anywhere within its length. If, however, the projected dimensions of the bottom of the cargo tank above the double bottom fall entirely within the area of the double bottom tank or space which meets the minimum height requirement and provided the side bulkheads bounding the cargo tank above are vertical or have a slope of not more than 45° from the vertical, credit may be given to the part of the double bottom tank defined by the projection of the cargo tank bottom. For similar cases where the wing tanks above the double bottom are segregated ballast tanks or void spaces, such credit may also be given. This would not, however, preclude in the above cases credit being given to a $PA_s$ value in the first case and to a $PA_c$ value in the second case where the respective vertical or horizontal protection complies with the minimum distances prescribed in 18.1.3.4.

18.1.3.8 Projected dimensions should be used as shown in examples of figures 18.1.3.3 to 18.1.3.8. Figures 18.1.3.7 and 18.1.3.8 represent measurement of the height for the calculation of $PA_c$ for double bottom tanks with sloping tank top. Figures 18.1.3.9 and 18.1.3.10 represent the cases where credit is given in calculation of $PA_s$ to part or the whole of a double bottom tank.

![Figure 18.1.3.1](image1.png)

**Figure 18.1.3.1**

Measurement of minimum width of wing ballast tank at ends of ship without of double bottom tank, $w$ must be at least 2 metres along the entire length of the tank for the tank to be used in the calculation of $PA_c$.

![Figure 18.1.3.2](image2.png)

**Figure 18.1.3.2**

Measurement of minimum height of double bottom tank at ends of ship, $h$ must be at least 2 metres or $B/15$, whichever is less, along the entire length of the tank for the tank to be used in the calculation of $PA_s$.

![Figure 18.1.3.3](image3.png)

**Figure 18.1.3.3**

Calculation of $PA_c$ and $PA_s$ for double bottom tank amidships

- If $h_{db}$ is at least 2 metres of $B/15$, whichever is less, along entire tank length,
  
  $PA_c = h_{db} \times $ double bottom tank length $\times 2 \ (m^2)$
  
  $PA_s = B \times $ double bottom tank length $\ (m^3)$

- If $h_{db}$ is less than 2 metres of $B/15$, whichever is less,
  
  $PA_c = h_{db} \times $ double bottom tank length $\times 2 \ (m^2)$
  
  $PA_s = 0$
**Figure 18.1.3.4**

Calculation of $PA_c$ and $PA_s$ for double bottom tank at ends of ship.

If $h_{db}$ is at least 2 metres or $\frac{B}{15}$, whichever is less, along entire tank length,

$$PA_c = h \times \text{double bottom tank length} \times 2 \ (\text{m}^2)$$

$$PA_s = B \times \text{double bottom tank length} \ (\text{m}^2)$$

If $h_{db}$ is less than 2 metres or $\frac{B}{15}$, whichever is less,

$$PA_c = h \times \text{double bottom tank length} \times 2 \ (\text{m}^2)$$

$$PA_s = 0$$

**Figure 18.1.3.5**

Calculation of $PA_c$ and $PA_s$ for wing tank amidships.

If $w$ is 2 metres or more,

$$PA_c = D \times \text{tank length} \times 2 \ * \ (\text{m}^2)$$

$$PA_s = b \times \text{tank length} \times 2 \ * \ (\text{m}^2)$$

If $w$ is less than 2 metres,

$$PA_c = 0$$

$$PA_s = b \times \text{tank length} \times 2 \ * \ (\text{m}^2)$$

*(to include port and starboard)*

**Figure 18.1.3.6**

Calculation of $PA_c$ and $PA_s$ for wing tank end of ship.

If $w$ is 2 metres or more,

$$PA_c = D \times \text{tank length} \times 2 \ * \ (\text{m}^2)$$

$$PA_s = b \times \text{tank length} \times 2 \ * \ (\text{m}^2)$$

If $w$ is less than 2 metres,

$$PA_c = 0$$

$$PA_s = b \times \text{tank length} \times 2 \ * \ (\text{m}^2)$$

*(to include port and starboard)*

**Figure 18.1.3.7**

Measurement of $h$ for calculation of $PA_c$ for double bottom tanks with sloping tank tops (1)

$$PA_c = h \times \text{double bottom tank length} \times 2 \ *$$

*(to include port and starboard)*
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PART 2

Section view

Figure 18.1.3.8
Measurement of h for calculation of \( PA_c \) for double bottom tanks with sloping tank tops (2).

\[ PA_c = h \times \text{double bottom tank length} \times 2^* \ (\text{m}^2) \]

* (to include port and starboard)

Section view

Figure 18.1.3.9
Calculation of \( PA_s \) for double bottom tank without clearly defined turn of bilge area - when wing tank is cargo tank.

If \( h \) is less than 2 metres or \( \frac{B}{15} \), whichever is less, anywhere along the tank length, but \( h_{db} \) is at least 2 metres or \( \frac{B}{15} \), whichever is less, along the entire tank length within the width of 2\( b \), then:

\[ PA_s = 2b \times \text{cargo tank length} \ (\text{m}^2) \]

Section view

Figure 18.1.3.10
Calculation of \( PA_s \) for double bottom tank without clearly defined turn of bilge area - when wing tank is segregated ballast tank or void space.

If \( h \) is less than 2 metres or \( \frac{B}{15} \), whichever is less, anywhere along the tank length, but \( h_{db} \) is at least 2 metres or \( \frac{B}{15} \), whichever is less, along the entire tank length within the width of 2\( b \), then:

\[ PA_s = B \times \text{cargo tank length} \ (\text{m}^2) \]

18.1.3.9 Pump room bottom protection

18.1.3.9.1 This regulation applies to oil tankers of 5,000 tonnes deadweight and above constructed on or after 1 January 2007.

18.1.3.9.2 The pump-room shall be provided with a double bottom such that 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 pump-room and the ship’s base line measured at right angles to the ship’s base line is not less than specified below:

\[ h = \frac{B}{15} \ (\text{m}) \]

or

\[ h = 2 \ (\text{m}) \], whichever is the lesser.

The minimum value of \( h = 1 \ (\text{m}) \).

18.1.3.9.3 In case of pump rooms whose bottom plate is located above the base line by at least the minimum height required in 18.1.3.2 above (e.g. gondola stern designs), there will be no need for a double bottom construction in way of the pump-room, see Figure 18.1.3.9.3.

Figure 18.1.3.9.3

18.1.3.9.4 Ballast pumps shall be provided with suitable arrangements to ensure efficient suction from double bottom tanks.

18.1.3.9.5 Notwithstanding the provisions of paragraphs 18.1.3.9.2 and 18.1.3.9.3 above, where the flooding of the pump-room would not render the ballast or cargo pumping system inoperative, a double bottom need not be fitted.

18.1.3.9.6 The term “pump-room” means a cargo pump room. Ballast piping is permitted to be located within the pump-room double bottom provided any damage to that piping does not render the ship’s pumps located in the “pump room” ineffective.

18.1.3.9.7 The double bottom protecting the “pump-room” can be a void tank, a ballast tank or, unless prohibited by other regulations, a fuel oil tank.

18.1.3.9.8 Bilge wells may be accepted within the double bottom provided that such wells are as small as practicable and the distance between the well bottom and the ship’s base line measured at right angles to the ship’s base line is not less than 0.5\( h \).

18.1.3.9.9 Where a portion of the pump-room is located below the minimum height required in 18.1.3.9.2, then only that portion of the pump room is required to be a double bottom.
18.1.4.1 Double hull and double bottom requirements for oil tankers

18.1.4.1.1 This regulation shall apply to oil tankers of 600 tons deadweight and above delivered on or after 6 July 1996 as follows:

1. for which the building contract is placed on or after 6 July 1993, or
2. in the absence of a building contract, the keels of which are laid or which are at a similar stage of construction on or after 6 January 1994, or
3. the delivery of which is on or after 6 July 1996, or
4. which have undergone a major conversion:
   1. for which the contract is placed after 6 July 1993; or
   2. in the absence of a contract, the construction work of which is begun after 6 January 1994; or
   3. which is completed after 6 July 1996.

18.1.4.2 Every oil tanker of 5,000 tons deadweight and above shall:

1. in lieu of 18.1.3.1 to 18.1.3.4, as applicable, comply with the requirements of 18.1.4.3 unless it is subject to the provisions of 18.1.4.4 and 18.1.4.5; and
2. comply, if applicable, with the requirements of 18.1.4.6.

18.1.4.3 The entire cargo tank length shall be protected by ballast tanks or spaces other than cargo and fuel oil tanks as follows:

1. Wing tanks or spaces
   Wing tanks or spaces shall extend either for the full depth of the ship's side or from the top of the double bottom to the uppermost deck, disregarding a rounded gunwale where fitted. They shall be arranged such that the cargo tanks are located inboard of the moulded line of the side shall plating, nowhere less than the distance \( w \) which, as shown in figure 18.1.4.3, is measured at any cross-section at right angles to the side shell, as specified below:

\[
\begin{align*}
\text{\( w \)} & = 0.5 + \frac{D}{20,000} \text{[m]} \quad \text{or} \\
\text{\( w \)} & = 2.0 \text{ m}, \text{ whichever is the lesser.}
\end{align*}
\]

The minimum value of \( w = 1.0 \text{ m}. \)

2. Double bottom tanks or spaces
   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 18.1.4.3 is not less than specified below:

\[
\begin{align*}
\text{\( h \)} & = \frac{B}{15} \text{ [m]} \quad \text{or} \\
\text{\( h \)} & = 2.0 \text{ m}, \text{ whichever is the lesser.}
\end{align*}
\]

The minimum value of \( h = 1.0 \text{ m} \).

3. Turn of the bilge area or at locations without a clearly defined turn of the bilge.

When the distances \( h \) and \( w \) are different, the distance \( w \) shall have preference at levels exceeding 1.5 \( h \) above the baseline as shown in figure 18.1.4.3.

4. The aggregate capacity of ballast tanks
   On crude oil tankers of 20,000 tons deadweight and above and product carriers of 30,000 tons deadweight and above, the aggregate capacity of wing tanks, double bottom tanks, forepeak tanks and afterpeak tanks shall not be less than the capacity of segregated ballast tanks necessary to meet the requirements of 18.1.2. Wing tanks or spaces and double bottom tanks used to meet the requirements of 18.1.2 shall be located as uniformly as practicable along the cargo tank length. Additional segregated ballast capacity provided for reducing longitudinal hull girder bending stress, trim, etc., may be located anywhere within the ship.

5. Suction wells in cargo tanks
   Suction wells in cargo tanks may protrude into the double bottom below the boundary line defined by the distance \( h \) provided that such wells are as small, as practicable and the distance between the well bottom and bottom shell plating is not less than 0.5 \( h \).

6. Ballast and cargo piping
   Ballast piping and other piping such as sounding and vent piping to ballast tanks shall not pass through cargo tanks. Cargo piping and similar piping to cargo tanks shall not pass through ballast tanks. Exemptions to this requirement may be granted for short lengths of piping, provided that they are completely welded or equivalent.

18.1.4.4

1. Double bottom tanks or spaces as required by 18.1.4.3.2 may be dispensed with, provided that the design of the oil tanker is such that the cargo and vapour pressure exerted on the bottom shell plating forming a single boundary between the cargo and the sea does not exceed the external hydrostatic water pressure, as expressed by the following formula:

\[
f \cdot h_c \cdot \rho_c \cdot g + 100 \Delta_p \leq d_w \cdot \rho_s \cdot g
\]

where:

\[
\begin{align*}
\text{\( h_c \)} & = \text{height of cargo in contact with the bottom shell plating in metres;} \\
\text{\( \rho_c \)} & = \text{maximum cargo density in [\text{t/m}^3];} \\
\text{\( d_w \)} & = \text{minimum operating draught under any expected loading condition in metres;} \\
\text{\( \rho_s \)} & = \text{density of sea water in [\text{t/m}^3];} \\
\text{\( \Delta_p \)} & = \text{maximum set pressure of pressure/vacuum valve provided for the cargo tank in bars;} \\
\text{\( f \)} & = \text{safety factor = 1.1;} \\
\text{\( g \)} & = \text{standard acceleration of gravity [9.81 m/s}^2].
\end{align*}
\]

2. Any horizontal partition necessary to fulfil the above requirements shall be located at
a height of not less than \( \frac{B}{6} \) of 6 metres, whichever is the lesser, but not more than 0.6\( D \), above the baseline where \( D \) is the moulded depth amidships.

3 The location of wing tanks or spaces shall be as defined in 18.1.4.3.1 except that, below a level 1.5 h above the baseline where h is as defined in 18.1.4.3.2, the cargo tank boundary line may be vertical down to the bottom plating, as shown in figure 18.1.4.4.

18.1.4.5 Other methods of design and construction of oil tankers may also be accepted as alternatives to the requirements prescribed in 18.1.4.3, provided that such methods ensure at least the same level of protection against oil pollution in the event of collision or stranding and are approved in principle by the Marine Environment Protection Committee based on guidelines developed by the Organization.

18.1.4.6 For oil tankers of 20,000 tons deadweight and above the damage assumptions prescribed in Rules, Part 5 - Subdivision shall be supplemented by the following assumed bottom raking damage:

1 longitudinal extent:

1 ships of 75,000 tons deadweight and above:

0.6 L measured from the forward perpendicular

2 ships of less than 75,000 tons deadweight:

0.4 L measured from the forward perpendicular

2 transverse extent: \( \frac{B}{3} \) anywhere in the bottom

3 vertical extent: breach of the outer hull.

18.1.4.7 Oil tankers of less than 5,000 tons deadweight shall:

1 at least be fitted with double bottom tanks or spaces having such a depth that the distance h specified in 18.1.4.3.2 complies with the following:

\[ h = \frac{B}{15} \text{ (m)} \]

with a minimum value of \( h = 0.76 \text{ m} \);

in the turn of the bilge area and at locations without a clearly defined turn of the bilge, the cargo tank boundary line shall run parallel to the line of the mid-ship flat bottom as shown in figure 18.1.4.7; and

2 be provided with cargo tanks so arranged that the capacity of each cargo tank does not exceed 700 m\(^3\) unless wing tanks or spaces are arranged in accordance with 18.1.4.3.1 complying with the following:

\[ w = 0.4 + \frac{2.4DW}{20,000} \text{ [m]} \]

with a minimum value of \( w = 0.76 \text{ m} \).

18.1.4.8 Oil shall not be carried in any space extending forward of a collision bulkhead located in accordance with regulation II-1/11 of the International Convention for the Safety of Life at Sea, 1974, as amended. An oil tanker that is not required to have a collision bulkhead in accordance with that regulation shall not carry oil in any space extending forward of the transverse plane perpendicular to the centreline that is located as if it were a collision bulkhead located in accordance with that regulation.

18.1.4.9 In approving the design and construction of oil tankers to be built in accordance with the provisions of this regulation, Register shall have due regard to the general safety aspects including the need for the maintenance and inspections of wing and double bottom tanks or spaces.
PART 2

18.1.5 Limitation of size and arrangement of cargo tanks

18.1.5.1 Cargo tanks of oil tankers shall be of such size and arrangement that the hypothetical outflow, referred to in Regulation 25 of Annex I of MARPOL 73/78, anywhere in the length of the ship does not exceed 30,000 cubic metres or 400·√DWT, whichever is the greater, but subject to a minimum of 40,000 cubic metres.

18.1.5.2

.1 The volume of any one wing cargo oil tank of an oil tanker shall not exceed 75 per cent of the limits of the hypothetical oil outflow referred to in 18.1.5.1.

.2 The volume of any one centre cargo oil tank shall not exceed 50,000 cubic metres.

.3 However, in segregated ballast oil tankers as defined in 18.1.2, the permitted volume of a wing cargo oil tank situated between two segregated ballast tanks, each exceeding \( l \cdot \) in length, may be increased to the maximum limit of hypothetical oil outflow provided that the width of the wing tanks exceeds \( t \).

The length of each cargo tank shall not exceed 10 m or one of the values specified in Table 18.1.5.3:

<table>
<thead>
<tr>
<th>Number of longitudinal bulkheads inside the cargo tanks</th>
<th>Permissible length of cargo tanks</th>
</tr>
</thead>
<tbody>
<tr>
<td>–</td>
<td>( \frac{0.5 b}{B} + 0.1 ) \cdot L, max. 0.2L</td>
</tr>
<tr>
<td>1</td>
<td>( \frac{0.25 b}{B} + 0.15 ) \cdot L, max. 0.2L</td>
</tr>
<tr>
<td>Wing cargo tanks: 0.2L</td>
<td></td>
</tr>
<tr>
<td>Centre tanks:</td>
<td></td>
</tr>
<tr>
<td>1) ( \frac{b}{B} \geq 0.2; 0.2L</td>
<td></td>
</tr>
<tr>
<td>2) ( \frac{b}{B} &lt; 0.2; 0.2L</td>
<td></td>
</tr>
</tbody>
</table>
| - where no centreline longitudinal bulkhead is provided| \( \left( \frac{0.5 b}{B} + 0.1 \right) \cdot L 

\left( \frac{0.25 b}{B} + 0.15 \right) \cdot L 

Note: \( b_i \) = minimum distance from the ship's side to the outer longitudinal bulkhead of the tank in question measured inboard at right angles to the centreline at the level corresponding to the assigned summer freeboard.

18.1.5.4 In order not to exceed the volume limits established by 18.1.5.1, 18.1.5.2 and 18.1.5.3 and irrespective of the accepted type of cargo transfer system installed, when such system interconnects two or more cargo tanks, valves or other similar closing devices shall be provided for separating the tanks from each other. These valves or devices shall be closed when the tanker is at sea.

18.1.5.5 Lines of piping which run through cargo tanks in a position less than \( t \) from the ship's side or less than \( t_c \) from the ship's bottom shall be fitted with valves or similar closing devices at the point at which they open into any cargo tank. These valves shall be kept closed at sea at any time when the tanks contain cargo oil, except that they may be opened only for cargo transfer needed for the purpose of trimming of the ship.

18.1.5.6 This regulation does not apply to oil tankers delivered on or after 1 January 2010.
18.1.6 Oil fuel tank protection

18.1.6.1 This regulation shall apply to all ships with an aggregate oil fuel capacity of 600 m³ and above which are delivered on or after 1 August 2010. Ship delivered on or after 1 August 2010 means a ship:

1. for which the building contract is placed on or after 1 August 2007; or
2. in the absence of a building contract, the keels of which are laid or which are at a similar stage of construction on or after 1 February 2008; or
3. the delivery of which is on or after 1 August 2010; or
4. which have undergone a major conversion:
   1. for which the contract is placed after 1 August 2007; or
   2. in the absence of contract, the construction work of which is begun after 1 February 2008; or
   3. which is completed after 1 August 2010.

18.1.6.2 For ships, other than self-elevating drilling units, having an aggregate oil fuel capacity of 600 m³ and above, oil fuel tanks shall be located above the moulded line of the bottom shell plating nowhere less than the distance $h$ as specified below:

$$h = \frac{B}{20} \text{ m or,}$$

$$h = 2.0 \text{ m, whichever is the lesser.}$$

The minimum value of $h = 0.76$ m

In the turn of the bilge area and at locations without a clearly defined turn of the bilge, the oil fuel tank boundary line shall run parallel to the line of the midship flat bottom as shown in Figure 18.1.4.7.

18.1.6.3 For ships having an aggregate oil fuel capacity of 600 m³ or more but less than 5,000 m³, oil fuel tanks shall be located inboard of the moulded line of the side shell plating, nowhere less than the distance $w$ which, as shown in Figure 18.1.4.3, is measured at any cross-section at right angles to the side shell, as specified below:

$$w = 0.4 + 2.4 \frac{C}{20,000} \text{ [m]}$$

The minimum value of $w = 1.0$ m, however for individual tanks with an oil fuel capacity of less than 500 m³ the minimum value is 0.76 m.

18.1.6.4 For ships having an aggregate oil fuel capacity of 5,000 m³ and over, oil fuel tanks shall be located inboard of the moulded line of the side shell plating, nowhere less than the distance $w$ which, as shown in Figure 18.1.4.3, is measured at any cross-section at right angles to the side shell, as specified below:

$$w = 0.5 + 2.4 \frac{C}{20,000} \text{ [m]}$$

$$w = 2.0 \text{ m, whichever is the lesser.}$$

The minimum value of $w = 1.0$ m

18.1.6.5 For the purpose of maintenance and inspection, any oil fuel tanks that do not border the outer shell plating shall be located no closer to the bottom shell plating than the minimum value of $h$ in 18.1.6.2 and no closer to the side shell plating than the applicable minimum value of $w$ in 18.1.6.3 and 18.1.6.4.

18.1.6.6 The distance "$h$" should be measured from the moulded line of the bottom shell plating at right angle to it, see Figure 18.1.4.7.

18.1.6.6.1 For vessels designed with a skeg, the skeg should not be considered as offering protection for the fuel oil tanks. For the area within skeg’s width the distance “$h$” should be measured perpendicular to a line parallel to the baseline at the intersection of the skeg and the moulded line of the bottom shell plating as indicated in Figure 18.1.6.6.1.

18.1.6.6.2 For vessels designed with a permanent trim, the distance “$h$” should be measured perpendicular to the moulded line of the bottom shell plating at the relevant frames where fuel tanks are to be protected.

18.1.6.7 For vessels designed with deadrising bottom, the distance “1.5$h$” should be measured from the moulded line of the bottom shell plating but at right angle to the baseline, as indicated in Figure 18.1.6.7.

18.1.6.8 Alternatively to paragraphs 18.1.6.2 and either 18.1.6.3 or 18.1.6.4, ships shall comply with the accidental oil fuel outflow performance standard specified in paragraph 11 of Regulation 12A of the revised Annex I to MARPOL 73/78 as adopted by resolution MEPC.141 (54).

18.1.7 Tank deck openings

18.1.7.1 Any tank openings, e.g. tank cleaning openings, ullage plugs, etc. are not to be arranged in enclosed spaces.

18.1.7.2 The number, dimensions and position of holes in the deck are to be submitted to the Register for approval.

18.1.8 Minimum thickness

18.1.8.1 In cargo and ballast tanks within the cargo area the thickness of primary structural members is not to be less than the following minimum value:

$$t_{\text{min}} = 6.5 + 0.02 \cdot L \text{ [mm]}$$

where:
18.1.9 Testing of cargo and ballast tanks

18.1.9.1 For testing of cargo and segregated ballast tanks as well as cofferdams including cofferdam/engine room bulkhead see Section 11.6.

18.1.9.2 Where one tank boundary is formed by the ship's shell the leak test is to be carried out before launching. For all other tanks leak testing may be carried out afloat. Erection welds as well as welds on assembly openings are to be coated before leak testing is carried out. This applies also to manual weld connections of bulkheads with tank boundaries and of collaring arrangements at intersections of tank boundaries, and e.g. frames, beams, girders etc. When it is ensured that similar liquids will be carried in adjacent tanks, the latter weld connections may be coated before leak testing is carried out.

All other welds on tank boundaries may be coated before leak testing is carried out provided that it is ensured by suitable measures (e.g. by visual examination of the welds) that all welding is completed and the surfaces of the welds do not exhibit any cracks or pores.

18.1.9.3 Where leak testing in accordance with 18.1.9.2 is not carried out and the tanks are pressure tested with water, the bulkheads are, in general, to be tested from one side. The testing should be carried out on the building berth or in drydock. Subject to agreement by the Register the pressure testing may be carried out afloat. Water testing may be carried out after application of a coating before leak testing is carried out.

Where in lieu of a cofferdam a pump room is situated between cargo tank and machinery space the engine room/pump-room bulkhead need not be watertested.

18.1.9.4 The operational tests may be carried out afloat or during the sea trials. In the course of these tests at least two cargo tanks and two segregated ballast tanks are to be pressure tested to the test head given in 18.1.9.5 to 18.1.9.7.

18.1.9.5 For cargo tanks a test head corresponding to a head of water up to the top of the overflow pipe is to be applied.

18.1.9.6 Cargo tanks fitted with pressure relief valves and/or intended for the carriage of cargoes with a density of more than \( \rho = 1,025 \text{ t/m}^3 \) are to be tested with a head of water of at least:

\[
h_p = 2,4 \cdot \rho [\text{m}] \text{ or } 10 \cdot \rho_v [\text{m}],
\]

(whichever is greater).

where:

\[
\rho = \text{density of liquid in } [\text{t/m}^3];
\]

\[
\rho_v = \text{see Section 3.4.1}.
\]

For aft peak tanks the requirements of Section 11.1.7.3 apply.

18.1.10 Location of fuel tanks in cargo area on oil and chemical tankers

On oil and chemical tankers, carrying liquid cargoes having a flashpoint not exceeding 60 °C and/or toxic liquid cargoes (toxic liquid cargoes include those for which toxic vapour detection is specified in column “k” of the table of chapter 17 of the IBC Code), fuel tanks located with a common boundary to cargo or slop tanks shall not be situated within nor extend partly into the cargo tank block. Such tanks may, however, be situated aft and/or forward of the cargo tank block. They may be accepted when located as independent tanks on open deck in the cargo area subject to spill and fire safety considerations.

The arrangement of independent fuel tanks and associated fuel piping systems, including the pumps, can be as for fuel tanks and associated fuel piping systems located in the machinery spaces. For electrical equipment, requirements to hazardous area classification must however be met.

\[ L \leq 300 \text{ m}. \]

For secondary structures (e.g. local stiffeners) \( t_{\text{min}} \) need not be taken greater than 9,0 mm.

18.2 STRENGTH OF GIRDERs AND TRANSVERSES

18.2.1 General

18.2.1.1 Girders and transverses may be predesigned according to Section 11.2.3. Subsequently a stress analysis according to 18.2.2 is to be carried out. All structural elements exposed to compressive stresses are to be subjected to a buckling analysis according to 4.6.

18.2.1.2 Brackets fitted in the corners of transverses and tripping brackets fitted on longitudinals are to have smooth transitions at their toes.

18.2.1.3 Well rounded drain holes for oil and air holes are to be provided. No such holes and no welding scallops shall be placed near the constraint points of stiffeners and girders and near the toes of brackets.

18.2.1.4 Transverses are to be effectively supported to resist loads acting vertically on their webs.

\[ \text{Figure 18.1.10} \]

Cargo tank block is the part of the ship extending from the aft bulkhead of the aftmost cargo or slop tank to the forward bulkhead of the forward most cargo or slop tank, extending to the full depth and beam of the ship, but not including the area above the deck of the cargo or slop tank.

\[ \text{Figure 18.1.10} \]

Cargo tank block is the part of the ship extending from the aft bulkhead of the aftmost cargo or slop tank to the forward bulkhead of the forward most cargo or slop tank, extending to the full depth and beam of the ship, but not including the area above the deck of the cargo or slop tank.

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18.2.2 Stress analysis

18.2.2.1 A three-dimensional stress analysis is to be carried out for girders and transverses for the load conditions resulting from tank arrangement and drafts.

\[ d = \frac{d_{\text{max}} + d_{\text{min}}}{2} \]

- load case 3: cargo tanks filled, heeled condition;
- load case 4: ballast tanks filled

where:

\[ d_{\text{max}} = \text{maximum ballast draft} \]

18.2.2.2 For double hull vessels the following basic load cases are to be considered, according to Fig. 18.2.2.2.

Considereation of additional load cases may be required by the Register if deemed necessary.

The dynamic allowances according to 3.2.3, 3.2.4, 3.3.1 and 3.4 are to be taken into account.

The internal pressure is to be determined in accordance with the formula for \( p_{1} \) as per 3.4.1.1.

\[ \varphi = \text{design angle of heel according to 3.4.1.1;} \]
\[ \varphi_{\text{max}} = \arctan (0.5 \cdot D/B). \]

The basic lead cases are as follows:

- load case 1: cargo tanks filled
\[ d = d_{\text{max}} \]
- load case 2: cargo tanks filled

18.2.2.4 Transverse bulkhead girders are to be examined for the following load conditions:

- centre and wing tanks full, adjacent tanks empty;
- centre tank full, wing tanks empty;
- centre tank empty, wing tanks full.

18.2.3 Permissible stresses

18.2.3.1 Under load assumption according to 18.2.2 the following permissible stress values in the transverses and in the bulkhead girders are:

- bending and axial stresses:
\[ \sigma = 150 / k \text{ [N/mm}^2\text{]} \]
- shear stress:
\[ \tau = 100 / k \text{ [N/mm}^2\text{]} \]
- equivalent stress:
\[ \sigma_{\text{eq}} = \sqrt{\sigma^2 + 3 \cdot \tau^2} = 180 / k \text{ [N/mm}^2\text{]} \]

where:

\[ \sigma = \text{stress in longitudinal direction of the girder, [N/mm}^2\text{]} \]

The stress values as per 11.2.3.2 are not to be exceeded when the load \( p_{2} \) as per 3.4.1.2 is applied.

18.2.3.2 In the longitudinal girders at deck and bottom, the combined stress resulting from local bending of the girder and longitudinal hull girder bending of the ship's hull under sea load is not to exceed 230/\( k \text{ [N/mm}^2\text{]} \).

18.2.3.4 Cross ties

The cross sectional area of the cross ties due to compressive loads is not to be less than:

\[ A_{k} = \frac{P}{9.5 - 4.5 \cdot 10^{-3} \cdot \lambda^{2}} \text{ [cm}^2\text{]}, \text{ for } \lambda \leq 100; \]
\[ A_{k} = \frac{P \cdot \lambda^{2}}{5 \cdot 10^{-5}} \text{ [cm}^2\text{]}, \text{ for } \lambda > 100 \]

where:

\[ \lambda = \frac{l}{i} \text{ degree of slenderness;} \]
\[ l = \text{unsupported span, in [cm];} \]
\[ i = \text{radius of gyration} = \sqrt{l / A_{k}} \text{ [cm];} \]
\[ I = \text{smallest moment of inertia, in [cm}^4\text{];} \]
\[ p = \text{load} p_{1} \text{ or } p_{2} \text{ [kN/m}^2\text{]}, \text{ according to 3.4.1 and 3.4.2;} \]
\[ P = A \cdot p \text{ [kN]} \text{ (for the first approximation);} \]
\[ A = \text{area supported by one cross tie, in } [m^2]. \]

Finally the sectional area \( A_s \) is to be checked for the load \( P \) resulting from the transverse strength calculation.

**18.3 OILTIGHT LONGITUDINAL AND TRANSVERSE BULKHEADS**

**18.3.1 Scantlings**

**18.3.1.1** The scantlings of bulkheads are to be determined according to Section 11 however, the thicknesses are not to be less than the minimum thickness as per 18.1.7.

**18.3.1.2** The top and bottom strakes of the longitudinal bulkheads are to have a width of not less than 0,1 \( D \), and their thickness is not to be less than:

- top strake of plating: \( t_{min} = 0,75 \times \text{deck thickness} \);
- bottom strake of plating: \( t_{min} = 0,75 \times \text{bottom thickness} \).

**18.3.1.3** The section modulus of horizontal stiffeners of longitudinal bulkheads is to be determined as for longitudinals according to Section 8.2., however, it is not to be less than \( W_2 \) according to Section 11.2.3.

**18.3.1.4** The stiffeners are to be continuous in way of the girders. They are to be attached to the webs of the girders in such a way that the support force can be transmitted observing \( \tau = 100/k [N/mm^2] \).

**18.3.2 Cofferdam bulkheads**

Cofferdam bulkheads forming boundaries of cargo tanks are to have the same strength as cargo tanks bulkheads. Where they form boundaries of ballast tanks or tanks for consumables the requirements of Section 11 are to be complied with. For cofferdam bulkheads not serving as tank bulkheads, e.g. pump-room bulkheads, the scantlings for watertight bulkheads are as required by Section 10.

**18.4 WASH BULKHEADS**

**18.4.1 General**

**18.4.1.1** The total area of perforation in wash bulkheads is to be approximately \( 5 \div 10 \) per cent of the bulkhead area.

**18.4.1.2** The scantlings of the top and bottom strakes of plating of a perforated bulkhead are to be as required by 18.3.1.2. Large openings are to be avoided in way of these strakes.

**18.4.2 Scantlings**

**18.4.2.1** The plate thickness of the transverse wash bulkheads is to be determined in such a way as to support the forces induced by the side shell, the longitudinal bulkheads and the longitudinal girders. The shear stress is not to exceed \( 100/k [N/mm^2] \).

Beyond that, the buckling strength of plate panels is to be examined.

The plate thickness is not to be less than the minimum thickness according to 18.1.7.

**18.4.2.2** The stiffeners and girders are to be determined as required for an oiltight bulkhead. The pressure \( p \) according to Section 3.4.2 is to be substituted for \( p \).

**18.5 ACCESS ARRANGEMENTS**

**18.5.1 Tank hatches**

**18.5.1.1** Oiltight tank hatches are to be kept to the minimum number and size necessary for access and venting.

**18.5.1.2** Openings in decks are to be elliptical and with their major axis in the longitudinal direction, wherever this is practicable. Deck longitudinals in way of hatches should be continuous within 0,4 \( L \) amidships. Where this is not practicable, compensation is to be provided for lost cross sectional area.

**18.5.1.3** Coaming plates are to have a minimum thickness of 10 mm.

**18.5.1.4** Hatch covers are to be of steel with a thickness of not less than 12,5 mm. Where their area exceeds 1,2 \( m^2 \), the covers are to be stiffened. The covers are to close oiltight.

**18.5.1.5** Requirements according to 18.5.1.3 and 18.5.1.4 may be adopted provided this is compatible with hatch dimensions or special stiffenings, in small tankers.

**18.6 STRUCTURAL DETAILS AT THE SHIP’S END**

**18.6.1 General**

**18.6.1.1** For every oil tanker subject to Regulation 18 of MARPOL 73/78 Annex I, the strengthening of bottom forward is to be based on the draught obtained by using segregated ballast tanks only, see 18.1.2 and 18.1.3.

These requirements do not apply to CSR bulk carriers.

**18.6.1.2** The following requirements are based on the assumption that the bottom forward of the forward cofferdam and abaft the aft cofferdam bulkhead is framed transversely.

**18.6.1.3** For the forepeak and afterpeak, the requirements of Section 8.1.5 apply.

**18.6.2 Fore body**

**18.6.2.1** Floor plates are to be fitted at every frame and their scantlings are to be determined according to Section 7.1.1.2.3.

**18.6.2.2** Every alternate bottom longitudinal is to be continued forward as far as practicable by an intercostal side girder of same thickness and at least half the depth of the plate floors. The width of their flange is not to be less than 75 mm.

**18.6.2.3** The sides may be framed transversely or longitudinally in accordance with Section 8.
18.6.3 Aft body

18.6.3.1 Between the aft cofferdam bulkhead and the afterpeak bulkhead the bottom structure is to comply with Section 7.

18.6.3.2 The sides may be framed transversely or longitudinally in accordance with Section 8.

18.7 SMALL TANKERS

18.7.1 General

18.7.1.1 The following requirements apply to tankers of less than 90 [m] in length. Small tankers are coastal tankers, bunkering boats and water tankers. Unless otherwise mentioned in this Section, the requirements of 18.1 to 18.6 are applicable.

18.7.1.2 Small tankers may be framed either longitudinally or transversely, or a combined system may be adopted with the ship's sides being framed transversely and the bottom and strength deck longitudinally. For the strength deck, the longitudinal framing system is recommended.

18.7.1.3 The strength deck may extend from side to side, or may consist of a main deck and a raised trunk deck.

18.6.1.4 Two oiltight longitudinal bulkheads, or else one oiltight centerline bulkhead, may be fitted, extending continuously through all cargo tanks from cofferdam to cofferdam.

18.7.2 Girders and transverses

18.7.2.1 Girders and transverses are to be determined according to 11.2.3. If deemed necessary, the Register may request a stress and buckling analysis.

18.7.3 Transverse framing

18.7.3.1 Scantlings
The section modulus of the transverse frames in the cargo tank area is not to be less than:

\[ W_1 = k \cdot 0.55 \cdot s \cdot l^2 \cdot p \, [\text{cm}^3], \]

or

\[ W_2 = k \cdot 0.44 \cdot s \cdot l^2 \cdot p_2 \, [\text{cm}^3], \]

where:
- \( k \), \( l \), \( p \) and \( p_2 \) according to 11.2.1.
- The scantlings of the frame section are to be maintained throughout the whole depth \( D \).

18.7.3.2 End attachment

18.7.3.2.1 At their ends, the transverse frames are to be provided with flanged brackets according to Section 2.4.2. The bilge bracket is to fill the entire round of the bilge and is to be connected to the adjacent bottom longitudinal.

The bracket at the upper end of the frame is to be attached to the adjacent deck longitudinal.

18.7.3.2.2 Where the unsupported span is considerable, flats or brackets are to be fitted to support the frame against tripping. The transverse frames are to be attached to the stringers by means of flats or brackets extending to the face plate of the stringer in such a way that the force of support can be transmitted.

18.7.4 Deck

18.7.4.1 The scantlings of the strength deck are to be determined according to Section 6.

The plate thickness is not to be less than:
- for longitudinal framing:
  \[ t_{\text{min}} = \frac{s \cdot 10^3}{85 - 0.15 \cdot L} \, [\text{mm}]; \]

- for transverse framing:
  \[ t_{\text{min}} = \frac{s \cdot 10^3}{65 - 0.2 \cdot L} \, [\text{mm}]. \]

The thickness of deck plating is not to be less than the minimum thickness as given under 18.1.7 or the thickness required for tank bulkhead plating.

18.7.5 Shell plating

The thickness of the shell plating is to be determined according to Section 5. The thickness of the shell plating is not to be less than the minimum thickness according to 18.1.7 or the thickness required for tank bulkhead plating.

18.7.6 Separation of oil fuel tanks from tanks for other liquids

18.7.6.1 Upon special approval on small ships the arrangement of cofferdams (according to 11.1.4) between oil fuel and lubricating oil tanks may be dispensed with provided that the common boundary is continuous, i.e. it does not abut at the adjacent tank boundaries, see Fig. 18.7.6.1.

18.7.6.2 Where the common boundary cannot be constructed continuously according to Fig. 18.7.6.1, the fillet welds on both sides of the common boundary are to be welded in two layers and the throat thickness is not to be less than 0.5 \( \cdot t \) (\( t \) = plate thickness);

- stiffeners or pipes do not penetrate the common boundary;

- the corrosion addition \( t_k \) for the common boundary is not less than 2.5 mm.

Figure 18.7.6.1
19   BARGES AND PONTOONS

19.1 GENERAL

19.1.1 Definitions

19.1.1.1 Barges are unmanned or manned vessels without self-propulsion, sailing in pushed or towed units. The ratios of the main dimensions of barges are in a range usual for seagoing ships. Their construction complies with the usual construction of seagoing ships; their cargo holds are suitable for the carriage of dry or liquid cargo.

19.1.1.2 Pontoons as defined in this Section are unmanned or manned floating units with or without self-propulsion. The ratios of the main dimensions of pontoons deviate from those usual for seagoing ships. Pontoons are designed to usually carry deck load or working equipment and have no holds for the carriage of cargo.

19.1.1.3 The requirements given in Sections 1 - 16 apply to barges and pontoons unless otherwise mentioned in this Section.

19.2 LONGITUDINAL STRENGTH

19.2.1 The scantlings of longitudinal members of barges and pontoons of 90 m and more in length are to be determined on the basis of longitudinal strength calculations. For barges of less than 100 m in length, the scantlings of longitudinal members are to be generally determined according to Section 6.1.4.

19.2.2 The midship section modulus may be 5% less than required according to Section 4.

19.2.3 Longitudinal strength calculations for the condition "Barge, fully loaded at crane" are required, where barges are intended to be lifted on board ship by means of cranes. The following permissible stresses are to be observed:

- bending stress:
  \[ \sigma_b = \frac{150}{k} \text{ [N/mm}^2\text{]} \]
- shear stress:
  \[ \tau = \frac{100}{k} \text{ [N/mm}^2\text{]} \]
  \[ k = \text{material factor according to Section 1.4.2.2.} \]

Special attention is to be paid to the transmission of lifting forces into the barge structure.

19.2.4 For pontoons carrying lifting equipment, rams etc. or concentrated heavy deck loads, calculation of the stresses in the longitudinal structures under such loads may be required. In such cases the stresses given under 19.2.3 are not to be exceed.

19.3 WATERTIGHT BULKHEADS AND TANK BULKHEADS

19.3.1 For barges and pontoons, the position of the collision bulkhead is to be determined according to 10.1.2.1.

Where in barges the form and construction of their ends is identical so that there is no determined fore or aft ship, a collision bulkhead is to be fitted at each end.

19.3.2 A watertight bulkhead is to be fitted at the aft end of the hold area. In the remaining part of the hull, watertight bulkheads are to be fitted as required for the purpose of watertight subdivision and for transverse strength.

19.3.3 The scantlings of watertight bulkheads and of tank bulkheads are to be determined according to Sections 10 and 11 respectively.

19.3.4 On barges intended to operate as linked push barges, depending on the aft ship design, a collision bulkhead may be required to be fitted in the aft ship.

19.3.5 Where tanks are intended to be emptied by compressed air, the maximum blowing-out pressure according to Section 3.4.1, is to be inserted in the formulae for determining the pressures \( p_1 \) and \( p_2 \).

19.4 ENDS

19.4.1 Where barges have typical ship-shape fore and aft ends, the scantlings of structural elements are to be determined according to Sections 7.1.1.2 and 8.1.5 respectively. The scantlings of fore and aft ends deviating from the normal ship shape are to be determined by applying the formulae analogously such as to obtain equal strength.

19.4.2 Where barges have raked ends with flat bottoms, at least one centre girder and one side girder on each side are to be fitted. The girders shall be spaced not more than 4.5 m apart. The girders shall be scarped into the midship structure. A raked fore-end with a flat bottom is to be strengthened according to Section 5.4.

19.4.3 In pontoons which are not assigned a notation for restricted service range or which are assigned the notation for restricted international service, the construction of the fore peak is to be reinforced against wash of the sea by additional longitudinal girders, stringers and web frames. In case of raked bottoms forward, the reinforcements are, if necessary, to be arranged beyond the collision bulkhead. If necessary, both ends are to be reinforced, see also 19.3.1.
20 TUGS

20.1 GENERAL

20.1.1 The requirements given in Sections 1 - 16 apply to tugs unless otherwise mentioned in this Section.

20.2 STERNFRAME, BAR KEEL

20.2.1 The cross sectional area of a solid sternframe is to be 20 per cent greater than required according to 12.3.2.1. For fabricated sternframes the thickness of the propeller post plating is to be increased by 20 per cent above the requirements of 12.3.2.2. The section modulus W of the sole piece in the athwartship direction is to be increased by 20 per cent above the modulus determined according to 12.3.4.

20.2.2 Where a bar keel is provided, its scantlings are to be determined by the following formulae:

\[
\begin{align*}
\text{height:} & \quad h = 1,1 L + 110 \text{ [mm]} \\
\text{thickness:} & \quad t = 0,6 L + 12 \text{ [mm]}
\end{align*}
\]

20.3 ENGINE ROOM CASINGS

20.3.1 The height of exposed engine room and boiler room casings is not to be less than 900 mm. Where the height of the casing is less than 1,8 m, the casing covers are to be of a specially strong construction.

20.3.2 The plate thickness of these casing walls and casing tops is not to be less than 5,0 mm. The thickness of the coamings is not to be less than 6,0 mm. The coamings are to be extend to the lower edges of the beams.

20.3.3 The stiffeners of the casing are to be connected to the beams of the casing top and are to extend to the lower edge of the coamings.
21 PASSENGER SHIPS

21.1 GENERAL

21.1.1 The requirements given in Section 1-16 apply to passenger ships unless otherwise mentioned in this Section.

21.1.2 A passenger ship as defined in this Section is a ship carrying more than 12 passenger on board.

21.2 WATERTIGHT SUBDIVISION

21.2.1 The subdivision of the vessel by means of transverse bulkheads is governed by the requirement of the flooding calculation. The smallest spacing a of the watertight transverse bulkheads (damage length) is not to be less than $0.03 L_c + 3.0$ m or $11.0$ m, whichever is the smaller (see Fig. 21.2.1).

\[ a = \frac{0.03 L_c + 3.0}{m} \]

21.2.2 A forepeak or collision bulkhead is to be fitted which is to be watertight up to the bulkhead deck. The collision bulkhead is to be situated not less than 0.05 $L_c$ and not more than 0.05 $L_c + 3.0$ m from F.P., measured at the deepest load waterline, see Fig. 21.2.3.

21.2.3 In the case of ships having any part of the underwater body extending forward of the forward perpendicular, e.g. a bulbous bow, the required distance specified in 21.2.2 is to be measured from a reference point located at a distance x forward of the forward perpendicular which is to be the least of (see Fig. 21.2.3):

\[ x = \frac{a}{2} \]
\[ x = 0.015 L_c \]
\[ x = 3.0 \text{ m} \]

Figure 21.2.3

21.2.4 Where a long forward superstructure is fitted the collision bulkhead shall be extended weathertight to the deck next above the bulkhead deck. The extension need not be fitted directly above the bulkhead below provided it is located within the limits prescribed in Sections 21.2.2 or 21.2.3 with the exception permitted by Section 21.2.5 and that the part of the deck which forms the step is made effectively weathertight. The extension shall be so arranged as to preclude the possibility of the bow door causing damage to it in the case of damage to, or detachment of, a bow door.

21.2.5 Where bow doors are fitted and a sloping loading ramp forms part of the extension of the collision bulkhead above the bulkhead deck the ramp shall be weathertight over its complete length. Ramps not meeting the above requirements shall be disregarded as an extension of the collision bulkhead. See also IACS Unified Interpretation SC93.

21.2.6 Deviating from the requirements of Section 10.1.2.2 the stern tube bulkhead or after peak bulkhead is to be extended to the bulkhead deck.

In all cases stern tubes shall be enclosed in watertight spaces of moderate volume. The stern gland shall be situated in a watertight shaft tunnel or other watertight space separate from the stern tube compartment and of such volume that, if flooded by leakage through the stern gland, the bulkhead deck will not be immersed. See also IACS Unified Interpretation SC93.

21.2.7 No doors, manholes, access openings, ventilation ducts or any other openings shall be fitted in the collision bulkhead below the bulkhead deck.
21.3 LONGITUDINAL STRENGTH

Longitudinal strength calculations are to be made in accordance with the requirements given in Section 4. For multi-deck arrangements, the effectiveness of superstructures will be specially considered.

21.4 DOUBLE BOTTOM

21.4.1 A double bottom is to be fitted extending from the fore peak bulkhead to the after peak bulkhead, as far as practicable and compatible with the design and proper operation of the ship.

21.4.2 The double bottom has to protect the ship's bottom up to the turn of the bilge. For this purpose, the intersecting line of the outer edge of the margin plate with the shell plating is not to be lower at any part than a horizontal plane, passing through the point of intersection with the frame line amidships of a transverse diagonal line inclined 25 degrees to the base line and cutting the base line at $B/2$ from the centre-line of the ship (see Fig. 21.4.2).

21.5 DECK STRUCTURE

21.5.1 Deck plating

21.5.1.1 For passenger ships, the thickness of deck plating (other than for vehicle decks) will generally be in accordance with Section 6. However, in view of the complexity of some multi-deck arrangements in association with large freeboards, deck thicknesses may require special consideration.

21.5.1.2 Vehicle deck plating is to satisfy the requirements for plating loaded by wheeled vehicles as specified in Section 6.2.2. Where vehicle decks are also to be used for the carriage of cargo, the thickness of plating derived from Section 6.2.1 is to be not less than would be required by Section 6.2.2.

21.5.2 Deck stiffening

21.5.2.1 For passenger ships, the deck stiffening is generally to be in accordance with Section 9 (using appropriate deck load). However, in view of the complexity of some multi-deck arrangements in association with large freeboards, deck stiffening may require special consideration.

21.6 BOTTOM AND SIDE SHELL

21.6.1 The thickness of side shell plating above, $1.6d$, including superstructures, may require special consideration depending on the particular structural arrangements, hull vertical bending and shear stresses and position of the shell above the waterline.

21.6.2 Opening in the side shell and superstructure plating for windows and doors are to be suitably stiffened and the thickness and grade of plating in way will be specially considered.

21.7 SIDE STRUCTURE

21.7.1 The scantlings of frames, or side longitudinals, web frames or transverses, and stringers below $1.6d$ above base are to satisfy the requirement of Section 8, but may be required to be confirmed by direct calculation. the scantling of these members above $1.6d$ from base may require special consideration on the basis of the particular structural arrangements, design deck loading, hull vertical bending stresses, and position of the member above the waterline.

21.7.2 Where ramp openings are fitted adjacent to the ship's side, adequate support for the side framing is to be provided.
ANNEX A ADDITIONAL REQUIREMENTS FOR EXISTING BULK CARRIERS

A.1 EVALUATION OF SCANTLINGS OF THE TRANSVERSE WATERTIGHT CORRUGATED BULKHEAD BETWEEN CARGO HOLD NO. 1 AND 2, WITH CARGO HOLD NO. 1 FLOODED

A.1.1 Application and definitions

These requirements apply to all bulk carriers of 150 m in length and above, in the foremost hold, intending to carry solid bulk cargoes having a density of 1.78 t/m³, or above, with single deck, topside tanks and hopper tanks, fitted with vertically corrugated transverse watertight bulkheads between cargo holds Nos. 1 and 2 where:

a) the foremost hold is bounded by the side shell only for ships which were contracted for construction prior to 1 July 1998, and have not been constructed in compliance with Section 17;
b) the foremost hold is double side skin construction of less than 760 mm breadth measured perpendicular to the side shell in ships, the keels of which were laid, or which were at a similar stage of construction, before 1 July 1999 and have not been constructed in compliance with Section 17.

The net scantlings of the transverse bulkhead between cargo holds Nos. 1 and 2 are to be calculated using the loads given in A.1.2, the bending moment and shear force given in A.1.3 and the strength criteria given in A.1.4.

Where necessary, steel renewal and/or reinforcements are required as per A1.6.

In these requirements, homogeneous loading condition means a loading condition in which the ratio between the highest and the lowest filling ratio, evaluated for the two foremost cargo holds, does not exceed 1.20, to be corrected for different cargo densities.

A.1.2 Load model

A.1.2.1 General

The loads to be considered as acting on the bulkhead are those given by the combination of the cargo loads with those induced by the flooding of cargo hold No. 1.

The most severe combinations of cargo induced loads and flooding loads are to be used for the check of the scantlings of the bulkhead, depending on the loading conditions included in the loading manual:

- homogeneous loading conditions;
- non homogeneous loading conditions.

Non homogeneous part loading conditions associated with multiport loading and unloading operations for homogeneous loading conditions need not to be considered according to these requirements.

A.1.2.2 Bulkhead corrugation flooding head

The flooding head $h_f$ (see Figure A.1.1) is the distance, in [m], measured vertically with the ship in the upright position, from the calculation point to a level located at a distance $d_f$, in [m], from the baseline equal to:

a) in general: $D$  

b) for ships less than 50,000 tonnes deadweight with Type B freeboard: $0,95 \times D$

$D$ being the distance, in [m], from the baseline to the freeboard deck at side amidship (see Figure A.1.1).

c) for ships to be operated at an assigned load line draught $d_l$ less than the permissible load line draught $d$, the flooding head defined in a) and b) above may be reduced by $d - d_l$.

![Figure A.1.1](image)

$V$ = volume cargo  

$P$ = calculation point

A.1.2.3 Pressure in the flooded hold

A.1.2.3.1 Bulk cargo loaded hold

Two cases are to be considered, depending on the values of $d_l$ and $d_f$, $d_l$ (see Figure A.1.1) being a distance from the baseline given, in [m], by:

$$d_l = \frac{M_c}{\rho_c \cdot l_c \cdot B} + \frac{V_{LS}}{l_c \cdot B} + (h_{HT} - h_{DB}) \times \frac{h_{HT}}{B} + h_{DB}$$

where:

- $M_c$ = mass of cargo, in tonnes, in hold No. 1
- $\rho_c$ = bulk cargo density, in [t/m³];
- $l_c$ = length of hold No. 1, in [m];
- $B$ = ship’s breadth amidship, in [m];
- $V_{LS}$ = volume, in [m³], of the bottom stool above the inner bottom;
- $h_{HT}$ = height of the hopper tanks amidship, in [m], from the baseline;
- $h_{DB}$ = height of the double bottom, in [m];
- $b_H$ = breadth of the hopper tanks amidship, in [m].

a) $d_l \geq d_f$

At each point of the bulkhead located at a distance between $d_l$ and $d_f$ from the baseline, the pressure $p_{c,f}$, in [kN/m²], is given by:

$$p_{c,f} = \rho \cdot g \cdot h_f$$

where:

- $\rho$ = sea water density, in [t/m³];
- $g$ = 9.81 [m/s²], gravity acceleration;
- $h_f$ = flooding head as defined in A.1.2.2.
At each point of the bulkhead located at a distance lower than \( d_f \) from the baseline, the pressure \( p_{c,f} \), in [kN/m²], is given by:
\[
p_{c,f} = \rho \cdot g \cdot h_f + \left[ \rho_c - \rho \cdot (1 - \text{perm}) \right] \cdot g \cdot h_1 \cdot \tan^2 \gamma
\]
where:
- \( \rho, g, h_f \) \( = \) as given above;
- \( \rho_c \) = bulk cargo density, in [t/m³];
- \( \text{perm} \) = permeability of cargo, to be taken as 0,3 for ore (corresponding bulk cargo density for iron ore may generally be taken as 3,0 t/m³);
- \( h_1 \) = vertical distance, in [m], from the calculation point to a level located at a distance \( d_f \), as defined above, from the base line (see Figure A.1.1)
- \( \gamma = 45^\circ - (\phi/2) \)
- \( \phi \) = angle of repose of the cargo, in degrees, and may generally be taken as 35° for iron ore.

The force \( F_{c,f} \), in [kN], acting on a corrugation is given by:
\[
F_{c,f} = s_1 \cdot \frac{\rho \cdot g \cdot (d_f - d_1)^2}{2} + \rho \cdot g \cdot (d_f - d_1) \cdot (h_1 - h_{DB} - h_{LS})
\]
where:
- \( s_1 \) = spacing of corrugations, in [m], (see Figure A.1.2.a);
- \( \rho, g, d_1, h_{DB} \) = as given above;
- \( d_f \) = as given in A.1.2.2;
- \( (p_{c,f})_u \) = pressure, in [kN/m²], at the lower end of the corrugation;
- \( h_{LS} \) = height of the lower stool, in [m], from the inner bottom.

At each point of the bulkhead located at a distance between \( d_f \) and \( d_1 \) from the baseline, the pressure \( p_{c,f} \), in [kN/m²], is given by:
\[
p_{c,f} = \rho_c \cdot g \cdot h_1 \cdot \tan^2 \gamma
\]
where:
- \( \rho, g, h_1, \gamma \) = as given in a) above.

At each point of the bulkhead located at a distance lower than \( d_f \) from the baseline, the pressure \( p_{c,f} \), in [kN/m²], is given by:
\[
p_{c,f} = \rho \cdot g \cdot h_f + \left[ \rho_c - \rho \cdot (1 - \text{perm}) \cdot h_f \right] \cdot g \cdot \tan^2 \gamma
\]
where:
- \( \rho, g, h_f, \phi, h_1, \text{perm} \), \( = \) as given in a) above
- \( \text{The force } F_{c,f} \), in [kN], acting on a corrugation is given by:
\[
F_{c,f} = s_1 \left[ \rho_c \cdot g \cdot \left( \frac{(d_f - d_1)^2}{2} \right) \cdot \tan^2 \gamma + \frac{\rho_c \cdot g \cdot (d_f - d_1) \cdot (h_1 - h_{DB} - h_{LS})}{2} \right]
\]
where:
- \( s_1, \rho, g, \gamma, (p_{c,f})_u, h_{LS} \) = as given in a) above;
- \( d_1, h_{DB} \) = as given in A.1.2.3.1;
- \( d_f \) = as given in A.1.2.2.

A.1.2.3.2 Empty hold

At each point of the bulkhead, the hydrostatic pressure \( p_f \) induced by the flooding head \( h_f \) is to be considered.

The force \( F_f \), in [kN], acting on a corrugation is given by:
\[
F_f = s_1 \cdot \frac{\rho \cdot g \cdot (d_f - h_{DB} - h_{LS})^2}{2}
\]
where:
- \( s_1, \rho, g, h_{LS} \) = as given in A.1.2.3.1 a);
- \( h_{DB} \) = as given in A.1.2.3.1;
- \( d_f \) = as given in A.1.2.2.

A.1.2.4 Pressure in the non-flooded bulk cargo loaded hold

At each point of the bulkhead, the pressure \( p_c \), in [kN/m²], is given by:
\[
p_c = \rho_c \cdot g \cdot h_1 \cdot \tan^2 \gamma
\]
where:
- \( \rho, g, h_1, \gamma \) = as given in A.1.2.3.1 a)

The force \( F_c \), in [kN], acting on a corrugation is given by:
\[
F_c = \rho_c \cdot g \cdot s_1 \cdot \frac{(d_f - h_{DB} - h_{LS})^2}{2} \cdot \tan^2 \gamma
\]
where:
- \( \rho_c, g, s_1, h_{LS}, \gamma \) = as given in A.1.2.3.1 a);
- \( d_1, h_{DB} \) = as given in A.1.2.3.1.

A.1.2.5 Resultant pressure

A.1.2.5.1 Homogeneous loading conditions

At each point of the bulkhead structures, the resultant pressure \( p \), in [kN/m²], to be considered for the scantlings of the bulkhead is given by:
\[
p = p_{c,f} + 0,8 \cdot p_f
\]

The resultant force \( F \), in [kN], acting on a corrugation is given by:
The bending capacity is to comply with the following relationship:

\[ 10^3 \cdot \frac{M}{0.5 \cdot Z_{le} \cdot \sigma_{a,le} + Z_{m} \cdot \sigma_{a,m}} \leq 1.0 \]

where:
- \( M \) = bending moment, in [kN·m], as given in A.1.3.1,
- \( Z_{le} \) = section modulus of one half pitch corrugation, in [cm³], at the lower end of corrugations, to be calculated according to A.1.4.3,
- \( Z_{m} \) = section modulus of one half pitch corrugation, in [cm³], at the mid-span of corrugations, to be calculated according to A.1.4.4,
- \( \sigma_{a,le} \) = allowable stress, in [N/mm²], as given in A.1.4.5, for the lower end of corrugations,
- \( \sigma_{a,m} \) = allowable stress, in [N/mm²], as given in A.1.4.5, for the mid-span of corrugations.

In no case \( Z_{le} \) is to be taken greater than the lesser of 1.15·Zₑ and 1.15·Zₑ for calculation of the bending capacity. \( Z_{le} \) being defined below.

In case effective shedder plates are fitted which:
- are not knuckled;
- are welded to the corrugations and the top of the lower stool by one side penetration welds or equivalent;
- are fitted with a minimum slope of 45° and their lower edge is in line with the stool side plating;
- or effective gusset plates are fitted which:
- are fitted in line with the stool side plating;
- have material properties at least equal to those provided for the flanges.

The section modulus of corrugations is to be calculated with

\[ Z'_{a} = Z_{a} + 10^{3} \cdot \frac{Q \cdot h_{g} - 0.5 \cdot h_{g}^{2} \cdot s_{1} \cdot p_{g}}{\sigma_{a}} \]  

where:

- \( Z_{a} \) = section modulus of one half pitch corrugation, in \([cm^3]\), to be determined by dividing the shear area as specified in A.1.4.4, in way of the upper end of the section modulus of corrugations at the lower end (cross-section \( \leftarrow \) in Figures A.1.4a and A.1.4b), not to be taken greater than:  
  \[ 10 \cdot s_{gw} \]  
- \( s_{gw} \) = width of the corrugation webs, in \([cm]\), see Figures A.1.4a and A.1.4b, not to be taken greater than:  
  \[ \frac{10}{7} \cdot s_{gw} \]  
- \( h_{g} \) = height of gusset plate, in \([m]\), see Figures A.1.4a and A.1.4b, not to be taken greater than:  
  \[ \frac{10}{7} \cdot h_{g} \]  

When calculating the section modulus of the corruagation webs fully effective. In case effective gusset plates are fitted, when calculating the section modulus of corrugations the area of flange plates may be increased as specified in b) above. No credit can be given to shedder plates only.

For angles less than 45°, the effectiveness of the corrugation webs may be obtained by linear interpolation between 30% for 0° and 100% for 45°.

A.1.4.4 Section modulus of corrugations at cross-sections other than the lower end

The section modulus is to be calculated with the corrugation webs considered effective and the compression flange having an effective flange width, \( b_{ef} \), not larger than as given in A.1.4.6.1.

If the corrugation webs are not supported by local brackets below the stool top (or below the inner bottom) in the lower part, the section modulus of the corrugations is to be calculated considering the corrugation webs 30% effective.

a) Provided that effective shedder plates, as defined in A.1.4.2, are fitted (see Figures A.1.3a and A.1.3b), when calculating the section modulus of corrugations at the lower end (cross-section \( \leftarrow \) in Figures A.1.3a and A.1.3b), the area of flange plates, in \([cm^2]\), may be increased by:

\[ 2.5 \cdot a \cdot \sqrt{f_{f} - t_{sh}} \cdot \sqrt{\frac{\sigma_{Fsh}}{\sigma_{ff}}} \]  

(not to be taken greater than 2.5 \( \cdot a \cdot t_{f} \))

where:

\[ a = \text{width, in \([m]\), of the corrugation flange (see Figure A.1.2a);} \]
\[ t_{sh} = \text{net shedder plate thickness, in \([mm]\);} \]
\[ t_{f} = \text{net flange thickness, in \([mm]\);} \]
\[ \sigma_{Fsh} = \text{minimum upper yield stress, in \([N/mm^2]\), of the material used for the shedder plates;} \]
\[ \sigma_{ff} = \text{minimum upper yield stress, in \([N/mm^2]\), of the material used for the corrugation flanges.} \]
RULES FOR THE CLASSIFICATION OF SHIPS

PART 2

A.1.4.6 Effective compression flange width and shear buckling check

A.1.4.6.1 Effective width of the compression flange of corrugations

The effective width \( b_{cf} \), in [m], of the corrugation flange is given by:

\[
b_{cf} = C_e \cdot a
\]

where:

\[
C_e = \frac{2.25}{\beta} - \frac{1.25}{\beta^2} \quad \text{for} \quad \beta > 1.25
\]

\[
C_e = 1.0 \quad \text{for} \quad \beta \leq 1.25
\]

\[
\beta = 10^3 \cdot \frac{a}{t_f} \sqrt{\frac{\sigma_F}{E}}
\]

\[
t_f = \text{net flange thickness, in [mm];}
\]

\[
a = \text{width, in [m], of the corrugation flange (see Figure A.1.2a);}
\]

\[
\sigma_F = \text{minimum upper yield stress, in [N/mm}^2\text{], of the material;}
\]

\[
E = \text{modulus of elasticity of material as given in A.1.4.6.1;}
\]

\[
t_n = 14.9 \cdot s_n \cdot \left[ \frac{p}{\sigma_F} \right]^{0.5}
\]

\[
s_w = \text{width, in [m], to be taken equal to the width of the corrugation flange or web, whichever is the greater (see Figure A.1.2a)}
\]

A.1.4.7 Local net plate thickness

The bulkhead local net plate thickness \( t \), in [mm], is given by:

\[
t = 14.9 \cdot s_w \cdot \left[ \frac{p}{\sigma_F} \right]^{0.5}
\]

where:

\[
s_w = \text{plate width, in [m], to be taken equal to the width of the corrugation flange or web, whichever is the greater (see Figure A.1.2a)}
\]

\[
p = \text{resultant pressure, in [kN/m}^2\text{], as defined in A.1.2.5, at the bottom of each strake of plating; in all cases, the net thickness of the lowest strake is to be determined using the resultant pressure at the top of the lower stool, or at the inner bottom, if no lower stool is fitted or at the top of shedders, if shedder or gusset/shedder plates are fitted.}
\]

\[
\sigma_F = \text{minimum upper yield stress, in [N/mm}^2\text{], of the material.}
\]

For built-up corrugation bulkheads, when the thicknesses of the flange and web are different, the net thickness of the narrower plating is to be not less than \( t_n \), in [mm], given by:

\[
t_n = 14.9 \cdot s_n \cdot \left[ \frac{p}{\sigma_F} \right]^{0.5}
\]

\[
s_w = \text{the width, in [m], of the narrower plating.}
\]

The net thickness of the wider plating, in [mm], is to be not taken less than the maximum of the following values:

\[
t_w = 14.9 \cdot s_w \cdot \left[ \frac{p}{\sigma_F} \right]^{0.5}
\]

\[
t_w = \sqrt{\frac{440 \cdot s_w^2 \cdot p}{\sigma_F}}
\]

where \( \Delta p \) is the actual net thickness of the narrower plating and not to be greater than:

\[
14.9 \cdot s_w \cdot \left[ \frac{p}{\sigma_F} \right]^{0.5}
\]

A.1.5 Local details

1.5.1 As applicable, the design of local details is to comply with the Register’s requirements for the purpose of transferring the corrugated bulkhead forces and moments to the boundary structures, in particular to the double bottom and cross-deck structures.

1.5.2 In particular, the thickness and stiffening of gusset and shedder plates, installed for strengthening purposes, is to comply with the Register’s requirements, on the basis of the load model in A.1.2.

1.5.3 Unless otherwise stated, weld connections and materials are to be dimensioned and selected in accordance with the Register’s requirements.

A.1.6 Corrosion addition and steel renewal

Renewal/reinforcement shall be done in accordance with the following requirements and the guidelines contained in the A.1.7.

a) Steel renewal is required where the gauged thickness \( t_g \) is less than \( t_{net} + 0.5 \) [mm], \( t_{net} \) being the thickness used for the calculation of bending capacity and shear stresses as given in A.1.4.2 or the local net plate thickness as given in A.1.4.7. Alternatively, reinforcing doubling strips may be used providing the net thickness is not dictated by shear strength require-
ments for web plates (see A.1.4.5 and A.1.4.6.2) or by local pressure requirements for web and flange plates (see A.1.4.7).

Where the gauged thickness \( t_i \) is within the range \( t_{net} + 0.5 \text{ [mm]} \) and \( t_{net} + 1.0 \text{ [mm]} \), coating (applied in accordance with the coating manufacturer’s requirements) or annual gauging may be adopted as an alternative to steel renewal.

b) Where steel renewal or reinforcement is required, a minimum thickness of \( t_{net} + 2.5 \text{ [mm]} \) is to be replenished for the renewed or reinforced parts.

c) When:

\[
0.8 \cdot \left( \sigma_{Ffl} \cdot t_{fl} \right) \geq \sigma_{FS} \cdot t_{st}
\]

where:

- \( \sigma_{Ffl} \) = minimum upper yield stress, in \([N/mm^2]\), of the material used for the corrugation flanges;
- \( \sigma_{FS} \) = minimum upper yield stress, in \([N/mm^2]\), of the material used for the lower stool side plating or floors (if no stool is fitted);
- \( t_{fl} \) = flange thickness, in \([mm]\), which is found to be acceptable on the basis of the criteria specified in a) above or, when steel renewal is required, the replenished thickness according to the criteria specified in b) above.

above flange thickness dictated by local pressure requirements (see A.1.4.7) need not be considered for this purpose:

\[ t_{st} = \text{as built thickness, in [mm], of the lower stool side plating or floors (if no stool is fitted).} \]

 Gussets with shedder plates, extending from the lower end of corrugations up to \( 0.1 \cdot l \), or reinforcing doubling strips (on bulkhead corrugations and stool side plating) are to be fitted.

If gusset plates are fitted, the material of such gusset plates is to be the same as that of the corrugation flanges. The gusset plates are to be connected to the lower stool shelf plate or inner bottom (if no lower stool is fitted) by deep penetration welds (see Figure A.1.5).

d) Where steel renewal is required, the bulkhead connections to the lower shelf plate or inner bottom (if no lower stool is fitted) are to be at least made by deep penetration welds (see Figure A.1.5).

e) Where gusset plates are to be fitted or renewed, their connections with the corrugations and the lower stool shelf plate or inner bottom (if no stool is fitted) are to be at least made by deep penetration welds (see Figure A.1.5).
A.1.7 Guidance on renewal/reinforcement of vertically corrugated transverse watertight bulkhead between cargo holds Nos. 1 and 2

A.1.7.1 The need for renewal or reinforcement of the vertically corrugated transverse watertight bulkhead between cargo holds Nos. 1 and 2 will be determined by the Register on a case by case basis using the criteria given in this Section in association with the most recent gaugings and findings from survey.

A.1.7.2 In addition to class requirements, the assessment of this Section of the transverse corrugated bulkhead will take into account the following:

a) Scantlings of individual vertical corrugations will be assessed for reinforcement/renewal based on thickness measurements obtained in accordance with the Register’s guidance for thickness measurements at their lower end, at mid-depth and in way of plate thickness changes in the lower 70%.

These considerations will take into account the provision of gussets and shedder plates and the benefits they offer, provided that they comply with A.1.4.2 and A.1.6.

(b) Taking into account the scantlings and arrangements for each case, permissible levels of diminution will be determined and appropriate measures taken in accordance with A.1.6.

A.1.7.3 Where renewal is required, the extent of renewal is to be shown clearly in plans. The vertical distance of each renewal zone is to be determined by considering the requirements of this Section, and in general is to be not less than 15% of the vertical distance between the upper and lower end of the corrugation -measured at the ship’s centreline.

A.1.7.4 Where the reinforcement is accepted by adding strips, the length of the reinforcing strips is to be sufficient to allow it to extend over the whole depth of the diminished plating. In general, the width and thickness of strips should be sufficient to comply with the requirements of this Section. The material of the strips is to be the same as that of the corrugation plating. The strips are to be attached to the existing bulkhead plating by continuous fillet welds. The strips are to be suitably tapered or connected at ends in accordance with the Register’s practice.
A.1.7.5 Where reinforcing strips are connected to the inner bottom or lower stool shelf plates, one side full penetration welding is to be used. When reinforcing strips are fitted to the corrugation flange and are connected to the lower stool shelf plate, they are normally to be aligned with strips of the same scantlings welded to the stool side plating and having a minimum length equal to the breadth of the corrugation flange.

A.1.7.6 Figure A.1.7 gives a general arrangement of structural reinforcement.

Notes to Figure A.1.7 on reinforcement:
1. Square or trapezoidal corrugations are to be reinforced with plate strips fitted to each corrugation flange sufficient to meet the requirements of this Section.
2. The number of strips fitted to each corrugation flange is to be sufficient to meet the requirements of this Section.
3. The shedder plate may be fitted in one piece or prefabricated with a welded knuckle (gusset plate).
4. Gusset plates, where fitted, are to be welded to the shelf plate in line with the flange of the corrugation, to reduce the stress concentrations at the corrugation corners. Ensure good alignment between gusset plate, corrugation flange and lower stool sloping plate. Use deep penetration welding at all connections. Ensure start and stop of welding is as far away as practically possible from corners of corrugation.
5. Shedder plates are to be attached by one side full penetration welds onto backing bars.
6. Shedder and gusset plates are to have a thickness equal to or greater than the original bulkhead thickness. Gusset plate is to have a minimum height (on the vertical part) equal to half of the width of the corrugation flange. Shedders and gussets are to be same material as flange material.

A.1.8 Guidance to assess capability of carriage of high density cargoes on existing bulk carriers according to the strength of transverse bulkhead between cargo holds Nos. 1 and 2

Figure A.1.8 contains, for guidance only, a flow chart for assessment of capability of high density cargoes carriage according to the strength of transverse bulkhead between cargo holds Nos. 1 and 2.
Guidance to Assess Capability of Carriage of High Density Cargoes on Existing Bulk Carriers according to the Strength of Transverse Bulkhead between Cargo Holds No. 1 and 2

Carriage of cargoes having \( \rho_c \geq 1.78 \text{ t/m}^3 \)?
- No need for further assessment
- Yes

Check for \( \rho_c = 1.78 \text{ t/m}^3 \)
- Check satisfactory
  - Yes
  - No
- Reinforce (2)

Check for \( \rho_c > 1.78 \text{ t/m}^3 \)
- Yes
- No

Calculate allowable density \( \rho_c \)
- \( \rho_c \geq 1.78 \text{ t/m}^3 \)
- Cargoes having \( \rho_c \leq 1.78 \text{ t/m}^3 \) can be carried
- Only cargoes having \( \rho_c \leq 1.78 \text{ t/m}^3 \) can be carried
- Cargoes having \( \rho_c \leq \rho_c \) can be carried

Notes:
1. \( \rho_c \) typical of cargoes to be carried; in any case a value of 3.0 t/m³, corresponding to ore cargo, is to be considered.
2. In deciding the reinforcement needed, consideration will be given to the effects of restricting the cargo distribution (homogeneous loading condition or reduction in the ship deadweight).

Figure A.1.8
A.2 EVALUATION OF ALLOWABLE HOLD LOADING OF CARGO HOLD NO. 1 WITH CARGO HOLD NO. 1 FLOODED

A.2.1 Application and definitions

These requirements apply to all bulk carriers of 150 m in length and above, in the foremost hold, intending to carry solid bulk cargoes having a density of 1.78 t/m³, or above, with single deck, topside tanks and hopper tanks, where:

a) the foremost hold is bounded by the side shell only for ships which were contracted for construction prior to 1 July 1998, and have not been constructed in compliance with Section 17,

b) the foremost hold is double side skin construction less than 760 mm breadth measured perpendicular to the side shell in ships, the keels of which were laid, or which were at a similar stage of construction, before 1 July 1999 and have not been constructed in compliance with Section 17.

Early completion of a special survey coming due after 1 July 1998 to postpone compliance is not allowed.

The loading in cargo hold No. 1 is not to exceed the allowable hold loading in the flooded condition, calculated as per A.2.4, using the loads given in A.2.2 and the shear capacity of the double bottom given in A.2.3.

In no case, the allowable hold loading in flooding condition is to be taken greater than the design hold loading in intact condition.

A.2.2 Load model

A.2.2.1 General

The loads to be considered as acting on the double bottom of hold No. 1 are those given by the external sea pressures and the combination of the cargo loads with those induced by the flooding of hold No. 1.

The most severe combinations of cargo induced loads and flooding loads are to be used, depending on the loading conditions included in the loading manual:

- homogeneous loading conditions;
- non homogeneous loading conditions;
- packed cargo conditions (such as steel mill products).

For each loading condition, the maximum bulk cargo density to be carried is to be considered in calculating the allowable hold limit.

A.2.2.2 Inner bottom flooding head

The flooding head \( h_f \) (see Figure A.2.1) is the distance, in [m], measured vertically with the ship in the upright position, from the inner bottom to a level located at a distance \( d_f \), in [m], from the baseline equal to:

- \( D \) in general;
- \( 0.95 \cdot D \) for ships less than 50,000 tonnes deadweight with Type B freeboard.

\( D \) being the distance, in [m], from the baseline to the freeboard deck at side amidship (see Figure A.2.1).

A.2.3 Shear capacity of the double bottom of hold No. 1

The shear capacity \( C \) of the double bottom of hold No. 1 is defined as the sum of the shear strength at each end of:

- all floors adjacent to both hoppers, less one half of the strength of the two floors adjacent to each stool, or transverse bulkhead if no stool is fitted (see Figure A.2.2),
- all double bottom girders adjacent to both stools, or transverse bulkheads if no stool is fitted.

The strength of girders or floors which run out and are not directly attached to the boundary stool or hopper girder is to be evaluated for the one end only.
Note that the floors and girders to be considered are those inside the hold boundaries formed by the hoppers and stools (or transverse bulkheads if no stool is fitted). The hopper side girders and the floors directly below the connection of the bulkhead stools (or transverse bulkheads if no stool is fitted) to the inner bottom are not to be included.

When the geometry and/or the structural arrangement of the double bottom are such to make the above assumptions inadequate, to the Register’s discretion, the shear capacity C of the double bottom is to be calculated according to the Register’s criteria.

In calculating the shear strength, the net thicknesses of floors and girders are to be used. The net thickness $t_{net}$, in [mm], is given by:

$$t_{net} = t - t_c$$

where:

- $t$ = as built thickness, in [mm], of floors and girders;
- $t_c$ = corrosion diminution, equal to 2 mm, in general; a lower value of $t_c$ may be adopted, provided that measures are taken, to the Register’s satisfaction, to justify the assumption made.

### A.2.3.1 Floor shear strength

The floor shear strength in way of the floor panel adjacent to hoppers $S_{f1}$, in [kN], and the floor shear strength in way of the openings in the “outermost” bay (i.e. that bay which is closest to hopper) $S_{f2}$, in [kN], are given by the following expressions:

$$S_{f1} = 10^{-3} \cdot A_f \cdot \frac{\tau_c}{\eta_1}$$

$$S_{f2} = 10^{-3} \cdot A_{f,h} \cdot \frac{\tau_c}{\eta_2}$$

where:

- $A_f$ = sectional area, in [mm$^2$], of the floor panel adjacent to hoppers;
- $A_{f,h}$ = net sectional area, in [mm$^2$], of the floor panels in way of the openings in the “outermost” bay (i.e. that bay which is closest to hopper);
- $\sigma_f$ = minimum upper yield stress, in [N/mm$^2$], of the material;
- $\tau_c$ = allowable shear stress, in [N/mm$^2$], to be taken equal to: $\sigma_f / \sqrt{3}$
- $\eta_1 = 1,10$
- $\eta_2 = 1,20$

$\eta_2$ may be reduced down to 1,10 where appropriate reinforcements are fitted to the Register’s satisfaction.

### A.2.3.2 Girder shear strength

The girder shear strength in way of the girder panel adjacent to stools (or transverse bulkheads, if no stool is fitted) $S_{g1}$, in [kN], and the girder shear strength in way of the largest opening in the “outermost” bay (i.e. that bay which is closest to stool, or transverse bulkhead, if no stool is fitted) $S_{g2}$, in [kN], are given by the following expressions:

$$S_{g1} = 10^{-3} \cdot A_g \cdot \frac{\tau_c}{\eta_1}$$

$$S_{g2} = 10^{-3} \cdot A_{g,h} \cdot \frac{\tau_c}{\eta_2}$$

where:

- $A_g$ = minimum sectional area, in [mm$^2$], of the girder panel adjacent to stools (or transverse bulkheads, if no stool is fitted);
- $A_{g,h}$ = net sectional area, in [mm$^2$], of the girder panel in way of the largest opening in the “outermost” bay (i.e. that bay which is closest to stool, or transverse bulkhead, if no stool is fitted);
- $\tau_c$ = allowable shear stress, in [N/mm$^2$], as given in A.2.3.1;
- $\eta_1 = 1,10$
- $\eta_2 = 1,15$

$\eta_2$ may be reduced down to 1,10 where appropriate reinforcements are fitted to the Register’s satisfaction.

### A.2.4 Allowable hold loading

The allowable hold loading $W$, in [t], is given by:

$$W = \rho_c \cdot V \cdot \frac{1}{F}$$

where:

- $F = 1.05$ in general;
- $1.00$ for steel mill products;
- $\rho_c$ = cargo density, in [t/m$^3$] (see A.2.2.1);
- $V$ = volume, in [m$^3$], occupied by cargo at a level $h_l$

$$h_l = \frac{X}{\rho_c \cdot g}$$

$X$ = for bulk cargoes, the lesser of $X_1$ and $X_2$ given by:

$$X_1 = \frac{Z + \rho \cdot g \cdot (E - h_f)}{1 + \rho \cdot \rho_e \cdot \perm \cdot \perm - 1}$$

$$X_2 = \frac{Z + \rho \cdot g \cdot (E - h_f \cdot \perm \cdot \perm)}{1 + \rho \cdot \rho_e \cdot \perm \cdot \perm}$$

$X$ = for steel products, $X$ may be taken as $X_0$, using $\perm = 0$;
- $\rho =$ sea water density, in [t/m$^3$];
- $g = 9.81$ m/s$^2$, gravity acceleration;
- $E = d_f \cdot 0.1 \cdot D$;
- $d_f \cdot D$ = as given in A.2.2.2;
- $h_f$ = flooding head, in [m], as defined in A.2.2.2;
- $\perm$ = permeability of cargo, to be taken as 0.3 for ore (corresponding bulk cargo density for iron ore may generally be taken as 3.0 t/m$^3$).

$Z$ = the lesser of $Z_1$ and $Z_2$ given by:

$$Z_1 = \frac{C_b}{A_{DB,b}}$$

$$Z_2 = \frac{C_e}{A_{DB,e}}$$

$C_b$ = shear capacity of the double bottom, in [kN], as defined in A.2.3, considering, for each floor, the lesser of the shear strengths $S_{g1}$ and $S_{g2}$ (see A.2.3.1) and, for each girder, the less-
er of the shear strengths $S_{g1}$ and $S_{g2}$ (see A.2.3.2);

$$C_e = \text{shear capacity of the double bottom, in [kN], as defined in A.2.3, considering, for each floor, the shear strength } S_{f1} \text{ (see A.2.3.1) and, for each girder, the lesser of the shear strengths } S_{g1} \text{ and } S_{g2} \text{ (see A.2.3.2);}$$

$$A_{DB,h} = \sum_{i=1}^{i=n} S_i \cdot B_{DB,i}$$

$$A_{DB,h} = \sum_{i=1}^{i=n} S_i \cdot (B_{DB} - s)$$

$n$ = number of floors between stools (or transverse bulkheads, if no stool is fitted);

$S_i$ = space of $i$th-floor, in [m];

$B_{DB,i} = B_{DB} - s$, for floors whose shear strength is given by $S_{f1}$ (see A.2.3.1);

$B_{DB,i} = B_{DB,h}$, for floors whose shear strength is given by $S_{f2}$ (see A.2.3.1);

$B_{DB}$ = breadth of double bottom, in [m], between hoppers (see Figure A.2.3);

$B_{DB,h}$ = distance, in [m], between the two considered openings (see Figure A.2.3);

$s$ = spacing, in [m], of double bottom longitudinals adjacent to hoppers.

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**Figure A.2.3**
A.3 IMPLEMENTATION OF THE ADDITIONAL REQUIREMENTS A.1 AND A.2

A.3.1 Application and implementation timetable

A.3.1.1 The requirements A.1 and A.2 are to be applied in conjunction with the damage stability requirements set forth in A.3.2. Compliance is required:

1. for ships which were 20 years of age or more on 1 July 1998, by the due date of the first intermediate, or the due date of the first special survey to be held after 1 July 1998, whichever comes first;
2. for ships which were 15 years of age or more but less than 20 years of age on 1 July 1998, by the due date of the first special survey to be held after 1 July 1998, but not later than 1 July 2002;
3. for ships which were 10 years of age or more but less than 15 years of age on 1 July 1998, by the due date of the first intermediate, or the due date of the first special survey to be held after the date on which the ship reaches 15 years of age but not later than the date on which the ship reaches 17 years of age;
4. for ships which were 5 years of age or more but less than 10 years of age on 1 July 1998, by the due date, after 1 July 2003, of the first intermediate or the first special survey after the date on which the ship reaches 10 years of age, whichever occurs first;
5. for ships which were less than 5 years of age on 1 July 1998, by the date on which the ship reaches 10 years of age.

A.3.1.2 Completion prior to 1 July 2003 of an intermediate or special survey with a due date after 1 July 2003 can be accepted.

A.3.2 Damage stability

A.3.2.1 Bulk carriers which are subject to compliance with the requirements A.1 and A.2 shall, when loaded to the summer loadline, be able to withstand flooding of the foremost cargo hold in all loading conditions and remain afloat in a satisfactory condition of equilibrium, as specified in SOLAS regulation XII/4.3 to 4.7.

A.3.2.2 A ship having been built with an insufficient number of transverse watertight bulkheads to satisfy this requirement may be exempted from the application of the requirements A.1, A.2 and this requirement provided the ship fulfills the requirement in SOLAS regulation XII/9.

A.3.2.3 For application of the requirements in SOLAS regulation XII/9 see IACS Unified Interpretation SC 182.

A.3.3 Details

A.3.3.1 Surveys to be held

The term "survey to be held" is interpreted to mean that the survey is "being held" until it is "completed".

Note: 1) See A.3.3 for details.

A.3.3.2 Due dates and completion allowance

A.3.3.2.1 Intermediate survey:

A.3.3.2.1.1 Intermediate survey carried out either at the second or third annual survey: 3 months after the due date (i.e. 2nd or 3rd anniversary) can be used to carry out and complete the survey;

A.3.3.2.1.2 Intermediate survey carried out between the second and third annual survey: 3 months after the due date of the 3rd Annual Survey can be used to carry out and complete the survey;

A.3.3.2.2 Special survey: 3 months extension after the due date may be allowed subject to the terms/conditions of PR4;

A.3.3.2.3 Ships controlled by "1 July 2002": same as for special survey;

A.3.3.2.4 Ships controlled by "age 15 years" or "age 17 years": same as for special survey.

A.3.3.3 Intermediate survey interpretations / Applications

A.3.3.3.1 If the 2nd anniversary is prior to or on 1 July 1998 and the intermediate survey is completed prior to or on 1 July 1998, the ship need not comply until the next special survey.

A.3.3.3.2 If the 2nd anniversary is prior to or on 1 July 1998 and the intermediate survey is completed within the window of the 2nd annual survey but after 1 July 1998, the ship need not comply until the next special survey.

A.3.3.3.3 If the 2nd anniversary is prior to or on 1 July 1998 and the intermediate survey is completed outside the window of the 2nd annual survey and after 1 July 1998, it is taken that the intermediate survey is held after 1 July 1998 and between the second and third annual surveys. Therefore, the ship shall comply no later than 3 months after the 3rd anniversary.

A.3.3.3.4 If the 2nd anniversary is after 1 July 1998 and the intermediate survey is completed within the window of the 2nd annual survey but prior to or on 1 July 1998, the ship need not comply until the next special survey.

A.3.3.3.5 If the 3rd anniversary is prior to or on 1 July 1998 and the intermediate survey is completed prior to or on 1 July 1998, the ship need not comply until the next special survey.

A.3.3.3.6 If the 3rd anniversary is prior to or on 1 July 1998 and the intermediate survey is completed within the window of the 3rd annual survey but after 1 July 1998, the ship need not comply until the next special survey.

A.3.3.3.7 If the 3rd anniversary is after 1 July 1998 and the intermediate survey is completed within the window prior to or on 1 July 1998, the ship need not comply until the next special survey.
A.3.3.4 Special survey interpretations / Applications

A.3.3.4.1 If the due date of a special survey is after 1 July 1998 and the special survey is completed within the 3 month window prior to the due date and prior to or on 1 July 1998, the ship need not comply until the next relevant survey (i.e. special survey for ships under 20 years of age on 1 July 1998, intermediate survey for ships 20 years of age or more on 1 July 1998).

A.3.3.5 Early completion of an intermediate survey (coming due after 1st July 1998) to postpone compliance is not allowed:

A.3.3.5.1 Early completion of an intermediate survey means completion of the survey prior to the opening of the window (i.e. completion more than 3 months prior to the 2nd anniversary since the last special survey).

A.3.3.5.2 The intermediate survey may be completed early and credited from the completion date but in such a case the ship will still be required to comply not later than the 3 months after the 3rd anniversary.

A.3.3.6 Early completion of a special survey (coming due after 1st July 1998) to postpone compliance is not allowed:

A.3.3.6.1 Early completion of a special survey means completion of the survey more than 3 months prior to the due date of the special survey.

A.3.3.6.2 The special survey may be completed early and credited from the completion date, but in such a case the ship will still be required to comply by the due date of the special survey.
**A.4 REQUIREMENTS OF THE SOLAS 1974, CH. XII, REG. 12 & 13 FOR BULK CARRIERS**

**A.4.1 Requirements for hold, ballast and dry space water ingress alarms**

**A.4.1.1** This requirement is applicable to bulk carriers of single side skin construction as defined in the *Rules for the classification of ships, Part 1 – General requirements, Chapter 1 – General information, Section 4.2.*

**A.4.1.2** Bulk carriers the keels of which are laid or which are at a similar stage of construction before 1 July 2004 shall comply with the requirements of this regulation not later than the date of the annual, intermediate or renewal survey of the ship to be carried out after 1 July 2004, whichever comes first.

**A.4.1.3** Bulk carriers shall be fitted with water level detectors in each cargo hold, giving audible and visual alarms as follows:

- a) one when the water level above the inner bottom in any hold reaches a height of 0,5 m and
- b) another at a height not less than 15% of the depth of the cargo hold but not more than 2 m.

On bulk carriers to which regulation A.3.2.2 applies, detectors with only the latter alarm need be installed.

The water level detectors shall be fitted in the aft end of the cargo holds.

For cargo holds which are used for ballast, an alarm overriding device may be installed.

The visual alarms shall clearly discriminate between the two different water levels detected in each hold.

**A.4.1.4** In any ballast tank forward of the collision bulkhead, giving an audible and visual alarm when the liquid in the tank reaches a level not exceeding 10% of the tank capacity. An alarm overriding device may be installed to be activated when the tank is in use.

**A.4.1.5** In any dry or void space other than a chain cable locker, any part of which extends forward of the foremost cargo hold, giving an audible and visual alarm at a water level of 0,1 m above the deck.

Such alarms need not be provided in enclosed spaces the volume of which does not exceed 0,1% of the ship’s maximum displacement volume.

**A.4.1.6** The audible and visual alarms specified in items A.4.1.3 to A.4.1.5 shall be located on the navigation bridge.

**A.4.1.7** The visual and audible alarms are to be in accordance with the relevant requirements for bilge alarms in the *Rules, Part 12 – Electrical Equipment, 19.8.*

**A.4.1.8** For application of these requirements see also *IACS Unified Interpretation SC 180.*

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**A.4.2 Requirements for availability of pumping systems**

**A.4.2.1** This requirement is applicable to bulk carriers of single side skin construction as defined in the *Rules for the classification of ships, Part 1 – General requirements, Chapter 1 – General information, Section 4.2.*

**A.4.2.2** Bulk carriers the keels of which are laid or which are at a similar stage of construction before 1 July 2004 shall comply with the requirements of this regulation not later than the date of the first intermediate or renewal survey of the ship to be carried out after 1 July 2004, but, in no case, later than 1 July 2007.

**A.4.2.3** On bulk carriers, the means for draining and pumping ballast tanks forward of the collision bulkhead and bilges of dry spaces any part of which extends forward of the foremost cargo hold shall be capable of being brought into operation from a readily accessible enclosed space, the location of which is accessible from the navigation bridge or propulsion machinery control position without traversing exposed freeboard or superstructure decks.

Where pipes serving such tanks or bilges pierce the collision bulkhead, valve operation by means of remotely operated actuators may be accepted, as an alternative to the valve control specified in the *Rules, Part 8 – Piping, 1.6 (see SOLAS 1974, Reg. II-1/12),* provided that the location of such valve controls complies with this regulation.

For application of these requirements see also *IACS Unified Interpretation SC 179.*

**A.4.3 Installation, testing and survey**

The system is to be installed and tested in accordance with the approved documentation and the manufacturer’s specifications. At the initial installation and at each subsequent Intermediate and Special Survey, the Surveyor is to verify the proper operation of the water detection system.
### A.5 ADDITIONAL REQUIREMENTS FOR LOADING CONDITIONS, LOADING MANUALS AND LOADING INSTRUMENTS FOR BULK CARRIERS, ORE CARRIERS AND COMBINATION CARRIERS

#### A.5.1 Application

Bulk Carriers, Ore Carriers and Combination Carriers of 150 m length and above, which are contracted for construction before 1st July 1998 are to be provided with an approved loading instrument of a type to the satisfaction of the Register not later than their entry into service or 1st January 1999, whichever occurs later.

In addition, Bulk Carriers of 150 m length and above where one or more cargo holds are bounded by the side shell only, which were contracted for construction before 1st July 1998 are to be provided with an approved loading manual with typical loading sequences where the vessel is loaded from commencement of cargo loading to reaching full deadweight capacity, for homogeneous conditions, relevant part load conditions and alternate conditions where applicable.

Typical unloading sequences for these conditions shall also be included. Section A.5.5 contains guidance for loading and unloading sequences for existing bulk carriers.

#### A.5.2 Definitions, see 17.4.2.

#### A.5.3 Conditions of approval of loading manuals, see 17.4.3.

#### A.5.4 Condition of approval of loading instruments, see 17.4.4.

#### A.5.5 Guidance for loading / unloading sequences for existing bulk carriers

- one full load alternate hold condition, if the ship is approved for alternate hold loading.

#### A.5.5.1 Section A.5.1 requires that single side skin bulk carriers of 150m length and above, which are contracted for construction before 1st July 1998, are to be provided, before 1st July 1999 or their entry into service, whichever occurs later, with an approved loading manual with typical loading sequences where the ship is loaded from commencement of cargo loading to reaching full deadweight capacity, for homogeneous conditions, relevant part loaded conditions and alternate conditions where applicable. Typical unloading sequences shall be included.

#### A.5.5.2 This requirement will necessitate shipowners and operators to prepare and submit for approval typical loading and unloading sequences.

#### A.5.5.3 The minimum acceptable number of typical sequences is:

- one homogeneous full load condition,
- one part load condition where relevant, such as block loading or two port unloading.

#### A.5.5.4 The shipowner/operator should select actual loading/unloading sequences, where possible, which may be port specific or typical.

#### A.5.5.5 Section A.5.1 requires that bulk carriers of 150m length and above, where one or more cargo holds are bounded by the side shell only, which were contracted for construction before 1st July 1998, are to be provided with an approved loading manual with typical loading sequences where the ship is loaded from commencement of cargo loading to reaching full deadweight capacity, for homogeneous conditions, relevant part loaded conditions and alternate conditions where applicable. Typical unloading sequences shall be included.

#### A.5.5.6 For each loading condition a summary of all steps is to be included. This summary is to highlight the essential information for each step such as:

- How much cargo is filled in each hold during the different steps,
- How much ballast is discharged from each ballast tank during the different steps,
- The maximum still water bending moment and shear at the end of each step,
- The ship’s trim and draught at the end of each step.

#### A.5.5.7 The approved typical loading/unloading sequences, may be included in the approved loading manual or take the form of an addendum prepared for purposes of complying with the Register’s requirements. A copy of the approved typical loading/unloading sequences is to be placed onboard the ship.

#### A.5.5.7 It is recommended that IACS Rec. 83 be taken into account when compiling the typical loading and unloading sequences described in Section A.5.5.
A.6 PROVISION OF DETAILED INFORMATION ON SPECIFIC CARGO HOLD FLOODING SCENARIOS

A.6.1 Application

A.6.1.1 This requirement is applicable only to bulk carrier specified in A.1.1 but not capable of complying A.3.2.1 (SOLAS regulation XII/4.2).

A.6.1.2 Where bulk carriers are shown to be not capable of complying with the requirement specified in A.6.1.1 (SOLAS reg. XII/4.2) due to the design configuration of their cargo holds, SOLAS reg. XII/9 permits relaxation from the application of regulations 4.2 and 6 on the basis of compliance with certain other requirements, including provision of detailed information on specific cargo hold flooding scenarios.

A.6.1.3 The information should comprise at least the following:
- Specific cargo hold flooding scenarios;
- Instructions for evacuation preparedness;
- Details of the ship’s means for leakage detection.

A.6.2 Specific cargo hold flooding scenarios

A.6.2.1 Flooding assumption

A.6.2.1.1 The flooding of the foremost cargo hold is to be used as the starting point for any respective flooding scenario. Subsequent flooding of other spaces can only occur due to progressive flooding.

A.6.2.1.2 The permeability of a loaded hold shall be assumed as 0.9 and the permeability of an empty hold shall be assumed as 0.95, unless a permeability relevant to a particular cargo is assumed for the volume of a flooded hold occupied by cargo and a permeability of 0.95 is assumed for the remaining empty volume of the hold. The permeability of a hold loaded with packaged cargo shall be assumed as 0.7.

A.6.2.2 Loading conditions to be considered:

A.6.2.2.1 Flooding scenarios should be developed for loading conditions loaded down to the summer load line even if not in compliance with the requirement A.3.2.1 (SOLAS regulation XII/4.2). The scope to be covered should include at least the following:
- A homogenous and, if applicable, an alternate hold loading condition are to be considered;
- In case one or more loading conditions meet the requirement A.3.2.1 (SOLAS regulation XII/4.2) this should be noted;
- A packaged cargo condition, if applicable.

A.6.2.2.2 In case the vessel is able to withstand flooding of the foremost hold at a lower draught, guidance in the form of limiting KG/GM curves, based on the flooding assumptions in A.6.2.1, should be provided. Curves should indicate the assumed trim and whether the foremost hold is homogeneously loaded, loaded with high density cargo (alternate hold loading), loaded with packaged cargo or empty.

A.6.2.3 Presentation of results

The results should clearly indicate the reasons for non-compliance with the survival criteria given in reg. XII/4.3 of the SOLAS and explain the implication regarding the need to abandon ship e.g. immersion of a watertight closing appliance if the stability characteristics are otherwise satisfactory may indicate that there is no immediate danger of foundering, provided the bulkhead strength is adequate, particularly if the weather conditions are favourable and bilge pumping can cope with any progressive flooding.

A.6.3 Guidance for evacuation

A.6.3.1 The following guidance with regard to preparation for evacuation is in the most general terms. Responsibility for the preparation of detailed information rests with the operator of the ship.

A.6.3.2 In any case of detection of severe flooding (made in accordance with A.4), preparations for abandoning the vessel shall be envisaged in accordance with the applicable rules and procedures, such as SOLAS III, STCW and the ISM Code.

A.6.3.3 In the context of severe weather conditions the weather itself may have substantial influence on the development of the flooding and consequently the time remaining to execute the abandoning of the ship could be much shorter than estimated in any pre-assessed flooding scenario.
A.7 RENEWAL CRITERIA FOR SIDE SHELL FRAMES AND BRACKETS IN SINGLE SIDE SKIN BULK CARRIERS AND SINGLE SIDE SKIN OBO CARRIERS (IACS UR S 31)

A.7.1 Application and definitions

A.7.1.1 These requirements apply to the side shell frames and brackets of cargo holds bounded by the single side shell of bulk carriers constructed with single deck, top-side tanks and hopper tanks in cargo spaces intended primarily to carry dry cargo in bulk, which were not built in accordance with requirements in Section 17.2.5.

In addition, these requirements also apply to the side shell frames and brackets of cargo holds bounded by the single side shell of Oil/Bulk/Ore (OBO) carriers of single side skin construction.

In the case a vessel as defined above does not satisfy above definition in one or more holds, these requirements do not apply to these individual holds.

For the purpose of this Section, “ships” means both “bulk carriers” and “OBO carriers” as defined above, unless otherwise specified.

A.7.1.2 Bulk carriers of single side skin construction, as defined in A.7.1.1, are to be assessed for compliance with these requirements and steel renewal, reinforcement or coating, where required, is to be carried out in accordance with the following schedule and at subsequent intermediate and special surveys.

.1 For bulk carriers which will be 15 years of age or more on 1 January 2004 by the due date of the first intermediate or special survey after that date;
.2 For bulk carriers which will be 10 years of age or more on 1 January 2004 by the due date of the first special survey after that date;
.3 For bulk carriers which will be less than 10 years of age on 1 January 2004 by the date on which the ship reaches 10 years of age.

Completion prior to 1 January 2004 of an intermediate or special survey with a due date after 1 January 2004 cannot be used to postpone compliance. However, completion prior to 1 January 2004 of an intermediate survey the window for which straddles 1 January 2004 can be accepted.

A.7.1.3 OBO carriers of single side skin construction, as defined in A.7.1.1, are to be assessed for compliance with these requirements and steel renewal, reinforcement or coating, where required, is to be carried out in accordance with the following schedule and at subsequent intermediate and special surveys.

.1 For OBO carriers which will be 15 years of age or more on 1 July 2005 by the due date of the first intermediate or special survey after that date;
.2 For OBO carriers which will be 10 years of age or more on 1 July 2005 by the due date of the first special survey after that date;
.3 For OBO carriers which will be less than 10 years of age on 1 July 2005 by the date on which the ship reaches 10 years of age.

Completion prior to 1 July 2005 of an intermediate or special survey with a due date after 1 July 2005 cannot be used to postpone compliance. However, completion prior to 1 July 2005 of an intermediate survey the window for which straddles 1 July 2005 can be accepted.

A.7.1.4 These requirements define steel renewal criteria or other measures to be taken for the webs and flanges of side shell frames and brackets as per A.7.3.

A.7.1.5 Reinforcing measures of side frames are also defined as per A.7.3.3.

A.7.1.6 Finite element or other numerical analysis or direct calculation procedures cannot be used as an alternative to compliance with the requirements of this Section, except in cases off unusual side structure arrangements or framing to which the requirements of this Section can not be directly applied. In such cases, the analysis criteria and the strength check criteria are to be in accordance with these Rules.

A.7.1.7 It is recommended that IACS Rec. No.94 be taken into account as the guideline for application of these requirements.

A.7.2 Ice strengthened ships

A.7.2.1 Where ships are reinforced to comply with an ice class notation, the intermediate frames are not to be included when considering compliance with these requirements.

A.7.2.2 The renewal thicknesses for the additional structure required to meet the ice strengthening notation are to be based on the Register’s requirements.

A.7.2.3 If the ice class notation is requested to be withdrawn, the additional ice strengthening structure, with the exception of tripping brackets (see A.7.3.1.2.1.b and A.7.3.1.3), is not to be considered to contribute to compliance with S31.

A.7.3 Renewal or other measures

A.7.3.1 Criteria for renewal or other measures

A.7.3.1.1 Symbols

\[ t_M = \text{thickness as measured, in [mm]} \]
\[ t_{REN} = \text{thickness at which renewal is required, see A.7.3.1.2} \]
\[ t_{REN,d/t} = \text{thickness criteria based on d/t ratio, see A.7.3.1.2.1.} \]
\[ t_{RENS} = \text{thickness criteria based on strength, see A.7.3.1.2.2.} \]
\[ t_{COAT} = 0.75 \times t_{S12} \]
\[ t_{S12} = \text{thickness, in [mm], as required in 17.2.5.3 for frame webs and in 17.2.5.4 for upper and lower bracket webs} \]
\[ t_{AB} = \text{thickness as built, in [mm]} \]
\[ t_{C} = \text{see Table A.7.3.1.1.} \]
The following equation: less than the thickness (according to 1.4.2.2 for higher tensile steel.

In calculating the web depth of the lower brackets, the following will apply:

- The web depth of lower bracket may be measured from the intersection of the sloped bulkhead of the hopper tank and the side shell plate, perpendicularly to the face plate of the lower bracket (see Fig. A.7.3).
- Where stiffeners are fitted on the lower bracket plate, the web depth may be taken as the distance between the side shell and the stiffener, between the stiffeners or between the outermost stiffener and the face plate of the brackets, whichever is the greatest.

b) Tripping bracket alternative

When \( t_M \) is less than \( t_{REN,d/t} \) at section b), of the side frames, see Fig. A.7.2, tripping brackets in accordance with A.7.3.3 may be fitted as an alternative to the requirements for the web depth to thickness ratio of side frames, in which case \( t_{REN,d/t} \) may be disregarded in the determination of \( t_{REN} \) in accordance with A.7.3.1.2. The value of \( t_M \) is to be based on zone B according to Fig. A.7.4.

c) Immediately abaft collision bulkhead

For the side frames, including the lower bracket, located immediately abaft the collision bulkheads, whose scantlings are increased in order that their moment of inertia is such to avoid undesirable flexibility of the side shell, when their web as built thickness \( t_{AB} \) is greater than 1.65 \( t_{REN,S} \), the thickness \( t_{REN,d/t} \) may be taken as the value \( t'_{REN,d/t} \) obtained from the following equation:

\[
t'_{REN,d/t} = \frac{t_{REN}}{R}
\]

where \( t_{REN,S} \) is obtained from A.7.4.3.

A.7.3.1.2 Criteria for webs (Shear and other checks)

The webs of side shell frames and brackets are to be renewed when the measured thickness (\( t_M \)) is equal to or less than the thickness (\( t_{REN} \)) as defined below:

\( t_{REN} \) is the greatest of:

(a) \( t_{COAT} - t_C \)
(b) 0.75 \( t_{AB} \)
(c) \( t_{REN,d/t} \) (applicable to Zone A and B only)
(d) \( t_{REN,S} \) (where required by A.7.3.1.2.2)

A.7.3.1.2.1 Thickness criteria based on \( d/t \) ratio

Subject to b) and c) below, \( t_{REN,d/t} \) is given by the following equation:

\( t_{REN,d/t} = \frac{t}{R} \)

where:

\[
R = \begin{cases} 
65 & \text{for symmetrically flanged frames} \\
55 & \text{for asymmetrically flanged frames} \\
87 & \text{for lower brackets, see } a) \text{ below:} \\
73 & \text{for asymmetrically flanged frames} \\
k = 1.0 & \text{for ordinary hull structural steel and according to 1.4.2.2 for higher tensile steel.}
\end{cases}
\]

In no instance is \( t_{REN,d/t} \) for lower integral brackets to be taken as less than \( t_{REN,d/t} \) for the frames they support.

a) Lower brackets

Lower brackets are to be flanged or face plate is to be fitted.

In calculating the web depth of the lower brackets, the following will apply:

- The web depth of lower bracket may be measured from the intersection of the sloped bulkhead of the hopper tank and the side shell plate, perpendicularly to the face plate of the lower bracket (see Fig. A.7.3).
- Where stiffeners are fitted on the lower bracket plate, the web depth may be taken as the distance between the side shell and the
A.7.3.2 Thickness measurements, steel renewal, sand blasting and coating

For the purpose of steel renewal, sand blasting and coating, four zones A, B, C and D are defined, as shown in Figure A.7.1. When renewal is to be carried out, surface preparation and coating are required for the renewed structures as given in Section 1.4.5 for cargo holds of new buildings.

Representative thickness measurements are to be taken for each zone and are to be assessed against the criteria in A.7.3.1.

When zone B is made up of different plate thicknesses, the lesser thickness is to be used for the application of the requirements in this Section.

In case of integral brackets, when the criteria in A.7.3.1 are not satisfied for zone A or B, steel renewal, sand blasting and coating, as applicable, are to be done for both zones A and B.

In case of separate brackets, when the criteria in A.7.3.1 are not satisfied for zone A or B, steel renewal, sand blasting and coating is to be done for each one of these zones, as applicable.

When steel renewal is required for zone C according to A.7.3.1, it is to be done for both zones B and C. When sand blasting and coating is required for zone C according to A.7.3.1, it is to be done for zones B, C and D.

When steel renewal is required for zone D according to A.7.3.1, it needs only to be done for this zone. When sand blasting and coating is required for zone D according to A.7.3.1, it is to be done for both zones C and D.

Special consideration may be given by the Register to zones previously renewed or re-coated, if found in “as-new” condition (i.e., without breakdown or rusting).

When adopted, on the basis of the renewal thickness criteria in A.7.3.1, in general coating is to be applied in compliance with the requirements of Section 1.4.5.2, as applicable.

Where, according to the requirements in A.7.3.1, a limited number of side frames and brackets are shown to require coating over part of their length, the following criteria apply:

a) The part to be coated includes:
   - the web and the face plate of the side frames and brackets,
   - the hold surface of side shell, hopper tank and topside tank plating, as applicable, over a width not less than 100 mm from the web of the side frame.

b) Epoxy coating or equivalent is to be applied.

In all cases, all the surfaces to be coated are to be sand blasted prior to coating application.

When flanges of frames or brackets are to be renewed according to this Section, the outstanding breadth to thickness ratio is to comply with the requirements in 17.2.5.5.

A.7.3.3 Reinforcing measures

Reinforcing measures are constituted by tripping brackets, located at the lower part and at midspan of side frames (see A.7.4). Tripping brackets may be located at every two frames, but lower and midspan brackets are to be fitted in line between alternate pairs of frames.

The thickness of the tripping brackets is to be not less than the as-built thickness of the side frame webs to which they are connected.

Double continuous welding is to be adopted for the connections of tripping brackets to the side shell frames and shell plating.

Where side frames and side shell are made of higher strength steel (HSS), normal strength steel (NSS) tripping brackets may be accepted, provided the electrodes used for welding are those required for the particular (HSS) grade, and the thickness of the tripping brackets is equal to the frame web thickness, regardless of the frame web material.

A.7.3.4 Weld throat thickness

In case of steel renewal the welded connections are to comply with requirements in 17.2.5.7.

A.7.3.5 Pitting and grooving

If pitting intensity is higher than 15% in area (see Fig. A.7.5), thickness measurement is to be taken to check pitting corrosion.

The minimum acceptable remaining thickness in pits or grooves is equal to:

- 75% of the as built thickness, for pitting or grooving in the frame and brackets webs and flanges;
- 70% of the as built thickness, for pitting or grooving in the side shell, hopper tank and topside tank plating attached to the side frame, over a width up to 30 mm from each side of it.

A.7.3.6 Renewal of all frames in one or more cargo holds and renewal of damaged frames

A.7.3.6.1 When all frames in one or more holds are required to be renewed according to this Section, the compliance with the requirements in 17.2.5 may be accepted in lieu of the compliance with the requirements in this Section, provided that:

- It is applied at least to all the frames of the hold(s)
- The coating requirements for side frames of “new ships” are complied with
- The section modulus of side frames is calculated according to the Register’s Rules.
A.7.3.6.2 In case of renewal of a damaged frame already complying with requirements of this Section, the following requirements apply:
- The conditions accepted in compliance with requirements of this Section are to be restored as a minimum.
- For localised damages, the extension of the renewal is to be carried out according to the standard Register's practice.

A.7.4 Strength check criteria

In general, loads are to be calculated and strength checks are to be carried out for the aft, middle and forward frames of each hold. The scantlings required for frames in intermediate positions are to be obtained by linear interpolation between the results obtained for the above frames.

When scantlings of side frames vary within a hold, the required scantlings are also to be calculated for the mid frame of each group of frames having the same scantlings.

The scantlings required for frames in intermediate positions are to be obtained by linear interpolation between the results obtained for the calculated frames.

A.7.4.1 Load model

The following loading conditions are to be considered:
- Homogeneous heavy cargo (density greater than 1.78 t/m³).
- Homogeneous light cargo (density less than 1.78 t/m³).
- Non homogeneous heavy cargo, if allowed.
- Multi port loading/unloading conditions need not be considered.

A.7.4.1.1 Forces

The forces \( P_{fr,a} \) and \( P_{fr,b} \), in [kN], to be considered for the strength checks at sections a) and b) of side frames (specified in Fig. A.7.2; in the case of separate lower brackets, section b) is at the top of the lower bracket), are given by:

\[
\begin{align*}
&P_{fr,a} = P_s + \max (P_1, P_2), \\
&P_{fr,b} = P_{fr,a} - 2h_B.
\end{align*}
\]

where:

\( P_s = \) still water force, \( u \) [kN],

\[
= sh \left( \frac{P_{sw} + P_{lw}}{2} \right), \text{ when the upper end of the side frame span } h \text{ (see Fig. A.7.1) is below the load water line},
\]

\[
= sh \left( \frac{P_{sw} + P_{lw}}{2} \right), \text{ when the upper end of the side frame span } h \text{ (see Fig. A.7.1) is at or above the load water line},
\]

\( P_1 = \) wave force, in [kN], in head sea,

\[
= sh \left( \frac{P_{sw} + P_{lw}}{2} \right).
\]

\( P_2 = \) wave force, in [kN], in beam sea,

\[
= sh \left( \frac{P_{sw} + P_{lw}}{2} \right).
\]

\( h, h_B = \) side frame span and lower bracket length, in [m], defined in Fig. A.7.1 and A.7.2, respectively.

\( h' = \) distance, in [m], between the lower end of side frame span and the load water line.

\( s = \) frame spacing, in [m],

\(
p_{sw}, p_{lw} = \text{ still water pressure, in [kN/m²], at the upper and lower end of the side frame span } h \text{ (see Fig. A.7.1), respectively.}
\)

\( p_{1,U}, p_{2,L} = \text{ wave pressure, in [kN/m²], as defined in A.7.4.1.2.1 below for the upper and lower end of the side frame span } h, \text{ respectively.}
\)

\( p_{2,U}, p_{2,L} = \text{ wave pressure, in [kN/m²], as defined in A.7.4.1.2.2 below for the upper and lower end of the side frame span } h, \text{ respectively.}
\)

A.7.4.1.2 Wave pressure

1) Wave pressure \( p_1 \)

- The wave pressure \( p_1 \), in [kN/m²], at and below the waterline is given by:

\[
p_1 = 1.50 \left[ p_{11} + 135 \left( \frac{B}{2(B+75)} - 1.2(d-z) \right) \right],
\]

\( p_{11} = 3k_s + k_f \).

- The wave pressure \( p_1 \), in [kN/m²], above the waterline is given by:

\[
p_1 = p_{uw} - 7.50 (z-d)
\]

2) Wave pressure \( p_2 \)

- The wave pressure \( p_2 \), in [kN/m²], at and below the waterline is given by:

\[
p_2 = 13.0 \left[ 0.5B \frac{50C_s}{2(B+75)} + C_B \frac{0.5B+k_f}{14} \left( 0.7 + \frac{2z}{d} \right) \right]
\]

- The wave pressure \( p_2 \), in [kN/m²], above the waterline is given by:

\[
p_2 = p_{2uw} - 5.0 (z-d)
\]

where:

\( p_{uw} = p_1 \) wave sea pressure at the waterline

\( p_{2uw} = p_2 \) wave sea pressure at the waterline

\( L = \) Rule length, in [m], see 1.2.3.1

\( B = \) greatest moulded breadth, in [m], see 1.2.3.2

\( C_B = \) block coefficient, see 1.2.6.1, but not to be taken less than 0.6

\( d = \) maximum design draught, in [m], see 1.2.3.4

\( C = \) coefficient, see 4.2.2

\[
= 10.75 - \left( \frac{300-L}{100} \right)^{1.5}, \text{ for } 90 \leq L \leq 300 \text{ m}
\]
\[ C_r = \frac{(1.25 - 0.025 \sqrt{GM})}{k_r} \]

\[ k = 1.2, \text{ for ships without bilge keel} \]

\[ k = 1.0, \text{ for ships with bilge keel} \]

\[ k_r = \text{roll radius of gyration. If the actual value of } k_r \text{ is not available} \]

\[ k_r = 0.39 \cdot B, \text{ for ships with even distribution of mass in transverse section (e.g. alternate heavy cargo loading or homogeneous light cargo loading)} \]

\[ k_r = 0.25 \cdot B, \text{ for ships with uneven distribution of mass in transverse section (e.g. homogeneous heavy cargo distribution)} \]

\[ GM = 0.12 \cdot B, \text{ if the actual value of } GM \text{ is not available} \]

\[ z = \text{vertical distance, in [m], from the baseline to the load point} \]

\[ k_s = \frac{C_B + 0.83}{C_B}, \text{ at aft end of } L \]

\[ = C_s, \text{ between 0.2L and 0.6L, from aft end of } L \]

\[ = \frac{1.33}{C_B}, \text{ at forward end of } L. \]

Between the above specified points, \( k_s \) is to be interpolated linearly.

\[ k_f = 0.8 \cdot C. \]

### A.7.4.2 Allowable stresses

The allowable normal and shear stresses \( \sigma_a \) and \( \tau_a \), in [N/mm²], in the side shell frames and brackets are given by:

\[ \sigma_a = 0.9 \cdot \sigma_y \]

\[ \tau_a = 0.4 \cdot \sigma_y \]

where \( \sigma_y \) is the minimum upper yield stress, in [N/mm²], of the material.

### A.7.4.3 Shear strength check

Where \( t \) in the lower part of side frames, as defined in Fig. A.7.1, is equal to or less than \( t_{90\text{deg}} \), shear strength check is to be carried out in accordance with the following.

The thickness \( t_{\text{REN,Sa}} \), in [mm], is the greater of the thicknesses \( t_{\text{REN,SA}} \) and \( t_{\text{REN,SB}} \) obtained from the shear strength check at sections a) and b) (see Fig. A.7.2 and A.7.4.1) given by the following, but need not be taken in excess of 0.75 \( t_{90\text{deg}} \).

\[ t_{\text{REN,SA}} = \frac{1000 \ k_s \ P_{fr,a}}{d_a \sin \phi \ \tau_a} \]

- at section b):

\[ t_{\text{REN,SB}} = \frac{1000 \ k_s \ P_{fr,b}}{d_b \sin \phi \ \tau_a} \]

where:

\[ k_s = \text{shear force distribution factor, to be taken equal to 0.6} \]

\[ P_{fr,a}, P_{fr,b} = \text{pressure forces defined in A.7.4.1} \]

\[ d_a, d_b = \text{bracket and frame web depth, in [mm], at sections a) and b), respectively (see Fig. A.7.2); in case of separate (non integral) brackets, } d_b \text{ is to be taken as the minimum web depth deducing possible scallops} \]

\[ \phi = \text{angle between frame web and shell plate} \]

\[ \tau_a = \text{allowable shear stress, in [N/mm²], defined in A.7.4.2.} \]

### A.7.4.4 Bending strength check

Where the lower bracket length or depth does not meet the requirements in 17.2.5.4, the actual section modulus, in [cm³], of the brackets and side frames at sections a) and b) is to be not less than:

- at section a):

\[ Z_a = \frac{1000 P_{fr,a} \ h}{m_a \sigma_a} \]

- at section b):

\[ Z_b = \frac{1000 P_{fr,a} \ h}{m_b \sigma_a} \]

where:

\[ P_{fr,a} = \text{pressure forces defined in A.7.4.1} \]

\[ h = \text{side frame span, in [m], see Fig. A.7.1} \]

\[ \sigma_a = \text{allowable normal stress, in [N/mm²], defined in A.7.4.2} \]

\[ m_a, m_b = \text{bending moment coefficients defined in Table A.7.2.} \]
Table A.7.2  Bending moment coefficients \( m_a \) and \( m_b \)

<table>
<thead>
<tr>
<th></th>
<th>( m_a )</th>
<th>( m_b )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( h_b = 0.08 \cdot h )</td>
<td>( h_b = 0.1 \cdot h )</td>
</tr>
<tr>
<td>Empty holds of ships approved to operate in non homogeneous loading conditions</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>Other cases</td>
<td>12</td>
<td>20</td>
</tr>
</tbody>
</table>

Note 1: Non homogeneous loading condition means a loading condition in which the ratio between the highest and the lowest filling ratio, evaluated for each hold, exceeds 1.20 corrected for different cargo densities.

Note 2: For intermediate values of the bracket length \( h_b \), the coefficient \( m_b \) is obtained by linear interpolation between the table values.

The actual section modulus of the brackets and side frames is to be calculated about an axis parallel to the attached plate, based on the measured thicknesses. For precalculations, alternative thickness values may be used, provided they are not less:

- \( t_{REN} \), for the web thickness
- the minimum thicknesses allowed by the Register’s renewal criteria for flange and attached plating.

The attached plate breadth is equal to the frame spacing, measured along the shell at midspan of \( h \).

If the actual section moduli at sections a) and b) are less than the values \( Z_a \) and \( Z_b \), the frames and brackets are to be renewed or reinforced in order to obtain actual section moduli not less than 1.2 \( Z_a \) and 1.2 \( Z_b \), respectively.

In such a case, renewal or reinforcements of the flange are to be extended over the lower part of side frames, as defined in Fig. A.7.1.
Figure A.7.1

Figure A.7.2

Figure A.7.3

200 RULES FOR THE CLASSIFICATION OF SHIPS

PART 2

2020
Figure A.7.4

- Tripping bracket not welded to frame flange
- Distance from knuckle not greater than 200 mm

Figure A.7.5

- 5% SCATTERED
- 10% SCATTERED
- 15% SCATTERED
- 20% SCATTERED
- 25% SCATTERED
A.8  RESTRICTIONS FROM
SAILING WITH ANY HOLD EMPTY
FOR BULK CARRIERS (SOLAS 1974,
CH. XII, REG. 14)

A.8.1  Bulk carriers of 150 m in length and upwards of
single-side skin construction, if not meeting:

- the requirements in regulation 5.1 of the SOLAS
  1974, Ch. XII, and Section 17.2.4.4 of these Rules,
  respectively (for withstanding flooding of any one
cargo hold); and

- criteria for side structures of bulk carriers of single-
side skin construction as defined in Section 17.2.5
(IACS UR S12, Rev. 2.1 or subsequent revisions) or
Annex A.7 (UR S31),

where carry cargoes having a density of 1.78 t/m$^3$ and above
shall not sail with any hold loaded to less than 10% of the
hold's maximum allowable cargo weight when in the full load
condition.

A.8.2  The applicable full load condition for this regu-
lation is a load equal to or greater than 90% of the ship's
deadweight at the relevant assigned freeboard.

A.8.3  This requirement is applicable to bulk carriers
from 1st July 2006 or the date on which the ship reaches 10
years of age, whichever is later.

Note: Bulk carriers constructed before 1st July 1999 not
meeting the requirements in regulation 5.1 of the SOLAS
1974, Ch. XII.

A.8.4  Restrictions imposed by Regulation 14 of the
SOLAS 1974, Ch. XII, shall be identified and recorded in the
ship's booklet (Loading Manual).

A.8.5  In accordance with Reg. 8.3 of the SOLAS
1974, Ch. XII, a bulk carrier to which requirement A.8.4
applies shall be permanently marked on the side shell at mid-
ships, port and starboard, with a solid equilateral triangle.

Triangle having sides of 500 mm and its apex
300 mm below the deck line, and painted a contrasting colour
to that of the hull.
ANNEX B ADDITIONAL REQUIREMENTS FOR OIL TANKERS OF 130 M IN LENGTH AND UPWARDS AND OF OVER 10 YEARS OF AGE

B.1 CRITERIA FOR LONGITUDINAL STRENGTH OF HULL GIRDER FOR OIL TANKERS

B.1.1 General

B.1.1.1 These criteria is to be used for the evaluation of longitudinal strength of the hull girder of oil tankers of 130 m in length and upwards and of over 10 years of age.

B.1.1.2 In order that ship’s longitudinal strength to be evaluated can be recognized as valid, fillet welding between longitudinal internal members and hull envelopes is to be in sound condition so as to keep integrity of longitudinal internal members with hull envelopes.

B.1.2 Evaluation of longitudinal strength

On oil tankers of 130 m in length and upwards and of over 10 years of age, the longitudinal strength of the ship’s hull girder is to be evaluated in compliance with the requirements of this Section on the basis of the thickness measured, renewed or reinforced, as appropriate, during the special survey.

B.1.2.1 Calculation of transverse sectional areas of deck and bottom flanges of hull girder

B.1.2.1.1 The transverse sectional areas of deck flange (deck plating and deck longitudinals) and bottom flange (bottom shell plating and bottom longitudinals) of the ship’s hull girder is to be calculated by using the thickness measured, renewed or reinforced, as appropriate, during the special survey.

B.1.2.1.2 If the diminution of sectional areas of either deck or bottom flange exceeds 10% of their respective as-built area (i.e. original sectional area when the ship was built), either one of the following measures is to be taken:

1. to renew or reinforce the deck or bottom flange so that the actual sectional area is not less than 90% of the as-built area; or
2. to calculate the actual section moduli \(W_{act}\) of transverse section of the ship’s hull girder by applying the calculation method specified by paragraph B.1.3, by using the thickness measured, renewed or reinforced, as appropriate, during the special survey.

B.1.2.2 Requirements for transverse section moduli of hull girder

B.1.2.2.1 The actual section moduli of transverse section of the ship’s hull girder calculated in accordance with the foregoing paragraph B.1.2.1.2.2 is to satisfy either of the following provisions, as applicable:

1. for ships constructed on or after 1 July 2002, the actual section moduli \(W_{act}\) of the transverse section of the ship's hull girder calculated in accordance with the requirements of the foregoing paragraph B.1.2.1.2.2 should not to be less than the diminution limits determined by the Register *; or
2. for ships constructed before 1 July 2002, the actual section moduli \(W_{act}\) of the transverse section of the ship's hull girder calculated in accordance with the requirements of the foregoing paragraph B.1.2.1.2.2 is to meet the criteria for minimum section modulus for ships in service required by the Register, provided that in no case \(W_{act}\) is to be less than the diminution limit of the minimum section modulus \(W_{oc}\) as specified by paragraph B.1.4.

B.1.3 Calculation criteria of section moduli of midship section of hull girder

B.1.3.1 When calculating the transverse section modulus of the ship’s hull girder, the sectional area of all continuous longitudinal strength members is to be taken into account.

B.1.3.2 Large openings, i.e. openings exceeding 2.5 m in length or 1.2 m in breadth and scallops, where scallop welding is applied, are always to be deducted from the sectional areas used in the section modulus calculation.

B.1.3.3 Smaller openings (manholes, lightening holes, single scallops in way of seams, etc.) need not be deducted provided that the sum of their breadths or shadow area breadths in one transverse section does not reduce the section modulus at deck or bottom by more than 3% and provided that the height of lightening holes, draining holes and single scallops in longitudinals or longitudinal girder does not exceed 25% of the web depth, for scallops maximum 75 mm.

B.1.3.4 A deduction-free sum of smaller opening breadths in one transverse section in the bottom or deck area of \(0.06(B - 2\Delta b)\) (where \(B =\) breadth of ship, \(2\Delta =\) total breadth of large openings) may be considered equivalent to the above reduction in sectional modulus.

B.1.3.5 The shadow area will be obtained by drawing two tangent lines with an opening angle of 30°.

B.1.3.6 The deck area will be obtained by drawing two tangent lines with an opening angle of 30°.

B.1.3.7 The bottom modulus is related to the moulded deck line at side.

B.1.3.8 Continuous trunks and longitudinal hatch coamings are to be included in the longitudinal sectional area provided they are effectively supported by longitudinal bulk-

* The actual transverse section modulus of the hull girder of oil tankers calculated under paragraph B.1.2.2.1.1 of this Section is not to be less than 90% of the required section modulus for new buildings specified in IACS Unified Requirements S7** or S11 (see also paragraphs 4.3.2 and 4.3.4 of these Rules), whichever is the greater.

** \(C = 1.0 - C_w\) is to be used for the purpose of this calculation.
heads or deep girders. The deck modulus is then to be calculated by dividing the moment of inertia by the following distance, provided this is greater than the distance to the deck line at side:

\[
y_\gamma = y \left( 0.9 + 0.2 \frac{x}{B} \right)
\]

where:
- \(y\) = distance from neutral axis to top of continuous strength member,
- \(x\) = distance from top of continuous strength member to centreline of the ship.
- \(x\) and \(y\) to be measured to the point giving the largest value of \(y_\gamma\).

B.1.3.9 Longitudinal girders between multi-hatchways will be considered by special calculations.

B.1.4 Diminution limit of minimum longitudinal strength of ships in service

B.1.4.1 The diminution limit of the minimum section modulus, \(W_{mc}\), of oil tankers in service is given by the following formula:

\[
W_{mc} = CL^2 B (C_b + 0.7) \cdot k \quad [\text{cm}^3]
\]

where:
- \(L\) = Rule length of ship, in [m], as defined in 1.2.3.1.
- \(B\) = greatest moulded breadth, in [m], as defined in 1.2.3.2.
- \(C_b\) = moulded block coefficient, as defined in 1.2.6.1. \(C_b\) is not to be taken less than 0.60.
- \(C = 0.9 \cdot C_w\)
- \(C_w = 10.75 \cdot \left( \frac{300 - L}{100} \right)^{1.5}\) for 130 m \(\leq L \leq 300\) m;
- \(C_w = 10.75 \cdot \left( \frac{L - 350}{150} \right)^{1.5}\) for 350 m \(\leq L \leq 500\) m;
- \(k\) = material factor, e.g.:
  - \(k = 1.0\), for mild steel with yield stress of 235 N/mm² and over,
  - \(k = 0.78\), for high tensile steel with yield stress of 315 N/mm² and over,
  - \(k = 0.72\), for high tensile steel with yield stress of 355 N/mm² and over.

B.1.4.2 Scantlings of all continuous longitudinal members of the ship’s hull girder based on the section modulus requirement of paragraph B.1.4.1 above are to be maintained within 0.4\(L\) amidships. However, in special cases, based on consideration of type of ship, hull form and loading conditions, the scantlings may be gradually reduced towards the end of 0.4\(L\) part, bearing in mind the desire not to inhibit the ship’s loading flexibility.

B.1.4.3 However, the above standard may not be applicable to ships of unusual type or design, e.g. for ships of unusual main proportions and/or weight distributions.

B.2 EVALUATION RESULT OF LONGITUDINAL STRENGTH OF THE HULL GIRDER OF OIL TANKERS

B.2.1 This section applies to ships regardless of the date of construction:

Transverse sectional areas of deck flange (deck plating and deck longitudinals) and bottom flange (bottom shell plating and bottom longitudinals) of the ship’s hull girder have been calculated by using the thickness measured, renewed or reinforced, as appropriate, during the special survey most recently conducted after the ship reached 10 years of age, and found that the diminution of the transverse sectional area does not exceed 10% of the as-built area, as shown in the Table 1:

<table>
<thead>
<tr>
<th>Transverse sectional area of hull girder flange</th>
<th>Measured [cm²]</th>
<th>As-built [cm²]</th>
<th>Diminution [cm²] or [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Section 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deck flange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom flange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse Section 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deck flange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom flange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse Section 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deck flange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom flange</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B.2.2 This section applies to ships constructed on or after 1 July 2002:

Section moduli of transverse section of the ship’s hull girder have been calculated by using the thickness of structural members measured, renewed or reinforced, as appropriate, during the special survey most recently conducted after the ship reached 10 years of age in accordance with the provisions of paragraph B.1.2.2.1.1 of this Section, and are found to be within their diminution limits determined by the Register *, as shown in the Table 2:

<table>
<thead>
<tr>
<th>Transverse sectional area of hull girder flange</th>
<th>Measured [cm²]</th>
<th>As-built [cm²]</th>
<th>Diminution [cm²] or [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Section 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deck flange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom flange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse Section 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deck flange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom flange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse Section 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deck flange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom flange</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2

<table>
<thead>
<tr>
<th>Transverse Section</th>
<th>Upper deck</th>
<th>Bottom</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The actual transverse section modulus of the hull girder of oil tankers calculated under paragraph B.1.2.2.1.1 of this Section is not to be less than 90% of the required section modulus for new buildings specified in IACS Unified Requirements S7* or S11 (see also paragraphs 4.3.2 and 4.3.4 of these Rules), whichever is the greater.

Notes:
*1 $W_{act}$ means the actual section moduli of the transverse section of the ship’s hull girder calculated by using the thickness of structural members measured, renewed or reinforced, as appropriate, during the special survey, in accordance with the provisions of paragraph B.1.2.2.1.1.

*2 $W_{req}$ means diminution limit of the longitudinal bending strength of ships, as calculated in accordance with the provisions of paragraph B.1.2.2.1.1 of this Section.

The calculation sheets for $W_{act}$ are to be attached to this report.

B.2.3 This section applies to ships constructed before 1 July 2002:

Section moduli of transverse section of the ship’s hull girder have been calculated by using the thickness of structural members measured, renewed or reinforced, as appropriate, during the special survey most recently conducted after the ship reached 10 years of age in accordance with the provisions of paragraph B.1.2.2.1.2 of this Section, and found to meet the criteria required by the Register and that $W_{act}$ is not less than $W_{mc}$ (defined in *2 below) as specified in paragraph B.1.4.1, as shown in the Table 3:

Table 3

<table>
<thead>
<tr>
<th>Transverse Section</th>
<th>Upper deck</th>
<th>Bottom</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
*1 As defined in note *1 of Table 2.
*2 $W_{mc}$ means the diminution limit of minimum section modulus calculated in accordance with provisions of paragraph B.1.2.2.1.2 of this Section.

Describe the criteria for acceptance of the minimum section modulus of the ship’s hull girder for ships in service required by the Register.
ANNEX C  WATER LEVEL DETECTORS ON SINGLE HOLD CARGO SHIPS OTHER THAN BULK CARRIERS (SOLAS 1974, CH. II-1, REG. 25)

C.1.1 Single hold cargo ships other than bulk carriers constructed before 1 January 2007 shall comply with the requirements of this regulation not later than the date of the first intermediate or renewal survey of the ship to be carried out after 1 January 2007, whichever comes first.

C.1.2 For the purpose of this regulation, freeboard deck has the meaning defined in the International Convention on Load Lines, 1996, as amended.

C.1.3 Ships having a length \( L \) of less than 100 m if constructed before 1 July 1998, and a single cargo hold below the freeboard deck or cargo holds below the freeboard deck which are not separated by at least one bulkhead made watertight up to that deck, shall be fitted in such space or spaces with water level detectors*.

C.1.4 The water level detectors required by paragraph C.1.3 shall:

1. give an audible and visual alarm at the navigation bridge when the water level above the inner bottom in the cargo hold reaches a height of not less than 0.3 m, and another when such level reaches not more than 15% of the mean depth of the cargo hold; and

2. be fitted at the aft end of the hold, or above its lowest part where the inner bottom is not parallel to the designed water-line. Where webs or partial watertight bulkheads are fitted above the inner bottom, Administrations may require the fitting of additional detectors.

C.1.5 The water level detectors required by paragraph C.1.3 need not be fitted in ships complying with regulation XII/12, or in ships having watertight side compartments each side of the cargo hold length extending vertically at least from inner bottom to freeboard deck.

C.1.6 For application of these requirements see also IACS Unified Interpretation SC 180.

* Refer to the Performance standards for water level detectors on bulk carriers and single hold cargo ships other than bulk carriers, adopted by the Maritime Safety Committee by resolution MSC.188(79).
ANNEX D  GUIDELINES FOR DIRECT CALCULATIONS OF SHIP STRUCTURE

D.1  BASIC GUIDELINES FOR DIRECT CALCULATION OF SHIP STRUCTURES

D.1.1  General

The objective of this Appendix to the Rules is to provide basic guidelines and instructions for application of direct calculations to ship structural response and feasibility (measured by adequacy criteria/parameters).

Direct calculation consists of the following steps, see also Figure D.1.1:

1. detailed determination of calculation objective: preliminary or final control of adequacy, modelling of part or total structure, type of analysis (linear or non-linear response analysis) and approach for determination of loads,
2. selection of static, quasi-static and dynamic loads on structure resulting from the Rules, model testing or direct calculation (seakeeping program),
3. modelling of the structure by the finite element method (FEM) for response calculation,
4. determination of force and displacement boundary conditions,
5. response calculation (displacements and stresses) and definition of demand (design loads or critical response to design loads),
6. capability calculation,
7. control of adequacy criteria (plasticity, buckling, fatigue) by relating obtained response to design loads and requested structural capability in accordance with the Rules, evaluation of adequacy measures and proposals for structural modifications.

D.1.2  Types and extent of response analysis by the finite element method

D.1.2.1  Requested types of analysis for approval of the ship's structure by direct calculation

D.1.2.1.1  Response analysis by linear fem analysis

This type of analysis implies small displacements and linear elastic behaviour of material. For most structural elements this analysis provides correct response to design loads.

D.1.2.1.2  Response analysis by non-linear fem and 'linear' buckling

1. Geometrically non-linear FEM analysis is applied for relatively flexible structures with large displacements and buckling of structural parts, that cannot be comprised by the analytical calculations or formulae for buckling, respectively.
2. Materially non-linear FEM analysis assumes structural calculations in plastic domain.
3. Hull girder ultimate strength analysis (according to incremental-iterative method prescribed by the Rules) in order to determine hull girder longitudinal ultimate load-capacity in terms of the ultimate vertical bending moment that could be sustained at the position of the critical transverse section.

Most non-linear FEM buckling analyses occur within elastic-plastic domains and consequently both types of non-linearities shall be included into FEM models.

The present guideline deals with direct calculation within linear FEM response analysis and with non-linear calculation of feasibility (adequacy) criteria by analytical methods e.g. ultimate strength on element level (plate, stiffened plate, beam, etc).

Non-linear FEM analysis shall be specially required in case of non-compliance with the requirements in D.1.2.1.1.

D.1.2.2  Extent of analysis

Depending on the objective of the analysis and in order to avoid too excessive FEM models, direct calculation may be performed by combining different FEM models having appropriate mesh density (coarse mesh/fine mesh/very fine mesh), see Table D.1.2.2.

<table>
<thead>
<tr>
<th>Model</th>
<th>Type of model</th>
<th>Type of mesh</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2-D FEM transverse section models (eg. midship s.)</td>
<td>coarse or fine mesh</td>
<td>2.1.3</td>
</tr>
<tr>
<td>B</td>
<td>2-D FEM grillage model and other 2D sub-structures</td>
<td>coarse or fine mesh</td>
<td>2.1.4</td>
</tr>
<tr>
<td>C</td>
<td>3-D FEM model e.g. 3-hold model</td>
<td>coarse or fine mesh</td>
<td>2.1.5</td>
</tr>
<tr>
<td>D</td>
<td>3-D FEM full ship model</td>
<td>coarse mesh</td>
<td>2.1.6</td>
</tr>
<tr>
<td>E</td>
<td>2-D/3-D FEM structural components model</td>
<td>fine and very fine mesh</td>
<td>2.1.7</td>
</tr>
</tbody>
</table>

Force and/or displacement boundary conditions for model (E) may be obtained from model (A) – (D).

Definition for density of fine and coarse mesh is given in D.2.1.5.2 and definition for very fine mesh is given in D.2.1.7.3.

Levels of calculation, based on extent of the analysis, are given in Figure D.1.2.2-1.

1) Refers to the Rules for the Classification of Ships, Part 2 – Hull
Figure D.1.1  Direct calculation procedure
Figure D.1.2.2-1  Levels of direct calculation execution

Figure D.1.2.2-2 shows the following LEVEL 2 local tanker models:
- 3-D FEM 3-hold models – fine/coarse mesh
- Corrugated bulkhead structure details – very fine mesh

Global model – fine/coarse mesh

Very fine mesh models

Figure D.1.2.2-2  Various FEM models for the calculation of tanker structure
D.1.3 Theoretical assumptions and superposition of responses

D.1.3.1 Primary response - D1 (hull girder bending and torsion) may be calculated by:
   .1 extended beam theory
   .2 full ship 3-D FEM model.

Distribution of bending moments and shear forces in transverse sections due to the hull girder bending is to be obtained from the standard calculation of longitudinal strength.

Distribution of primary shear and normal stresses obtained from beam model is to be applied as imposed force (stress) boundary conditions for partial 3-D FEM models.

D.1.3.2 Secondary response - D2 (combined plate and girder bending) may be calculated by:
   .1 eccentric beam element combined with adjoin plate elements,
   .2 2-D (grillage, frame) or 3-D FEM beam model. Hybrid beam element (beam macro-element) is used with effective plate widths, as specified in the Rules.
   .3 3-D FEM model (stiffened or standard membranes, plates, shells).

Shear correction is to be applied with beam element.

D.1.3.3 Tertiary response - D3 (local stresses due to bending of longitudinals or plating between longitudinals) are to be calculated by:
   .1 analytical methods (e.g. beam and/or plate bending theory),
   .2 FEM methods (fine or very fine mesh of finite elements).

D.1.3.4 In the case of response calculations in linear domain, superposition of all three response levels may be applied. Superposition may be carried out:
   .1 directly – by using special macro-elements
   .2 by superimposing the results of separate calculations (D.1.3.1-D.1.3.3).

D.1.4 As built and net scantlings of structural elements

D.1.4.1 All calculations are performed on the basis of 'net'element thickness without corrosion addition.

D.1.4.2 If modelling of the structure is performed by means of 'as built’ dimensions, the applied computing program is to include option for automatic deduction of corrosion additions, as specified in the Rules, 2.9.

D.1.5 Requested documentation and form of report

D.1.5.1 Documentation to be submitted to the Register for approval is to include as follows:
   .1 list of documentation used for structural model development and determination of loads,
   .2 main ship's particulars,
   .3 detailed description of FEM model, including:
      - element types,
      - explanation of imposed assumptions and simplifications,
      - explanation of differences related to drawings of structures,
   .4 characteristics of used materials,
   .5 definitions of the displacement and force (stress) boundary conditions,
   .6 visual verification of FEM model (sufficient number of model views),
   .7 description of selected loading conditions including relevant Q and M diagrams,
   .8 design load cases and load components, including:
      - distribution of cargo and structure mass,
      - external hydrostatic and hydrodynamic loads,
      - loads due to cargo in tanks or on decks,
      - loads due to ship’s motion,
      - loads due to wave bending moments and wave shear forces,
      - other loads,
   .9 presentation of load components implemented into the FEM model and verification of accuracy of applied loads (values of reaction forces, etc.),
   .10 graphical plot of deformed structure, verification of physical acceptability of model displacements, table of significant displacements,
   .11 graphical plot of normal, shear and equivalent stresses of all structural elements for control of element adequacy with respect to the allowable stresses as specified in the Rules,
   .12 graphical plot or table of the results of buckling control of structural elements in accordance with the Rules (realised safety factor),
   .13 table or plot of locations, load cases (demands), capability values and adequacy factors (for yielding, buckling, etc) where the Rules requirements are not satisfied,
   .14 additional comments of results and proposals for revision,
   .15 description and licence of applied software.

Consultation with the Register (considering the given requirements) is recommended prior to commencement of works to ensure quality and efficiency of direct calculation procedure.

D.1.5.2 Application of alternative methods, not complying with principles of the subject Guidelines, shall be separately considered.
D.2 FEM STRUCTURAL MODELS

D.2.1 FEM models (A-E) and determination of the displacement boundary conditions

D.2.1.1 Structural model

Model is to enable physically acceptable distribution of displacements and stresses in the structure by applying appropriate mesh density and element types.

Finite element stress distribution (dependent on the applied shape functions) is the basis for determination of the number of elements necessary to approximate physically acceptable distribution of response.

Example: Three rows of elements along the depth of the girder web (with constant stresses along the element edges) may approximate linearly varying distribution of stresses for bending of girder web. The same may be also obtained by one beam element, but only outside the influence of brackets.

Macro-elements (e.g. finite elements incorporating discrete stiffeners on the plate field) can also be used as structural units in coarse mesh models, combining numerical and analytical approaches to the logical substructures such as stiffened panels, bracketed and locally reinforced girders, cells, etc. Most of the local safety (or failure) criteria, e.g. different buckling failure modes of stiffened panels, require specified force and displacement boundary conditions. They are available only if such logical structural parts as the complete stiffened panels between girders and frames are modeled (CRS CREST).

The macro-element formulation is based upon the following principles:

(a) enhancing of the number of standard finite element descriptors (geometry, scantlings, material) with additional structural details (brackets, stiffeners, etc.) whose energy absorption is dependent on the basic element shape functions.

(b) combining of FEM-calculated displacement and stress fields with superimposed analytically calculated local fields (e.g. tertiary stresses in the plate field between stiffeners).

(c) assuring that response fields ad (a) and (b) are sufficient for the evaluation of the subset of local adequacy criteria. If we define the failure element as the minimal structural model capable of supporting certain failure functions, then the macro-element provides such support for most of the yield, buckling, local vibration or fatigue criteria.

(d) If they are formulated as iso-parametric elements they can easily follow the ship hull shape, or be stable elements in different geometrical changes.

Available macro-elements in CRS CREST software are:

1. bracketed beam macro-element permitting modeling of brackets on beams. It is obtained by combining the axial super-element and the beam with rigid length (replaces brackets).

2. stiffened panel macro-element is obtained by placing discrete stiffeners on a displacement field of a membrane and of a plate.

Depending on the objective of the analysis, direct calculation may be performed by combination of different FEM models mentioned in D.1.2.2 and Table D.1.2.2. Basic aspects of modelling, for all defined models, are described in this section.

D.2.1.2 Definition of coordinate system

For all models specified in the present Guidelines the global right-hand Cartesian coordinate system is defined as follows:

X-axis is a base line in the ship's longitudinal plane of symmetry, positive forward.

Y-axis is lying in the ship's longitudinal plane of symmetry, positive upwards from the base line.

Z-axis is perpendicular to the ship's longitudinal plane of symmetry, positive to starboard.

Displacements in X direction are denoted as $u$.

Rotations about X axis are denoted as $\theta_x$.

Displacements in Y direction are denoted as $v$.

Rotations about Y axis are denoted as $\theta_y$.

Displacements in Z direction are denoted as $w$.

Rotations about X axis are denoted as $\theta_z$.

D.2.1.3 2-D FEM transverse sections models–model A

The models are to provide:

- calculation of primary stress distribution for bending and torsion of the hull girder,

- calculation of secondary structural response of the transverse girders with attached plating for the web frame considered,

- analysis of secondary response for the racking cases.

In principle, full transverse section of hull is modelled. However, for symmetrical sections, only a half section, taking account of relevant boundary conditions, may be modeled. Examples of coarse mesh models are given in Figure D.2.1.3.
D.2.1.3.1 Application: calculation of the primary response distribution for the hull cross-section

The calculation is to be applied for:
- determination of warping and primary stresses (normal, shear) in the hull girder cross-section for control of permissible levels of stresses/displacements, see Rules, 4.5.3,
- determination of the force boundary conditions (distribution of stresses) in cross-sections of the partial 3D-FEM hull models.

In calculation of the ship's hull primary response, appropriate type (A-D) of FEM model is to be selected together with the appropriate calculation method:
- where hull girder beam idealisation is applicable, the combination of 1D hull global beam model (analytical or FEM) and 2D FEM model of the characteristic hull cross sections (model A) may be used. Note: this model is used in CREST CRS computing system [2].
- where decks are partially effective in the longitudinal strength calculations (e.g. multi-deck passenger ships) or where major yielding of upper decks is likely to occur, the calculations are to be specially considered. In such a case CRS may require 3-D FEM model with adequate hull length (model C) or full ship model (model D).

Check of stresses and warping are to be carried out at the following sections:
- position of maximum bending moment – midship section (1/2 L),
- position of maximum shear force – (1/4L and 3/4L),
- any other specific position.

For the stress calculation due to bending and torsion including torsion/shear centre calculation for simpler transverse sections, analytical method of shear stresses flows may be applied, but numerical approach based on FEM is recommended (see computing system CREST CRS, ref.[2]).

Finite elements mesh to be used for the calculation of shear flow is to enable determination of parabolic distribution of shear stresses over the section by means of:
- sufficiently dense mesh of simple elements (constant shear by element),
- correction of shear flow by element for greater elements (parabolic shear distribution by element).

Standard finite (line) elements have one degree of freedom by node (section warping) and accordingly assure constant shear stresses by element (see computing system CREST CRS providing parabolic distribution, ref. [2]).

Only longitudinally effective hull material is to be taken into the calculation. In this case, “shadow area rule” may be applied, see Rules, 4.3.1.3, relating to determination of material efficiency abait the hatches, shell plating openings or partially longitudinal elements (e.g. partial longitudinal bulkheads, hatch coamings).

Within the area of major bending moment and/or transverse force locations normal stresses are to be corrected to the influence of shear stresses for reaching maximum stresses within critical areas of sheer strake and deck stringer.

As to the matter of hull “open” section torsion with restrained warping the twist angles and appropriate derivations may be calculated by analytical approach [3] or by finite beam element method [4].

D.2.1.3.2 Application in the calculations of secondary stresses (Transverse strength)

Direct calculation of web frame for control of transverse strength is to be performed with the following sections:
- minimum stiffness sections – hatchway section,
- maximum local load sections,
- midship section.

Assumption for the calculation is so called “cylindrical bending” of the hull segment represented by given web frame. With 2D idealisation other 3D effects of the remaining ship’s structure to bending of web frame are to be considered and consequently relevant boundary conditions are to be generated.

FEM model is to include all relevant transverse structural components (floors, beams, frames, pillars, solid web frames) within a concerned section. Modelling of actual stiffness of frames is to be performed with sufficient accuracy and used finite elements are to properly present distribution of stresses within structural components (e.g. linear varying stress distribution over the girder depth).

Macroelements of stiffened membrane plate may be used for modelling floors with local stiffeners or high web girders.
Membrane elements with linear (or higher order) distribution of normal stresses along the edge may represent solid girder web, while face plates may be modelled by rod elements of equivalent section area.

Frames and beams are mostly modelled by beam finite (macro) elements, for which validity of the beam theory may be assumed. Pillars are modelled by rod elements.

Beam joint brackets (e.g. bracketed joint of beam and frame) are to be modelled by means of beam macro-elements with rigid ends. Shear correction of beam elements is to be included.

Type of beam FE element to be used is to be specified (hybrid, eccentric).

As a segment supporting modelled web usually web frame spacing is to be taken, from which follows the definition of load width and effective breadth of longitudinal strength elements, included in the transverse bending, see Rules 2.5.

The effect of longitudinal structure supporting considered frame within the hold and/or space is to be accurately determined, as follows:

- bending and shear stiffness of longitudinal elements (double bottom girders, longitudinal bulkheads etc.) supporting transverse girder at the relevant node, is modelled with spring or rod elements of equivalent stiffness,
- stiffness of structural components taken as closed boxes (e.g. hopper side tanks and topside tanks) is modelled by spring system of equivalent bending and torsion stiffness (see computing system CREST CRS)

D.2.1.4 Application in the calculations of grillage response and other 2D sub-structures – model B

These models are used in cases when it is possible to describe correctly the boundary conditions at their edges and/or sections to the remaining structural part (simply supported, clamped, partially clamped, symmetry conditions).

Typical usage of these models is applied with secondary response calculation of ship's girder system attached to the plating, e.g. for calculations of ship's grillage (bottom, decks, double side, bulkheads, etc.).

Where concept of effective breadth is applied for the plating, models are to be built with beam elements and nodes in system neutral axis. Shear effect to the girder deflection is to be included and effective breadth is to be calculated in accordance with Rules, 2.5.

When beam flange/plating is modelled with membrane/plate elements, beam elements are to have correction for eccentricity of beam-only centre of gravity in relation to the beam toe (with plating connection) where FEM idealisation 2D structure nodes are located.

D.2.1.5 3-D FEM partial hull models- model C

The present models are intended for performing the calculation of primary and secondary response by FEM with:

- ship's hull girder bending,
- ship's torsion,
- response analysis in case of ship's racking

Tertiary response may be calculated analytically and then superimpose to primary and secondary response.

Structural model is to enable correct application of design load cases (e.g. alternative loading).

These models can generate the displacement boundary conditions for direct calculations of structural details through very fine FEM meshes using top-down approach, see D.2.1.7.

D.2.1.5.1 Hull structural part to be modeled, is determined as follows:

- for tankers: three holds within cargo space inside the parallel midbody, see Figure D.2.1.5.1-1
- for bulk carriers: three holds within cargo space midbody, see Figure D.2.1.5.1-2
- for other types of ships on agreement with the Register.

The model is also to include additional ring of web frame spacing fore and aft the end transverse bulkheads.

Smaller partial models (1/2+1+1/2 hold) will be specially considered in the terms of the model boundary conditions effect to the stress field of the considered structural part.

Calculation results are considered relevant only for the central hold and/or space.

In case the structure in fore or aft part essentially differs from the modelled space, necessity of additional models or extension of existing model is to be considered with the Register.

In case of transversely symmetric structure (symmetric with respect to C.L.) only one side of the structure is to be modelled or half model, respectively. For such models, the following is to be applied:

- In case the asymmetric load is considered computing program is to be designed for distribution of load to the symmetric component ((port side load + starboard side load)/2) and antisymmetric component ((port side load – starboard side load)/2).
- If the computing program is not designed for such option, both structural sides are to be modelled, although the ship is structurally symmetric.
Figure D.2.1.5.1-1  3-D FEM partial tanker hull model

Figure D.2.1.5.1-2  3-D FEM partial bulk carrier hull model
D.2.1.5.2 3-D FEM model mesh density

(a) macroelement based coarse mesh:
- longitudinally: max two (2) macroelement of framed shell between web frames where secondary framing (longitudinals) is included into model,
- transversely: sufficient density of macroelements (membranes, beams) for ensuring correct stress response field by the elements, see D.2.1.3.2,
- vertically: one (1) macroelement over the floor depth, see D.2.1.3.2.

(b) finite elements based fine mesh:
- transversely: one element between stiffeners,
- longitudinally: two (2) elements between web frames,
- vertically: three (3) elements over the floor depth,
- stiffeners may be modelled by applying 1D element type (rod, beam).

In places where stress concentration is expected to occur, meshes specified in (a) are to provide more precise fineness additionally to the level of meshes specified in (b), in order to ensure more accurate boundary conditions for FEM models with very fine mesh, see D.2.1.7.

D.2.1.5.3 Displacement boundary conditions

D.2.1.5.3.1 Displacement boundary conditions are prescribed values of degrees of freedom in the nodes within the model section with the remaining structure or within specific given nodes or physical supports, respectively.

Force boundary conditions are given in those section nodes (ring free edge) for which the displacement boundary conditions are not imposed.

Displacement boundary conditions are to suppress model displacements as rigid body (translations and rotations).

Displacement boundary conditions may be prescribed as suppressed degrees of freedom (displacement=0) or as prescribed displacement values in the model nodes.

Displacement boundary conditions may be prescribed in actual sections with remaining structure – additional rings, see D.2.1.5.1 or at the points of heavy transverse sub-structures (transverse bulkheads).

Boundary conditions of symmetry and anti-symmetry for half model are prescribed in all nodes within longitudinal symmetric plane in accordance with Table D.2.1.5.3.1.

Table D.2.1.5.3.1

<table>
<thead>
<tr>
<th>DISPLACEMENT BOUNDARY CONDITIONS</th>
<th>TRANSLATIONS</th>
<th>ROTATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>u</td>
<td>v</td>
</tr>
<tr>
<td>SIMMETRY</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ASYMmetry</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

1= restrained; 0= free

Note: for the definition of coordinate system see 2.1.2.

Supports are generally arranged in the intersections of structural elements of strong sub-structures for more effective taking up and distribution of concentrated reaction force, obtained in the node of support.

D.2.1.5.3.2 Boundary conditions may be also prescribed through the spring system, where displacement depends of the given spring stiffness value in the relevant node. The spring system enables static stability of the model and better presentation of the effect of the remaining structure to the evaluated model.

Equivalent stiffness of the spring elements should substitute stiffness of actual substructures as realistically as possible:
- deck, bottom and inner bottom at horizontal bending,
- longitudinal bulkheads, side, double side at vertical bending,
by means of which the remaining structure is supporting the model.

In this case, stiffness effect of smaller girders (girder in double bottom, deck girders and stringers) may be disregarded and consequently the springs need not to be generated at the positions of such elements.

Stiffnesses of springs supporting substructures, such as bottom, inner bottom, decks, sides, longitudinal bulkheads, are to be calculated on the basis of elementary formulae for beam shear stiffness.

Length of substructure $D$ corresponds to transverse bulkhead spacing. Substructure has the shear surface $A_s$ (only plating is to be taken in the section area) and shear modulus $G$.

Rod elements of $d$ in length, section area $A_s$, with Young's modulus of elasticity $E$, connecting substructure node to the node, where all displacements are suppressed, have the function of springs. Specified nodes determine the direction of spring's effect through their coordinates.

Spring stiffness $k_{spring}$ is determined by formula:

$$k_{spring} = \frac{E \cdot A_s}{d} = \frac{c \cdot G \cdot A_s}{D}$$

Where rod element section area is determined by formula:

$$a = \frac{G}{E} \cdot \frac{d}{D} \cdot A_s$$

where:

Constant $c$ is taken as $c=1/n$,

$n =$ number of springs within substructure section, to which its stiffness is to be distributed.
D.2.1.5.3.3 For modelling of response due, the springs to vertical and horizontal bending of ship’s hull are to be applied at both model ends, in the positions of at least one strong substructure. The springs are to be distributed along the substructure at least in two positions, see Figures D.2.1.5.3.3-1 and D.2.1.5.3.3-2:

- vertical springs (global axis Y direction): on the bottom and longitudinal bulkhead top, side or double side,
- transverse spring (global axis Z direction): on the positions of deck, bottom etc. at left (and starboard) side,
- longitudinal springs (global axis X direction): to be placed as needed on the positions as for transverse springs. Small unbalanced longitudinal forces are to be generally taken up by fitting rigid supports in appropriate neutral lines.

In such a case, rotation of bulkhead to one of the model ends is to be enabled, by applying spring supports in the symmetry plane of the model, and at the other end the spring supports are to be provided on the positions of all strong longitudinal substructures.

As to the more complex problems regarding asymmetric loads, possibility and advantage of full ship model is to be considered, with respect to modelling of equivalent stiffness in the sections of smaller partial models. In all such cases, the agreement with the Register is to be obtained.

D.2.1.6 3-D FEM full ship hull model - model D

D.2.1.6.1 The present models should be produced for the ships:

- where there is unequal distribution of structural elements along the ship’s hull,
- where the load conditions require control of structural integrity at several locations,
- where there is problematic determination of boundary conditions in partial 3D FEM models, see D.2.1.5.

The following ships are included into this group:

- passenger and cruise ships,
- multi-deck (car carriers, Ro-Pax) and multi-hull ships,
- containers ships,
- high-speed ships,
- naval ships,
- special sea-going objects such as pontoons, docks, etc.

Any other non-standard ship’s structures, regarding the size and extent of the model, will be agreed with the Register.

These models are obligatory for multi-deck ships (passenger and Ro-Pax ships) where the degree of participation of a superstructure deck into the longitudinal strength, is unknown.

Long superstructures of such ships are to be fully modelled in a way that their effect to the ship’s longitudinal strength is correctly applied.

Short superstructures which are not included into the longitudinal strength are to be modelled in a way that distribution of their own weight, is correctly presented.

Specified models are intended for the calculation of the primary and secondary response by FEM.

Tertiary response may be calculated by analytical method and then superimposed to the primary and secondary response.

Coarse mesh of macroelements, defined in D.2.1.5.2 a), is the most rational approach to modelling so large FEM models. Characteristic model of large passenger ship is shown in Figure D.2.1.6-1.
Figure D.2.1.6.1  Coarse mesh of macroelements for 3-D FEM ship's full hull model

These models also generate displacement boundary conditions for direct calculations of structural details, by means of fine FEM meshes, see D.2.1.7.

D.2.1.6.2 Displacement boundary conditions for these models are intended to prevention of ship's motion as a rigid body, and may be applied in accordance with Table D.2.1.6.2.

Table D.2.1.6.2

<table>
<thead>
<tr>
<th>DISPLACEMENT BOUNDARY CONDITIONS</th>
<th>TRANSLATIONS</th>
<th>ROTATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>u  v  w  θx  θy  θz</td>
<td></td>
</tr>
<tr>
<td>Fore collision bulkhead, keel node</td>
<td>1  1  1  0  0  0</td>
<td></td>
</tr>
<tr>
<td>Node of transom (or aft collision bulkhead), deck (around N.L.) and port side</td>
<td>0  1  1  0  0  0</td>
<td></td>
</tr>
<tr>
<td>Node of transom (or aft collision bulkhead), deck (around N.L.) and starboard side</td>
<td>0  1  0  0  0  0</td>
<td></td>
</tr>
</tbody>
</table>

1= restrained; 0= free
Note: for the definition of coordinate system see 2.1.2.

Boundary conditions of half models in the symmetry level are given in Table D.2.1.6.3

D.2.1.6.3 Balancing the model

FEM model is to be in quasi-static condition of balance at any considered loading cases.

Unbalanced forces in fiction supports in direction of all three axes, are to be small, not more than 0.5% of the ship's displacement.

Unbalanced moments are to be below 6% of the maximum bending moment, for each of the loading case.

Variations from the values of displacement, trim and vertical bending moment are considered satisfactorily, if within the following tolerances:
- 0.5% of displacement,
- 0.1° of trim angle,
- 5% of still water bending moment.

D.2.1.7 2-D and 3-D fine and very fine FEM mesh of structural details– E model

Stress concentrations are not possible to be obtained from the previously described FEM models (A-D), where lesser mesh density as well as model simplifications have been applied, or from the equivalent modelling of stiffness, respectively, where local geometry of structural components has been neglected.

Stress level and distribution are restricted by formulation of applied finite element (order of used shape functions). In order to reach required accuracy of maximum stresses amount and their correct position, refinement of elements mesh is to be performed (fine and very fine mesh).

D.2.1.7.1 Structural details are to be modelled, with very fine mesh of finite elements, at the locations where can appear:
- increased stress level (as required by the Register),
- increased stress level in the elements of coarser models, see D.2.1.3 to D.2.1.6, that can result in high stresses within structural details, included by the same, but are not modelled in details.

D.2.1.7.2 Before commencement of modelling, the list of structural details is to be agreed with the Register, which is to be modelled by very fine meshes, subject to the kind of detail and type of ship, so that appropriate mesh for correct determination of boundary conditions could be ensured.

D.2.1.7.3 Mesh density of finite elements is defined subject to the kind of structural detail. In principle, the following notes should be followed:
- transitions from coarse to fine mesh or very fine mesh are to be performed gradually, reducing size of finite elements when approaching considered structural detail ("spider's web" mesh, etc.),
- element's dimensions are not to be less than its thickness,
- element's dimensions are not to exceed 20 t or 200 mm, where t is element's thickness,
- special care is to be given to modelling of curved contour (e.g. bracket free edge)
- model extent is to be such that ends of finer model, to which boundary conditions are
applied, are to be sufficiently spaced from the considered detail, for the reduction of effect of boundary conditions to the results – St. Venant principle,
- the model ends are recommended to correspond to the locations of substructures or strong girders,
- local geometry (lightening openings, additional framing, brackets and other details) are to be modelled in accordance with classification and/or workshop documentation.
Examples of very fine FEM mesh of structural details are shown in Figure D.2.1.7.3.

Figure D.2.1.7.3  3-D FEM models of ship’s structural details (very fine mesh)

D.2.1.7.4 One of the following models is applied in the calculation of the stress concentration by means of very fine FEM models, see Figure D. 2.1.7.4:

D.2.1.7.5 Fine mesh model loads are prescribed directly to the model, in accordance with considered load cases, from which displacement boundary conditions have been taken (may be applicable as force boundary conditions, where more appropriate).

D.2.2  Selection of elements and/or macroelements and mesh density

Type of finite element and mesh density is selected according to expected response field, which is to be accurately presented, see D.2.3. Generally, mesh of macro elements (complex finite elements) corresponds to the mesh of strong girders in the structure.
Likewise, strong girders at the edges of macroelements provide boundary conditions for automatic control of feasibility of individual macroelement (buckling). In this case, macroelement (stiffened panel, strong girder) is not to comprise more than 4 spacing of stiffeners.

<table>
<thead>
<tr>
<th>METHOD</th>
<th>CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-model method (top-down approach)</td>
<td>At the model level with coarser mesh displacement boundary conditions for finer models are generated. Minimum linear interpolation of field displacement to boundary conditions is required (− − − −) according to the displacement in the nodes of coarser mesh.</td>
</tr>
<tr>
<td>Superelement Method</td>
<td>Model with fine mesh is statically condensed and directly included as stiffness into coarser model through freedom degrees connected to nodes (super nodes: •• ••) and specialised software is required.</td>
</tr>
<tr>
<td>Method of direct implementation of fine mesh model to coarse model (D.2.1.3-D.2.1.6)</td>
<td>It is useful to a certain extent of fine mesh density, but effectiveness and flexibility of calculation is reduced.</td>
</tr>
</tbody>
</table>

Figure D.2.1.7.4  Methods of stress concentration calculation by very fine FEM models

D.2.2.1  Beam elements and macroelements

D.2.2.1.1  Standard beam element (characteristics):

(a) 6 (3) degrees of freedom by node, axial stiffness (rod), bending and torsion stiffness (beam),
(b) includes correction of deflection due to shear.

D.2.2.1.2  Beam macroelement (see also CREST CRS, ref. [2]):

(a) axial stiffness of bracket at the model edges may be included through the super element composed of three rod elements (bracket, free span, bracket) of different section area,
(b) rigid ends are included by standard procedure of transition of vector displacement from the element end node to the inner end point of the rigid element part, on the basis of the following kinematics assumptions:
- rotation in both nodes is the same,
- translation of inner node is sum of translations of end node and product of its rotation with the length of rigid end (spacing between end and inner node).

D.2.2.2 Membrane finite elements

Standard membrane finite elements are triangles, rectangular and quadrilateral elements with ratio of adjacent sides less than 1:4.

If possible, triangle elements and acute angles of all types of elements are to be avoided.

Angles of quadrangular elements are to be greater than 60° and less than 120°, while for triangular elements are to be greater than 30° and less than 120°.

D.2.2.3 Finite Plate Elements

As ditto in D.2.2.2.

D.2.2.4 Macroelements of framed membranes and plates

As ditto in D.2.2.2.

Stiffeners within the macroelement's field are modelled on their actual positions (see computing system CREST CRS [2]).

On agreement with the Register, exceptionally in coarse meshes the following may be used:
- orthotropic elements with equivalent thickness in two directions,
- equivalent stiffeners at the edges of elements with the stiffness corresponding to the sum of stiffeners stiffness in the field.

D.2.2.5 Special Elements

Pillars are modelled with rod elements.

D.2.3 Equivalent modelling of the structural element properties

Equivalent modelling is used for simplification of a model for coarse and fine meshes.

Modelling is to provide actual stiffness of the structure, but not necessarily the distribution of stresses within the equivalent structure.

Stress distribution and level around equivalent structural part are to be unchanged.

Equivalent modelling is always to extend at the safety side, i.e. obtained response is to exceed the actual one while capability is to be less than actual.

The following notes are to be considered:
- beam girders in beam-membrane model are modelled with effective width of plating (beam elements with effective width of plating),
- for small eccentricities of ship's strong girders, the nodes of element's mesh are to be placed in the plating,
- small openings in the girders or plating are to be larger openings (e.g. manholes) may be taken into consideration by deleting the element or by reduction of girder's thickness, as follows: neglected,
- proportionally to the portion of openings in the height of girder,
- proportionally to the portion of opening in the girder area,
- small brackets on the girders may be neglected,
- partial stiffeners may be also neglected.

D.2.4 Modeling procedure and verification of the model

Control of development and verification of model are essential for the application of FEM numerical method. Only the computing program with graphical presentation of model and response is acceptable and feature of automatic data generators is highly desirable, in order to reduce effort and consequently inevitable failures.

For the purpose of ensuring modelling quality, the following is to be recommended:
- control of input of numerical data through the team work (i.e. checks, double-checks, etc.),
- visual verification of special data groups (plate thickness, type of material, profile characteristics etc.),
- application of test load (or actual load) for the verification of:
  - consistency of model (potential “cracks” due to unconnected elements – free edges)
  - boundary conditions (e.g. illogical response), etc.

D.3 LOADING OF THE STRUCTURE

D.3.1 General

D.3.1.1 Selection of design loading conditions and loads cases

Design load cases (LCa) for given loading conditions (LCo) are to include all relevant load components, as prescribed in accordance with the Rules.

Design loading cases for given loading condition are to set all essential structural elements into condition of the most significant (design) response, in relation to which the capability of structural element is evaluated.

In principle, the most unfavourable responses will be obtained by structural analysis for extreme sea loading conditions (sagging and hogging) of the hull girder and for the inclined ship.

Loading conditions, related to longitudinal strength, are specified in the Rules, 4.2.1.2.
Dynamic loads from the ship’s motion as a rigid body produce inertial structural loads. Masses of ship and cargo are multiplied by global vector of ship’s translational accelerations (for heaving, swaying and surging), or alternatively, ship’s local angular accelerations (pitching, rolling and yawing), subject to the mass position in relation to rotation centre, are to be calculated.

For simplified determination of design load cases, it is recommended that load cases are prescribed by concentrated masses or distribution of mass (structure and cargo) instead of local pressures/forces.

Vector of ship’s acceleration is stated in the Rules, 3.5, or is obtained by sea-keeping calculation, previously approved by the Register.

For determination of load cases for selected loading condition, the application of Turkstra’s rule may be considered, so that only one of the components in the considered case has the extreme value, since the simultaneous maximum of more load components is not probable, unless expressly prescribed by the Rules.

D.3.1.2 Determination of design load cases

As specified in D.3.1.1, design load cases are to bring structural elements into condition of maximum possible (design) response. It will require control of the sagging and hogging condition of the elements with structurally possible boundary conditions at their edges, respectively:

- that the elements will be loaded by pressure or mass (inertial loads) in both directions of the normal to the element, in case this is permissible by loading cases,
- bending of adjacent elements will define degree of elastic restraint of the considered element, and thus for adjacent elements load in both directions or unloaded condition is to be considered.

Example 1: Outer shell plating panel in double bottom – design load cases:
- maximum draught and empty double bottom will produce critical hogging of the shell plating panel,
- maximum tank filling in double bottom and minimum draught will produce critical sagging of the shell plating panel.

Specified load cases are to be additionally considered with respect to the:
- boundary conditions effect (adjacent tanks, full and/or empty),
- appropriate level of superimposed primary stresses.

Example 2: For evaluation of panel boundary conditions we consider joining node (cross joint) of four spaces a, b, c and d separated e.g. by longitudinal and transverse watertight bulkheads (LWB or TBW) or joining node (A) three spaces (tank) a, b and c separated e.g. by inner bottom plating and watertight floor, see Figure D.3.1.2. For combination full (=1) and empty (=0) in the first case 16 different load cases may be obtained (abcd = 1000, 1001, 1010, 1011,..., 0111), and in the second case eight different load cases (abc= 100, 101, 110, 111,...,011).

Figure D.3.1.2

Each of the specified cases produces different state of deformation in bulkheads or inner bottom plating, from which some will be critical, while some of them cannot appear at all for the assigned loading conditions.

The designer is to consider sufficiency and adequacy of load cases in relation to the stated conditions, especially for sagging (resulting buckling or plastic deformation of plating) and hogging of panel (resulting buckling or plastic deformation of stiffener flange). For the selection of load cases, special attention is to be given to the most inconvenient combination, resulting in the most significant level of primary stresses.

In the case of a part of inner bottom plating a-b, see Figure D.3.1.2, it is evident that among critical (design) load cases there will be combinations 101 (sagging) and 010 (hogging), related to unfavourable boundary conditions, stated in node (A).

The Register may require control of omitted load cases, if considered critical.

D.3.2 Load components

Load components applied in direct calculation are to be in accordance with the Rules and given load conditions.

For specific types of ships, other than loads specified in this Section, additional requirements for loads are to be considered and applied, in accordance with the Rules, Section 17-21, subject to the type of ship.
D.3.2.1 Load from lightship weight

Load from lightship weight is to be taken into consideration for all types of direct calculations. If actual structural mass is known (Trim and Stability Book), idealized mass, obtained through FEM model, is to be adapted to the actual structural mass. Lightship weight is obtained by multiplying structural mass with adequate acceleration vectors, according to D.3.2.4.

D.3.2.2 Hydrostatic and hydrodynamic external sea loads

Subject to the design load condition and ship's draught, as defined in D.3.1, values of the load to the shell plating and upper deck are to be determined in accordance with the Rules, 3.2.

D.3.2.3 Loads from cargo in tanks and decks

Subject to the design loading condition, the load of tank's structure is calculated in accordance with the Rules, 3.4. Deck load from cargo and accommodation deck load are to be determined in accordance with the Rules, 3.3. It is recommended to recalculate the pressures (force per unit area) to masses per unit area, see D.3.1.1.

D.3.2.4 Loads from ship's motion

Dynamic loads due to ship's motion are given through acceleration vector components, in accordance with the Rules, 3.5. Rotation centre may be placed at 0.05 L from amidships toward stern.

D.3.2.5 Loads from wave moments and transverse forces

For all types of direct calculations in the considered section, bending moments and shear forces, specified in the text below, are to be applied and/or achieved.

D.3.2.5.1 Vertical bending moments \( M_L \) and shear forces \( F_S \) in still water are to be determined in accordance with the Rules, 4.2.1.

D.3.2.5.2 Vertical bending moments \( M_W \) and shear forces \( F_W \) induced by waves, are to be determined in accordance with the Rules, 4.2.2 and 4.2.3.

D.3.2.5.3 Additional bending moments caused by slamming \( M_SL \) are to be determined in accordance with the Rules, 4.5.1.

D.3.2.5.4 Wave induced horizontal bending moments \( M_WH \) are to be determined in accordance with the Rules, 4.5.2.

D.3.2.5.5 Torsional loads respectively distribution of twisting moments for ships with “open” sections (container ships, bulk carriers, etc.), catamarans, semi-submersibles etc., are to be specially considered on agreement with the Register. Torsion stiffness at pure torsion, torsion stiffness with restrained warping and centre of torsion are to be determined by FEM procedure from CREST CRS system [2] or any other acceptable analytical method.

D.3.2.6 Other Loads

Loads of heavier equipment, main engine, containers, etc. are to be modelled at their actual positions, taking into account distance of the mass centre of gravity from the supporting points. Inertial forces taken up by supporting points are to be correctly distributed, subject to the type of support.

Wheeled loads in Ro-Ro ships should be specially considered and applied in agreement with the Register.

D.3.2.7 Special notes for loads of 3-D FEM full ship model

D.3.2.7.1 Where 3-D FEM full ship model loads are given, the notes specified in D.2.1.6.3 (relating to model balancing), as well the following instructions will be valid:

- if distribution of actual light ships mass is known (from the Trim and Stability Book), idealized mass obtained by FEM model is to be adapted to the actual mass (addition for mass of neglected stiffening, painting, welds, pipes, etc.),
- wave load for these models is given in the agreement with the Register.

D.3.2.7.2 Loads to wetted surface of global 3D FEM model could be given simultaneously or separately in two forms:

1. Sinusoidal quasi-static design wave of length \( \lambda \), including correction for Smith's effect:

\[
p = p_w e^{-kd}
\]

where:

- \( p_w \) = wave hydrostatic pressure,
- \( k = 2\pi / \lambda \) wave number,
- \( d = \) distance of the considered point from the wave axis. It is assumed that design wave defined in this manner generates wave bending moments as specified in D.3.2.5.2.

In this manner primary (hull girder bending) and secondary (coupled bending of structural girder and plating) stresses within shell plating panels (membrane stresses) are obtained from FEM model.

2. By means of design pressures, according to the Rules, 3.2, for obtaining realistic total stresses (primary + secondary + tertiary) due to bending of plating and panel stiffeners, for the calculation of shell plating panel feasibility (interaction formulae, see Section D.5).

In the feasibility formulae greater of the values specified under (1) and (2) is relevant.

D.3.3 Determination of equivalent loads in the model nodes

For the continuous loads (by side, by area or by volume) the equivalent nodal loads are to be determined using the work equivalency principle between work of the distributed load on the displacement field of the respective element and the work of equivalent nodal forces on the corresponding nodal displacement field.

Specified transformation is to be used by the applied computer program.
D.3.4 Force boundary conditions in the partial model sections

D.3.4.1 Hull bending and torsion moments, sectional stress distribution

Depending on the prescribed boundary moments of the vertical and horizontal bending and torsion moment or angles of twist, the equivalent distribution of force boundary conditions (normal stresses distribution) is obtained for the end sections of partial models, including:

- vertical bending $\sigma_V$,
- horizontal bending $\sigma_H$,
- restrained warping $\sigma_W$ (warping stress).

Distribution of force boundary conditions is given in accordance with extended beam theory (see computing program CREST CRS) or on the basis of analytical method of sufficient accuracy.

For the case of hull girder bending, normal stresses $\sigma_V$ and $\sigma_H$ are to be corrected due to influence of the sheer stress, i.e. in the sheer strake and deck stringer.

For the case of torsion with restrained warping, distribution of normal stresses $\sigma_W$ (determined by the means of second derivations of the angle of twist obtained from the hull girder torsion calculation (to be submitted to the Register) is to be imposed.

Distribution of normal stresses for plates and profiles of adequate scantlings is to be converted into distributed load, and in accordance with D.3.3 it is to be converted into equivalent FEM model nodal forces.

D.3.4.2 Transverse forces due to hull bending and torsion and their distribution

On the basis of prescribed transverse forces due to (1) vertical and (2) horizontal bending at the model ends and (3) angles of twist and its derivations in torsion with restrained warping, equivalent shear stress distribution representing force boundary conditions, is obtained at end sections of partial models, namely:

- vertical and horizontal bending $\tau_V$, $\tau_H$,
- primary shear stresses (pure torsion) $\tau_1$,
- secondary shear stresses (restrained warping) $\tau_2$.

Distribution of specified boundary stresses is given in accordance with extended beam theory (see computing program CREST CRS) or according to analytical method of appropriate accuracy.

Distribution of shear stresses for plates and profiles of adequate scantlings are converted into distributed load and in accordance with D.3.3 it is converted into equivalent FEM model nodal forces.

D.3.5 Verification of loads model

D.3.5.1 For 3-D FEM models of ship's part, see D.2.1.5, and full ship, see D.2.1.6, the following data related to the verification of load model, should be submitted:

1. diagrams of vertical transverse forces and bending moments as well as twisting moments, obtained from loads applied on FEM model, where such load cases are considered,
2. table with bending moment and shear force values for individual sections,
3. applied acceleration components,
4. graphical or tabular presentation of external sea load distribution upon the plating and model exposed deck,
5. graphical or tabular presentation of the load (pressure) distribution upon the tank plating and/or model deck,
6. resulting unbalanced forces and moments in the sections.

D.4 STRUCTURAL RESPONSE CALCULATION BY FINITE ELEMENTS METHOD

D.4.1 General

Boundary conditions may be provided by e.g. excluding relevant rows and columns from the stiffness matrix or modification of stiffness of diagonal matrix element and load vector, etc.

For half hull models and transversely asymmetric loads, the following will be allowed:

1. decomposition of asymmetric load vector to symmetric and anti-symmetric component,
2. equations system is to be solved separately for adequate symmetry and anti-symmetry boundary conditions,
3. resulting displacement vector is to be obtained by inverse transformation in relation to (1).

Transversely asymmetric structures are to be modelled in full (both sides).

Solution of FEM equation system is to be consistent, whilst stiffness matrix is to be positively definitive (internal control in the equation system solver).

Values of reaction forces are to be within permissible tolerances, especially for full ship model, see D.2.1.6.3.

Partial models calculation results, see D.2.1.5, in the zones adjacent to model section, are not to be considered in accordance with St. Venant principle, but are to be reasonable. When using sub-model, see D.2.1.7, the same principle is to be applied.

D.4.2 Calculation and presentation of structural displacements

For presentation of displacements, the following should be submitted:
D.4.3 Calculation and presentation of structural stresses

For presentation of stresses, the load levels included into calculation are to be clearly presented (primary, secondary, tertiary).

Components of the stress tensor are presented in the local coordinate system of elements and are calculated for the following reference points:

- element centre of gravity,
- element boundary nodes,
- Gauss points for numerically integrated elements.

Where stresses are presented with unique colour by element or contour lines for given stress level (so called iso-lines), the type of the stress tensor component, reference point and used type of presentation are to be stated (mean value or maximum on element).

Graphical layout of stresses for coarse and fine mesh should include the following stress components by element:

- mean normal stresses in both directions ($\sigma_1$, $\sigma_2$),
- mean shear stresses ($\tau$),
- equivalent stresses ($\sigma_{VM}$, where is $\sigma_{VM} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2 + 3 \tau^2}$)

Presenting of principal stresses ($\sigma_1$, $\sigma_2$) by element in relation with local coordination system (stress trajectory), may be used as alternative method.

Graphical layout of the stress components is to be presented in sufficient number of views, so that they can be clearly indicated with any relevant stress components: principal stresses-$\sigma_1$, $\sigma_2$, ... in sufficient number of views.

D.5 CALCULATION OF STRUCTURAL FEASIBILITY
ACCORDING TO CRITERIA OF THE REGISTER

D.5.1 Basic principles

D.5.1.1 Structural Elements Safety Criteria - General

Library of safety criteria includes mathematical formulation of different failure modes (serviceability and structural collapse) in the form of design constraints. The constraints are forming the envelope in the design space with feasible combinations of structural variables, which meet all restrictions.

Feasibility is determined by the relation of:

- increased or extreme load ($M = \delta D_c$), where $\delta$ is given load factor, whilst $D_c$ is characteristic load or response obtained for that load,
- usable capability or capacity of structure ($C = \varepsilon C_{max}$), where $\varepsilon$ is given utility factor, whilst $C_{max}$ is combination of loads or responses (load effects) causing structural limit state.

Loads $D$ (demand) are set directly as forces or moments to the considered structural components or as responses/stresses at the structural element. They are connected via equilibrium equation of acting force and resulting stresses so the criteria may defined as $F < F_{crit}$ or as $\sigma < \sigma_{crit}$, taking account of $F = \sigma A$.

Plastic capability or capacity is $C_{max} = \sigma F = R_M$ or $C_{max} = F$ or $C_{max} = M_D$, depending on selected material.

Calculation of capability $C$ for different methods of buckling ($\sigma_{crit}$ or $F_{crit}$) is given in the Rules, 4.6.

Yielding criteria are given in D.5.2 for different structural parts. Buckling criteria are given in D.5.3

D.5.1.2 Determination of feasibility criteria

Criteria (constraints, limit states) are determined in the following ways:

- through realised safety margin $M = \varepsilon C_{max} - \delta D_c$; ($M > 0$),
- through realised safety factor $\gamma = \varepsilon C_{max} / \delta D_c = C_{max} / (\gamma HRB D_c)$; ($\gamma > 1$),

where:

- $C_{max}$ is capability (capacity) for given element, whilst $D_c$ is its load for considered load case. In factor $\gamma HRB$, the utility factor $\varepsilon HRB$ and load factor $\delta HRB$ are implicitly included.

Factor $\gamma$ shows size of additional safety beyond prescribed factor $\gamma HRB$ through

- realised adequacy factor (or adequacy parameter [2, 4]) $\gamma = (\gamma - 1)/(\gamma + 1)$; ($\gamma \geq 0$)
D.5.1.3 Structural adequacy factor (normalised safety factor)

In direct calculation, feasibility is expressed in the simplest way through adequacy factor, since thus the unique approach for all criteria is provided (plasticity, buckling).

Adequacy factor $g$ may assume the value $-1 < g < 1$.

Value $g = 0$ corresponds to the limit or failure surface, separating feasible structures from unfeasible ones.

Realised safety factor is obtained from the following formula:

$$\gamma = \frac{1 + g}{1 - g}$$

based on adequacy factor $g$ given in output results (e.g. CREST CRS [2]).

Direct relation of calculated capability and characteristic load of structural elements is obtained from the following formula:

$$C_{\text{max}} / D_c = \gamma_{\text{HRB}} = \frac{1 + g}{1 - g}$$

where $C_{\text{max}} / D_c$ is material yield point, whilst $\sigma_{\text{dop}}$ is permissible stress as per the Rules. Factor $\gamma_{\text{HRB}}$ is specified in Table D.5.2-2.

Where feasibility calculation is performed by using $\gamma_{\text{HRB}}$ (e.g. by CREST CRS program) the minimum value of the permissible adequacy factor amounts:

$$g_{\text{min}} = 0.$$

Where feasibility calculation is performed for $\gamma_{\text{HRB}} = 1$, the minimum value of the permissible adequacy factor is to be corrected for actual $\gamma_{\text{HRB}}$ as per the following formula:

$$g_{\text{HRB}} = (\gamma_{\text{HRB}} - 1) / (\gamma_{\text{HRB}} + 1)$$

Minimum adequacy factors $g_{\text{HRB}}$ are stated in Table D.5.2-2.

D.5.2 Library of feasibility criteria - yielding

Criteria of structural feasibility, related to permissible stress levels (Yield), are stated in Table D.5.1.1.

The permissible stresses $\sigma_{\text{dop}}$ are specified in Table D.5.2-1, in accordance with the Rules, subject to material coefficient $k$, see the Rules, 1.4.2 and Table 1.4.2.2.

Factor $\gamma_{\text{HRB}}$ for yielding is calculated from the formula $C_{\text{max}} = R_{\text{yH}}$ and from permissible stresses:

$$\gamma_{\text{HRB}} = R_{\text{yH}} / \sigma_{\text{dop}}$$

where $R_{\text{yH}}$ = material yield point, whilst $\sigma_{\text{dop}}$ is permissible stress as per the Rules. Factor $\gamma_{\text{HRB}}$ is specified in Table D.5.2-2.

Where feasibility calculation is performed by using $\gamma_{\text{HRB}}$ (e.g. by CREST CRS program) the minimum value of the permissible adequacy factor amounts:

$$g_{\text{min}} = 0.$$

Where feasibility calculation is performed for $\gamma_{\text{HRB}} = 1$, the minimum value of the permissible adequacy factor is to be corrected for actual $\gamma_{\text{HRB}}$ as per the following formula:

$$g_{\text{HRB}} = (\gamma_{\text{HRB}} - 1) / (\gamma_{\text{HRB}} + 1)$$

Minimum adequacy factors $g_{\text{HRB}}$ are stated in Table D.5.2-2.
Table D.5.2-1

<table>
<thead>
<tr>
<th>No.</th>
<th>Structural element</th>
<th>Rule</th>
<th>Demand D1(^1), D2(^2), D3(^3)</th>
<th>Permissible stresses (\sigma_{\text{dop}})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[\sigma_{\text{VM}}^4] equivalent</td>
</tr>
<tr>
<td>1.</td>
<td>- General</td>
<td>4.3.2</td>
<td>D1</td>
<td>175/k</td>
</tr>
<tr>
<td>2.</td>
<td>PLATING</td>
<td>5.1.2</td>
<td>D1+D2+D3</td>
<td>230/k</td>
</tr>
<tr>
<td></td>
<td>- bottom</td>
<td>5.2.1.2</td>
<td>D2+D3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- side</td>
<td>5.3.1.2</td>
<td>D2+D3</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>DOUBLE BOTTOM</td>
<td>7.2.8.2/3</td>
<td>D1+D2+D3</td>
<td>230/k</td>
</tr>
<tr>
<td></td>
<td>- floors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- long. girders</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>DOUBLE BOTTOM</td>
<td>7.2.8.2.1</td>
<td>D2_{\text{pop}}+0.3 (D2_{\text{uzd}}+ D1)</td>
<td>170/k</td>
</tr>
<tr>
<td></td>
<td>- floors</td>
<td>7.2.8.2.1</td>
<td>D1+D2_{\text{uzd}}+0.3 D2_{\text{pop}}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- long. girders</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>FRAMING</td>
<td>8.1.2.1.4</td>
<td>D2+D3</td>
<td>180/k</td>
</tr>
<tr>
<td></td>
<td>- frames, web frames</td>
<td>8.2.4.2</td>
<td>D2+D3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- longitudinals</td>
<td>8.2.3.1</td>
<td>D1+D2+D3</td>
<td>230/k</td>
</tr>
<tr>
<td>6.</td>
<td>DECK</td>
<td>9.1.2</td>
<td>D2+D3</td>
<td>180/k</td>
</tr>
<tr>
<td></td>
<td>- general</td>
<td>9.4.2.1</td>
<td>D2+D3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- cantilever beams</td>
<td>9.4.2.1</td>
<td>D2+D3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- beams</td>
<td>9.5.2.3</td>
<td>D1+D2+D3</td>
<td>230/k</td>
</tr>
<tr>
<td></td>
<td>- top of coaming</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- flange of girder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- top of coaming</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- flange of girder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- coaming at deck level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>TANKS</td>
<td>11.2.3.2</td>
<td>D2+D3, (static-test)</td>
<td>180/k</td>
</tr>
<tr>
<td></td>
<td>- stiffeners and girders</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>STIFFENED PANEL</td>
<td>D1+D2+D3</td>
<td>D1+D2+D3</td>
<td>230/k</td>
</tr>
<tr>
<td></td>
<td>- plating</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- stiffeners</td>
<td>D1+D2+D3</td>
<td>D1+D2+D3</td>
<td>230/k</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D2+D3</td>
<td>D2+D3</td>
<td>180/k</td>
</tr>
<tr>
<td>9.</td>
<td>STRONG TRANSVERSE GIRDER</td>
<td>D1+D2+D3</td>
<td>D1+D2+D3</td>
<td>230/k</td>
</tr>
<tr>
<td>10.</td>
<td>STRONG LONGITUDINAL GIRDER</td>
<td>D1+D2+D3</td>
<td>D1+D2+D3</td>
<td>230/k</td>
</tr>
</tbody>
</table>

**2D/3D FEM models - very fine mesh**

<table>
<thead>
<tr>
<th>Rule</th>
<th>Direct notch stress</th>
<th>(D_{\text{max}}) (D1+D2+D3)</th>
<th>(1.1 R_{\text{dH}})</th>
</tr>
</thead>
</table>

**Notes:**

1) \(D1\) = primary loads (demand) calculated as per D.1.3.1
2) \(D2\) = secondary loads (demand) calculated as per D.1.3.2
3) \(D3\) = tertiary loads (demand) calculated as per D.1.3.3
4) \(\sigma_{\text{VM}} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2 + 3\tau^2}\)
5) \(\sigma\) = normal stresses, including all stress components (bending + axial) in different directions subject to element type,
6) \(\tau\) = mean shear stresses by element.
Table D.5.2-2

<table>
<thead>
<tr>
<th>No.</th>
<th>Structural element</th>
<th>Rule</th>
<th>Demand D1, D2, D3</th>
<th>Factor γHRB and min. adequacy factor (gHRB) for stress criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td>Equivalent stress</td>
</tr>
<tr>
<td>1.</td>
<td>- General</td>
<td>4.3.2</td>
<td>D1</td>
<td>1.34 (0.145)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.4.2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>PLATING</td>
<td>5.1.2</td>
<td>D1+D2+D3</td>
<td>1.02 (0.010)</td>
</tr>
<tr>
<td></td>
<td>- bottom</td>
<td>5.2.1.2</td>
<td>D2+D3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- side</td>
<td>5.3.1.2</td>
<td>D2+D3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.2.8.2/3</td>
<td>D1+D2+D3</td>
<td>1.02 (0.010)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.2.8.2.1</td>
<td>D2 (p)</td>
<td>1.57 (0.222)</td>
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<tr>
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<td></td>
<td>7.2.8.2.1</td>
<td>D2 (p)</td>
<td>1.57 (0.222)</td>
</tr>
<tr>
<td>3.</td>
<td>DOUBLE BOTTOM</td>
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<td>D2+D3</td>
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<td>- floors</td>
<td>7.2.8.2.1</td>
<td>D2 (p)</td>
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</tr>
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<td></td>
<td>- long. girders</td>
<td>7.2.8.2.1</td>
<td>D1+D2+D3</td>
<td>1.35 (0.149)</td>
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<td></td>
<td></td>
<td>8.1.2.1.4</td>
<td>D2+p+0.3 (D2sat+D1)</td>
<td>1.38 (0.160)</td>
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<td></td>
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<td>8.2.4.2</td>
<td>D2+D3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.2.3.1</td>
<td>D2+D3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.2.3.1</td>
<td>D1+D2+D3</td>
<td>1.02 (0.010)</td>
</tr>
<tr>
<td>4.</td>
<td>DOUBLE BOTTOM</td>
<td>9.1.2</td>
<td>D2+D3</td>
<td>1.31 (0.134)</td>
</tr>
<tr>
<td></td>
<td>- floors</td>
<td>9.4.2.1</td>
<td>D2+D3</td>
<td>1.31 (0.134)</td>
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<td>- long. girders</td>
<td>9.5.2.3</td>
<td>D2+D3</td>
<td>1.31 (0.134)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.5.2.3</td>
<td>D1+D2+D3</td>
<td>1.02 (0.010)</td>
</tr>
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<td></td>
<td></td>
<td>9.5.2.3</td>
<td>D1+D2+D3</td>
<td>1.02 (0.010)</td>
</tr>
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<td></td>
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<td>9.5.2.3</td>
<td>D1+D2+D3</td>
<td>1.02 (0.010)</td>
</tr>
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<td></td>
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<td>9.5.2.3</td>
<td>D1+D2+D3</td>
<td>1.02 (0.010)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.5.2.3</td>
<td>D1+D2+D3</td>
<td>1.02 (0.010)</td>
</tr>
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<td>7.</td>
<td>TANKS</td>
<td>11.2.3.2</td>
<td>D2+D3</td>
<td>1.31 (0.134)</td>
</tr>
<tr>
<td></td>
<td>- stiffeners and girders</td>
<td>11.2.3.2</td>
<td>D2+D3, (static-test)</td>
<td>1.31 (0.134)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.2.3.2</td>
<td>D2+D3</td>
<td>1.31 (0.134)</td>
</tr>
<tr>
<td>8.</td>
<td>STIFFENED PANEL</td>
<td>1.31 (0.134)</td>
<td>D2+D3</td>
<td>1.31 (0.134)</td>
</tr>
<tr>
<td></td>
<td>- plating</td>
<td>1.31 (0.134)</td>
<td>D2+D3</td>
<td>1.31 (0.134)</td>
</tr>
<tr>
<td></td>
<td>- stiffeners</td>
<td>1.31 (0.134)</td>
<td>D2+D3</td>
<td>1.31 (0.134)</td>
</tr>
<tr>
<td>9.</td>
<td>STRONG TRANSVERSE</td>
<td>1.31 (0.134)</td>
<td>D2+D3</td>
<td>1.31 (0.134)</td>
</tr>
<tr>
<td></td>
<td>GIRDER</td>
<td>1.31 (0.134)</td>
<td>D2+D3</td>
<td>1.31 (0.134)</td>
</tr>
<tr>
<td>10.</td>
<td>STRONG LONGITUDINAL</td>
<td>1.31 (0.134)</td>
<td>D2+D3</td>
<td>1.31 (0.134)</td>
</tr>
<tr>
<td></td>
<td>GIRDER</td>
<td>1.31 (0.134)</td>
<td>D2+D3</td>
<td>1.31 (0.134)</td>
</tr>
</tbody>
</table>

2D/3D FEM models - very fine mesh

<table>
<thead>
<tr>
<th>No.</th>
<th>Rule</th>
<th>Dmax (D1+D2+D3)</th>
<th>Factor γHRB and min. adequacy factor (gHRB) for stress criteria</th>
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</thead>
<tbody>
<tr>
<td>11</td>
<td>Direct notch stress</td>
<td>0.91 (-0.047)</td>
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</table>

D.5.3 Library of feasibility criteria - buckling

Criteria for verification of feasibility at structural buckling (*Buckling*) are specified in Table D.5.1.1, in accordance with the Rules, 4.6.

The required safety factors are included into feasibility criteria of CREST program, in accordance with the Rules.

Global safety factor for buckling and adequacy factor (gHRB) are specified in Table D.5.3.
Table D.5.3

<table>
<thead>
<tr>
<th>No.</th>
<th>Structural element</th>
<th>Rule</th>
<th>Demand D1, D2, D3</th>
<th>Safety factor and minimum adequacy factor for buckling criteria (valid for all models)</th>
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<tbody>
<tr>
<td>1.</td>
<td>STIFFENED PANEL</td>
<td></td>
<td>D1+D2+D3</td>
<td>1.0 (0.0)</td>
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<td></td>
<td>- plating (local buckling)</td>
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<td>D1+D2+D3</td>
<td>1.1 (0.048)</td>
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<td></td>
<td>- stiffeners</td>
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<td></td>
</tr>
<tr>
<td>2.</td>
<td>STRONG TRANSVERSE GIRDER</td>
<td></td>
<td>D1+D2+D3</td>
<td>1.1 (0.048)</td>
</tr>
<tr>
<td>3.</td>
<td>STRONG LONGITUDINAL GIRDER</td>
<td></td>
<td>D1+D2+D3</td>
<td>1.1 (0.048)</td>
</tr>
</tbody>
</table>

D.5.4 Presentation of the results of the feasibility criteria verification (yielding and buckling)

For presentation of feasibility criteria the following is to be submitted:

- graphic layout of realised safety factor $\gamma$ (adequacy factor $g$) for all elements in relation to the given feasibility criteria in accordance with the Rules, in sufficient number of views,
- identification (graphical and/or tabular layout) of structural elements, load cases and feasibility criteria (yielding, buckling), where Rules requirements are not satisfied,
- comment relating to those structural elements for which the Rules requirements are not met, with respect to feasibility criteria due to equivalent or simplified modelling (especially for coarse mesh models),
- detailed control of stress condition of those structural elements, for which the Rules requirements for feasibility criteria (buckling or yielding) are not met,
- additional comments to the results

D.5.5 Modification of structural elements

All structural elements, which do not meet the feasibility criteria, as per Section 5, should be modified by changing their dimensions.

All changes should be clearly documented and submitted to the Register.

In case of performing new FEM calculation, the procedure for verification and presentation of results, should be repeated, in accordance with Sections 4 and 5, in this case for the re-dimensionalized structure.

D.6 REFERENCES