FOREWORD

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CHANGES – CURRENT

This is a new document.
The rules enter into force 1 July 2016.
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SECTION 1 STRENGTH PRINCIPLES

1 General

1.1 Symbols

\( w \) = section modulus \([\text{cm}^3]\) of an ordinary stiffener or primary supporting member with an attached plating of width \( b_p \)

\( h_w \) = web height \([\text{mm}]\) of an ordinary stiffener or a primary supporting member

\( t_w \) = web thickness \([\text{mm}]\) of an ordinary stiffener or a primary supporting member

\( b_f \) = face plate width \([\text{mm}]\) of an ordinary stiffener or a primary supporting member

\( t_f \) = face plate thickness \([\text{mm}]\) of an ordinary stiffener or a primary supporting member

\( t_p \) = thickness \([\text{mm}]\) of the plating attached to an ordinary stiffener or a primary supporting member

\( s \) = spacing \([\text{m}]\) of ordinary stiffeners

\( S \) = spacing \([\text{m}]\) of primary supporting members

\( \ell \) = span \([\text{m}]\) of an ordinary stiffener or a primary supporting member measured between the supporting members

\( \ell_b \) = length \([\text{m}]\) of brackets

\( I \) = moment of inertia \([\text{cm}^4]\) of an ordinary stiffener or a primary supporting member without attached plating, around its neutral axis parallel to the plating

\( I_B \) = moment of inertia \([\text{cm}^4]\) of an ordinary stiffener or a primary supporting member with bracket and without attached plating, around its neutral axis parallel to the plating, calculated at mid-length of the bracket

\( k \) = material factor defined in Pt.2 Ch.5 Sec.1 [2.4] and Pt.2 Ch.5 Sec.1 [3.2].

2 General strength principles

2.1 Structural continuity

2.1.1 The variation in scantlings between the midship region and the fore and aft parts shall be gradual.

2.1.2 Attention shall be paid to the structural continuity:

— in way of changes in the framing system
— at the connections of primary or ordinary stiffeners
— in way of the ends of the fore and aft parts, and machinery space
— in way of ends of superstructures.

2.1.3 Where stress concentrations may occur in way of structural discontinuities, adequate compensation and reinforcements shall be provided.

2.1.4 Primary supporting members shall be arranged in such a way that they ensure adequate continuity of strength. Abrupt changes in height or in cross-section shall be avoided.

2.2 Rounding of scantlings

2.2.1 Plate thicknesses

The rounding of plate thicknesses shall be obtained from the following procedure:

a) the net thickness (see [6]) is calculated in accordance with the rule requirements

b) corrosion addition \( t_C \) (see [7]) is added to the calculated net thickness, and this gross thickness is rounded to the nearest half-millimetre
c) the rounded net thickness is taken equal to the rounded gross thickness, obtained in b), minus the corrosion addition \( t_c \).

### 2.2.2 Stiffener section moduli

Stiffener section moduli as calculated in accordance with the rule requirements shall be rounded off to the nearest standard value; however, no reduction may exceed 3%.

### 3 Plating

#### 3.1 Insert plates and doublers

3.1.1 A local increase in plating thickness is generally to be achieved through insert plates. Local doublers, which are normally only allowed for temporary repair, may however be accepted by the Society on a case-by-case basis.

In any case, doublers and insert plates shall be made of materials of a quality at least equal to that of the plates on which they are welded.

3.1.2 Doubler having width [mm] greater than:
- 20 times their thickness, for thicknesses equal to or less than 15 mm
- 25 times their thickness, for thicknesses greater than 15 mm

shall be fitted with slot welds, to be effected according to Pt.2 Ch.5 Sec.2 [2.6].

3.1.3 When doublers fitted on the outer shell and strength deck within 0.5 · L amidships are accepted by the Society, their width and thickness shall be such that slot welds are not necessary according to the requirements in [3.1.2]. Outside this area, the possibility of fitting doublers requiring slot welds will be considered on a case-by-case basis.

### 4 Ordinary stiffeners

#### 4.1 Stiffeners not perpendicular to the attached plating

Where the angle between the section web and the attached plating is less than 70°, the actual section modulus may be obtained [cm\(^3\)] from the following formula:

\[
W = W_0 \cdot \sin \alpha
\]

where:
- \( W \): actual section modulus [cm\(^3\)]
- \( W_0 \): actual section modulus [cm\(^3\)] of the stiffener assumed to be perpendicular to the plating
- \( \alpha \): angle between the stiffener web and the attached plating, to be measured at mid-span of the section.

#### 4.2 Span of ordinary stiffeners

4.2.1 The span \( \ell \) of ordinary stiffeners shall be measured as shown in Figure 1 to Figure 4.

Instead of the true length of curved frames, the length of the chord between the supporting points can be selected.
Figure 1 Ordinary stiffener without brackets

Figure 2 Ordinary stiffener with a stiffener at one end

Figure 3 Ordinary stiffener with end bracket

Figure 4 Ordinary stiffener with a bracket and a stiffener at one end
4.3 Width of attached plating

4.3.1 Yielding check
The width of the attached plating to be considered for the yielding check of ordinary stiffeners shall be obtained [m] from the following formulae:

— where the plating extends on both sides of the ordinary stiffener:

\[ b_p = s \]

— where the plating extends on one side of the ordinary stiffener (i.e. ordinary stiffeners bounding openings):

\[ b_p = 0.5 \cdot s \]

4.3.2 Buckling check
The attached plating to be considered for the buckling check of ordinary stiffeners is defined in Sec.2 [2.2].

4.4 Sections
The main characteristics of sections frequently used are given in Sec.5.

4.5 Built sections

4.5.1 Geometric properties
The geometric properties of built sections as shown in Figure 5 may be calculated as indicated in the following formulae.

\[
A_{sh} = \frac{h_w \cdot t_w}{100}
\]

The section modulus of a built section with attached plating of sectional area \( A_s \) [mm\(^2\)] shall be obtained [cm\(^3\)] from the following formula:

\[
W_s = 10 \cdot \frac{A_s}{h_s}
\]
The distance from mid-plate thickness of face plate to neutral axis shall be obtained [cm] from the following formula:

\[ w = \frac{h_w \cdot t_f \cdot b_f}{1000} + \frac{t_w \cdot h_w^2 \cdot w}{6000} \left( 1 + \frac{A_a - t_f \cdot b_f}{A_a + t_w \cdot h_w} \right) \]

The moment of inertia of a built section with attached plating shall be obtained [cm\(^4\)] from the following formula:

\[ I = w \cdot v \]

These formulae are applicable provided that:

\[ A_a \geq t_f \cdot b_f \]

\[ \frac{h_w}{t_p} \geq 10 \]

\[ \frac{h_w}{t_f} \geq 10 \]

### 4.6 End connections

#### 4.6.1 Continuous ordinary stiffeners

Where ordinary stiffeners are continuous through primary supporting members, they shall be connected to the web plating so as to ensure proper transmission of loads, e.g. by means of one of the connection details shown in Figure 6 to Figure 9. In the case of high values for the design loads, additional stiffening is required. Connection details other than those shown in Figure 6 to Figure 9 may be considered by the Society on a case-by-case basis. In some cases, the Society may require the details to be supported by direct calculations submitted for review.
Figure 6 End connection of ordinary stiffener without collar plate

Figure 7 End connection of ordinary stiffener: Collar plate

Figure 8 End connection of ordinary stiffener: One large collar plate
Hull girder strength

**4.6.2 Intercostal ordinary stiffeners**
Where ordinary stiffeners are terminated at primary supporting members, brackets shall be fitted to ensure the structural continuity. Their section modulus and their sectional area shall not be less than those of the ordinary stiffeners.

All brackets for which:

\[
\frac{\ell_b}{t} > 60
\]

\( \ell_b \) = length \([\text{mm}]\) of the free edge of the bracket  
\( t \) = bracket net thickness \([\text{mm}]\)

shall be flanged or stiffened by a welded face plate.

The sectional area \([\text{cm}^2]\) of the flange or the face plate shall not be less than 0.01·\( \ell_b \).

The width of the face plate shall be not less than 10·\( t \).

**4.6.3 Bracketed ordinary stiffeners**

4.6.3.1 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.

4.6.3.2 The net thickness of brackets shall be not less than:

\[
t = c \cdot \frac{W}{\sqrt{k_1}}
\]

\( c \) = 1.2 for non-flanged brackets  
0.95 for flanged brackets  
\( k_1 \) = material factor \( k \) for the section according Pt.2 Ch.5 Sec.1 \([2.4]\) and Pt.2 Ch.5 Sec.1 \([3.2]\)  
\( W \) = section modulus of smaller section \([\text{cm}^3]\)  
\( t_{\min} \) = 5.0 mm  
\( t_{\max} \) = web thickness of smaller section

4.6.3.3 The arm length of brackets shall not be less than:
\[ \ell = 100 \text{ mm} \]

\[ c_t = \sqrt{\frac{t}{t_a}} \]

\[ t_a = \text{"as built" thickness of bracket [mm]} \]

\[ W = \text{see [4.6.3.2]} \]

\[ k^2 = \text{material factor k for the bracket according to Pt.2 Ch.5 Sec.1 [2.4] and Pt.2 Ch.5 Sec.1 [3.2]} \]

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

**Guidance note:**
For deviating arm lengths, the thickness of brackets is to be estimated by direct calculations considering sufficient safety against buckling.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t---e---

**4.6.3.4** The throat thickness \( a \) of the welded connection shall be determined acc. to Pt.2 Ch.5 Sec.2 [4.8].

**4.6.3.5** Where flanged brackets are used, the width of flange shall be determined according to the following formula:

\[ b = 40 + \frac{W}{30} \text{ [mm]} \]

\( b \) shall not be taken less than 50 mm and need not be taken greater than 90 mm.

**4.6.4 Snipped ends of stiffeners**
Stiffeners may be snipped at the ends if the thickness of the plating supported by the stiffeners is not less than:

\[ t = c \cdot \sqrt{\frac{p \cdot s \cdot (\ell - 0.5 \cdot s)}{R_{EH}}} \]

\( p = \text{stiffener design load [kN/m}^2]\)

\( c = \text{coefficient} \)

\( = 15.8 \text{ for watertight bulkheads and for tank bulkheads} \)

\( = 19.6 \text{ for all other components} \)

**5 Primary supporting members**

**5.1 Span of primary supporting members**
The span of primary supporting members shall be determined in compliance with [4.2].
5.2 Width of attached plating

5.2.1 Girders

5.2.1.1 The effective width of plating \( e_m \) of frames and girders may be determined according to Table 1, considering the type of loading.

Special calculations may be required for determining the effective width of one-sided or non-symmetric flanges.

5.2.1.2 The effective cross sectional area of plates shall not be less than the cross sectional area of the face plate.

5.2.1.3 The effective width of stiffeners and girders subjected to compressive stresses may be determined according to Sec.2 [2.2], but is in no case to be taken greater than the effective width determined by [5.2.1.1].

Table 1 Effective width \( e_m \) of frames and girders

<table>
<thead>
<tr>
<th>( \ell/e )</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>≥ 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>( e_{m1}/e )</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>
</tr>
<tr>
<td>( e_{m2}/e )</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>
</tr>
</tbody>
</table>

\( e_{m1} \) shall be applied where girders are loaded by uniformly distributed loads or else by not less than 6 equally spaced single loads.

\( e_{m2} \) shall be applied where girders are loaded by 3 or less single loads.

Intermediate values may be obtained by direct interpolation

\( \ell = \) length between zero-points of bending moment curve, i.e. unsupported span in case of simply supported girders and \( 0.6 \times \) unsupported span in case of constraint of both ends of girder

\( e = \) width of plating supported, measured from centre to centre of the adjacent unsupported fields

5.2.2 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 width of plating at the respective cross section may approximately be taken as the distance of the cross section from the point on which the load is acting, however, not greater than the spacing of the cantilevers.

5.2.3 Corrugated bulkheads

Where primary supporting members are attached to corrugated bulkheads, the effective width of plating shall be determined as follows:

— when primary supporting members are parallel to the corrugations and are welded to the corrugation flanges, the width of the attached plating shall be calculated in accordance with [5.2.1] and [5.2.2], and shall be taken not greater than the corrugation flange width

— when primary supporting members are perpendicular to the corrugations, the width of the attached plating shall be taken equal to the width of the primary supporting member face plate.
5.3 Geometric properties
The geometric properties of primary supporting members (including primary supporting members of double hull structures, such as double bottom floors and girders) are generally determined in accordance with [4.5.1], reducing the web height \( h_w \) by the depth of the cut-outs for the passage of the ordinary stiffeners, if any.

5.4 Bracketed end connections
5.4.1 Arm lengths of end brackets shall be equal, as far as practicable.
The height of end brackets shall be not less than that of the weakest primary supporting member.

5.4.2 The scantlings of end brackets are generally to be such that the section modulus of the primary supporting member with end brackets is not less than that of the primary supporting member at mid-span.

5.4.3 The bracket web thickness shall not be less than that of the weakest primary supporting member.

5.4.4 The face plate of end brackets shall have a width not less than the width of the primary supporting member faceplates.
Moreover, the thickness of the face plate shall not be less than that of the bracket web.

5.4.5 In addition to the above requirements, the scantlings of end brackets shall comply with the applicable requirements given in Ch.4 Sec.2 to Ch.4 Sec.5.

5.5 Bracketless end connections
5.5.1 In the case of bracketless end connections between primary supporting members, the strength continuity shall be obtained as schematically shown in Figure 10 or by any other method which the Society may consider equivalent.

5.5.2 In general, the continuity of the face plates shall be ensured.

![Figure 10 Connection of two primary supporting members](image)
5.6 Cut-outs and holes

5.6.1 Cut-outs for the passage of ordinary stiffeners shall be as small as possible and well rounded with smooth edges.
In general, the depth of cut-outs shall not be greater than 50% of the depth of the primary supporting member. Other cases shall be covered by calculations submitted to the Society.

5.6.2 Openings may not be fitted in way of toes of end brackets.

5.7 Stiffening arrangement

5.7.1 General
Webs of primary supporting members are generally to be stiffened where the height [mm] is greater than 100 t, where t is the web thickness [mm] of the primary supporting member.
In general, the web stiffeners of primary supporting members shall be spaced not more than 110 t.

5.7.2 Longitudinal framing system
In way of each longitudinal the transverses shall be stiffened. This stiffener shall extend between the longitudinal and the upper faceplate of the transverse, without any connection with that faceplate.
The stiffener shall be made of a flat, the width b and thickness t of which [mm] shall not be less than:

\[
\begin{align*}
\quad & b = \frac{20}{3} \sqrt{\frac{w_l}{3}} \\
\quad & t = \frac{2}{3} \sqrt{\frac{w_l}{3}}
\end{align*}
\]

\(w_l\) being the section modulus of the longitudinal [cm³].
However, on deck transverses, side shell transverses or longitudinal bulkhead transverses, stiffeners may be provided only every two longitudinal spacings.
The Society may waive this requirement where the transverse is a rolled section or where it is otherwise covered by calculations.
The sectional area of the welded connection of the transverse stiffener to the longitudinal and to the transverses shall be not less than the stiffener rule sectional area.

5.7.3 Tripping brackets (see Figure 11) welded to the face plate are generally to be fitted:
— at intervals not exceeding 20 times the face plate width
— at the toe of end brackets
— at rounded/knuckled face plates
— in way of cross ties
— in way of concentrated loads.
Where the width of the symmetrical face plate is greater than 400 mm, backing brackets shall be fitted in way of the tripping brackets.
5.7.4 The arm length of tripping brackets shall be not less than the greater of the following values [m]:

\[ d = 0.38 \cdot b \]

\[ = 0.85 \cdot b \cdot \sqrt{\frac{s_t}{t}} \]

\( b \) = height [m] of tripping brackets, shown in Figure 11
\( s_t \) = spacing [m] of tripping brackets
\( t \) = thickness [mm] of tripping brackets.

5.7.5 The thickness of the tripping brackets shall not be less than the web thickness of the primary supporting member.

6 Hull scantling principles

6.1 Calculation point

6.1.1 General
The calculation point shall be considered with respect to the reference co-ordinate system defined in Ch.1 Sec.1 [1.4].

6.1.2 Plating
The elementary plate panel is the smallest unstiffened part of plating. Unless otherwise specified, the loads shall be calculated:
— for longitudinal framing, at the lower edge of the elementary plate panel or, in the case of horizontal plating, at the point of minimum y-value among those of the elementary plate panel considered
— for transverse framing, at the lower edge of the strake

6.1.3 Ordinary stiffeners
Unless otherwise specified, the loads shall be calculated at mid-span of the ordinary stiffener considered.

6.1.4 Primary supporting members
Unless otherwise specified, the loads shall be calculated at mid-span of the primary supporting member considered.
6.2 Bracket coefficients

6.2.1 Ordinary stiffeners
These requirements apply to ordinary stiffeners without end brackets, with a bracket at one end or with two equal end brackets.
The bracket coefficients $\beta_b$ and $\beta_s$, of ordinary stiffeners shall be obtained from Table 2.

**Table 2 Bracket coefficients**

<table>
<thead>
<tr>
<th>Brackets at ends</th>
<th>$\beta_b$</th>
<th>$\beta_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0.90</td>
<td>0.95</td>
</tr>
<tr>
<td>2</td>
<td>0.81</td>
<td>0.90</td>
</tr>
</tbody>
</table>

6.2.2 Primary supporting members
Parameters of conventional end brackets are given in Figure 12. Special consideration shall be given to conditions different from those shown.
The bracket coefficients $\beta_b$ and $\beta_s$, of primary supporting members shall be determined using the following formulae, and shall not be less than the values given in Table 2:

$$\beta_b = \left(1 - \sum_{i=1}^{n} \frac{\ell_{bi}}{\ell}\right)^2$$

$$\beta_s = 1 - \sum_{i=1}^{n} \frac{\ell_{bi}}{\ell}$$

- $\ell$ = span [m] of primary supporting member, defined in [4.2]
- $\ell_{bi} = \ell_b - 0.25 \cdot h_w$
  - $\ell_{bi} \geq 0$
- $\ell_b$ = MIN (d; b)
- d, b = length [m] of brackets arms, defined in Figure 12
- $h_w$ = height [m] of the primary supporting member (see Figure 12)
- n = number of end brackets

6.3 Coefficients for vertical structural members $\lambda_b$ and $\lambda_s$

6.3.1 The coefficients $\lambda_b$ and $\lambda_s$ to be used for the scantlings of vertical structural members shall be determined as follows:

$$\lambda_s = 2 \lambda_b - 1$$

$\lambda_b$ is the greater of:

$$1 + 0.2 \cdot \frac{p_{sd} - p_{su}}{p_{sd} + p_{su}}$$
Hull girder strength

Formula:

\[
\frac{p_{Su}}{p_{Sd}} = 1 - 0.2 \cdot \frac{p_{Sd} - p_{Su}}{p_{Sd} + p_{Su}}
\]

- \( p_{Su} \) = still water pressure \([\text{kN/m}^2]\) at the upper end of the structural member considered
- \( p_{Sd} \) = still water pressure \([\text{kN/m}^2]\) at the lower end of the structural member considered.

Figure 12 Characteristics of primary supporting member brackets

6.4 Plate panels

6.4.1 Thickness

The required thickness of plating subjected to lateral pressures may be reduced according to the aspect ratio and curvature of the panel considered, according to the formula:

\[
t = t_0 \cdot c_a \cdot c_r
\]

- \( t_0 \) = plating thickness \([\text{mm}]\) as required in terms of the lateral pressure
- \( c_a \) = aspect ratio defined in [6.4.2]
- \( c_r \) = coefficient of curvature defined in [6.4.3].
6.4.2 Aspect ratio
The aspect ratio of a plate panel is given by the following formula:

\[ c_a = 1.21 \cdot \sqrt{1 + 0.33 \cdot \left( \frac{s}{\ell} \right)^2} - 0.69 \cdot \frac{s}{\ell} \leq 1 \]

- \( s \) = length [m] of the shorter side of the plate panel
- \( \ell \) = length [m] of the longer side of the plate panel

6.4.3 Curvature of plate panels
The coefficient of curvature of a plate panel is given by the following formula:

\[ c_r = 1 - 0.5 \cdot \frac{s}{r} \geq 0.75 \]

- \( r \) = radius of curvature [m]

7 Net strength characteristic calculation

7.1 General

7.1.1 The scantlings obtained by applying the criteria specified in these rules are net scantlings, i.e. those which provide the strength characteristics required to sustain the loads, excluding any addition for corrosion. Exceptions are the scantlings of:
- rudder structures and hull appendages in Pt.3 Ch.6 Sec.1.
- massive pieces made of steel forgings, steel castings or iron castings

7.1.2 The required strength characteristics are:
- thickness, for plating including that which constitutes primary supporting members
- section modulus, shear sectional area, moments of inertia and local thickness, for ordinary stiffeners and, as the case may be, primary supporting members
- section modulus, moments of inertia and single moment for the hull girder

7.1.3 The vessel shall be built at least with the gross scantlings obtained by reversing the procedure described in [7.2].

7.2 Designer’s proposal based on gross scantlings

7.2.1 General criteria
If the designer provides the gross scantlings of each structural element, the structural checks shall be carried out on the basis of the net strength characteristics, derived as specified in [7.2.2] to [7.2.5].

7.2.2 Plating
The net thickness shall be obtained by deducting the corrosion addition \( t_C \) from the gross thickness.

7.2.3 Ordinary stiffeners
The net transverse section shall be obtained by deducting the corrosion addition \( t_C \) from the gross thickness of the elements which constitute the stiffener profile.
The net strength characteristics shall be calculated for the net transverse section. As an alternative, the net section modulus may be obtained from the following formula:

\[ w = w_G \cdot (1 - \alpha \cdot t_C) - \beta \cdot t_C \]

\( w_G \) = stiffener gross section modulus [cm³]
\( \alpha, \beta \) = coefficients defined in Table 3.

**Table 3 Coefficients \( \alpha \) and \( \beta \)**

<table>
<thead>
<tr>
<th>Type of ordinary stiffeners</th>
<th>( \alpha )</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat bars</td>
<td>0.066</td>
<td>1.6</td>
</tr>
<tr>
<td>Flanged Profiles</td>
<td>0.101</td>
<td>1.6</td>
</tr>
<tr>
<td>Bulb profiles:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- ( w_G &gt; 200 \text{ cm}^3 )</td>
<td>0.070</td>
<td>0.4</td>
</tr>
<tr>
<td>- ( w_G &gt; 200 \text{ cm}^3 )</td>
<td>0.035</td>
<td>7.4</td>
</tr>
</tbody>
</table>

**7.2.4 Primary supporting members**

The net transverse section shall be obtained by deducting the corrosion addition \( t_C \) from the gross thickness of the elements which constitute the primary supporting members.

The net strength characteristics shall be calculated for the net transverse section.

**7.2.5 Hull girder**

For the hull girder, the net hull transverse sections shall be considered as being constituted by plating and stiffeners having net scantlings calculated on the basis of the corrosion additions \( t_C \), according to [7.2.2] to [7.2.4].

**7.3 Designer’s proposal based on net scantlings**

**7.3.1 Net strength characteristics and corrosion additions**

If the designer provides the net scantlings of each structural element, the structural checks shall be carried out on the basis of the proposed net strength characteristics.

The designer shall also provide the corrosion additions or the gross scantlings of each structural element. The proposed corrosion additions shall be not less than the values specified in [8].

**7.3.2 Hull girder net strength characteristic calculation**

For the hull girder, the net hull girder transverse sections shall be considered as being constituted by plating and stiffeners having the net scantlings proposed by the designer.

**8 Corrosion additions**

**8.1 Values of corrosion additions**

**8.1.1 General**

The values of the corrosion additions specified in this Section shall be applied in relation to the relevant corrosion protection measures prescribed in Pt.2 Ch.5 Sec.3 [2].

The designer may define values of corrosion additions greater than those specified in [8.1.2].
8.1.2 Corrosion additions for steel other than stainless steel

The corrosion addition for each of the two sides of a structural member, \( t_{C1} \) or \( t_{C2} \), is specified in Table 4.

- for plating with a net thickness greater than 8 mm, the total corrosion addition \( t_C \) [mm] for both sides of the structural member is obtained by the following formula:
  \[
  t_C = t_{C1} + t_{C2}
  \]

- for plating with a net thickness less than or equal to 8 mm, the smallest of the following values shall be applied:
  - 25% of the net thickness of the plating
  - \( t_C = t_{C1} + t_{C2} \)

For an internal member within a given compartment, the total corrosion addition \( t_C \) is obtained from the following formula:

\[
 t_C = 2 \cdot t_{C1}
 \]

When a structural element is affected by more than one value of corrosion addition (e.g. plate in a dry bulk cargo hold extending in the double bottom), the scantling criteria are generally to be applied considering the severest value of corrosion addition applicable to the member.

8.1.3 Corrosion additions for stainless steel and aluminium alloys

For structural members made of stainless steel or aluminium alloys, the corrosion addition shall be taken equal to 0.25 mm, for one side exposure (\( t_{C1} = t_{C2} = 0.25 \) mm).

**Table 4 Corrosion additions [mm] for one side exposure (\( t_{C1} \) or \( t_{C2} \))**

<table>
<thead>
<tr>
<th>Compartment type</th>
<th>General 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballast tank</td>
<td>1.00</td>
</tr>
<tr>
<td>Cargo tank and fuel oil tank</td>
<td></td>
</tr>
<tr>
<td>Plating of horizontal surfaces</td>
<td>0.75</td>
</tr>
<tr>
<td>Plating of non-horizontal surfaces</td>
<td>0.50</td>
</tr>
<tr>
<td>Ordinary stiffeners and primary supporting members</td>
<td>0.50</td>
</tr>
<tr>
<td>Dry bulk cargo hold</td>
<td></td>
</tr>
<tr>
<td>General</td>
<td>1.00</td>
</tr>
<tr>
<td>Inner bottom plating</td>
<td></td>
</tr>
<tr>
<td>Side plating for single hull vessel</td>
<td></td>
</tr>
<tr>
<td>Inner side plating for double hull vessel</td>
<td></td>
</tr>
<tr>
<td>Transverse bulkhead plating</td>
<td>1.75</td>
</tr>
<tr>
<td>Frames. ordinary stiffeners and primary supporting members</td>
<td>0.50</td>
</tr>
<tr>
<td>Hopper well of dredging vessels</td>
<td>2.00</td>
</tr>
<tr>
<td>Accommodation space</td>
<td>0.00</td>
</tr>
<tr>
<td>Compartments and areas other than those mentioned above</td>
<td>0.50</td>
</tr>
</tbody>
</table>

1) General: corrosion additions are applicable to all members of the considered item.
SECTION 2 PROOF OF BUCKLING STRENGTH

1 Definitions

- \(a\) = length of single or partial plate field [mm]
- \(b\) = breadth of single plate field [mm]
- \(\alpha\) = aspect ratio of single plate field
  \[\text{where } \alpha = \frac{a}{b}\]
- \(n\) = number of single plate field breadths within the partial or total plate field
- \(t\) = nominal plate thickness [mm]
  \[\text{where } t = t_a - t_c \text{ [mm]}\]
- \(t_a\) = plate thickness as built [mm]
- \(t_c\) = corrosion addition according to Sec.1 [8] [mm]
- \(\sigma_x\) = membrane stress in x-direction [N/mm²]
- \(\sigma_y\) = membrane stress in y-direction [N/mm²]
- \(\tau\) = shear stress in the x-y plane [N/mm²]

Compressive and shear stresses shall be taken positive, tension stresses shall be taken negative.

**Figure 1 Definition of plate fields subject to buckling**

**Guidance note:**

If the stresses in the x- and y-direction already contain the Poisson effect, the following modified stress values may be used:

Both stresses \(\sigma_x^*\) und \(\sigma_y^*\) are to be compressive stresses, in order to apply the stress reduction according to the following formulae:

\[
\sigma_x = \left(\sigma_x^* - 0.3 \cdot \sigma_y^*\right)/0.91
\]

\[
\sigma_y = \left(\sigma_y^* - 0.3 \cdot \sigma_x^*\right)/0.91
\]

\(\sigma_x^*, \sigma_y^*\) = stresses containing the Poisson effect

Where compressive stress fulfils the condition \(\sigma_x^* < 0.3 \cdot \sigma_y^*\), then \(\sigma_y = 0\) and \(\sigma_x = \sigma_x^*\).

Where compressive stress fulfils the condition \(\sigma_y^* < 0.3 \cdot \sigma_x^*\), then \(\sigma_x = 0\) and \(\sigma_y = \sigma_y^*\).
When at least $\sigma_x^*$ or $\sigma_y^*$ is tension stress, then $\sigma_x = \sigma_x^*$ and $\sigma_y = \sigma_y^*$.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

$\psi$ = edge stress ratio according to Table 2
$F_1$ = correction factor for boundary condition at the long. stiffeners according to Table 1

**Table 1 Correction factor F1**

<table>
<thead>
<tr>
<th>1.0</th>
<th>for stiffeners sniped at both ends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guidance values where both ends are effectively connected to adjacent structures * :</td>
<td></td>
</tr>
<tr>
<td>1.05</td>
<td>for flat bars</td>
</tr>
<tr>
<td>1.10</td>
<td>for bulb sections</td>
</tr>
<tr>
<td>1.20</td>
<td>for angle and tee-sections</td>
</tr>
<tr>
<td>1.30</td>
<td>for girders of high rigidity(e.g. bottom transverses)</td>
</tr>
</tbody>
</table>

*Exact values may be determined by direct calculations.

$\sigma_e$ = reference stress

$$\sigma_e = 0.9 \cdot E \left( \frac{t}{b} \right)^2 \text{[N/mm}^2\text{]}$$

$E$ = Young’s modulus

- $2.06 \cdot 10^5$ N/mm$^2$ for steel
- $0.69 \cdot 10^5$ N/mm$^2$ for aluminium alloys

$R_{eh}$ = nominal yield point [N/mm$^2$] for hull structural steels according to Pt.2 Ch.5 Sec.1 [2].

$S$ = safety factor

- 1.1 in general
- 1.2 for structures which are exclusively exposed to local loads
- 1.05 for combinations of statistically independent loads

For constructions of aluminium alloys, the safety factors shall be increased in each case by 0.1.

$\lambda$ = reference degree of slenderness

$$\lambda = \sqrt{\frac{R_{eh}}{K \cdot \sigma_e}}$$

$K$ = buckling factor according to Table 2 and Table 3

In general, the ratio of plate field breadth to plate thickness shall not exceed $b/t = 100$.

### 2 Proof of single plate fields

#### 2.1

Proof shall be provided that the following condition is complied with for the single plate field $a \cdot b$:
Each term of the above condition shall not exceed 1.0.
The reduction factors $\kappa_x$, $\kappa_y$ and $\kappa_\tau$ are given in Table 2 and/or Table 3.
Where $\sigma_x \leq 0$ (tension stress), $\kappa_x = 1.0$.
Where $\sigma_y \leq 0$ (tension stress), $\kappa_y = 1.0$.
The exponents $e_1$, $e_2$ and $e_3$ as well as the factor $B$ are calculated or set respectively:

<table>
<thead>
<tr>
<th>Exponents $e_1$ to $e_3$ and factor $B$</th>
<th>plate field</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>plane</td>
</tr>
<tr>
<td>$e_1$</td>
<td>$1 + \kappa_x^4$</td>
</tr>
<tr>
<td>$e_2$</td>
<td>$1 + \kappa_y^4$</td>
</tr>
<tr>
<td>$e_3$</td>
<td>$1 + \kappa_x \cdot \kappa_y \cdot \kappa_\tau^2$</td>
</tr>
<tr>
<td>$B$</td>
<td>$(\kappa_x \cdot \kappa_y)^5$</td>
</tr>
<tr>
<td>$\sigma_x$ and $\sigma_y$ positive</td>
<td></td>
</tr>
<tr>
<td>compression stress</td>
<td></td>
</tr>
<tr>
<td>$B$</td>
<td>$(\kappa_x \cdot \kappa_y)^5$</td>
</tr>
<tr>
<td>$\sigma_x$ or $\sigma_y$ negative</td>
<td>$1$</td>
</tr>
<tr>
<td>tension stress</td>
<td></td>
</tr>
</tbody>
</table>

### 2.2 Effective width of plating

The effective width of plating may be determined by the following formulae:

- $b_m = \kappa_x \cdot b$ for longitudinal stiffeners
- $a_m = \kappa_y \cdot a$ for transverse stiffeners

see also Figure 1.

The effective width of plating shall not be taken greater than the effective breadth obtained from Sec.1 [4.3] and Sec.1 [5.2]
### Table 2 Plane plate fields

<table>
<thead>
<tr>
<th>Load case</th>
<th>Edge stress ratio $\psi$</th>
<th>Aspect ratio $\alpha$</th>
<th>Buckling factor $K$</th>
<th>Reduction factor $\kappa$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$1 \geq \psi \geq 0$</td>
<td>$\alpha &gt; 1$</td>
<td>$K = \frac{8.4}{\psi+1.1}$</td>
<td>$\kappa_x = 1$ for $\lambda \leq \lambda_e$</td>
</tr>
<tr>
<td></td>
<td>$0 &gt; \psi &gt; -1$</td>
<td>$\psi \leq -1$</td>
<td>$K = 7.63 - \psi (6.26 - 10\psi)$</td>
<td>$\kappa_x = \frac{1.22}{\lambda - \lambda_e}$ for $\lambda &gt; \lambda_e$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$K = (1-\psi)^2 \cdot 5.975$</td>
<td></td>
<td>$c = (1.25 - 0.12\psi) \leq 1.25$</td>
</tr>
<tr>
<td>2</td>
<td>$1 \geq \psi \geq 0$</td>
<td>$\alpha \geq 1$</td>
<td>$K = F_1\left{1 + \frac{1}{\alpha^2}\right}^2 \frac{2.1}{(\psi+1.1)}$</td>
<td>$\kappa_y = \frac{1}{\lambda} \cdot \frac{R+P^2}{(H-R)}$</td>
</tr>
<tr>
<td></td>
<td>$0 &gt; \psi &gt; -1$</td>
<td>$1 \leq \alpha \leq 1.5$</td>
<td>$R = \lambda \cdot \frac{1}{\alpha}$</td>
<td>$c = (1.25 - 0.12\psi) \leq 1.25$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha &gt; 1.5$</td>
<td>$R = 0.22$</td>
<td>for $\lambda &gt; \lambda_e$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$K = F_1\left{1 + \frac{1}{\alpha^2}\right}^2 \frac{2.1(1+\psi)}{1.1}$</td>
<td>$\lambda_e = \frac{h}{2} \left(1 + \sqrt{1 - \frac{0.88}{c^2}}\right)$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$- \frac{\psi}{\alpha^2} (13.9 - 10\psi)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$K = F_1\left{1 + \frac{1}{\alpha^2}\right}^2 \frac{2.1(1+\psi)}{1.1}$</td>
<td>$\lambda^2 = \lambda^2 - 0.5$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$- \frac{\psi}{\alpha^2} (5.87 + 1.87 \alpha^2)$</td>
<td>$1 \leq \alpha \leq 3$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$+ \frac{8.6}{\alpha^2} - 10\psi$</td>
<td>$c_1 = 1$ for $\sigma_y$ due to direct loads</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$K = F_1\left{1 - \frac{\psi}{\alpha}\right}^2 5.975$</td>
<td>$c_1 = 0$ for $\sigma_y$ due to bending (in general)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$1 \leq \alpha \leq \frac{3(1-\psi)}{4}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$K = F_1\left{1 - \frac{\psi}{\alpha}\right}^2 3.9675$</td>
<td>$c_1 = 0$ for $\sigma_y$ due to bending in extreme load cases (e.g. w. t. bulkheads)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$+ 0.5375 \left(\frac{1-\psi}{\alpha}\right)^2$</td>
<td>$H = \lambda \cdot \frac{2\lambda}{c(T+12T^2 - 4)} \geq R$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$+ 1.87$</td>
<td>$T = \lambda + \frac{14}{15\lambda} \cdot \frac{1}{3}$</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$1 \geq \psi \geq 0$</td>
<td>$\alpha &gt; 0$</td>
<td>$K = \frac{4(0.425 + 1/\alpha^2)}{3\psi + 1}$</td>
<td>$\kappa_x = 1$ for $\lambda \leq 0.7$</td>
</tr>
<tr>
<td></td>
<td>$0 &gt; \psi &gt; -1$</td>
<td>$\psi \leq -1$</td>
<td>$K = 4 \left(0.425 + \frac{1}{\alpha^2}\right)(1 + \psi)$</td>
<td>$\kappa_y = \frac{1}{\lambda} \cdot \frac{1}{0.51}$ for $\lambda &gt; 0.7$</td>
</tr>
<tr>
<td>4</td>
<td>$1 \geq \psi \geq 0$</td>
<td>$\alpha &gt; 0$</td>
<td>$K = \left(0.425 + \frac{1}{\alpha^2}\right) \frac{3 - \psi}{2}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$0 &gt; \psi &gt; -1$</td>
<td>$\psi \leq -1$</td>
<td>$K = \left(0.425 + \frac{1}{\alpha^2}\right) \frac{3 - \psi}{2}$</td>
<td></td>
</tr>
<tr>
<td>Load case</td>
<td>Edge stress ratio ( \psi )</td>
<td>Aspect ratio ( \alpha )</td>
<td>Buckling factor ( K )</td>
<td>Reduction factor ( \kappa )</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------</td>
<td>------------------</td>
<td>------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>( \alpha \geq 1 )</td>
<td>( K = K_t \cdot \sqrt{3} )</td>
<td>( \kappa_t = 1 \text{ for } \lambda \leq 0.84 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( 0 &lt; \alpha &lt; 1 )</td>
<td>( K_t = \left[ 5.34 + \frac{4}{\alpha^2} \right] )</td>
<td>( \kappa_t = \frac{0.84}{\lambda} \text{ for } \lambda &gt; 0.84 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>( K = K' \cdot r )</td>
<td>( r = (1 - \frac{d_h}{a})(1 - \frac{d_h}{b}) )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>with ( d_h/a \leq 0.7 ) and ( d_h/b \leq 0.7 )</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>( \alpha \geq 1.64 )</td>
<td>( K = 1.28 )</td>
<td>( \kappa_x = 1 \text{ for } \lambda \leq 0.7 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \alpha &lt; 1.64 )</td>
<td>( K = \frac{1}{\alpha^2} + 0.56 + 0.13 \alpha^2 )</td>
<td>( \kappa_x = \frac{1}{\lambda^2 + 0.51} \text{ for } \lambda &gt; 0.7 )</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>( \alpha \geq \frac{2}{3} )</td>
<td>( K = 6.97 )</td>
<td>( \kappa_x = 1 \text{ for } \lambda \leq 0.83 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \alpha &lt; \frac{2}{3} )</td>
<td>( K = \frac{1}{\alpha^2} + 2.5 + 5 \alpha^2 )</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>( \alpha \geq 4 )</td>
<td>( K = 4 )</td>
<td>( \kappa_x = 1.13 \left( \frac{1}{\lambda} - \frac{0.22}{\lambda^2} \right) \text{ for } \lambda &gt; 0.83 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( 4 &gt; \alpha &gt; 1 )</td>
<td>( K = 4 + \left[ \frac{4 - \alpha}{3} \right]^4 \cdot 2.74 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \alpha \leq 1 )</td>
<td>( K = \frac{4}{\alpha^2} + 2.07 + 0.67 \alpha^2 )</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>( \alpha \geq 4 )</td>
<td>( K = 6.97 )</td>
<td>( \kappa_x = 1.13 \left( \frac{1}{\lambda} - \frac{0.22}{\lambda^2} \right) \text{ for } \lambda &gt; 0.83 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( 4 &gt; \alpha &gt; 1 )</td>
<td>( K = 6.97 + \left[ \frac{4 - \alpha}{3} \right]^4 \cdot 3.1 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \alpha \leq 1 )</td>
<td>( K = \frac{4}{\alpha^2} + 2.07 + 4 \alpha^2 )</td>
<td></td>
</tr>
</tbody>
</table>

**Explanations for boundary conditions**
- Dotted line: plate edge free
- Dash line: plate edge simply supported
- Solid line: plate edge clamped
Table 3 Curved plate field $R/t \leq 2500$

<table>
<thead>
<tr>
<th>Load case</th>
<th>Aspect ratio $b/R$</th>
<th>Buckling factor $K$</th>
<th>Reduction factor $\kappa$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>$b \leq 1.63 \frac{R}{\sqrt{4t}}$</td>
<td>$K = \frac{b}{R - t} + 3 \left( \frac{R}{b} \cdot \frac{t}{0.175} \right)$</td>
<td>$\kappa_x = 1 \quad \text{for } \lambda \leq 0.4$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\kappa_x = 1.274 - 0.686 \lambda \quad \text{for } 0.4 &lt; \lambda \leq 1.2$</td>
</tr>
<tr>
<td>1b</td>
<td>$b &gt; 1.63 \frac{R}{\sqrt{4t}}$</td>
<td>$K = 0.3 \frac{b^2}{R^2} + 2.25 \left( \frac{R^2}{b^2} \right)$</td>
<td>$\kappa_x = 0.65 \frac{\lambda^2}{\lambda}$ \quad $\text{for } \lambda &gt; 1.2$</td>
</tr>
</tbody>
</table>

2

| 2         | $b \leq 0.5 \frac{R}{\sqrt{4t}}$ | $K = 1 + \frac{b^2}{3 R - t}$ | $\kappa_y = 1 \quad \text{for } \lambda \leq 0.25$ |
|           | $b > 0.5 \frac{R}{\sqrt{4t}}$ | $K = 0.267 \frac{b^2}{R - t} \left[ 3 - \frac{b}{r} \right] \geq 0.4 \frac{b^2}{R^2}$ | $\kappa_y = 1.233 - 0.933 \lambda \quad \text{for } 0.25 < \lambda \leq 1$ |
|           |                    | $\geq 0.4 \frac{b^2}{R^2}$ | $\kappa_y = 0.3 / \lambda \quad \text{for } 1 < \lambda \leq 1.5$ |
|           |                    | $\geq 0.4 \frac{b^2}{R^2}$ | $\kappa_y = 0.2 / \lambda^2 \quad \text{for } \lambda > 1.5$ |

3

| 3         | $b \leq \frac{R}{\sqrt{4t}}$ | $K = 0.6 \cdot \frac{b}{\sqrt{R - t}} + \frac{\sqrt{R - t}}{b} - 0.3 \frac{R - t}{b^2}$ | $\kappa_t = 1 \quad \text{for } \lambda \leq 0.4$ |
|           | $b > \frac{R}{\sqrt{4t}}$ | $K = 0.3 \frac{b^2}{R^2} + 0.291 \left( \frac{R^2}{b^2} \right)$ | $\kappa_t = 1.274 - 0.686 \lambda \quad \text{for } 0.4 < \lambda \leq 1.2$ |

4

| 4         | $b \leq 8.7 \frac{R}{\sqrt{4t}}$ | $K = K_t \cdot \sqrt{3}$ | $\kappa_t = 0.65 \frac{\lambda^2}{\lambda^2}$ \quad $\text{for } \lambda > 1.2$ |
|           | $b > 8.7 \frac{R}{\sqrt{4t}}$ | $K_t = \left[ \frac{28.3 + 0.67 \cdot b^3}{R^2 + t^2} \right]^{0.5}$ | $\kappa_t = 0.65 \frac{\lambda^2}{\lambda^2}$ \quad $\text{for } \lambda > 1.2$ |

Explanations for boundary conditions:

- plate edge free
- plate edge simply supported
- plate edge clamped

1 For curved plate fields with a very large radius the $\lambda$-value need not to be taken less than one derived for the expanded plane field.
2 For curved plate fields, e.g. the bilge strake, which are located within plane partial or total fields, the reduction factor $\kappa$ may be taken as below:

Load case 1b: $\kappa_x = 0.892 \leq 1.0$; load case 2b: $\kappa_y = 0.655 \leq 1.0$
Guidance note:
The effective width $e'_m$ of stiffened flange plates of girders may be determined as follows:

Stiffening parallel to web of girder:

\[ e'_m = n \cdot b_m \]
\[ n = \text{integer number of the stiffener spacing } b \text{ inside the effective breadth } e_m \]
\[ n = \text{int} \left( \frac{e_m}{b} \right) \]

Stiffening perpendicular to web of girder:

\[ a \geq e_m \]
\[ e'_m = n \cdot a_m < e_m \]
\[ n = 2.7 \cdot \frac{e_m}{a} \leq 1 \]

\[ e = \text{width of plating supported according to Sec.1 [4.3] and Sec.1 [5.2]} \]

For \( b \geq e_m \) or \( a < e_m \) respectively, \( b \) and \( a \) have to be exchanged.

\( a_m \) and \( b_m \) for flange plates are in general to be determined for \( \psi = 1 \).

Stress distribution between two girders:

\[ \sigma_x(y) = \sigma_{x1} \cdot \left( 1 - \frac{y}{e} \left[ 3 + c_1 - 4 \cdot c_2 - 2 \cdot \frac{y}{e} (1 + c_1 - 2 \cdot c_2) \right] \right) \]

\[ c_1 = \frac{\sigma_{x2}}{\sigma_{x1}} \quad 0 \leq c_1 \leq 1 \]

\[ c_2 = \frac{1.5}{e} \cdot \left( e_m^1 + e_m^2 \right) - 0.5 \]

\[ e_m^1 = \frac{e_m^1}{e_m^1} \]

\[ e_m^2 = \frac{e_m^2}{e_m^2} \]

\[ \sigma_{x1}, \sigma_{x2} = \text{normal stresses in flange plates of adjacent girder 1 and 2 with spacing e} \]

\[ y = \text{distance of considered location from girder 1} \]

Scantlings of plates and stiffeners are in general to be determined according to the maximum stresses \( \sigma_x(y) \) at girder webs and stiffeners respectively. For stiffeners under compression arranged parallel to the girder web with spacing \( b \), no lesser value than \( 0.25 \cdot R_{eh} \) shall be inserted for \( \sigma_x(y=b) \).

Shear stress distribution in the flange plates may be assumed linearly.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

2.3 Webs and flanges

For non-stiffened webs and flanges of sections and girders, proof of sufficient buckling strength shall be provided as for single plate fields according to [2.1].

**Guidance note:**

Within 0.6 L amidships, the following guidance values are recommended for the ratio of web depth to web thickness and/or flange breadth to flange thickness:

**Flat bars:** 
\[ \frac{h_w}{t_w} \leq 19.5 \sqrt{k} \]

**Angle, tee and bulb sections:** 
\[ \frac{h_w}{t_w} \leq 60.0 \sqrt{k} \]
3 Proof of partial and total fields

3.1 Longitudinal and transverse stiffeners

Proof shall be provided that the continuous longitudinal and transverse stiffeners of partial and total plate fields comply with the conditions set out in [3.2] and [3.3].

3.2 Lateral buckling

\[
\frac{\sigma_a + \sigma_b}{R_{eh}} S \leq 1
\]

\( \sigma_a \) = uniformly distributed compressive stress in the direction of the stiffener axis [\( \text{N/mm}^2 \)]
\( \sigma_a = \sigma_x \) for longitudinal stiffeners
\( \sigma_a = \sigma_y \) for transverse stiffeners

\( \sigma_b \) = bending stress in the stiffeners
\[
\sigma_b = \frac{M_o + M_1}{W_{st} \cdot 10^3} \quad [\text{N/mm}^2]
\]

\( M_o \) = bending moment due to deformation \( w \) of stiffener

\[
= \frac{F_{Kl}}{c_f - p_z} \quad [\text{N}\cdot\text{mm}]
\]

\( (c_f - p_z) > 0 \)

\( M_1 \) = bending moment due to the lateral load \( p \)

for continuous longitudinal stiffeners:

\[
= \frac{p \cdot b \cdot a^2}{24 \cdot 10^3} \quad [\text{N}\cdot\text{mm}]
\]

for transverse stiffeners:

\[
= \frac{p \cdot a (n \cdot b)^2}{c_5 \cdot 8 \cdot 10^3} \quad [\text{N}\cdot\text{mm}]
\]

\( p \) = lateral load [\( \text{kN/m}^2 \)] according to Ch. 2

\( F_{Kl} \) = ideal buckling force of the stiffener [\( \text{N} \)]

\( F_{Klx} = \frac{\pi^2}{a^2} E \cdot l_1 \cdot 10^4 \) for long. stiffeners
Hull girder strength

\[ F_{Kiy} = \frac{\pi^2}{(n \cdot b)^2} \cdot E \cdot l_y \cdot 10^4 \text{ for transv. stiffeners} \]

\[ I_x, I_y = \text{moments of inertia of the longitudinal or transverse stiffener including effective width of plating according to 2.2 [cm}^4] \]

\[ I_x \geq \frac{b \cdot t^3}{12 \cdot 10^4} \]

\[ I_y \geq \frac{a \cdot t^3}{12 \cdot 10^4} \]

\[ p_x = \text{nominal lateral load of the stiffener due to } \sigma_x, \sigma_y \text{ and } \tau [\text{N/mm}^2] \]

for longitudinal stiffeners:

\[ p_x = \frac{t_s}{b} \left( \frac{\pi \cdot b}{a} \right)^2 \cdot 2 \cdot c_y + \sigma_y + \sqrt{2 \tau_1} \]

for transverse stiffeners:

\[ p_y = \frac{t_s}{a} \left( 2c_x \sigma_x + \left( \frac{\pi \cdot a}{n \cdot b} \right)(1 + \frac{A_y}{a \cdot t_y}) \right) + \sqrt{2 \tau_1} \]

\[ \sigma_{x1} = \sigma_x \left( 1 + \frac{A_x}{b \cdot t_a} \right) \]

\[ c_x, c_y = \text{factor taking into account the stresses vertical to the stiffener’s axis and distributed variable along the stiffener’s length} \]

\[ = 0.5 (1 + \psi) \text{ for } 0 \leq \psi \leq 1 \]

\[ = \frac{0.5}{1 - \psi} \text{ for } \psi < 0 \]

\[ \psi = \text{edge stress ratio according to Table 2} \]

\[ A_x, A_y = \text{sectional area of the longitudinal or transverse stiffener respectively [mm}^2] \]

\[ \tau_1 = \left[ \tau - \tau_0 \cdot E \left( \frac{m_1}{a^2} + \frac{m_2}{b^2} \right) \right] \geq 0 \]

for longitudinal stiffeners:

\[ \frac{a}{b} \geq 2.0 : m_1 = 1.47 \quad m_2 = 0.49 \]

\[ \frac{a}{b} < 2.0 : m_1 = 1.96 \quad m_2 = 0.37 \]

for transverse stiffeners:
Part 3 Chapter 3 Section 2

Hull girder strength


---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

\[
\frac{a}{n \cdot b} \geq 0.5 : m_1 = 0.37 \quad m_2 = \frac{1.96}{n^2}
\]

\[
\frac{a}{n \cdot b} < 0.5 : m_1 = 0.49 \quad m_2 = \frac{1.47}{n^2}
\]

\[
w = w_0 + w_1
\]

\[
w_0 = \text{assumed imperfection [mm]}
\]

\[
\frac{a}{250} \geq w_{ox} \leq \frac{b}{250} \quad \text{for long. stiffeners}
\]

\[
\frac{n \cdot b}{250} \geq w_{oy} \leq \frac{a}{250} \quad \text{for transv. stiffeners}
\]

however \( w_0 \leq 10 \text{ mm} \)

Guidance note:
For stiffeners snipped at both ends, \( w_o \) shall not be taken less than the distance from the midpoint of plating to the neutral axis of the profile including effective width of plating.

\[
w_1 = \text{deformation of stiffener due to lateral load } p \text{ at midpoint of stiffener span [mm]}
\]

In case of uniformly distributed load, the following values for \( w_1 \) may be used:

\[
\begin{align*}
\text{for longitudinal stiffeners: } w_1 &= \frac{p \cdot b \cdot a^4}{384 \cdot 10^7 \cdot E \cdot l_k} \\
\text{for transverse stiffeners: } w_1 &= \frac{5 \cdot a \cdot p (n \cdot b)^4}{384 \cdot 10^7 \cdot E \cdot I_y \cdot c_s^2}
\end{align*}
\]

\( c_f = \text{elastic support provided by the stiffener [N/mm}^2\text{]} \)

\( c_{fx} = \frac{E_{sx} \cdot \pi^2 \cdot (1 + c_{ps})}{a^2} \quad \text{for long. stiffeners} \)

\[
\begin{align*}
\text{for long. stiffeners: } c_{px} &= \frac{1}{1 + 0.91 \cdot \frac{c_{sx}}{c_{ps}} \left( \frac{12 \cdot 10^4 \cdot l_k}{t^3 \cdot b} - 1 \right)} \\
\text{for transv. stiffeners: } c_{fy} &= c_s \cdot F_{sy} \cdot \frac{\pi^2}{(n \cdot b)^2} \cdot (1 + c_{ps})
\end{align*}
\]

\( c_s = \text{factor accounting for the boundary conditions of the transverse stiffener} \)

\( = 1.0 \text{ for simply supported stiffeners} \)
Hull girder strength

3.3 Torsional buckling

3.3.1 Longitudinal stiffeners

\[
\frac{\sigma_x \cdot S}{\kappa_T \cdot R_{eh}} \leq 1.0
\]

\[\kappa_T = 1.0 \quad \text{for} \quad \lambda_T \leq 0.2\]

\[= \frac{1}{\phi + \sqrt{\phi^2 - \lambda_T^2}} \quad \text{for} \quad \lambda_T > 0.2\]

\[\varphi = 0.5 \left( 1 + 0.21 \left( \lambda_T - 0.2 \right) + \lambda_T^2 \right)\]
\[ \lambda_T = \text{reference degree of slenderness} \]
\[ \lambda_T = \sqrt{\frac{R_e h}{\sigma_{Klt}}} \]
\[ \sigma_{Klt} = \frac{E}{\frac{1}{b_1} \left( \frac{\pi^2}{a^2} + 0.385 \cdot c \right)} [N/mm^2] \]

For \( I_P, I_T, I_\omega \) see Figure 2 and Table 4.

![Figure 2 Main dimensions of typical longitudinal stiffeners](image)

**Figure 2 Main dimensions of typical longitudinal stiffeners**

- \( I_P \) = polar moment of inertia of the stiffener related to the point C [cm^4]
- \( I_T \) = St. Venant’s moment of inertia of the stiffener [cm^4]
- \( I_\omega \) = sectorial moment of inertia of the stiffener related to the point C [cm^6]
- \( \varepsilon \) = degree of fixation

\[ \varepsilon = 1 + 10^{-4} \left( \frac{a^4}{l_0 \left( \frac{b}{t^3} + \frac{4h_w}{3t_w^3} \right)} \right) \]

- \( h_w \) = web height [mm]
- \( t_w \) = web thickness [mm]
- \( b_f \) = flange breadth [mm]
- \( t_f \) = flange thickness [mm]
- \( A_w \) = web area \( h_w \cdot t_w \)
- \( A_f \) = flange area \( b_f \cdot t_f \)

### 3.3.2 Transverse stiffeners

For transverse stiffeners loaded by compressive stresses and which are not supported by longitudinal stiffeners, proof shall be provided in accordance with [3.3.1] analogously.
Table 4 Formulae for the calculation of moments of inertia $I_P$, $I_T$ and $I_\omega$

<table>
<thead>
<tr>
<th>Section</th>
<th>$I_P$</th>
<th>$I_T$</th>
<th>$I_\omega$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat bar</td>
<td>$\frac{h_w^3 \cdot t_w}{3 \cdot 10^4}$</td>
<td>$\frac{h_w \cdot t_w^3}{3 \cdot 10^4} \left(1 - 0.63 \frac{t_w}{h_w}\right)$</td>
<td>$\frac{h_w^3 \cdot t_w^3}{36 \cdot 10^6}$</td>
</tr>
<tr>
<td>Sections with bulb or flange</td>
<td>$\left(\frac{A_w \cdot h_w^2}{3} + A_f \cdot e_f^2\right) 10^{-4}$</td>
<td>$\frac{h_w \cdot t_w^3}{3 \cdot 10^4} \left(1 - 0.63 \frac{t_w}{h_w}\right)$</td>
<td>for bulb and angle sections: $\frac{A_f \cdot e_f^2 \cdot b_f^2}{12 \cdot 10^6} \left(\frac{A_f + 2.6 A_w}{A_f + A_w}\right)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>for tee-sections: $\frac{b_f^3 \cdot t_f \cdot e_f^2}{12 \cdot 10^5}$</td>
</tr>
</tbody>
</table>
SECTION 3 STRENGTH CHECK IN TESTING CONDITIONS

1 Symbols

\( t \) = net thickness [mm] of plating

\( w \) = net section modulus [cm\(^3\)] of ordinary stiffeners

\( A_{sh} \) = net web sectional area [cm\(^2\)]

\( k \) = material factor defined Pt.2 Ch.5 Sec.1 [2.4] and Pt.2 Ch.5 Sec.1 [3.2]

\( s \) = spacing [m] of ordinary stiffeners

\( S \) = spacing [m] of primary supporting members

\( \ell \) = span [m] of stiffeners

\( \eta \) = \( 1 - s / (2 \cdot \ell) \)

\( z \) = Z co-ordinate [m] of the calculation point

\( z_{TOP} \) = Z co-ordinate [m] of the highest point of the tank

\( z_{AP} \) = Z co-ordinate [m] of the deck line of the deck to which the air pipes extend, to be taken not less than \( z_{TOP} \)

\( p_{pv} \) = setting pressure [kN/m\(^2\)] of safety valves or maximum pressure [kN/m\(^2\)] in the tank during loading/unloading, whichever is the greater

\( d_{AP} \) = distance from the top of air pipe to the top of the compartment [m]

\( p_{ST} \) = testing pressure [kN/m\(^2\)] defined in [3].

\( \sigma_1 \) = hull girder normal stress [N/mm\(^2\)] to be determined in testing conditions.

2 Strength check

2.1 General

2.1.1 The requirements of this section provide the minimum scantlings of platings and structural members of compartments subjected to testing conditions.

Where the test conditions are subject to induce additional loads, the strength check is to be carried out by direct calculation.

These requirements are not applicable to bottom shell plating and side shell plating.

2.2 Plating

2.2.1 The net thickness [mm] of plating of compartments or structures defined in Table 2 is to be not less than:

\[ t = s \cdot \sqrt{k \cdot p_{ST}} \]

where the testing pressure \( p_{ST} \) is defined in [3].

2.3 Structural members

2.3.1 The net section modulus \( w \) [cm\(^3\)] and the net shear sectional area \( A_{sh} \) [cm\(^2\)] of structural members of compartments or structures defined in Table 2 are to be not less than the values obtained from the formulae given in Table 3.
### Table 1 Resistance partial safety factors $\gamma_R$

<table>
<thead>
<tr>
<th>Structures</th>
<th>Ordinary stiffeners</th>
<th>Primary supporting members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fore peak structures</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>Structures located aft of the collision bulkhead</td>
<td>1.02</td>
<td>1.02 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.15 2)</td>
</tr>
<tr>
<td>1) in general</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) for bottom and side girders.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 3 Testing pressures

#### 3.1 Still water pressure

3.1.1 The still water pressure to be considered as acting on plates and stiffeners subjected to tank testing is to be obtained, in [kN/m²], from the formulae in Table 2.

The testing conditions of tanks and watertight or weathertight structures are determined by requirements of Pt.2 Ch.5 Sec.4.

<table>
<thead>
<tr>
<th>Compartment or structure to be tested</th>
<th>Still water pressure $p_{ST}$ [kN/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double bottom tanks</td>
<td>$p_{ST} = 9.81 \left( Z_{TOP} - Z \right) + d_{AP}$</td>
</tr>
<tr>
<td>Double side tanks Fore peaks used as tank</td>
<td>The greater of the following:</td>
</tr>
<tr>
<td>After peaks used as tank</td>
<td>$p_{ST} = 9.81 \left( Z_{TOP} - Z \right) + d_{AP}$</td>
</tr>
<tr>
<td></td>
<td>$p_{ST} = 9.81 \left( Z_{TOP} - Z + 1 \right)$</td>
</tr>
<tr>
<td>Cargo tank bulkheads Deep tanks</td>
<td>The greater of the following:</td>
</tr>
<tr>
<td>Independent cargo tanks</td>
<td>$p_{ST} = 9.81 \left( Z_{TOP} - Z \right) + d_{AP}$</td>
</tr>
<tr>
<td>Residual cargo tanks</td>
<td>$p_{ST} = 9.81 \left( Z_{TOP} - Z + 1 \right)$</td>
</tr>
<tr>
<td>Ballast compartments</td>
<td>The greater of the following:</td>
</tr>
<tr>
<td>Fuel oil bunkers</td>
<td>$p_{ST} = 9.81 \left( Z_{TOP} - Z \right) + d_{AP}$</td>
</tr>
<tr>
<td>Cofferdams</td>
<td>$p_{ST} = 9.81 \left( Z_{TOP} - Z + 1 \right)$</td>
</tr>
<tr>
<td>Double bottom Fore peaks not used as tank</td>
<td>$p_{ST} = 9.81 \left( Z_{TOP} - Z \right)$</td>
</tr>
<tr>
<td>After peaks not used as tank</td>
<td>$p_{ST} = 9.81 \left( Z_{TOP} - Z + 1 \right)$</td>
</tr>
</tbody>
</table>
### Table 3 Strength check of stiffeners in testing conditions

<table>
<thead>
<tr>
<th>Stiffener</th>
<th>$w$</th>
<th>$A_{sh}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical stiffeners</td>
<td>$w = \frac{4.36 \cdot \gamma_R \cdot k \cdot \lambda_b \cdot \beta_b \cdot p_{ST} \cdot \eta_1 \cdot a \cdot \ell^2}{m}$</td>
<td>$A_{sh} = 0.045 \cdot \gamma_R \cdot k \cdot \lambda_s \cdot \beta_s \cdot \eta_1 \cdot p_{ST} \cdot a \cdot \ell$</td>
</tr>
<tr>
<td>Transverse stiffeners</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal stiffeners</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal stiffeners (in case of testing afloat)</td>
<td>$w = \frac{1000 \cdot \lambda_{bs} \cdot \beta_s \cdot p_{ST} \cdot a \cdot \ell^2}{m \cdot \left( \frac{230}{\gamma_R} - \sigma_1 \right)}$</td>
<td>$A_{sh} = 0.045 \cdot \gamma_R \cdot k \cdot \lambda_s \cdot \beta_s \cdot \eta_2 \cdot p_{ST} \cdot a \cdot \ell$</td>
</tr>
</tbody>
</table>

- $a$  = $s$ for ordinary stiffeners
- $\eta_1$  = $\eta$ for ordinary stiffeners
- $\beta_b$, $\beta_S$ = bracket coefficients defined in Sec.1 [6.2]
- $\lambda_b$, $\lambda_S$ = coefficients for vertical structural members defined in Sec.1 [6.3]
- $\gamma_R$ = resistance partial safety factor defined in Table 1
- $m$ = boundary coefficient, to be taken equal to:
  - 12 in general, for stiffeners considered as clamped
  - 8 for stiffeners considered as simply supported
  - 10.6 for stiffeners clamped at one end and simply supported at the other
SECTION 4 DIRECT CALCULATION

1 Symbols

1.1 Symbols

\[ R_{eH} = \text{minimum yielding stress [N/mm}^2\text{]} \text{ of the material} \]
\[ \gamma_R = \text{partial safety factor covering uncertainties regarding resistance, defined in Table 1.} \]

2 General

2.1 Application

2.1.1 This section gives guidance on how to perform yielding and buckling checks of structural members by direct calculations.

Such direct calculation may be adopted instead of rule scantling formulae or for the analysis of structural members not covered by the rules.

2.1.2 Yielding check

The yielding check is to be carried out according to:

— [3] for structural members analysed through isolated beam models
— [4] for structural members analysed through three dimensional beam or finite element models

2.1.3 Buckling check

The buckling check is to be carried out according to Sec.2 on the basis of the stresses in primary supporting members calculated according to [3] or [4] depending on the structural model adopted.

2.2 Analysis documentation

2.2.1 For any direct calculation carried out, the following information is to be submitted to the society:

— reference to the calculation program used with identification of the version number and results of the validation test, if the results of the program have not been already submitted to the Society approval
— extent of the model, element types and properties, material properties and boundary conditions
— loads given in print-out or suitable electronic format. In particular, the method used to take into account the interaction between the overall, primary and local loadings is to be described. The direction and intensity of pressure loads, concentrated loads, inertia and weight loads are to be provided
— stresses given in print-out or suitable electronic format
— buckling checks
— identification of the critical areas, where the results of the checkings exceed 97.5 % of the permissible rule criteria defined in [4.3] and Sec.2.

2.2.2 According to the results of the submitted calculations, the Society may request additional runs of the model with structural modifications or local mesh refinements in highly stressed areas.
2.3 Net scantlings

2.3.1 All scantlings referred to in this section are net, i.e., they do not include any margin for corrosion. The gross scantlings are obtained as specified in Sec.1 [7].

2.4 Resistance partial safety factors

2.4.1 The values of resistance partial safety factor covering uncertainties on resistance to be considered for checking structural members are specified in Table 1 for analyses based on different calculation models.

**Table 1 Resistance partial safety factor $\gamma_R$**

<table>
<thead>
<tr>
<th>Calculation model</th>
<th>Yielding check</th>
<th></th>
<th>Buckling check</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>General</td>
<td>Watertight bulkhead</td>
<td></td>
</tr>
<tr>
<td>Isolated beam model:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- in general</td>
<td>1.02</td>
<td>1.02</td>
<td>1.10</td>
</tr>
<tr>
<td>- bottom and side girders</td>
<td>1.15</td>
<td>NA 1)</td>
<td></td>
</tr>
<tr>
<td>- collision bulkhead</td>
<td>NA 1)</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>Three dimensional beam model</td>
<td>1.20</td>
<td>1.02</td>
<td>1.02</td>
</tr>
<tr>
<td>Coarse mesh finite element model</td>
<td>1.20</td>
<td>1.02</td>
<td>1.02</td>
</tr>
<tr>
<td>Fine mesh finite element model</td>
<td>1.05</td>
<td>1.02</td>
<td>1.02</td>
</tr>
</tbody>
</table>

1) NA = not applicable

3 Yielding check of structural members analysed through an isolated beam structural model

3.1 General

3.1.1 The following requirements apply for the yielding check of structural members, which may be analysed through an isolated beam model:
- subjected to lateral pressure or to wheeled loads
- for those contributing to the hull girder longitudinal strength and to hull girder normal stresses.

3.1.2 The yielding check is also to be carried out for structural members subjected to specific loads, such as concentrated loads.

3.2 Load point

3.2.1 Lateral pressure

Unless otherwise specified, lateral pressure is to be calculated at mid-span of the structural member considered.
3.2.2 Hull girder normal stresses
For longitudinal structural members contributing to the hull girder longitudinal strength, the hull girder normal stresses are to be calculated in way of the neutral axis of the structural member with attached plating.

3.3 Load model
3.3.1 General
The external pressure and the pressures induced by the various types of cargoes and ballast are to be considered, depending on the location of the structural member under consideration and the type of compartments adjacent to it, in accordance with Ch.2 Sec.3.

3.3.2 Pressure load in service conditions
The pressure load in service conditions is to be determined according to Ch.2 Sec.3 [4] and Ch.2 Sec.3 [5].

3.3.3 Wheeled loads
For structural members subjected to wheeled loads, the yielding check may be carried out according to [3.4] considering uniform pressures equivalent to the distribution of vertical concentrated forces, when such forces are closely located, taking into account the most unfavourable case.

3.3.4 Hull girder normal stresses
The hull girder normal stresses to be considered for the yielding check of structural members are to be determined according to Sec.11 [3.4].

3.4 Checking criteria
3.4.1 It is to be checked that the normal stress $\sigma$ and the shear stress $\tau$ are in compliance with the following formulae:

$$0.98 \cdot \frac{R_{EH}}{\gamma_R} \geq \sigma$$
$$0.49 \cdot \frac{R_{EH}}{\gamma_R} \geq \tau$$

4 Yielding check of structural members analysed through a three dimensional structural model
4.1 General
4.1.1 The following requirements apply for the yielding check of structural members which are to be analysed through a three dimensional structural model:
- subjected to lateral pressure or to wheeled loads
- for those contributing to the hull girder longitudinal strength and to hull girder normal stresses.

4.1.2 The yielding check is also to be carried out for structural members subjected to specific loads, such as concentrated loads.
4.2 Analysis criteria

The analysis of structural members based on three dimensional models is to be carried out according to:
— the requirements in Sec.6 for structural members subjected to lateral pressure
— the requirements in Sec.7 for structural members subjected to wheeled loads.

4.3 Checking criteria

4.3.1 General

For all types of analysis (see Sec.6 [2]), it is to be checked that the equivalent Von Mises stress $\sigma_{VM}$, calculated according to Sec.6 [5] is in compliance with the following formula:

$$0.98 \cdot \frac{R_{EH}}{\gamma_R} \geq \sigma_{VM}$$

4.3.2 Additional criteria for analyses based on fine mesh finite element models

Fine mesh finite element models are defined with reference to Sec.6 [3.4.3].

For all the elements of the fine mesh models, it is to be checked that the normal stresses $\sigma_1$ and $\sigma_2$ and the shear stress $\tau_{12}$, calculated according to Sec.6 [5] are in compliance with the following formulae:

$$0.98 \cdot \frac{R_{EH}}{\gamma_R} \geq \text{MAX}(\sigma_1, \sigma_2)$$

$$0.49 \cdot \frac{R_{EH}}{\gamma_R} \geq \tau_{12}$$

4.3.3 Specific case of structural members subjected to wheeled loads

For all types of analysis (see Sec.7), it is to be checked that the equivalent Von Mises stress $\sigma_{VM}$, calculated according to Sec.7 is in compliance with the following formula:

$$0.98 \cdot \frac{R_{EH}}{\gamma_R} \geq \sigma_{VM}$$

5 Torsion

5.1 Torsion of catamarans

A method for the determination of scantlings of deck beams connecting the hulls of a catamaran subject to torsional moment is given in Sec.8.
SECTION 5 GEOMETRIC PROPERTIES OF STANDARD SECTIONS

1 Angles, flats and bulb flats

1.1 Notice

1.1.1 Table 1 and Table 2 give main characteristics of angles, bulb flats and flats currently used, with an attached plating 500 mm wide having a thickness equal to that of the section web.

1.1.2 The sections are listed in the order of increasing values of the section moduli. For each section, the data are listed in the following order:
— dimensions of the rolled section [mm]
— then, in brackets:
— the sectional area [cm$^2$] of the section
— the section modulus [cm$^3$] with the attached plating defined in [1.1.1]
— the mean variation of the section modulus [cm$^3$] for each 10% variation in sectional area of the attached plating

The values shown in Table 1 and Table 2 are generally valid for sectional area of the attached plating variations not exceeding 50%.

1.1.3 Examples

a) Consider a DIN bulb flat 200 x 9 welded to a 600 x 10 plating. The data shown in Table 1 are:

200 x 9 (23.60 209.1 1.98)

23.60 = sectional area [cm$^2$] of the section
209.1 = section modulus [cm$^3$] with the attached plating 9 mm thick and 500 mm wide
1.98 = mean increase of the section modulus for each 10% increase in sectional area of the attached plating

The section modulus obtained is thus equal to:

209.1 + 1.98·(60 − 45)·10/45 = 215.7 cm$^3$

b) If the same bulb flat is attached to a 400 x 8 plating, then the section modulus will be:

209.1 + 1.98·(32 − 45)·10/45 = 203.4 cm$^3$

2 Channels

2.1 Notice

2.1.1 Table 3 gives main characteristics of European standard channels currently used, with an attached plating 500 mm wide having a thickness equal to that of the channel web (a).

2.1.2 The channels are listed in the order of increasing values of the section moduli. For each channel, the data are listed in the following order:
— standard designation of the channel section
— dimensions of the channel [mm]
— sectional area [cm$^2$] of the channel
section modulus \([\text{cm}^3]\) with the attached plating defined in [2.1.1].

**Table 1 Geometric particulars with 500 mm wide attached plating of standard DIN unequal angles and bulb flats**

<table>
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<th>(w \ [\text{cm}^3])</th>
<th><strong>Unequal angles</strong></th>
<th><strong>Bulb flats</strong></th>
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<td>(1.42 2.5 0.02)</td>
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</tr>
<tr>
<td>3 40 x 20 x 3</td>
<td>(1.72 3.7 0.02)</td>
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<tr>
<td>4 40 x 20 x 4</td>
<td>(2.25 4.8 0.04)</td>
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<td>5 45 x 30 x 3</td>
<td>(2.19 5.7 0.03)</td>
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<tr>
<td>7 45 x 30 x 4</td>
<td>(2.87 7.5 0.05)</td>
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<td>9 45 x 30 x 5</td>
<td>(3.53 9.1 0.08)</td>
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<td>(3.46 10.5 0.06)</td>
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<td>50 x 30 x 5</td>
<td>(3.78 10.6 0.08)</td>
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<tr>
<td>11 60 x 4</td>
<td>(3.58 11.0 0.07)</td>
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<td>(4.18 12.4 0.09)</td>
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<td>(4.78 14.0 0.13)</td>
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<td>(8.66 37.7 0.29)</td>
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<td>(9.74 43.0 0.38)</td>
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<td><strong>Bulb flats</strong></td>
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### Table 2 Geometric particulars with 500 mm wide attached plating of standard DIN flats and equal angles

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<th><strong>Bulb flats</strong></th>
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<th><strong>Equal angles</strong></th>
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### Table 3 Geometric particulars with 500 mm wide attached plating of European standard channels

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SECTION 6 ANALYSES BASED ON THREE DIMENSIONAL MODELS

1 General

1.1 Application

1.1.1 The following requirements apply for the analysis criteria, structural modelling, load modelling and stress calculation of primary supporting members which are to be analysed through three dimensional structural models, according to Sec.4.

1.1.2 The following deals with that part of the structural analysis which aims at calculating the stresses in the primary supporting members in the midship area and, when necessary, in other areas, which are to be used in the yielding and buckling checks.

1.1.3 In some specific cases, some of simplifications or assumptions laid down below may not be deemed acceptable by the Society in relation to the type of structural model and the analysis performed.

1.1.4 The yielding and buckling checks of primary supporting members are to be carried out according to Sec.4.

2 Analysis criteria

2.1 General

All primary supporting members in the midship regions are normally to be included in the three dimensional model, with the purpose of calculating their stress level and verifying their scantlings.

When the primary supporting member arrangement is such that the Society can accept that the results obtained for the midship region are extrapolated to other regions, no additional analyses are required. Otherwise, analyses of the other regions are to be carried out.

2.2 Finite element model analyses

2.2.1 The analysis of primary supporting members is to be carried out by using fine mesh models, as defined in [3.4.3].

2.2.2 Areas which appear, from the primary supporting member analysis, to be highly stressed may be required to be further analysed through appropriately meshed structural models, as defined in [3.4.4].

2.3 Beam model analyses

Beam models may be adopted provided that:

— primary supporting members are not so stout that the beam theory is deemed inapplicable by the Society
— their behaviour is not substantially influenced by the transmission of shear stresses through the shell plating.

In any case, surface element models are to be adopted when deemed necessary by the Society on the basis of the vessel's structural arrangement.
3 Structural modelling of primary supporting members

3.1 Model setup

3.1.1 Elements
The structural model is to represent the primary supporting members with the plating to which they are connected.

Ordinary stiffeners are also to be represented in the model in order to reproduce the stiffness and inertia of the actual hull girder structure. The way ordinary stiffeners are represented in the model depends on the type of model (beam or surface element), as specified in [3.4] and [3.5].

3.1.2 Net scantlings
All the elements in [3.1.1] are to be modelled with their net scantlings according to Sec.1 [7]. Therefore, also the hull girder stiffness and inertia to be reproduced by the model are those obtained by considering the net scantlings of the hull structures.

3.2 Model extension

3.2.1 The longitudinal extension of the structural model is to be such that:
— the hull girder stresses in the area to be analysed are properly taken into account in the structural analysis
— the results in the areas to be analysed are not influenced by the unavoidable inaccuracy in the modelling of the boundary conditions.

3.2.2 The model may be limited to one cargo tank/hold length (one half cargo tank/hold length on either side of the transverse bulkhead; see Figure 1).
However, larger models may need to be adopted when deemed necessary by the Society considering the vessel’s structural arrangement.

3.2.3 In the case of structural symmetry with respect to the vessel’s centreline longitudinal plane, the hull structures may be modelled over half the vessel’s breadth.

![Figure 1 Model longitudinal extension](image)

3.3 Surface element modelling criteria

3.3.1 Modelling of primary supporting members
The analysis of primary supporting members based on fine mesh models, as defined in [3.4.3], is to be carried out by applying one of the following procedures (see Figure 2), depending on the computer resources:
— an analysis of the whole three dimensional model based on a fine mesh
— an analysis of the whole three dimensional model based on a coarse mesh, as defined in [3.4.2], from which the nodal displacements or forces are obtained to be used as boundary conditions for analyses based on fine mesh models of primary supporting members, e.g.:
— transverse rings
— double bottom girders
— side girders
— deck girders
— primary supporting members of transverse bulkheads
— primary supporting members which appear from the analysis of the whole model to be highly stressed.

![Figure 2 Surface element modelling criteria](image)

**3.3.2 Modelling of the most highly stressed areas**
The areas which appear from the analyses based on fine mesh models to be highly stressed may be required to be further analysed, using the mesh accuracy specified in [3.4.4].

**3.4 Surface element models**

**3.4.1 General**
Surface element models are generally to be based on linear assumptions. The mesh is to be executed using membrane or shell elements, with or without mid-side nodes.
Meshing is to be carried out following uniformity criteria among the different elements.

In general the quadrilateral elements are to be such that the ratio between the longer side length and the shorter side length does not exceed 4 and, in any case, is less than 2 for most elements. Their angles are to be greater than 60° and less than 120°. The triangular element angles are to be greater than 30° and less than 120°.

Further modelling criteria depend on the accuracy level of the mesh, as specified in [3.4.2] to [3.4.4].

### 3.4.2 Coarse mesh

The number of nodes and elements is to be such that the stiffness and inertia of the model properly represent those of the actual hull girder structure, and the distribution of loads among the various load carrying members is correctly taken into account.

To this end, the structural model is to be built on the basis of the following criteria:

- Ordinary stiffeners contributing to the hull girder longitudinal strength and which are not individually represented in the model are to be modelled by rod elements and grouped at regular intervals.
- Webs of primary supporting members may be modelled with only one element over their height.
- Face plates may be simulated with bars having the same cross section.
- The plating between two primary supporting members may be modelled with one element.
- Holes for the passage of ordinary stiffeners or small pipes may be disregarded.
- Manholes (and similar discontinuities) in the webs of primary supporting members may be disregarded, but the element thickness is to be reduced in proportion to the hole height and the web height ratio.

### 3.4.3 Fine mesh

The vessel's structure may be considered as finely meshed when each longitudinal ordinary stiffener is modelled; as a consequence, the standard size of surface elements used is based on the spacing of ordinary stiffeners.

The structural model is to be built on the basis of the following criteria:

- Webs of primary members are to be modelled with at least three elements on their height.
- The plating between two primary supporting members is to be modelled with at least two element stripes.
- The ratio between the longer side and the shorter side of elements is to be less than 3 in the areas expected to be highly stressed.
- Holes for the passage of ordinary stiffeners may be disregarded.

In some specific cases, some of the above simplifications may not be deemed acceptable by the Society in relation to the type of structural model and the analysis performed.

### 3.4.4 Mesh for the analysis of structural details

The structural modelling is to be accurate; the mesh dimensions are to be such as to enable a faithful representation of the stress gradients. The use of membrane elements is only allowed when significant bending effects are not present; in other cases, elements w are to be used.

### 3.5 Beam models

#### 3.5.1 Beams representing primary supporting members

Primary supporting members are to be modelled by beam elements with shear capabilities, positioned on their neutral axes.

#### 3.5.2 Variable cross-section primary supporting members

Where the geometric properties of primary support members vary along their length, the inertia characteristics of the modelling beams may be assumed as constant and equal to their average value along the length of the elements themselves.
3.5.3 Modelling of primary supporting members ends
The presence of end brackets may be disregarded; in such case their presence is also to be neglected for the evaluation of the beam inertia characteristics.
Rigid end beams are generally to be used to connect ends of the various primary supporting members, such as:
— floors and side vertical primary supporting members
— bottom girders and vertical primary supporting members of transverse bulkheads
— cross ties and side/longitudinal bulkhead primary supporting members

3.5.4 Beams representing hull girder characteristics
The stiffness and inertia of the hull girder is to be taken into account by longitudinal beams positioned as follows:
— on deck and bottom in way of side shell and longitudinal bulkheads, if any, for modelling the hull girder bending strength
— on deck, side shell, longitudinal bulkheads, if any, and bottom for modelling the hull girder shear strength

3.6 Boundary conditions for the three dimensional model

3.6.1 Structural model extended over at least three cargo tank/hold lengths
The whole three dimensional model is assumed to be fixed at one end, while shear forces and bending moments are applied at the other end to ensure equilibrium (see [4]).
At the free end section, rigid constraint conditions are to be applied to all nodes located on longitudinal members, in such a way that the transverse section remains plane after deformation.
When the hull structure is modelled over half the vessel’s breadth (see [3.2.3]), in way of the vessel’s centreline longitudinal plane, symmetry or anti-symmetry boundary conditions as specified in Table 1 are to be applied, depending on the loads applied to the model (symmetrical or anti-symmetrical, respectively).

Table 1 Symmetry and anti-symmetry conditions in way of the vessel’s centreline longitudinal plane

<table>
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<tr>
<th>Boundary conditions</th>
<th>DISPLACEMENTS in directions (^1)</th>
<th>(X)</th>
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<th>(Z)</th>
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<tr>
<td>Boundary conditions</td>
<td>ROTATION around axes (^1)</td>
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<tr>
<td>Anti-symmetry</td>
<td></td>
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<td>free</td>
<td>fixed</td>
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</table>

\(^1\) X, Y and Z directions and axes are defined with respect to the reference coordinate system in Ch.1 Sec.1 [1.4]

3.6.2 Structural model extended over one cargo tank/hold length
Symmetry conditions are to be applied at the fore and aft ends of the model, as specified in Table 2.
When the hull structure is modelled over half the vessel’s breadth (see [3.2.3]), in way of the vessel’s centreline longitudinal plane, symmetry or anti-symmetry boundary conditions as specified in Table 1 are to be applied, depending on the loads applied to the model (symmetrical or anti-symmetrical, respectively).
Vertical supports are to be fitted at the nodes positioned in way of the connection of the transverse bulkheads with longitudinal bulkheads, if any, or with sides.

**Table 2 Symmetry conditions at the model fore and aft ends**

<table>
<thead>
<tr>
<th>DISPLACEMENTS in directions</th>
<th>ROTATION around axes</th>
</tr>
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<tbody>
<tr>
<td>X fixed</td>
<td>Y free</td>
</tr>
<tr>
<td>X free</td>
<td>Y free</td>
</tr>
</tbody>
</table>

1) X, Y and Z directions and axes are defined with respect to the reference coordinate system in Ch.1 Sec.1 [1.4]

### 4 Load modelling of primary supporting members

#### 4.1 General

**4.1.1 Loading conditions and load cases in service conditions**

The loads are to be calculated for the most severe loading conditions, with a view to maximising the stresses in the longitudinal structure and primary supporting members.

The following loading conditions are generally to be considered:

— homogeneous loading conditions at draught T
— non-homogeneous loading conditions at draught T, when applicable
— partial loading conditions at the relevant draught
— ballast conditions at the relevant draught.

**4.1.2 Lightweight**

The lightweight of the modelled portion of the hull is to be uniformly distributed over the length of the model in order to obtain the actual longitudinal distribution of the still water bending moment.

**4.1.3 Structural model extended over half vessel’s breadth**

When the vessel is symmetrical with respect to its centreline longitudinal plane and the hull structure is modelled over half the vessel’s breadth, non-symmetrical loads are to be broken down into symmetrical and anti-symmetrical loads and applied separately to the model with symmetry and anti-symmetry boundary conditions in way of the vessel’s centreline longitudinal plane (see [3.6]).

#### 4.2 Local loads

**4.2.1 General**

Still water loads include:

— the still water external pressure, defined in Ch.2 Sec.3 [5].
— the still water internal loads, defined in Ch.2 Sec.3 [6]. for the various types of cargoes and for ballast.

**4.2.2 Distributed loads**

Distributed loads are to be applied to the plating panels.

In the analyses carried out on the basis of membrane surface element models or beam models, the loads distributed perpendicularly to the plating panels are to be applied on the ordinary stiffeners proportionally to their areas of influence. When ordinary stiffeners are not modelled or are modelled with rod elements (see [3.4]), the distributed loads are to be applied to the primary supporting members actually supporting the ordinary stiffeners.
4.2.3 Concentrated loads
When the elements directly supporting the concentrated loads are not represented in the structural model, the loads are to be distributed to the adjacent structures according to the actual stiffness of the structures transmitting them.

In the analyses carried out on the basis of coarse mesh surface element models or beam models, concentrated loads applied in five or more points almost equally spaced inside the same span may be applied as equivalent linearly distributed loads.

4.2.4 Cargo in sacks, bales and similar packages
The vertical loads are comparable to distributed loads. The loads on vertical walls may be disregarded.

4.2.5 Other cargoes
The modelling of cargoes other than those mentioned under [4.2.2] to [4.2.4] will be considered by the Society on a case by case basis.

4.3 Hull girder loads

4.3.1 Structural model extended over at least three cargo tank/hold lengths
The hull girder loads are constituted by:
— the still water and wave vertical bending moments
— the still water and wave vertical shear forces

and are to be applied at the model free end section. The shear forces are to be distributed to the plating according to the theory of bidimensional flow of shear stresses.

These loads are to be applied for the following two conditions:
— maximal bending moments at the middle of the central tank/hold within 0.4·L amidships
— maximal shear forces in way of the aft transverse bulkhead of the central tank/hold.

4.3.2 Structural model extended over one cargo tank/hold length
The normal and shear stresses induced by the hull girder loads are to be added to the stresses induced in the primary supporting members by local loads.

4.4 Additional requirements for the load assignment to beam models
Vertical and transverse concentrated loads are to be applied to the model, as shown in Figure 3, to compensate the portion of distributed loads which, due to the positioning of beams on their neutral axes, are not modelled.

In this Figure, $F_Y$ and $F_Z$ represent concentrated loads equivalent to the dashed portion of the distributed loads which is not directly modelled.

5 Stress calculation

5.1 Analyses based on surface element models

5.1.1 Stresses induced by local and hull girder loads
When finite element models extend over at least three cargo tank/hold lengths, both local and hull girder loads are to be directly applied to the model, as specified in [4.3.1]. In this case, the stresses calculated by the surface element program include the contribution of both local and hull girder loads.

When surface element models extend over one cargo tank/hold length, only local loads are directly applied to the structural model, as specified in [4.3.2]. In this case, the stresses calculated by the finite element
program include the contribution of local loads only. Hull girder stresses are to be calculated separately and superimposed on to the stresses induced by local loads.

**Figure 3 Concentrated loads equivalent to non-modelled distributed loads**

5.1.2 Stress components
Stress components are generally identified with respect to the element co-ordinate system, as shown, for example, in **Figure 4**. The orientation of the element co-ordinate system may or may not coincide with that of the reference coordinate system in Ch.1 Sec.1 [1.4].

The following stress components are to be calculated at the centroid of each element:

— the normal stresses $\sigma_1$ and $\sigma_2$ in the directions of the element co-ordinate system axes
— the shear stress $\tau_{12}$ with respect to the element co-ordinate system axes
— the Von Mises equivalent stress, obtained from the following formula:

$$\sigma_{VM} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \cdot \sigma_2 + 3 \cdot \tau_{12}^2}$$

5.1.3 Stress calculation points
Stresses are generally calculated by the computer programs for each element. The values of these stresses are to be used for carrying out the checks required.

5.2 Analyses based on beam models

5.2.1 Stresses induced by local and hull girder loads
Since beam models generally extend over one cargo tank/hold length (see [2.3.1] and [3.2.2]), only local loads are directly applied to the structural model, as specified in [4.3.2]. Therefore, the stresses calculated by the beam program include the contribution of local loads only. Hull girder stresses are to be calculated separately and superimposed on to the stresses induced by local loads.
5.2.2 Stress components
The following stress components are to be calculated:
— the normal stress $\sigma_1$ in the direction of the beam axis
— the shear stress $\tau_{12}$ in the direction of the local loads applied to the beam
— the Von Mises equivalent stress, obtained from the following formula:

$$\sigma_{VM} = \sqrt{\sigma_1^2 + 3 \cdot \tau_{12}^2}$$

5.2.3 Stress calculation points
Stresses are to be calculated at least for the following points of each primary supporting member:
— at the primary supporting member span where the maximum bending moment occurs
— at the connection of the primary supporting member with other structures, assuming as a section that formed by the member, the bracket (if any and if represented in the model) and the attached plating
— at the toe of the bracket (if any and if represented in the model) assuming as resistant section that formed by the member and the attached plating.

The values of the stresses are to be used for carrying out the checks required.
SECTION 7 ANALYSES OF PRIMARY SUPPORTING MEMBERS SUBJECTED TO WHEELED LOADS

1 General

1.1 Scope

1.1.1 The following requirements apply to the analysis criteria, structural modelling, load modelling and stress calculation of primary supporting members subjected to wheeled loads which are to be analysed through three dimensional structural models, according to Sec.4.

1.1.2 The purpose of these structural analyses is to determine:
— the distribution of the forces induced by the vertical acceleration acting on wheeled cargoes, among the various primary supporting members of decks, sides and possible bulkheads
— the behaviour of the above primary supporting members under the racking effects due to the transverse forces induced by the transverse acceleration acting on wheeled cargoes, when the number or location of transverse bulkheads is not sufficient to avoid such effects,
and to calculate the stresses in primary supporting members.
The above calculated stresses are to be used in the yielding and buckling checks.
In addition, the results of these analyses may be used, where deemed necessary by the Society, to determine the boundary conditions for finer mesh analyses of the most highly stressed areas.

1.1.3 When the behaviour of primary supporting members under the racking effects, due to the transverse forces induced by the transverse acceleration, is not to be determined, the stresses in deck primary supporting members may be calculated according to the simplified analysis in [6], provided that the conditions for its application are fulfilled (see [6.1]).

1.1.4 The yielding and buckling checks of primary supporting members are to be carried out according to Sec.4 [4.3].

1.2 Application

1.2.1 The requirements laid down in this section apply to vessels with structural arrangement is such that the following assumptions may be considered as being applicable:
— Primary supporting members of side and possible bulkheads may be considered fixed in way of the double bottom (this is generally the case when the stiffness of floors is at least three times that of the side primary supporting members).
— Under transverse inertial forces, decks behave as beams loaded in their plane and supported at the vessel ends; their effect on the vessel transverse rings (side primary supporting members and deck beams) may therefore be simulated by means of elastic supports in the transverse direction or transverse displacements assigned at the central point of each deck beam.

1.2.2 When the assumptions in [1.2.1] are considered by the Society as not being applicable, the analysis criteria are defined on a case by case basis, taking into account the vessel’s structural arrangement and loading conditions.

1.3 Information required
To perform these structural analyses, the following characteristics of vehicles loaded are necessary:
— load per axle
1.4 Lashing of vehicles

The presence of lashing for vehicles is generally to be disregarded, but may be given consideration by the Society, on a case by case basis, at the request of the involved parties.

2 Analysis criteria

2.1 Beam model analyses

2.1.1 For inland navigation vessels, beam models, built according to Sec.6 [3.5], may be adopted in lieu of the surface element models, provided that:
- Primary supporting members are not so stout that the beam theory is deemed inadequate by the Society.
- Their behaviour is not substantially influenced by the transmission of shear stresses through the shell plating.

2.1.2 Surface element models may need to be adopted when deemed necessary by the Society on the basis of the vessel’s structural arrangement.

3 Structural modelling of primary supporting members

3.1 Model setup

3.1.1 Elements

The structural model is to represent the primary supporting members with the plating to which they are connected. In particular, the following primary supporting members are to be included in the model:
- deck beams
- side primary supporting members
- primary supporting members of longitudinal and transverse bulkheads, if any
- pillars
- deck beams, deck girders and pillars supporting ramps and deck openings, if any

3.1.2 Net scantlings

All the elements in [3.1.1] are to be modelled with their net scantlings according to Sec.1 [7].

3.2 Model extension

3.2.1 The structural model is to represent a hull portion which includes the zone under examination and which is repetitive along the hull. The non-modelled hull parts are to be considered through boundary conditions as specified in [3.3].

In addition, the longitudinal extension of the structural model is to be such that the results in the areas to be analysed are not influenced by the unavoidable inaccuracy in the modelling of the boundary conditions.

3.2.2 Double bottom structures are not required to be included in the model, based on the assumptions in [1.2.1].
3.3 Boundary conditions for the three dimensional model

3.3.1 Boundary conditions at the lower ends of the model
The lower ends of the model (i.e. the lower ends of primary supporting members of side and possible bulkheads) are to be considered as being clamped in way of the inner bottom.

3.3.2 Boundary conditions at the fore and aft ends of the model
Symmetry conditions are to be applied at the fore and aft ends of the model, as specified in Table 1.

Table 1 Symmetry conditions at the model fore and aft ends

<table>
<thead>
<tr>
<th>DISPLACEMENTS in directions</th>
<th>ROTATION around axes</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>fixed</td>
<td>free</td>
</tr>
</tbody>
</table>
1) X, Y and Z directions and axes are defined with respect to the reference co-ordinate system in Ch.1 Sec.1 [1.4]

3.3.3 Additional boundary conditions at the fore and aft ends of models subjected to transverse loads
When the model is subjected to transverse loads, i.e. when the loads in inclined vessel conditions are applied to the model, the transverse displacements of the deck beams are to be obtained by means of a racking analysis and applied at the fore and aft ends of the model, in way of each deck beam.

For vessels with a traditional arrangement of fore and aft parts, a simplified approximation may be adopted, when deemed acceptable by the Society, defining the boundary conditions without taking into account the racking calculation and introducing springs, acting in the transverse direction, at the fore and aft ends of the model, in way of each deck beam (see Figure 1). Each spring, which simulates the effects of the deck in way of which it is modelled, has a stiffness obtained [kN/m] from the following formula:

\[
R_0 = \frac{24 \cdot E \cdot J_D \cdot \frac{1}{s_a} \cdot 10^3}{2 \cdot x^4 - 4 \cdot l_D \cdot x^3 + \frac{l_D^2}{x^2} + 15.6 \cdot \frac{1}{A_D} + \frac{1}{l_D^3} \cdot x}
\]

\( J_D = \) net moment of inertia \([m^4]\) of the average cross-section of the deck, with the attached side shell plating
\( A_D = \) net area \([m^2]\) of the average cross-section of deck plating
\( s_a = \) spacing of side vertical primary supporting members \([m]\)
\( x = \) longitudinal distance \([m]\) measured from the transverse section at mid-length of the model to any deck end
\( L_D = \) length of the deck \([m]\) to be taken equal to the vessel’s length. Special cases in which such value may be reduced will be considered by the Society on a case-by-case basis.
4 Load modelling

4.1 General

4.1.1 Hull girder and local loads
Only local loads are to be directly applied to the structural model. The stresses induced by hull girder loads are to be calculated separately and superimposed on the stresses induced by local loads.

4.1.2 Loading conditions and load cases: wheeled cargoes
The loads are to be calculated for the most severe loading conditions, with a view to maximising the stresses in primary supporting members. The loads transmitted by vehicles are to be applied taking into account the most severe axle positions for the vessel structures.

4.1.3 Loading conditions and load cases: dry uniform cargoes
When the vessel’s decks are also designed to carry dry uniform cargoes, the loading conditions which envisage the transportation of such cargoes are also to be considered. The still water and wave loads induced by these cargoes are to be calculated for the most severe loading conditions, with a view to maximising the stresses in primary supporting members.

4.2 Local loads

4.2.1 General
Still water loads include:
— the still water external pressure, defined in Ch.2 Sec.3 [5].
— the still water forces induced by wheeled cargoes, defined in Ch.2 Sec.3 [6.6].

4.2.2 Tyred vehicles
For the purpose of primary supporting members analyses, the forces transmitted through the tyres may be considered as concentrated loads in the tyre print centre. The forces acting on primary supporting members are to be determined taking into account the area of influence of each member and the way ordinary stiffeners transfer the forces transmitted through the tyres.
4.2.3 Non-tyred vehicles
The requirements in [4.2.2] also apply to tracked vehicles. In this case, the print to be considered is that below each wheel or wheelwork.
For vehicles on rails, the loads transmitted are to be applied as concentrated loads.

4.2.4 Distributed loads
In the analyses carried out on the basis of beam models or membrane surface element models, the loads distributed perpendicularly to the plating panels are to be applied on the primary supporting members proportionally to their areas of influence.

4.3 Hull girder loads
The normal stresses induced by the hull girder loads are to be superimposed on the stresses induced in the primary supporting members by local loads.

5 Stress calculation

5.1 Stresses induced by local and hull girder loads
Only local loads are directly applied to the structural model, as specified in [4.1.1]. Therefore, the stresses calculated by the program include the contribution of local loads only. Hull girder stresses are to be calculated separately and superimposed on the stresses induced by local loads.

5.2 Analyses based on surface element models

5.2.1 Stress components
Stress components are generally identified with respect to the element co-ordinate system, as shown, for example, in Figure 2. The orientation of the element co-ordinate system may or may not coincide with that of the reference coordinate system in Ch.1 Sec.1 [1.4].
The following stress components are to be calculated at the centroid of each element:
— the normal stresses $\sigma_1$ and $\sigma_2$ in the directions of element co-ordinate system axes
— the shear stress $\tau_{12}$ with respect to the element co-ordinate system axes
— the Von Mises equivalent stress, obtained from the following formula:

$$\sigma_{VM} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \cdot \sigma_2 + 3 \cdot \tau_{12}^2}$$
5.2.2 Stress calculation points
Stresses are generally calculated by the computer programs for each element. The values of these stresses are to be used for carrying out the checks required.

5.3 Analyses based on beam models

5.3.1 Stress components
The following stress components are to be calculated:
— the normal stress $\sigma_1$ in the direction of the beam axis
— the shear stress $\tau_{12}$ in the direction of the local loads applied to the beam
— the Von Mises equivalent stress, obtained from the following formula:

$$\sigma_{VM} = \sqrt{\sigma_1^2 + 3 \cdot \tau_{12}^2}$$

5.3.2 Stress calculation points
Stresses are to be calculated at least for the following points of each primary supporting member:
— at the primary supporting member span where the maximum bending moment occurs
— at the connection of the primary supporting member with other structures, assuming as resistant section that formed by the member, the bracket (if any and if represented in the model) and the attached plating
— at the toe of the bracket (if any and if represented in the model) assuming as resistant section that formed by the member and the attached plating.

The values of the stresses calculated in the above points are to be used for carrying out the checks required.
6 Grillage analysis of primary supporting members of decks

6.1 Application
For the sole purpose of calculating the stresses in deck primary supporting members, due to the forces induced by the vertical accelerations acting on wheeled cargoes, these members may be subjected to the simplified two dimensional analysis described in [6.2].
This analysis is generally considered as being acceptable for usual structural typology, where there are neither pillar lines, nor longitudinal bulkheads.

6.2 Analysis criteria

6.2.1 Structural modelling
A beam grillage model is used to represent the deck primary supporting members.

6.2.2 Model extension
The structural model is to represent a hull portion which includes the zone under examination and which is repetitive along the hull. The non-modelled hull parts are to be considered through boundary conditions as specified in [3.3].

6.3 Boundary conditions

6.3.1 Boundary conditions at the fore and aft ends of the model
Symmetry conditions are to be applied at the fore and aft ends of the model, as specified in Table 1.

6.3.2 Boundary conditions at the connections of deck beams with side vertical primary supporting members
Vertical supports are to be fitted at the nodes positioned in way of the connection of deck beams with side primary supporting members.

The contribution of flexural stiffness supplied by the side primary supporting members to the deck beams is to be simulated by springs, applied at their connections, having rotational stiffness, in the plane of the deck beam webs, obtained [kNm/rad] from the following formulae:

— for intermediate decks:

\[ R_f = \frac{3 \cdot E \cdot \left( l_1 + l_2 \right) \cdot \left( \ell_1 + \ell_2 \right)}{\ell_1 \cdot \ell_2 - \ell_1 \cdot \ell_2} \cdot 10^{-5} \]

— for the uppermost deck:

\[ R_f = \frac{6 \cdot E \cdot J_1}{\ell_1} \cdot 10^{-5} \]

\( \ell_1, \ell_2 \) = height [m] of the tween decks, respectively below and above the deck under examination (see Figure 3)

\( J_1, J_2 \) = net moments of inertia [cm^4] of side primary supporting members with attached shell plating, relevant to the tween decks, respectively below and above the deck under examination.
6.4 Load modelling
Hull girder and local loads are to be calculated and applied to the model according to [4].

6.5 Stress calculation
Stress components are to be calculated according to [5.1] and [5.3].
SECTION 8 TORSION OF CATAMARANS

1 Transverse strength in the special case of catamaran craft when the structure connecting both hulls is formed by a deck with single plate stiffened by m reinforced beams over the deck

1.1 Calculation example

1.1.1 General
Deck beams are assumed to be fixed into each hull. Consequently, deck beams shall be extended throughout the breadth of each hull, with the same scantlings all over their span, inside and outside the hulls.

1.1.2 Definitions
Refer to Figure 1.

\[ G = \text{centre of the stiffnesses } r_i \text{ of the m deck beams} \]
\[ O = \text{origin of abscissae, arbitrarily chosen} \]
\[ m = \text{number of deck transverses} \]
\[ x_i = \text{abscissa [m] of deck beam } i \text{ with respect to origin } O \]
\[ S_i = \text{span of deck beam } i \text{ [m] between the inner faces of the hulls} \]
\[ I_i = \text{bending inertia of deck beam } i \text{ [m}^4]\]
\[ E_i = \text{Young’s modulus of deck beam } i \text{, in [N/mm}^2]\]
\[ r_i = \text{stiffness of deck beam } i \text{ [N/m] equal to:} \]
\[ = \frac{12\cdot E_i \cdot S_i^3}{S_i^4} \cdot 10^6 \]
\[ a = \text{abscissa [m] of the centre } G \text{ with respect to the origin } O \]
\[ = \frac{\Sigma r_i \cdot x_i}{\Sigma r_i} \]

If \( F_i \) [N] is the force taken over by the deck beam \( i \), the deflection \( y_i \) [m] of the hull in way of the beam \( i \), is:

\[ y_i = \frac{F_i \cdot S_i^3 \cdot 10^{-6}}{12 \cdot E_i \cdot \frac{1}{S_i}} = \frac{E_i}{r_i} = d_i \cdot \omega \]

\[ d_i = \text{abscissa [m] of the deck beam } i \text{ with respect to the origin } G: \]
\[ = x_i - a \]
\[ \omega = \text{rotation angle [rad] of one hull in relation to the other around a transverse axis passing through } G. \]

1.1.3 Transverse torsional connecting moment
The catamaran transverse torsional connecting moment [kN·m] about a transverse axis is given by:

\[ M_{tt} = 0.125 \cdot \Delta \cdot L \cdot a_{CG} \cdot g \]

\[ \Delta = \text{vessel displacement} \text{ [t]} \]
\[ a_{CG} = \text{design vertical acceleration at LCG} \text{ [m/s}^2] \text{ to be taken not less than:} \]
\[ = 0.67 \cdot Soc \cdot \frac{v}{\sqrt{L}} \]
\[ v = \text{vessel speed} \text{ [m/s]} \]
\[ S_{oc} = \text{coefficient depending on the navigation notation } n \]
\[ = 0.1 \cdot (n + 1.1) \]
\[ n = \text{navigation coefficient defined in Ch.2 Sec.2} \]
\[ H = \text{significant wave height [m]} \]

Moreover, the transverse torsional moment may be expressed as:
\[ M_{tt} = F_i \cdot d_i \cdot 10^{-3} \]

### 1.1.4 Calculation of rotation angle

The rotation angle may be derived from [1.1.3] and is given by the formula:
\[ \omega = \frac{M_{tt}}{\Sigma r_i \cdot d_i^2} \cdot 10^3 \]

### 1.1.5 Determination of stresses in deck beams

As \( M_{tt}, r_i \) and \( d_i \) are known, \( \omega \) is thus deduced, then \( F_i \) [N], the bending moment \( M_i \) [N·m] and the corresponding normal and shear stresses can be evaluated in each beam:
\[ F_i = \omega \cdot r_i \cdot d_i \]
\[ M_i = F_i \cdot S_i / 2 \]

### 1.1.6 Checking criteria

It is to be checked that the normal stress \( \sigma \) and the shear stress are in compliance with the following formulae:
\[ \frac{R_{eh}}{\gamma_R \cdot \gamma_m} \geq \sigma \]
\[ 0.5 \cdot \frac{R_{eh}}{\gamma_R \cdot \gamma_m} \geq \tau \]

\[ R_{eh} = \text{minimum yield stress [N/mm}^2\text{]} \text{ of the material, to be taken equal to 235/k, unless otherwise specified} \]
\[ \gamma_R = \text{partial safety factor covering uncertainties regarding resistance, to be taken equal to 1.10} \]
\[ \gamma_m = \text{partial safety factor covering uncertainties regarding material, to be taken equal to 1.02}. \]
Figure 1 Transverse strength of catamaran
SECTION 9 HULL GIRDER STRENGTH PRINCIPLES

1 Symbols

\[ B = \text{breadth [m], defined in Ch.1 Sec.1 [1]} \]
\[ D = \text{depth [m], defined in Ch.1 Sec.1 [1]} \]
\[ C_B = \text{block coefficient, defined in Ch.1 Sec.1 [1]} \]
\[ T = \text{draught [m], defined in Ch.1 Sec.1 [1]} \]
\[ R = \text{loaded length ratio} \]
\[ = \frac{L - d_{AV} - d_{AR}}{L} \]
\[ \text{where } d_{AV} \text{ and } d_{AR} \text{ are parameters defined in Sec.10 [2.1.1]} \]
\[ L = \text{rule length [m], defined in Ch.1 Sec.1 [1]} \]

2 General

2.1 Application

2.1.1 The following requirements apply to vessels with length up to 135 m, of types and characteristics listed hereafter:
— self-propelled cargo carriers with machinery aft
  
  \[ 0.6 \leq R \leq 0.82 \]
  
  \[ 0.79 \leq C_B < 0.95 \]
— non-propelled cargo carriers
  
  \[ 0.8 \leq R \leq 0.92 \]
  
  \[ C_B \geq 0.92 \]
— passenger vessels with machinery aft
  
  \[ 0.79 \leq C_B < 0.95 \]
— service vessels with machinery amidships

2.1.2 For other vessel types or vessels of unusual design or loading sequences, a direct calculation of still water bending moment is to be carried out and submitted to the Society.
For direct calculation of still water bending moment is to be performed also if the actual lightship displacement shows at least 20% deviation from standard value derived from Sec.10 [6.1.1] or Sec.10 [6.2.1] as applicable.

2.1.3 For cargo carriers, the cargo is assumed to be homogeneously distributed, and loading and unloading are assumed such as not to create excessive stresses.

3 Standard loading conditions for cargo carriers

3.1 Lightship

For non-propelled carriers, the vessel is assumed empty, without supplies nor ballast.
For self-propelled carriers, the light standard loading conditions are:
— supplies: 100%
— ballast: 50%.
3.2 Fully loaded vessel
For non-propelled carriers, the vessel is considered to be homogeneously loaded at its maximum draught, without supplies nor ballast.
For self-propelled carriers, the vessel is considered to be homogeneously loaded at its maximum draught with 10% of supplies (without ballast).

3.3 Transitory conditions

3.3.1 General
Transitory standard conditions are listed in items [3.3.2] to [3.3.4].
For non-propelled carriers, the vessel is assumed without supplies nor ballast.
For self-propelled carriers, the vessel without ballast, is assumed to carry following amount of supplies:
— in hogging condition: 100% of supplies
— in sagging condition: 10% of supplies.

3.3.2 Loading/unloading in two runs
Loading and unloading are performed uniformly in two runs of almost equal masses.
For self-propelled vessels, the first loading/unloading run is carried out from the aft end of the cargo space, progressing to the fore end, the second run being performed from the fore end towards the aft end.
For non-propelled vessels, the two loading/unloading runs can be carried out from either the aft end or the fore end, progressing towards the opposite end.

3.3.3 Loading/unloading in one run
Loading and unloading are performed uniformly in one run, starting from the aft end of the cargo space, for self-propelled vessels, and from any cargo space end for non-propelled vessels.

3.3.4 Loading/unloading for liquid cargoes
Loading and unloading for liquid cargoes are assumed to be performed in two runs (see [3.3.2]), unless otherwise specified.

4 Non-homogeneous loading conditions

4.1 General
If requested, in addition to design bending moments occurring in standard loading conditions described in [3], the hull girder loads may be determined, by direct calculation, in any non-homogeneous loading conditions approved by the Society.
SECTION 10 DESIGN BENDING MOMENTS

1 Symbols

\[ L = \text{rule length} \ [\text{m}], \text{defined in Ch.1 Sec.1} \ [1] \]
\[ B = \text{breadth} \ [\text{m}], \text{defined in Ch.1 Sec.1} \ [1] \]
\[ D = \text{depth} \ [\text{m}], \text{defined in Ch.1 Sec.1} \ [1] \]
\[ T = \text{draught} \ [\text{m}], \text{defined in Ch.1 Sec.1} \ [1] \]
\[ C_B = \text{block coefficient}, \text{defined in Ch.1 Sec.1} \ [1] \]
\[ M_H = \text{design hogging bending moment} \ [\text{kNm}] \]
\[ M_S = \text{design sagging bending moment} \ [\text{kNm}] \]
\[ M_{H0} = \text{still water hogging bending moment in lightship conditions} \ [\text{kNm}] \]
\[ M_{S0} = \text{still water sagging bending moment in fully loaded conditions} \ [\text{kNm}] \]
\[ M_{H1} = \text{still water hogging bending moment while loading / unloading in one run} \ [\text{kNm}] \]
\[ M_{H2} = \text{still water hogging bending moment while loading / unloading in two runs} \ [\text{kNm}] \]
\[ M_{S1} = \text{still water sagging bending moment while loading/unloading in one run} \ [\text{kNm}] \]
\[ M_{S2} = \text{still water sagging bending moment while loading/unloading in two runs} \ [\text{kNm}] \]
\[ M_c = \text{correction value} \ [\text{kNm}], \text{given in [7]}, \text{taking into account the deviation from standard loading conditions, light ship weight and weight distribution} \]
\[ M_{ad} = \text{additional bending moment} \ [\text{kNm}], \text{defined in 6.}, \text{for \textbf{IN(0.6), IN(1.2) and IN(2)} ranges of navigation} \]
\[ F = \text{loading factor} \]
\[ F = \frac{P}{P_T} \]
\[ P = \text{actual cargo weight} \]
\[ P_T = \text{cargo weight corresponding to the maximum vessel draught} \ T \]

2 General

2.1 Definitions

2.1.1 Parameters \( d_{AV} \) and \( d_{AR} \)

\( d_{AV} \) and \( d_{AR} \) are defined as follows (see Figure 1):

\[ d_{AV} = \text{distance between fore cargo hold bulkhead or fore cargo tank bulkhead and fore end (FE)} \ [\text{m}] \]
\[ d_{AR} = \text{distance between aft cargo hold bulkhead or aft cargo tank bulkhead and aft end (AE)} \ [\text{m}] \]

Figure 1 Parameters \( d_{AV} \) and \( d_{AR} \)

2.1.2 Loaded lengths \( \ell_1 \) and \( \ell_2 \)

Loaded lengths \( \ell_1 \) and \( \ell_2 \) are parameters defined as:
\[ \ell_1 = \frac{-k_3}{k_2} \cdot L \]

\[ \ell_2 = \frac{-k_3}{k_4} \cdot L \]

\(k_2, k_3, k_4\) = coefficients, defined in Table 1.

**Table 1 Coefficients \(k_i\)**

<table>
<thead>
<tr>
<th>Vessels</th>
<th>Conditions</th>
<th>(k_1)</th>
<th>(k_2)</th>
<th>(k_3)</th>
<th>(k_4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-propelled</td>
<td>Hogging</td>
<td>0.063</td>
<td>0.01\cdot L</td>
<td>-0.743</td>
<td>3.479</td>
</tr>
<tr>
<td></td>
<td>Sagging</td>
<td>0</td>
<td>5</td>
<td>-1.213</td>
<td>4.736</td>
</tr>
<tr>
<td>Self-propelled</td>
<td>Hogging</td>
<td>-</td>
<td>3.455</td>
<td>-0.780</td>
<td>4.956</td>
</tr>
<tr>
<td></td>
<td>Sagging</td>
<td>-</td>
<td>4.433</td>
<td>-0.870</td>
<td>3.735</td>
</tr>
</tbody>
</table>

2.1.3 Loaded lengths \(L_1\) and \(L_2\)

Loaded lengths \(L_1\) and \(L_2\) are parameters defined as:

\[ L_1 = 0.5\cdot L - \ell_1 - d_{AV} \]
\[ L_2 = 0.5\cdot L - \ell_2 - d_{AR} \]

2.1.4 Loaded length ratios

Following coefficients are required for still water bending moment calculation:

\[ R_{11} = \frac{0.5\cdot L - d_{AV} - L_1}{L - d_{AV} - d_{AR}} \]
\[ R_{12} = \frac{L_1}{0.5\cdot L - d_{AV} - L_1} \]
\[ R_{21} = \frac{0.5\cdot L - d_{AR} - L_2}{L - d_{AV} - d_{AR}} \]
\[ R_{22} = \frac{L_2}{0.5\cdot L - d_{AR} - L_2} \]
3 Principle of calculation using formulae

3.1 Dry cargo carriers

3.1.1 Hogging conditions
The design bending moment in hogging conditions is given by the formula:

\[ M_H = \text{MAX} (M_1 ; M_2) \]
\[ M_1 = \text{total hogging bending moment of lightship [kNm]} \]
\[ = M_{H0} + M_{ad} + \Sigma M_c \]
\[ M_2 = \text{total hogging bending moment in corresponding transitory conditions:} \]
\[ - \text{for loading/unloading in one run:} \]
\[ = M_{H1} + \Sigma M_c \]
\[ - \text{for loading/unloading in two runs:} \]
\[ = M_{H2} + \Sigma M_c \]

3.1.2 Sagging conditions
The design bending moment in sagging conditions is given by the formula:

\[ M_S = \text{MAX} (M_3 ; M_4) \]
\[ M_3 = \text{total sagging bending moment of loaded vessel [kNm]} \]
\[ = M_{S0} + M_{ad} - \Sigma M_c \]
\[ M_4 = \text{total sagging bending moment in corresponding transitory conditions:} \]
\[ - \text{for loading/unloading in one run:} \]
\[ = M_{S1} - \Sigma M_c \]
\[ - \text{for loading/unloading in two runs:} \]
\[ = M_{S2} - \Sigma M_c \]

3.2 Tankers
Where the loading/unloading is carried out according to Sec.9 [3.3] for liquid cargoes:

— the hogging design bending moment is equal to:
\[ M_H = \text{MAX} (M_1 ; M_2) \]
with \[ M_2 = M_{H2} + \Sigma M_c \]
— the sagging design bending moment is equal to:
\[ M_S = \text{MAX} (M_3 ; M_4) \]
with \[ M_4 = M_{S2} - \Sigma M_c \]
where \[ M_1 \] and \[ M_3 \] are defined in [3.1].

3.3 Other vessels
For vessels other than cargo carriers:

— The hogging design bending moment is equal to:
\[ M_H = M_{H0} + M_{ad} \]
— The sagging design bending moment is equal to:
\[ M_S = M_{S0} + M_{ad} \]
4 Vertical shear force

4.1 Design shear force
The vertical design shear force [kN] is to be obtained from the following formula:

\[ T_v = \frac{\pi \cdot M}{L} \]

\( M \) = maximum design bending moment [kNm]
\( = \) \( \text{MAX} (M_H ; M_S) \)

5 Direct calculation

5.1 General

5.1.1 In the case of direct calculation, all calculation documents are to be submitted to the Society.

5.1.2 Design still water bending moments
The design still water bending moments are to be determined by direct calculation for:
— vessels of unusual type or design
— unusual loading/unloading sequences.
The actual hull lines, lightweight distribution and the characteristics of the intended service are generally to be taken into account.

5.1.3 Additional bending moment
An additional bending moment taking into account the stream and water conditions in the navigation zone is to be considered.
This additional bending moment may be calculated according to [7]. or determined by the designer.

6 Still water bending moments

6.1 Non-propelled cargo carriers

6.1.1 Standard light weights and weight distribution
The hull weight is assumed to be uniformly distributed over the vessel length, and [t] equal to:
— \( P_0 = 0.12 \cdot L \cdot B \cdot D \) for \( D < 3.7 \) m
— \( P_0 = 0.10 \cdot L \cdot B \cdot D \) for \( D \geq 3.7 \) m.

6.1.2 Standard cargo weight and cargo distribution
The cargo is assumed to be uniformly distributed over the cargo space, and its weight [t] is equal to:
\( P_0 = 0.9 \cdot L \cdot B \cdot T \cdot C_B \)

6.1.3 Still water bending moments
The hogging and sagging bending moments in still water conditions are to be obtained from formulae given in Table 2.
Where the actual lightship weight or location of the centre of gravity deviates by more than 10% with respect to the standard value, the still water bending moment is to be corrected using formulae given in Table 7. See also Sec.9 [2.1.2].

6.2 Self-propelled cargo carriers

6.2.1 Standard light weights and weight distribution
The formulae of still water bending moments are based on standard weights and weight distribution defined in Table 3.

6.2.2 Standard cargo weight and cargo distribution
The cargo is assumed to be uniformly distributed over the cargo space, and its weight [t] is equal to:

\[ P_0 = 0.85 \cdot L \cdot B \cdot T \cdot C_B \]

6.2.3 Still water bending moments
The hogging and sagging bending moments in still water conditions are to be obtained from formulae given in Table 4.

Where the weight or location of the centre of gravity of a lightship component deviates by more than 10% with respect to standard value (see Table 3), the still water bending moment is to be corrected using formulae given in Table 8. See also Sec.9 [2.1.2].

6.3 Passenger vessels
The values of the maximum still water bending moments in normal service conditions are to be supplied by the designer.

Where the direct calculation may not be carried out, the still water hogging bending moment [kNm] for passenger vessels (other than ro-ro vessels) with machinery aft may be determined using the following formula:

\[ M_{H0} = 0.273 \cdot L^2 \cdot B^{1.342} \cdot T^{0.172} \cdot (1.265 - C_B) \]

6.4 Dredgers
The values of the maximum still water bending moments in normal service conditions are to be supplied by the designer.

Where the direct calculation may not be carried out, the maximum still water bending moment is to be as required in [6.1] or [6.2] for hopper barges and hopper dredgers respectively.

6.5 Tugs and pushers

6.5.1 Application
The following requirements apply to tugs and pushers with engines arranged amidships and bunkers inside the engine room or adjoining it.

6.5.2 Still water bending moments
The values of the maximum hogging and sagging bending moments in normal service conditions are to be supplied by the designer.

Where the direct calculation may not be carried out, the still water bending moments [kNm] may be determined using the following formulae:

— still water hogging bending moment:
Hull girder strength

\[ M_{H0} = 1.96 \cdot L^{1.5} \cdot B \cdot D \cdot (1 - 0.9 \cdot C_B) \]

— still water sagging bending moment:
\[ M_{S0} = 0.01 \cdot L^2 \cdot B \cdot T \cdot (\varphi_1 + \varphi_2) \]

\[ \varphi_1 = 5.5 \cdot \left( 0.6 \cdot (1 + C_B) - \frac{X}{L} \right) \]

\[ \varphi_2 = 10 \cdot \frac{\Phi}{L^2 \cdot B} \]

\( X \) = length [m] of the machinery space increased by the length of adjacent bunkers
\( \Phi \) = total brake power of the propulsion installation [kW]

6.6 Pontoons

6.6.1 The still water bending moments are to be obtained by direct calculation, according to the intended loading conditions.

**Table 2 Non-propelled cargo carriers - still water bending moments**

<table>
<thead>
<tr>
<th>Load cases</th>
<th>Hogging moments [kNm]</th>
<th>Sagging moments [kNm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightship</td>
<td>( M_{H0} = 0.62 \cdot L^2 \cdot B^{0.84} \cdot T^{0.9} \cdot (1 - C_B) )</td>
<td>( M_{S0} = 1.4 \cdot L^{0.88} \cdot B^{1.17} \cdot T^2 \cdot C_B \cdot [R_{11} \cdot (0.52 \cdot L - 1.84 \cdot \ell_1) \cdot (1 - R_{12}) + R_{21} \cdot (0.5 \cdot L - 1.23 \cdot t_2) \cdot (1 - R_{22})] )</td>
</tr>
<tr>
<td>Fully loaded vessel</td>
<td>( M_{H1} = M_{H0} + (M_{S1} - M_{S0}) )</td>
<td>( M_{S1} = 0.7 \cdot L^{0.88} \cdot B^{1.17} \cdot T^2 \cdot C_B \cdot [R_{11} \cdot (0.52 \cdot L - 1.84 \cdot \ell_1) \cdot (1 - R_{12}) + 1.15 \cdot R_{21} \cdot (0.5 \cdot L - 1.23 \cdot t_2)] )</td>
</tr>
<tr>
<td>Loading and unloading in one run</td>
<td>( M_{H2} = M_{H0} + (M_{S2} - M_{S0}) )</td>
<td>( M_{S2} = 0.7 \cdot L^{0.88} \cdot B^{1.17} \cdot T^2 \cdot C_B \cdot [R_{11} \cdot (0.52 \cdot L - 1.84 \cdot \ell_1) \cdot (1 - R_{12}) + R_{21} \cdot (0.5 \cdot L - 1.23 \cdot t_2)] )</td>
</tr>
</tbody>
</table>

\( \ell_1, \ell_2 \) = parameters defined in [1.1.2]

\( R_{11}, R_{12} \) = coefficients defined in [1.1.4]

\( R_{21}, R_{22} \) = coefficients defined in [1.1.4].

1) In the case of partly filled barge, \( M_{S0} \) is to be substituted by \( M_{SF} \) given by the formula:

\[ M_{SF} = F \cdot (M_{H0} + M_{S0}) - M_{H0} \]

**Table 3 Self-propelled cargo carriers - standard weights and weight distribution**

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight [t] ( P_0 )</th>
<th>Centre of gravity from AE [m]</th>
<th>Location [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull:</td>
<td></td>
<td>( X_1 )</td>
<td>( X_2 )</td>
</tr>
<tr>
<td>D ≤ 3.7 m</td>
<td>0.150·L·B·D</td>
<td>0</td>
<td>L</td>
</tr>
<tr>
<td>D &gt; 3.7 m</td>
<td>0.100·L·B·D</td>
<td>0</td>
<td>L</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Item</th>
<th>Weight [t] $P_0$</th>
<th>Centre of gravity from AE [m]</th>
<th>Location [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$X_1$</td>
<td>$X_2$</td>
</tr>
<tr>
<td>Deckhouse:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D \leq 3.7$ m</td>
<td>$0.010\cdot L\cdot B\cdot D$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D &gt; 3.7$ m</td>
<td>$0.006\cdot L\cdot B\cdot D$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machinery (main)</td>
<td>$0.005\cdot L\cdot B\cdot T$</td>
<td>$d_{AR}$</td>
<td></td>
</tr>
<tr>
<td>Machinery Installations</td>
<td>$0.010\cdot L\cdot B\cdot T$</td>
<td>$d_{AR}$</td>
<td></td>
</tr>
<tr>
<td>Piping 1)</td>
<td>$0.005\cdot L\cdot B\cdot T$</td>
<td>$d_{AR}$</td>
<td>$L-d_{AV}$</td>
</tr>
<tr>
<td>Mooring gear</td>
<td>$0.005\cdot L\cdot B\cdot T$</td>
<td>$L-d_{AV}$ / 3</td>
<td></td>
</tr>
<tr>
<td>Supplies (fore)</td>
<td>$0.005\cdot \alpha_1\cdot L\cdot B\cdot T$</td>
<td>$L-d_{AV}$ / 2</td>
<td></td>
</tr>
<tr>
<td>Supplies (aft)</td>
<td>$0.005\cdot \alpha_1\cdot L\cdot B\cdot T$</td>
<td>$d_{AR}$ / 2</td>
<td></td>
</tr>
<tr>
<td>Ballast (fore):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D \leq 3.7$ m</td>
<td>$0.010\cdot \alpha_2\cdot L\cdot B\cdot D$</td>
<td>$L-d_{AV}$ / 2</td>
<td></td>
</tr>
<tr>
<td>$D &gt; 3.7$ m</td>
<td>$0.003\cdot \alpha_2\cdot L\cdot B\cdot D$</td>
<td>$L-d_{AV}$ / 2</td>
<td></td>
</tr>
<tr>
<td>Ballast (aft):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D \leq 3.7$ m</td>
<td>$0.010\cdot \alpha_2\cdot L\cdot B\cdot D$</td>
<td>$d_{AR}$ / 2</td>
<td></td>
</tr>
<tr>
<td>$D &gt; 3.7$ m</td>
<td>$0.003\cdot \alpha_2\cdot L\cdot B\cdot D$</td>
<td>$d_{AR}$ / 2</td>
<td></td>
</tr>
</tbody>
</table>

$d_{AR}, d_{AV}$ = parameters defined in [2.1]

$\alpha_1, \alpha_2$ = coefficients defined in Table 5.

1) for tankers.

### Table 4 Self-propelled cargo carriers - still water bending moments

<table>
<thead>
<tr>
<th>Load cases</th>
<th>Hoggng moments [kNm]</th>
<th>Sagging moments [kNm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightship</td>
<td>$M_{H0} = 0.273\cdot L^2\cdot B^{1.1342}\cdot t^{0.172}\cdot (1.265 - C_B)$</td>
<td>$M_{HS} = 0.417 \cdot L^2 \cdot B^{1.464} \cdot (0.712 - 0.622 \cdot C_B)$</td>
</tr>
<tr>
<td></td>
<td>$M_{HH} = 0.344\cdot L^2\cdot B^{1.213}\cdot t^{0.352}\cdot (1.198 - C_B)$</td>
<td></td>
</tr>
<tr>
<td>Fully loaded vessel</td>
<td>$M_{S0} = M_{CS} - M_{HS}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$M_{CS} = 0.4 \cdot F \cdot L^{1.86} \cdot B^{0.8} \cdot t^{0.48} \cdot (C_B - 0.47) \cdot [3.1 + R_{11} \cdot (10.68 \cdot L - 53.22 \cdot t_1) \cdot (1 - R_{12}) + R_{21} \cdot (0.17 \cdot L - 0.15 \cdot t_2) \cdot (1 - R_{22})]$</td>
<td></td>
</tr>
<tr>
<td>Loading and unloading in one run</td>
<td>$M_{H1} = M_{HH} + M_L$</td>
<td>$M_{S1} = 0.8 \cdot M_{S0} + M_L$</td>
</tr>
<tr>
<td>Loading and unloading in two runs</td>
<td>$M_{H2} = M_{HH} + 0.5 \cdot M_L$</td>
<td>$M_{S2} = 0.8 \cdot M_{S0} + 0.5 \cdot M_L$</td>
</tr>
</tbody>
</table>
Hull girder strength

### 7 Additional bending moments

#### 7.1 Ranges of navigation IN(1.2) and IN(2)

For ranges of navigation **IN(1.2)** and **IN(2)**, a wave-induced bending moment, taking into account the significant wave height [m] of the navigation area, is to be added to the still water bending moment.

The absolute value of the wave-induced bending moment amidships is to be obtained [kNm] from the following formula:

\[
M_{ad} = 0.021 \cdot n \cdot C \cdot L^2 \cdot B \cdot (C_B + 0.7)
\]

\( C = \) parameter, defined in Table 6

\( n = \) navigation coefficient, defined in Ch.2 Sec.2 [1.2]

For intermediate significant wave heights, the value of the wave-induced bending moment may be obtained by interpolation.

#### 7.2 Range of navigation IN(0.6)

For range of navigation **IN(0.6)**, the absolute value of the additional bending moment amidships is to be obtained [kNm] from the following formula:

\[
M_{ad} = 0.01 \cdot n \cdot C \cdot L^2 \cdot B \cdot (C_B + 0.7)
\]

where parameter \( C \) is defined in Table 6.
8 Correction formulae

8.1 Non-propelled cargo carriers
The correction formulae applicable to non-propelled cargo carriers are given in Table 7, where values of coefficients $k_1$, $k_2$, $k_3$, and $k_4$ are defined in Table 1.

8.2 Self-propelled cargo carriers
The correction formulae applicable to self-propelled cargo carriers are given in Table 8, where the coefficients $k_2$, $k_3$ and $k_4$ are given in Table 1.

Figure 2 Definition of distances $d$, $d_1$, $d_2$

Table 6 Values of parameter C

<table>
<thead>
<tr>
<th>Significant wave height</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$L &lt; 60$</td>
</tr>
<tr>
<td></td>
<td>$60 \leq L \leq 90$</td>
</tr>
<tr>
<td></td>
<td>$90 &lt; L$</td>
</tr>
<tr>
<td>$H &lt; 1.2 \text{ m}$</td>
<td>$C = (130 - 0.36 \cdot L) \cdot \frac{L}{1000}$</td>
</tr>
<tr>
<td></td>
<td>$C = 9.14 - 0.044 \cdot L$</td>
</tr>
<tr>
<td></td>
<td>$C = (90 - 0.36 \cdot L) \cdot \frac{L}{1000}$</td>
</tr>
<tr>
<td>$H \geq 1.2 \text{ m}$</td>
<td>$C = (118 - 0.36 \cdot L) \cdot \frac{L}{1000}$</td>
</tr>
<tr>
<td></td>
<td>$C = 10.75 - \left( \frac{300 - L}{100} \right)^{1.5}$</td>
</tr>
</tbody>
</table>

Table 7 Non-propelled cargo carriers - correction formulae

<table>
<thead>
<tr>
<th>Item</th>
<th>$x &gt; \frac{L}{2}$</th>
<th>$x \leq \frac{L}{2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrated weights or</td>
<td>$M_c = P \cdot (k_1 \cdot d_2 + k_2 \cdot d + k_3 \cdot L) - P_0 \cdot (k_1 \cdot d_2^2 + k_2 \cdot d_0 + k_3 \cdot L)$</td>
<td>$M_c = P \cdot (k_4 \cdot d + k_3 \cdot L) - P_0 \cdot (k_4 \cdot d_0 + k_3 \cdot L)$</td>
</tr>
<tr>
<td>loads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distributed weights or</td>
<td>$M_c = M - M_0$</td>
<td></td>
</tr>
<tr>
<td>loads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hull weight $^1$</td>
<td>$M_c = [0.0416 \cdot k_1 \cdot L^2 + (0.125 \cdot k_2 + k_3 + 0.125 \cdot k_4) \cdot L \cdot (P - P_0)$</td>
<td>$M_c = P \cdot (k_4 \cdot d + k_3 \cdot L) - P_0 \cdot (k_4 \cdot d_0 + k_3 \cdot L)$</td>
</tr>
</tbody>
</table>
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\[
M = P \cdot \{0.33 \times k_1 \times (d_2^2 + d_2 \times d_1 + d_1^2) + 0.5 \times k_2 \times (d_2 + d_1) + k_3 \times L\}
\]

\[
M_0 = P_0 \cdot \{0.33 \times k_1 \times (d_{02}^2 + d_{02} \times d_{01} + d_{01}^2) + 0.5 \times k_2 \times (d_{02} + d_{01}) + k_3 \times L\}
\]

\[
P = \text{actual weight or load [t]}
\]

\[
P_0 = \text{standard weight or load [t] defined in [6.1.2]}
\]

\[
d = \text{actual distance from midship [m] of centre of gravity of concentrated weights (see Figure 2)}:
\]

\[
= L / 2 - X \text{ for } X \leq L / 2
\]

\[
= X - L / 2 \text{ for } X > L / 2
\]

\[
d_0 = \text{standard distance from midship [m] of centre of gravity of concentrated weights (} \geq 0\)
\]

\[
d_{1,2} = \text{distances measured from midship [m] defining the extent of actual distributed weight (see Figure 2)}
\]

\[
d_{01,2} = \text{distances measured from midship [m] defining the extent of standard distributed weight}
\]

\[1) \text{ Uniform weight distribution}\]

<table>
<thead>
<tr>
<th>Table 8 Self-propelled cargo carriers - correction formulae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
</tr>
<tr>
<td>Concentrated weights or loads</td>
</tr>
<tr>
<td>Distributed weights or loads</td>
</tr>
<tr>
<td>Hull weight (1))</td>
</tr>
</tbody>
</table>

\[P = \text{actual weight or load [t]}\]

\[P_0 = \text{standard weight or load [t] defined in 6.2.2} \]

\[= 0, \text{ if not defined in 6.2.2}\]

\[d = \text{actual distance from midship [m] of the weight centre of gravity (see Figure 2)}:
\]

\[
= L / 2 - X \text{ for } X \leq L / 2
\]

\[
= X - L / 2 \text{ for } X > L / 2
\]

\[d_0 = \text{standard distance from midship [m] of the weight centre of gravity (} \geq 0\).
\]

\[1) \text{ Uniform weight distribution}\]
SECTION 11 STRENGTH CHARACTERISTICS OF THE HULL GIRDER TRANSVERSE SECTIONS

1 Symbols

\[ Z = \text{hull girder section modulus [cm}^3] \]
\[ M_H = \text{design hogging bending moment [kNm]} \]
\[ M_S = \text{design sagging bending moment [kNm]} \]

2 General

2.1 Scope

In the following, the criteria are specified for calculating the hull girder strength characteristics to be used for the checks, in association with the hull girder loads.

3 Characteristics of the hull girder transverse sections

3.1 Hull girder transverse sections

3.1.1 General

The hull girder transverse sections are to be considered as being constituted by the members contributing to the hull girder longitudinal strength, i.e. all continuous longitudinal members below the strength deck defined in [3.2], taking into account [3.1.2] to [3.1.5].

3.1.2 Longitudinal bulkheads with vertical corrugations

Longitudinal bulkheads with vertical corrugations may not be included in the hull girder transverse sections.

3.1.3 Members in materials other than steel

Where a member is made of a material other than steel, its contribution to the longitudinal strength will be determined by the Society on case-by-case basis.

3.1.4 Large openings and scallops

Large openings are:

— in the side shell plating: openings having a diameter greater than or equal to 300 mm
— in the strength deck: openings having a diameter greater than or equal to 350 mm.

Large openings and scallops, where scallop welding is applied, are always to be deducted from the sectional areas included in the hull girder transverse sections.

3.1.5 Lightening holes, draining holes and single scallops

Lightening holes, draining holes and single scallops in longitudinals or girders need not be deducted if their height is less than 0.25 \( h_W \), without being greater than 75 mm, where \( h_W \) is the web height [mm]. Otherwise, the excess is to be deducted from the sectional area or to be compensated.

3.2 Strength deck

3.2.1 The strength deck is, in general, the uppermost continuous deck.

In the case of a superstructure or deckhouses contributing to the longitudinal strength, the strength deck is the deck of the superstructure or the deck of the deckhouse.
3.2.2 For additional requirements about passenger vessels, see Pt.5 Ch.5.

3.3 Hull girder section modulus
The section modulus at any point of a hull transverse section is obtained [cm³] from the following formula:

\[ Z = \frac{I_Y}{100 |Z - N|} \]

\( I_Y = \) moment of inertia [cm⁴] of the hull girder transverse section defined in [3.1], about its horizontal neutral axis
\( N = \) z co-ordinate [m] of the centre of gravity of the hull transverse section
\( Z = \) z co-ordinate [m] of the calculation point of a structural element.

3.4 Hull girder normal stresses
The normal stresses induced by vertical bending moments are obtained [N/mm²] from the following formulae:

in hogging conditions: \( \sigma_1 = \frac{M_H}{Z} \cdot 10^3 \)

in sagging conditions: \( \sigma_1 = \frac{M_S}{Z} \cdot 10^3 \)
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