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## Symbols used in chapter 7

|               |   |            |  |
|---------------|---|------------|--|
| $L_1, L_2$    | : Lengths, in m, defined in Pt B, Ch 1, Sec 2, [2.1.1],   |            | section considered, without being taken greater than $0,3M_{WV,S}$ ,   |
| $E$           | : Young's modulus, in $N/mm^2$ , to be taken equal to: <ul style="list-style-type: none"> <li>• for steels in general:<br/><math>E = 2,06.10^5 N/mm^2</math></li> <li>• for stainless steels:<br/><math>E = 1,95.10^5 N/mm^2</math></li> <li>• for aluminium alloys:<br/><math>E = 7,0.10^4 N/mm^2</math></li> </ul>    | $M_{WV,H}$ | : Vertical wave bending moment, in kN.m, in hogging condition, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [3.1], |
|               |   | $M_{WV,S}$ | : Vertical wave bending moment, in kN.m, in sagging condition, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [3.1], |
| $\nu$         | : Poisson's ratio. Unless otherwise specified, a value of 0,3 is to be taken into account,  | $M_{WH}$   | : Horizontal wave bending moment, in kN.m, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [3.2],                     |
| $k$           | : Material factor, defined in: <ul style="list-style-type: none"> <li>• Pt B, Ch 4, Sec 1, [2.3], for steel,</li> <li>• Pt B, Ch 4, Sec 1, [4.4], for aluminium alloys,</li> </ul>  | $M_{WT}$   | : Wave torque, in kN.m, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [3.3].  |
| $R_y$         | : Minimum yield stress, in $N/mm^2$ , of the material, to be taken equal to $235/k N/mm^2$ , unless otherwise specified,  |            |  |
| $t_c$         | : Corrosion addition, in mm, defined in Pt B, Ch 4, Sec 2, Tab 2,   |            |  |
| $I_y$         | : Net moment of inertia, in $m^4$ , of the hull transverse section around its horizontal neutral axis, to be calculated according to Pt B, Ch 6, Sec 1, [2.4] considering the members contributing to the hull girder longitudinal strength as having their net scantlings,   |            |  |
| $I_z$         | : Net moment of inertia, in $m^4$ , of the hull transverse section around its vertical neutral axis, to be calculated according to Pt B, Ch 6, Sec 1, [2.4] considering the members contributing to the hull girder longitudinal strength as having their net scantlings,   |            |  |
| $x, y, z$     | : X, Y and Z co-ordinates, in m, of the calculation point with respect to the reference co-ordinate system defined in Pt B, Ch 1, Sec 2, [4],   |            |  |
| $N$           | : Z co-ordinate, in m, with respect to the reference co-ordinate system defined in Pt B, Ch 1, Sec 2, [4], of the centre of gravity of the hull transverse section constituted by members contributing to the hull girder longitudinal strength considered as having their net scantlings (see Pt B, Ch 6, Sec 1, [2]), |            |  |
| $M_{SW,H}$    | : Design still water bending moment, in kN.m, in hogging condition, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [2.2],   |            |  |
| $M_{SW,S}$    | : Design still water bending moment, in kN.m, in sagging condition, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [2.2],   |            |  |
| $M_{SW,Hmin}$ | : Minimum still water bending moment, in kN.m, in hogging condition, at the hull transverse   |            |  |

SECTION 1 PLATING

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

- $p_s$

: Still water pressure, in kN/m<sup>2</sup>, see [3.2.2]
- $p_w$

: Wave pressure and, if necessary, dynamic pressures, according to the criteria in Ch 5, Sec 5, [2] and Ch 5, Sec 6, [2], in kN/m<sup>2</sup> (see [3.2.2])
- $p_{SF}, p_{WF}$

: Still water and wave pressure, in kN/m<sup>2</sup>, in flooding conditions, defined in Ch 5, Sec 6, [9] (see [3.2.3])
- $F_s$

: Still water wheeled force, in kN, see [4.2.2]
- $F_{WZ}$

: Inertial wheeled force, in kN, see [4.2.2]
- $\sigma_{X1}$

: In-plane hull girder normal stress, in N/mm<sup>2</sup>, defined in:
  - [3.2.5] for the strength check of plating subjected to lateral pressure
  - [5.2.2] for the buckling check of plating
- $\tau_1$

: In-plane hull girder shear stress, in N/mm<sup>2</sup>, defined in [3.2.6]
- $R_{eH}$

: Minimum yield stress, in N/mm<sup>2</sup>, of the plating material, defined in Ch 4, Sec 1, [2]
- $\ell$

: Length, in m, of the longer side of the plate panel
- $s$

: Length, in m, of the shorter side of the plate panel
- $a, b$

: Lengths, in m, of the sides of the plate panel, as shown in Fig 2 to Fig 4

- $c_a$

: Aspect ratio of the plate panel, equal to:
$$c_a = 1,21 \sqrt{1 + 0,33 \left(\frac{s}{\ell}\right)^2} - 0,69 \frac{s}{\ell}$$
to be taken not greater than 1,0
- $c_r$

: Coefficient of curvature of the panel, equal to:
$$c_r = 1 - 0,5 s / r$$
to be taken not less than 0,5
- $r$

: Radius of curvature, in m
- $t$

: Net thickness, in mm, of a plate panel.

1 General

1.1 Net thicknesses

**1.1.1** As specified in Ch 4, Sec 2, [1], all thicknesses referred to in this Section are net, i.e. they do not include any margin for corrosion.  
The gross thicknesses are obtained as specified in Ch 4, Sec 2.

1.2 Partial safety factors

**1.2.1** The partial safety factors to be considered for the checking of the plating are specified in Tab 1.

1.3 Elementary plate panel

**1.3.1** The elementary plate panel is the smallest unstiffened part of plating.

Table 1 : Plating - Partial safety factors

| Partial safety factors covering uncertainties regarding:  | Symbol        | Strength check of plating subjected to lateral pressure |                   |                 |                                  |                               | Buckling check |
|---|---------------|---|-------------------|-----------------|----------------------------------|-------------------------------|----------------|
|   |               | General   | Sloshing pressure | Impact pressure | Watertight bulkhead plating (1)  | Testing check                 |                |
|   |               | see [3.2], [3.3.1], [3.4.1], [3.5.1] and [4]            |                   |                 | see [3.3.2], [3.4.2] and [3.5.2] | see [3.3.3], [3.4.3], [3.5.3] | see [5]        |
| Still water hull girder loads   | $\gamma_{S1}$ | 1,00  | 0                 | 0               | 1,00                             | N.A.                          | 1,00           |
| Wave hull girder loads  | $\gamma_{W1}$ | 1,15  | 0                 | 0               | 1,15                             | N.A.                          | 1,15           |
| Still water pressure  | $\gamma_{S2}$ | 1,00  | 1,00              | 1,00            | 1,00                             | 1,00                          | N.A.           |
| Wave pressure   | $\gamma_{W2}$ | 1,20  | 1,05              | 1,20            | 1,20                             | N.A.                          | N.A.           |
| Material  | $\gamma_m$    | 1,02  | 1,02              | 1,02            | 1,02                             | 1,02                          | 1,02           |
| Resistance  | $\gamma_R$    | 1,20  | 1,10              | 1,02            | 1,05 (2)                         | 1,05                          | 1,10           |
| (1) Applies also to plating of bulkheads or inner side which constitute boundary of compartments not intended to carry liquids. |               |   |                   |                 |                                  |                               |                |
| (2) For plating of the collision bulkhead, $\gamma_R = 1,25$  |               |   |                   |                 |                                  |                               |                |
| Note 1: N.A. = not applicable   |               |   |                   |                 |                                  |                               |                |

1.4 Load point

1.4.1 Unless otherwise specified, lateral pressure and hull girder stresses are to 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.

2 General requirements

2.1 General

2.1.1 The requirements in [2.2] to [2.6] are to be applied to plating in addition of those in [3] to [5].

2.2 Minimum net thicknesses

2.2.1 The net thickness of plating is to be not less than the values given in Tab 2.

2.3 Bilge plating

2.3.1 The net thickness of the longitudinally framed bilge plating, in mm, is to be not less than the greater of:

- value obtained from [3.3.1]
- value obtained from [5], to be checked as curved panel.

2.3.2 The net thickness of the transversely framed bilge plating, in mm, is to be not less than the greater of:

- $t = 0,7 [ \gamma_R \gamma_m (\gamma_{S2} p_S + \gamma_{W2} p_W) s_b ]^{0,4} R^{0,6} k^{1/2}$   
where :  
R : Bilge radius, in m  
 $s_b$  : Spacing of floors or transverse bilge brackets, in m
- value obtained from [5], to be checked as curved panel.

2.3.3 The net thickness bilge plating is to be not less than the actual thicknesses of the adjacent bottom or side plating, whichever is the greater.

2.4 Inner bottom of cargo holds intended to carry dry cargo

2.4.1 For ships with one of the following service notations:

- **general cargo ship**, intended to carry dry bulk cargo in holds
- **bulk carrier ESP**
- **ore carrier ESP**
- **combination carrier ESP**

the inner bottom net thickness is to be increased by 2 mm unless it is protected by a continuous wooden ceiling.

Table 2 : Minimum net thickness of plating (in mm)

| Plating   | Minimum net thickness  |
|---|--|
| Keel  | $3,8 + 0,040 L k^{1/2} + 4,5 s$  |
| Bottom <ul style="list-style-type: none"><li>• longitudinal framing</li><li>• transverse framing</li></ul>  | $1,9 + 0,032 L k^{1/2} + 4,5 s$<br>$2,8 + 0,032 L k^{1/2} + 4,5 s$   |
| Inner bottom <ul style="list-style-type: none"><li>• outside the engine room (1)</li><li>• engine room</li></ul>  | $1,9 + 0,024 L k^{1/2} + 4,5 s$<br>$3,0 + 0,024 L k^{1/2} + 4,5 s$   |
| Side <ul style="list-style-type: none"><li>• below freeboard deck (1)</li><li>• between freeboard deck and strength deck</li></ul>  | $2,1 + 0,031 L k^{1/2} + 4,5 s$<br>$2,1 + 0,013 L k^{1/2} + 4,5 s$   |
| Inner side <ul style="list-style-type: none"><li>• <math>L &lt; 120 m</math></li><li>• <math>L \geq 120 m</math></li></ul>  | $1,7 + 0,013 L k^{1/2} + 4,5 s$<br>$3,6 + 2,20 k^{1/2} + s$  |
| Weather strength deck and trunk deck, if any (2) <ul style="list-style-type: none"><li>• area within 0,4 L amidships<ul style="list-style-type: none"><li>- longitudinal framing</li><li>- transverse framing</li></ul></li><li>• area outside 0,4 L amidships (3)</li><li>• between hatchways</li><li>• at fore and aft part</li></ul> | $1,6 + 0,032 L k^{1/2} + 4,5 s$<br>$1,6 + 0,040 L k^{1/2} + 4,5 s$<br>$2,1 + 0,013 L k^{1/2} + 4,5 s$<br>$2,1 + 0,013 L k^{1/2} + 4,5 s$ |
| Cargo deck <ul style="list-style-type: none"><li>• general</li><li>• wheeled load only</li></ul>  | $8 s k^{1/2}$<br>4,5   |
| Accommodation deck <ul style="list-style-type: none"><li>• <math>L &lt; 120 m</math></li><li>• <math>L \geq 120 m</math></li></ul>  | $1,3 + 0,004 L k^{1/2} + 4,5 s$<br>$2,1 + 2,20 k^{1/2} + s$  |
| Platform in engine room <ul style="list-style-type: none"><li>• <math>L &lt; 120 m</math></li><li>• <math>L \geq 120 m</math></li></ul>   | $1,7 + 0,013 L k^{1/2} + 4,5 s$<br>$3,6 + 2,20 k^{1/2} + s$  |
| Transverse watertight bulkhead (4) <ul style="list-style-type: none"><li>• <math>L &lt; 120 m</math></li><li>• <math>L \geq 120 m</math></li></ul>  | $1,3 + 0,004 L k^{1/2} + 4,5 s$<br>$2,1 + 2,20 k^{1/2} + s$  |
| Longitud. watertight bulkhead (4) <ul style="list-style-type: none"><li>• <math>L &lt; 120 m</math></li><li>• <math>L \geq 120 m</math></li></ul>   | $1,7 + 0,013 L k^{1/2} + 4,5 s$<br>$3,6 + 2,20 k^{1/2} + s$  |
| Tank and wash bulkheads (4) <ul style="list-style-type: none"><li>• <math>L &lt; 120 m</math></li><li>• <math>L \geq 120 m</math></li></ul>   | $1,7 + 0,013 L k^{1/2} + 4,5 s$<br>$3,6 + 2,20 k^{1/2} + s$  |
| (1) Not applicable to ships with one of the service notations <b>passenger ship</b> and <b>ro-ro passenger ship</b> . For such ships, refer to the applicable requirements of Part D.   |  |
| (2) Not applicable to ships with one of the following service notations (for such ships, refer to the applicable requirements of Part D): <ul style="list-style-type: none"><li>• <b>ro-ro cargo ship</b></li><li>• <b>liquefied gas carrier</b></li><li>• <b>passenger ship</b></li><li>• <b>ro-ro passenger ship</b>.</li></ul>       |  |
| (3) The minimum net thickness is to be obtained by linearly interpolating between that required for the area within 0,4 L amidships and that at the fore and aft part.  |  |
| (4) Not applicable to ships with the service notation <b>liquefied gas carrier</b> .  |  |

## 2.5 Sheerstrake

### 2.5.1 Welded sheerstrake

The net thickness of a welded sheerstrake is to be not less than that of the adjacent side plating, taking into account higher strength steel corrections if needed.

In general, the required net thickness of the adjacent side plating is to be taken as a reference. In specific case, depending on its actual net thickness, this latter may be required to be considered when deemed necessary by the Society.

### 2.5.2 Rounded sheerstrake

The net thickness of a rounded sheerstrake is to be not less than the actual net thickness of the adjacent deck plating.

### 2.5.3 Net thickness of the sheerstrake in way of breaks of long superstructures

The net thickness of the sheerstrake is to be increased in way of breaks of long superstructures occurring within 0,5L amidships, over a length of about one sixth of the ship's breadth on each side of the superstructure end.

This increase in net thickness is to be equal to 40%, but need not exceed 4,5 mm.

Where the breaks of superstructures occur outside 0,5L amidships, the increase in net thickness may be reduced to 30%, but need not exceed 2,5 mm.

### 2.5.4 Net thickness of the sheerstrake in way of breaks of short superstructures

The net thickness of the sheerstrake is to be increased in way of breaks of short superstructures occurring within 0,6L amidships, over a length of about one sixth of the ship's breadth on each side of the superstructure end.

This increase in net thickness is to be equal to 15%, but need not exceed 4,5 mm.

## 2.6 Stringer plate

### 2.6.1 General

The net thickness of the stringer plate is to be not less than the actual net thickness of the adjacent deck plating.

### 2.6.2 Net thickness of the stringer plate in way of breaks of long superstructures

The net thickness of the stringer plate is to be increased in way of breaks of long superstructures occurring within 0,5L amidships, over a length of about one sixth of the ship's breadth on each side of the superstructure end.

This increase in net thickness is to be equal to 40%, but need not exceed 4,5 mm.

Where the breaks of superstructures occur outside 0,5L amidships, the increase in net thickness may be reduced to 30%, but need not exceed 2,5 mm.

### 2.6.3 Net thickness of the stringer plate in way of breaks of short superstructures

The net thickness of the stringer plate is to be increased in way of breaks of short superstructures occurring within 0,6L

amidships, over a length of about one sixth of the ship breadth on each side of the superstructure end.

This increase in net thickness is to be equal to 15%, but need not exceed 4,5 mm.

## 2.7 Deck plating protected by wood sheathing or deck composition

**2.7.1** The net thickness of deck plating protected by wood sheathing, deck composition or other arrangements deemed suitable by the Society may be reduced on a case by case basis. In any case this net thickness is to be not less than the minimum value given in Tab 2.

**2.7.2** The sheathing is to be secured to the deck to the satisfaction of the Society.

## 2.8 Corrugated bulkhead

**2.8.1** Unless otherwise specified, the net plating thickness of a corrugated bulkhead is to be not less than that obtained from [3] and [5] with  $s$  equal to the greater of  $b$  and  $c$ , where  $b$  and  $c$  are defined in Ch 4, Sec 7, Fig 3.

## 3 Strength check of plating subjected to lateral pressure

### 3.1 General

**3.1.1** The requirements of this Article apply for the strength check of plating subjected to lateral pressure and, for plating contributing to the longitudinal strength, to in-plane hull girder normal and shear stresses.

### 3.2 Load model

#### 3.2.1 General

The still water and wave lateral pressures induced by the sea and the various types of cargoes and ballast in intact conditions are to be considered, depending on the location of the plating under consideration and the type of the compartments adjacent to it, in accordance with Ch 5, Sec 1, [2.4].

The plating which constitute the boundary of compartments not intended to carry liquid (excluding bottom and side shell platings) is to be subjected to lateral pressure in flooding conditions.

The wave lateral pressures and hull girder loads are to be calculated in the mutually exclusive load cases "a", "b", "c" and "d" in Ch 5, Sec 4.

#### 3.2.2 Lateral pressure in intact conditions

The lateral pressure in intact conditions is constituted by still water pressure and wave pressure.

Still water pressure ( $p_s$ ) includes:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water internal pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Table 3 : Hull girder normal stresses

| Condition  | $\sigma_{S1}$ , in N/mm <sup>2</sup> (1)             | $\sigma_{WV1}$ , in N/mm <sup>2</sup>                         | $\sigma_{WH1}$ , in N/mm <sup>2</sup>             |
|--|--|---|---|
| $\frac{ \gamma_{S1}M_{SW,S} + 0,625\gamma_{W1}C_{FV}M_{WV,S} }{\gamma_{S1}M_{SW,H} + 0,625\gamma_{W1}C_{FV}M_{WV,H}} \geq 1$ | $\left  \frac{M_{SW,S}}{I_Y}(z - N) \right  10^{-3}$ | $\left  \frac{0,625F_D M_{WV,S}}{I_Y}(z - N) \right  10^{-3}$ | $\left  \frac{0,625M_{WH}}{I_Z}y \right  10^{-3}$ |
| $\frac{ \gamma_{S1}M_{SW,S} + 0,625\gamma_{W1}C_{FV}M_{WV,S} }{\gamma_{S1}M_{SW,H} + 0,625\gamma_{W1}C_{FV}M_{WV,H}} < 1$    | $\left  \frac{M_{SW,H}}{I_Y}(z - N) \right  10^{-3}$ | $\left  \frac{0,625M_{WV,H}}{I_Y}(z - N) \right  10^{-3}$     |   |
| (1) When the ship in still water is always in hogging condition, $M_{SW,S}$ is to be taken equal to 0.                       |  |   |   |
| <b>Note 1:</b><br>$F_D$ : Coefficient defined in Ch 5, Sec 2, [4].   |  |   |   |

Wave pressure ( $p_w$ ) includes:

- the wave pressure, defined in Ch 5, Sec 5, [2] for each load case “a”, “b”, “c” and “d”
- the inertial pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast, and for each load case “a”, “b”, “c” and “d”
- the dynamic pressures, according to the criteria in Ch 5, Sec 6, [2].

Sloshing and impact pressures are to be applied to plating of tank structures, when such tanks are partly filled and if a risk of resonance exists (see Ch 5, Sec 6, [2]).

3.2.3 Lateral pressure in flooding conditions

The lateral pressure in flooding conditions is constituted by the still water pressure  $p_{SF}$  and wave pressure  $p_{WF}$  defined in Ch 5, Sec 6, [9].

3.2.4 Lateral pressure in testing conditions

The lateral pressure in testing conditions is taken equal to:

- $p_{ST} - p_s$  for bottom shell plating and side shell plating
- $p_{ST}$  otherwise,

where  $p_s$  is the still water sea pressure defined in Ch 5, Sec 5, [1.1.1] for the draught  $T_1$  at which the testing is carried out.

If the draught  $T_1$  is not defined by the Designer, it may be taken equal to the light ballast draught  $T_B$  defined in Ch 5, Sec 1, [2.4.3].

3.2.5 In-plane hull girder normal stresses

The in-plane hull girder normal stresses to be considered for the strength check of plating are obtained, in N/mm<sup>2</sup>, from the following formulae:

- for plating contributing to the hull girder longitudinal strength:  
 $\sigma_{X1} = \gamma_{S1}\sigma_{S1} + \gamma_{W1}(C_{FV}\sigma_{WV1} + C_{FH}\sigma_{WH1} + C_{F\Omega}\sigma_{\Omega})$
- for plating not contributing to the hull girder longitudinal strength:  
 $\sigma_{X1} = 0$

where:

$\sigma_{S1}$ ,  $\sigma_{WV1}$ ,  $\sigma_{WH1}$ : Hull girder normal stresses, in N/mm<sup>2</sup>, defined in Tab 3

$\sigma_{\Omega}$  : Absolute value of the warping stress, in N/mm<sup>2</sup>, induced by the torque  $0,625 M_{WT}$  and obtained through direct calculation analyses based on a structural model in accordance with Ch 6, Sec 1, [2.6]

Table 4 : Combination factors  $C_{FV}$ ,  $C_{FH}$  and  $C_{F\Omega}$

| Load case | $C_{FV}$ | $C_{FH}$ | $C_{F\Omega}$ |
|-----------|----------|----------|---------------|
| “a”       | 1,0      | 0        | 0             |
| “b”       | 1,0      | 0        | 0             |
| “c”       | 0,4      | 1,0      | 1,0           |
| “d”       | 0,4      | 1,0      | 0             |

$C_{FV}$ ,  $C_{FH}$ ,  $C_{F\Omega}$ : Combination factors defined in Tab 4.

3.2.6 In-plane hull girder shear stresses

The in-plane hull girder shear stresses to be considered for the strength check of plating, subjected to lateral loads, which contributes to the longitudinal strength are obtained, in N/mm<sup>2</sup>, from the following formula:

$\tau_1 = \gamma_{S1}\tau_{S1} + 0,625C_{FV}\gamma_{W1}\tau_{W1}$

where:

$C_{FV}$  : Combination factor defined in Tab 4

$\tau_{S1}$  : Absolute value of the hull girder shear stresses, in N/mm<sup>2</sup>, induced by the maximum still water hull girder vertical shear force in the section considered

Table 5 : Hull girder shear stresses

| Structural element  | $\tau_{S1}$ , $\tau_{W1}$ in N/mm <sup>2</sup>   |
|---|--|
| Bottom, inner bottom and decks (excluding possible longitudinal sloping plates)   | 0  |
| Bilge, side, inner side and longitudinal bulkheads (including possible longitudinal sloping plates): <ul style="list-style-type: none"><li><math>0 \leq z \leq 0,25 D</math></li><li><math>0,25 D &lt; z \leq 0,75 D</math></li><li><math>0,75 D &lt; z \leq D</math></li></ul> | $\tau_0 \left( 0,5 + 2 \frac{z}{D} \right)$<br>$\tau_0$<br>$\tau_0 \left( 2,5 - 2 \frac{z}{D} \right)$ |
| <b>Note 1:</b><br>$\tau_0 = \frac{47}{k} \left\{ 1 - \frac{6,3}{\sqrt{L_1}} \right\} \text{ N/mm}^2$  |  |

$\tau_{W1}$  : Absolute value of the hull girder shear stresses, in N/mm<sup>2</sup>, induced by the maximum wave hull girder vertical shear force in the section considered.

$\tau_{S1}$  and  $\tau_{W1}$  are to be taken not less than the values indicated in Tab 5.

### 3.3 Longitudinally framed plating contributing to the hull girder longitudinal strength

#### 3.3.1 General

The net thickness of laterally loaded plate panels subjected to in-plane normal stress acting on the shorter sides is to be not less than the value obtained, in mm, from the following formula:

$$t = 14,9 C_a C_r S \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} P_S + \gamma_{W2} P_W}{\lambda_L R_y}}$$

where:

- for bottom, inner bottom and decks (excluding possible longitudinal sloping plates):

$$\lambda_L = \sqrt{1 - 0,95 \left( \gamma_m \frac{\sigma_{x1}}{R_y} \right)^2} - 0,225 \gamma_m \frac{\sigma_{x1}}{R_y}$$

- for bilge, side, inner side and longitudinal bulkheads (including possible longitudinal sloping plates):

$$\lambda_L = \sqrt{1 - 3 \left( \gamma_m \frac{\tau_1}{R_y} \right)^2 - 0,95 \left( \gamma_m \frac{\sigma_{x1}}{R_y} \right)^2} - 0,225 \gamma_m \frac{\sigma_{x1}}{R_y}$$

#### 3.3.2 Flooding conditions

The plating which constitute the boundary of compartments not intended to carry liquids (excluding bottom and side shell platings) is to be checked in flooding conditions. To this end, its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 14,9 C_a C_r S \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} P_{SF} + \gamma_{W2} P_{WF}}{\lambda_L R_y}}$$

where  $\lambda_L$  is defined in [3.3.1].

#### 3.3.3 Testing conditions

The plating of compartments or structures as defined in Ch 5, Sec 6, Tab 14 is to be checked in testing conditions. To this end, its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 14,9 C_a C_r S \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} P_{ST}}{R_y}}$$

### 3.4 Transversely framed plating contributing to the hull girder longitudinal strength

#### 3.4.1 General

The net thickness of laterally loaded plate panels subjected to in-plane normal stress acting on the longer sides is to be not less than the value obtained, in mm, from the following formula:

$$t = 17,2 C_a C_r S \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} P_S + \gamma_{W2} P_W}{\lambda_T R_y}}$$

where:

- for bottom, inner bottom and decks (excluding possible longitudinal sloping plates):

$$\lambda_T = 1 - 0,89 \gamma_m \frac{\sigma_{x1}}{R_y}$$

- for side, inner side and longitudinal bulkheads (including possible longitudinal sloping plates):

$$\lambda_T = \sqrt{1 - 3 \left( \gamma_m \frac{\tau_1}{R_y} \right)^2} - 0,89 \gamma_m \frac{\sigma_{x1}}{R_y}$$

#### 3.4.2 Flooding conditions

The plating which constitutes the boundary of compartments not intended to carry liquids (excluding bottom and side shell platings) is to be checked in flooding conditions. To this end, its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 17,2 C_a C_r S \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} P_{SF} + \gamma_{W2} P_{WF}}{\lambda_T R_y}}$$

where  $\lambda_T$  is defined in [3.4.1].

#### 3.4.3 Testing conditions

The plating of compartments or structures as defined in Ch 5, Sec 6, Tab 14 is to be checked in testing conditions. To this end, its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 14,9 C_a C_r S \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} P_{ST}}{R_y}}$$

### 3.5 Plating not contributing to the hull girder longitudinal strength

#### 3.5.1 General

The net thickness of plate panels subjected to lateral pressure is to be not less than the value obtained, in mm, from the following formula:

$$t = 14,9 C_a C_r S \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} P_S + \gamma_{W2} P_W}{R_y}}$$

#### 3.5.2 Flooding conditions

The plating which constitute the boundary of compartments not intended to carry liquids (excluding bottom and side shell platings) is to be checked in flooding conditions. To this end, its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 14,9 C_a C_r S \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} P_{SF} + \gamma_{W2} P_{WF}}{R_y}}$$

#### 3.5.3 Testing conditions

The plating of compartments or structures as defined in Ch 5, Sec 6, Tab 14 is to be checked in testing conditions. To this end, its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 14,9 C_a C_r S \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} P_{ST}}{R_y}}$$

4 Strength check of plating subjected to wheeled loads

4.1 General

4.1.1 The requirements of this Article apply for the strength check of plating subjected to wheeled loads.

4.2 Load model

4.2.1 General

The still water and inertial forces induced by the sea and the various types of wheeled vehicles are to be considered, depending on the location of the plating.

The inertial forces induced by the sea are to be calculated in load case “b”, as defined in Ch 5, Sec 4.

4.2.2 Wheeled forces

The wheeled force applied by one wheel is constituted by still water force and inertial force.

Still water force is the vertical force ( $F_S$ ) defined in Ch 5, Sec 6, [6.1].

Inertial force is the vertical force ( $F_{WZ}$ ) defined in Ch 5, Sec 6, [6.1], for load case “b”, with the acceleration  $a_{z1}$  calculated at  $x = 0,5L$ .

4.3 Plating

4.3.1 The net thickness of plate panels subjected to wheeled loads is to be not less than the value obtained, in mm, from the following formula:

t = C<sub>WL</sub>(nP<sub>0</sub>k)<sup>0.5</sup> – t<sub>c</sub>

where:

C<sub>WL</sub> : Coefficient to be taken equal to:

C<sub>WL</sub> = 2,15 – 0,05ℓ/s + 0,02(4 – ℓ/s)α<sup>0.5</sup> – 1,75α<sup>0.25</sup>

where ℓ/s is to be taken not greater than 3

α = A<sub>T</sub>/ℓs

A<sub>T</sub> : Tyre print area, in m<sup>2</sup>. In the case of double or triple wheels, the area is that corresponding to the group of wheels

ℓ, s : Lengths, in m, of, respectively, the longer and the shorter sides of the plate panel

n : Number of wheels on the plate panel, taken equal to:

- 1 in the case of a single wheel
- the number of wheels in a group of wheels in the case of double or triple wheels

P<sub>0</sub> : Wheeled force, in kN, taken equal to:

P<sub>0</sub> = γ<sub>S2</sub>F<sub>S</sub> + γ<sub>W2</sub>F<sub>W,Z</sub>

4.3.2 When the tyre print area is not known, it may be taken equal to:

A<sub>T</sub> = 9,81 nQ<sub>A</sub>/n<sub>W</sub>p<sub>T</sub>

where:

- n : Number of wheels on the plate panel, defined in [4.3.1]
- Q<sub>A</sub> : Axle load, in t
- n<sub>W</sub> : Number of wheels for the axle considered
- p<sub>T</sub> : Tyre pressure, in kN/m<sup>2</sup>. When the tyre pressure is not indicated by the designer, it may be taken as defined in Tab 6.

Table 6 : Tyre pressures p<sub>T</sub> for vehicles

| Vehicle type        | Tyre pressure p <sub>T</sub> , in kN/m <sup>2</sup> |                    |
|---------------------|---|--------------------|
|                     | Pneumatic tyres                                     | Solid rubber tyres |
| Private cars        | 250   | Not applicable     |
| Vans                | 600   | Not applicable     |
| Trucks and trailers | 800   | Not applicable     |
| Handling machines   | 1100  | 1600               |

4.3.3 For vehicles with the four wheels of the axle located on a plate panel as shown in Fig 1, the net thickness of deck plating is to be not less than the greater of the values obtained, in mm, from the following formulae:

t = t<sub>1</sub>

t = t<sub>2</sub> (1 + β<sub>2</sub> + β<sub>3</sub> + β<sub>4</sub>)<sup>0.5</sup>

where:

t<sub>1</sub> : Net thickness obtained, in mm, from [4.3.1] for n = 2, considering one group of two wheels located on the plate panel

t<sub>2</sub> : Net thickness obtained, in mm, from [4.3.1] for n = 1, considering one wheel located on the plate panel

β<sub>2</sub>, β<sub>3</sub>, β<sub>4</sub>: Coefficients obtained from the following formula, by replacing i by 2, 3 and 4, respectively (see Fig 1):

- for x<sub>i</sub> / b < 2:  
β<sub>i</sub> = 0,8 (1,2 – 2,02 α<sub>i</sub> + 1,17 α<sub>i</sub><sup>2</sup> – 0,23 α<sub>i</sub><sup>3</sup>)
- for x<sub>i</sub> / b ≥ 2:  
β<sub>i</sub> = 0

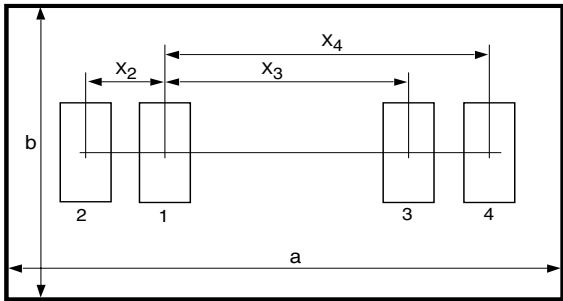
x<sub>i</sub> : Distance, in m, from the wheel considered to the reference wheel (see Fig 1)

b : Dimension, in m, of the plate panel side perpendicular to the axle

α<sub>i</sub> = x<sub>i</sub>/b



Figure 1 : Four wheel axle located on a plate panel



5 Buckling check

5.1 General

5.1.1 Application

The requirements of this Article apply for the buckling check of plating subjected to in-plane compression stresses, acting on one or two sides, or to shear stress.

Rectangular plate panels are considered as being simply supported. For specific designs, other boundary conditions may be considered, at the Society's discretion, provided that the necessary information is submitted for review.

5.1.2 Compression and bending with or without shear

For plate panels subjected to compression and bending along one side, with or without shear, as shown in Fig 2, side "b" is to be taken as the loaded side. In such case, the compression stress varies linearly from  $\sigma_1$  to  $\sigma_2 = \psi \sigma_1$  ( $\psi \leq 1$ ) along edge "b".

5.1.3 Shear

For plate panels subjected to shear, as shown in Fig 3, side "b" may be taken as either the longer or the shorter side of the panel.

5.1.4 Bi-axial compression and shear

For plate panels subjected to bi-axial compression along sides "a" and "b", and to shear, as shown in Fig 4, side "a" is to be taken as the side in the direction of the primary supporting members.

Figure 2 : Buckling of a simply supported rectangular plate panel subjected to compression and bending, with and without shear

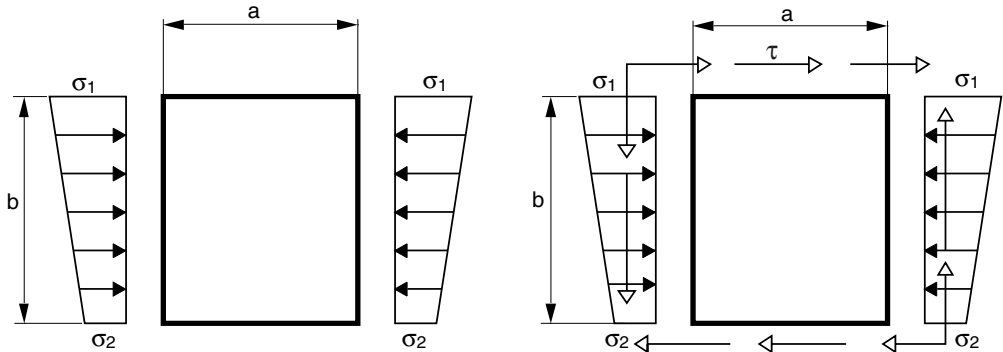


Figure 3 : Buckling of a simply supported rectangular plate panel subjected to shear

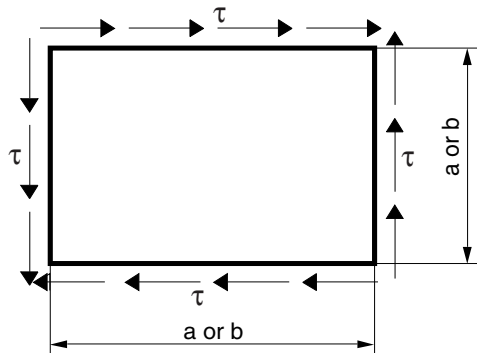


Figure 4 : Buckling of a simply supported rectangular plate panel subjected to bi-axial compression and shear

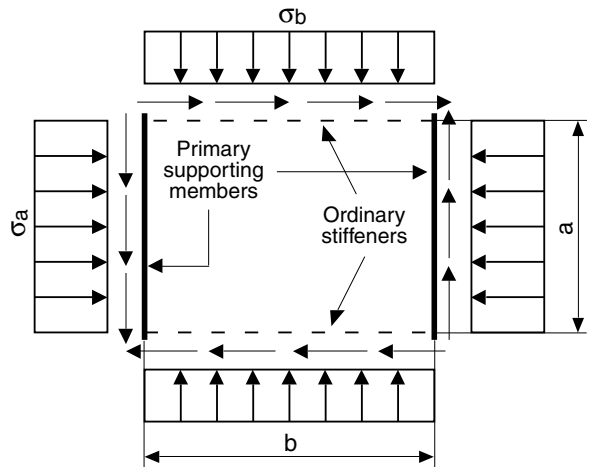


Table 7 : Hull girder normal compression stresses

| Condition   | $\sigma_{S1}$ in N/mm <sup>2</sup> (1) | $\sigma_{WV1}$ in N/mm <sup>2</sup>            | $\sigma_{WH1}$ in N/mm <sup>2</sup>              |
|---|--|--|--|
| $z \geq N$  | $\frac{M_{SW,S}}{I_Y}(z - N)10^{-3}$   | $\frac{0,625 F_D M_{WV,S}}{I_Y}(z - N)10^{-3}$ | $-\left \frac{0,625 M_{WH}}{I_Z}y\right 10^{-3}$ |
| $z < N$   | $\frac{M_{SW,H}}{I_Y}(z - N)10^{-3}$   | $\frac{0,625 M_{WV,H}}{I_Y}(z - N)10^{-3}$     |  |
| <p>(1) When the ship in still water is always in hogging condition, <math>\sigma_{S1}</math> for <math>z \geq N</math> is to be obtained, in N/mm<sup>2</sup>, from the following formula, unless <math>\sigma_{X1}</math> is evaluated by means of direct calculations (see [5.2.2]):</p> $\sigma_{S1} = \frac{M_{SW,Hmin}}{I_Y}(z - N)10^{-3}$ <p><b>Note 1:</b></p> <p><math>F_D</math> : Coefficient defined in Ch 5, Sec 2, [4].</p> |  |  |  |

5.2 Load model

5.2.1 Sign convention for normal stresses

The sign convention for normal stresses is as follows:

- tension: positive
- compression: negative.

5.2.2 In-plane hull girder compression normal stresses

The in-plane hull girder compression normal stresses to be considered for the buckling check of plating contributing to the longitudinal strength are obtained, in N/mm<sup>2</sup>, from the following formula:

$\sigma_{X1} = \gamma_{S1}\sigma_{S1} + \gamma_{W1}(C_{FV}\sigma_{WV1} + C_{FH}\sigma_{WH1} + C_{FQ}\sigma_Q)$

where:

- $\sigma_{S1}, \sigma_{WV1}, \sigma_{WH1}$ : Hull girder normal stresses, in N/mm<sup>2</sup>, defined in Tab 7
- $\sigma_Q$  : Compression warping stress, in N/mm<sup>2</sup>, induced by the torque 0,625M<sub>WT</sub> and obtained through direct calculation analyses based on a structural model in accordance with Ch 6, Sec 1, [2.6]

$C_{FV}, C_{FH}, C_{FQ}$ :Combination factors defined in Tab 4.  
 $\sigma_{X1}$  is to be taken as the maximum compression stress on the plate panel considered.

In no case may  $\sigma_{X1}$  be taken less than 30/k N/mm<sup>2</sup>.

When the ship in still water is always in hogging condition,  $\sigma_{X1}$  may be evaluated by means of direct calculations when justified on the basis of the ship’s characteristics and intended service. The calculations are to be submitted to the Society for approval.

Where deemed necessary, the buckling check is to be carried out in harbour conditions by considering a reduced wave bending moment equal to 0,1M<sub>WV</sub> given in Ch 5, Sec 2, [3.1].

5.2.3 In-plane hull girder shear stresses

The in-plane hull girder shear stresses to be considered for the buckling check of plating are obtained as specified in [3.2.6] for the strength check of plating subjected to lateral pressure, which contributes to the longitudinal strength.

5.2.4 Combined in-plane hull girder and local compression normal stresses

The combined in-plane compression normal stresses to be considered for the buckling check of plating are to take into account the hull girder stresses and the local stresses resulting from the bending of the primary supporting members. These local stresses are to be obtained from a direct structural analysis using the design loads given in Part B, Chapter 5.

With respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4.1], the combined stresses in x and y direction are obtained, in N/mm<sup>2</sup>, from the following formulae:

$\sigma_X = \sigma_{X1} + \gamma_{S2}\sigma_{X2,S} + \gamma_{W2}\sigma_{X2,W}$

$\sigma_Y = \gamma_{S2}\sigma_{Y2,S} + \gamma_{W2}\sigma_{Y2,W}$

where:

- $\sigma_{X1}$  : Compression normal stress, in N/mm<sup>2</sup>, induced by the hull girder still water and wave loads, defined in [5.2.2]
- $\sigma_{X2,S}, \sigma_{Y2,S}$ : Compression normal stress in x and y direction, respectively, in N/mm<sup>2</sup>, induced by the local bending of the primary supporting members and obtained from a direct structural analysis using the still water design loads given in Part B, Chapter 5
- $\sigma_{X2,W}, \sigma_{Y2,W}$ : Compression normal stress in x and y direction, respectively, in N/mm<sup>2</sup>, induced by the local bending of the primary supporting members and obtained from a direct structural analysis using the wave design loads given in Part B, Chapter 5.

5.2.5 Combined in-plane hull girder and local shear stresses

The combined in-plane shear stresses to be considered for the buckling check of plating are to take into account the hull girder stresses and the local stresses resulting from the bending of the primary supporting members. These local stresses are to be obtained from a direct structural analysis using the design loads given in Part B, Chapter 5.

The combined stresses are obtained, in N/mm<sup>2</sup>, from the following formula:

$\tau = \tau_1 + \gamma_{S2}\tau_{2,S} + \gamma_{W2}\tau_{2,W}$

where:

- $\tau_1$  : Shear stress, in N/mm<sup>2</sup>, induced by the hull girder still water and wave loads, defined in [5.2.3]
- $\tau_{2,S}$  : Shear stress, in N/mm<sup>2</sup>, induced by the local bending of the primary supporting members and obtained from a direct structural analysis using the still water design loads given in Part B, Chapter 5
- $\tau_{2,W}$  : Shear stress, in N/mm<sup>2</sup>, induced by the local bending of the primary supporting members and obtained from a direct structural analysis using the wave design loads given in Part B, Chapter 5.

5.3 Critical stresses

5.3.1 Compression and bending for plane panel

The critical buckling stress is to be obtained, in N/mm<sup>2</sup>, from the following formulae:

$\sigma_c = \sigma_E$  for  $\sigma_E \leq \frac{R_{eH}}{2}$   
 $\sigma_c = R_{eH} \left(1 - \frac{R_{eH}}{4\sigma_E}\right)$  for  $\sigma_E > \frac{R_{eH}}{2}$

where:

$\sigma_E$  : Euler buckling stress, to be obtained, in N/mm<sup>2</sup>, from the following formula:

$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2 K_1 \epsilon 10^{-6}$

$K_1$  : Buckling factor defined in Tab 8

$\epsilon$  : Coefficient to be taken equal to:

- $\epsilon = 1$  for  $\alpha \geq 1$
  - $\epsilon = 1,05$  for  $\alpha < 1$  and side “b” stiffened by flat bar
  - $\epsilon = 1,10$  for  $\alpha < 1$  and side “b” stiffened by bulb section
  - $\epsilon = 1,21$  for  $\alpha < 1$  and side “b” stiffened by angle or T-section
  - $\epsilon = 1,30$  for  $\alpha < 1$  and side “b” stiffened by primary supporting members.
- with  $\alpha = a / b$ .

5.3.2 Shear for plane panel

The critical shear buckling stress is to be obtained, in N/mm<sup>2</sup>, from the following formulae:

$\tau_c = \tau_E$  for  $\tau_E \leq \frac{R_{eH}}{2\sqrt{3}}$   
 $\tau_c = \frac{R_{eH}}{\sqrt{3}} \left(1 - \frac{R_{eH}}{4\sqrt{3}\tau_E}\right)$  for  $\tau_E > \frac{R_{eH}}{2\sqrt{3}}$

where:

$\tau_E$  : Euler shear buckling stress, to be obtained, in N/mm<sup>2</sup>, from the following formula:

$\tau_E = \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2 K_2 10^{-6}$

$K_2$  : Buckling factor to be taken equal to:

$K_2 = 5,34 + \frac{4}{\alpha^2}$  for  $\alpha > 1$   
 $K_2 = \frac{5,34}{\alpha^2} + 4$  for  $\alpha \leq 1$

$\alpha$  : Coefficient defined in [5.3.1].

Table 8 : Buckling factor  $K_1$  for plate panels

| Load pattern  | Aspect ratio                               | Buckling factor $K_1$   |
|---|--|---|
| $0 \leq \psi \leq 1$  | $\alpha \geq 1$                            | $\frac{8,4}{\psi + 1,1}$  |
|   | $\alpha < 1$                               | $\left(\alpha + \frac{1}{\alpha}\right)^2 \frac{2,1}{\psi + 1,1}$   |
| $-1 < \psi < 0$   |  | $(1 + \psi)K_1' - \psi K_1'' + 10\psi(1 + \psi)$  |
| $\psi \leq -1$  | $\alpha \frac{1-\psi}{2} \geq \frac{2}{3}$ | $23,9 \left(\frac{1-\psi}{2}\right)^2$  |
|   | $\alpha \frac{1-\psi}{2} < \frac{2}{3}$    | $\left(15,87 + \frac{1,87}{\left(\alpha \frac{1-\psi}{2}\right)^2} + 8,6 \left(\alpha \frac{1-\psi}{2}\right)^2\right) \left(\frac{1-\psi}{2}\right)^2$ |
| <p><b>Note 1:</b><br/><math>\psi = \frac{\sigma_2}{\sigma_1}</math><br/><math>K_1'</math> : Value of <math>K_1</math> calculated for <math>\psi = 0</math><br/><math>K_1''</math> : Value of <math>K_1</math> calculated for <math>\psi = -1</math></p> |  |   |

### 5.3.3 Bi-axial compression and shear for plane panel

The critical buckling stress  $\sigma_{c,a}$  for compression on side "a" of the panel is to be obtained, in N/mm<sup>2</sup>, from the following formula:

$$\sigma_{c,a} = \left( \frac{2,25}{\beta} - \frac{1,25}{\beta^2} \right) R_{eH}$$

where:

$\beta$  : Slenderness of the panel, to be taken equal to:

$$\beta = 10^3 \frac{a}{t} \sqrt{\frac{R_{eH}}{E}}$$

without being taken less than 1,25.

The critical buckling stress  $\sigma_{c,b}$  for compression on side "b" of the panel is to be obtained, in N/mm<sup>2</sup>, from the formulae in [5.3.1].

The critical shear buckling stress is to be obtained, in N/mm<sup>2</sup>, from the formulae in [5.3.2].

### 5.3.4 Compression and shear for curved panels

The critical buckling stress of curved panels subjected to compression perpendicular to curved edges is to be obtained, in N/mm<sup>2</sup>, from the following formulae:

$$\sigma_c = \sigma_E \quad \text{for } \sigma_E \leq \frac{R_{eH}}{2}$$

$$\sigma_c = R_{eH} \left( 1 - \frac{R_{eH}}{4\sigma_E} \right) \quad \text{for } \sigma_E > \frac{R_{eH}}{2}$$

where:

$\sigma_E$  : Euler buckling stress, to be obtained, in N/mm<sup>2</sup>, from the following formula:

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)} \left( \frac{t}{b} \right)^2 K_3 10^{-6}$$

$b$  : Width of curved panel, in m, measured on arc between two adjacent supports

$K_3$  : Buckling factor to be taken equal to:

$$K_3 = 2 \left\{ 1 + \sqrt{1 + \frac{12(1-\nu^2)}{\pi^4} \frac{b^4}{r^2 t^2} 10^6} \right\}$$

$r$  : Radius of curvature, in m.

The critical shear buckling stress is to be obtained, in N/mm<sup>2</sup>, from the following formulae:

$$\tau_c = \tau_E \quad \text{for } \tau_E \leq \frac{R_{eH}}{2\sqrt{3}}$$

$$\tau_c = \frac{R_{eH}}{\sqrt{3}} \left( 1 - \frac{R_{eH}}{4\sqrt{3}\tau_E} \right) \quad \text{for } \tau_E > \frac{R_{eH}}{2\sqrt{3}}$$

where:

$\tau_E$  : Euler shear buckling stress, to be obtained, in N/mm<sup>2</sup>, from the following formula:

$$\tau_E = \frac{\pi^2 E}{12(1-\nu^2)} \left( \frac{t}{b} \right)^2 K_4 10^{-6}$$

$K_4$  : Buckling factor to be taken equal to:

$$K_4 = \frac{12(1-\nu^2)}{\pi^2} \left( 5 + \frac{b^2}{rt} 10^2 \right)$$

$b, r$  : Defined above.

### 5.3.5 Compression for corrugation flanges

The critical buckling stress is to be obtained, in N/mm<sup>2</sup>, from the following formulae:

$$\sigma_c = \sigma_E \quad \text{for } \sigma_E \leq \frac{R_{eH}}{2}$$

$$\sigma_c = R_{eH} \left( 1 - \frac{R_{eH}}{4\sigma_E} \right) \quad \text{for } \sigma_E > \frac{R_{eH}}{2}$$

where:

$\sigma_E$  : Euler buckling stress, to be obtained, in N/mm<sup>2</sup>, from the following formula:

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)} \left( \frac{t_f}{V} \right)^2 K_5 10^{-6}$$

$K_5$  : Buckling factor to be taken equal to:

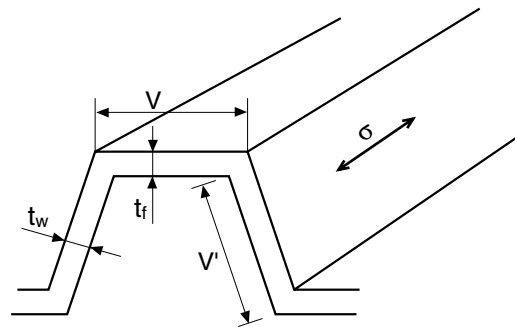
$$K_5 = \left( 1 + \frac{t_w}{t_f} \right) \left\{ 3 + 0,5 \frac{V'}{V} - 0,33 \left( \frac{V'}{V} \right)^2 \right\}$$

$t_f$  : Net thickness, in mm, of the corrugation flange

$t_w$  : Net thickness, in mm, of the corrugation web

$V, V'$  : Dimensions of a corrugation, in m, shown in Fig 5.

Figure 5 : Dimensions of a corrugation



## 5.4 Checking criteria

### 5.4.1 Acceptance of results

The net thickness of plate panels is to be such as to satisfy the buckling check, as indicated in [5.4.2] to [5.4.5] depending on the type of stresses acting on the plate panel considered. When the buckling criteria is exceeded, the scantlings may still be considered as acceptable, provided that the stiffeners located on the plate panel satisfy the buckling and the ultimate strength checks as specified in Ch 7, Sec 2, [4] and Ch 7, Sec 2, [5].

### 5.4.2 Compression and bending

For plate panels subjected to compression and bending on one side, the critical buckling stress is to comply with the following formula:

$$\frac{\sigma_c}{\gamma_R \gamma_m} \geq |\sigma_b|$$

where:

$\sigma_c$  : Critical buckling stress, in N/mm<sup>2</sup>, defined in [5.3.1], [5.3.4] or [5.3.5], as the case may be

$\sigma_b$  : Compression stress, in N/mm<sup>2</sup>, acting on side "b" of the plate panel, to be calculated, as specified in [5.2.2] or [5.2.4], as the case may be.

In equivalence to the previous criteria on the critical buckling stress, the net thickness, in mm, is to comply with the following formulae:

$$t = \frac{b}{\pi} \sqrt{\frac{12\gamma_R\gamma_m|\sigma_b|(1-\nu^2)}{EK_i\epsilon}} 10^3 \quad \text{for } \sigma_E \leq \frac{R_{eH}}{2}$$

$$t = \frac{b}{\pi} \sqrt{\frac{3R_{eH}^2(1-\nu^2)}{EK_i\epsilon(R_{eH}-\gamma_R\gamma_m|\sigma_b|)}} 10^3 \quad \text{for } \sigma_E > \frac{R_{eH}}{2}$$

where:

$K_i = K_1$ , defined in [5.3.1] for a plane panel

$K_i = K_3$ , defined in [5.3.4] for a curved panel.

### 5.4.3 Shear

For plate panels subjected to shear, the critical shear buckling stress is to comply with the following formula:

$$\frac{\tau_c}{\gamma_R\gamma_m} \geq |\tau_b|$$

where:

$\tau_c$  : Critical shear buckling stress, in N/mm<sup>2</sup>, defined in [5.3.2] or [5.3.4], as the case may be

$\tau_b$  : Shear stress, in N/mm<sup>2</sup>, acting on the plate panel, to be calculated as specified in [5.2.3] or [5.2.5], as the case may be.

In equivalence to the previous criteria on the critical shear buckling stress, the net thickness, in mm, is to comply with the following formulae:

$$t = \frac{b}{\pi} \sqrt{\frac{12\gamma_R\gamma_m|\tau_b|(1-\nu^2)}{EK_i}} 10^3 \quad \text{for } \tau_E \leq \frac{R_{eH}}{2\sqrt{3}}$$

$$t = \frac{b}{\pi} \sqrt{\frac{R_{eH}^2(1-\nu^2)}{EK_i\left(\frac{R_{eH}}{\sqrt{3}} - \gamma_R\gamma_m|\tau_b|\right)}} 10^3 \quad \text{for } \tau_E > \frac{R_{eH}}{2\sqrt{3}}$$

where:

$K_i = K_2$ , defined in [5.3.2] for a plane panel

$K_i = K_4$ , defined in [5.3.4] for a curved panel.

### 5.4.4 Compression, bending and shear

For plate panels subjected to compression, bending and shear, the combined critical stress is to comply with the following formulae:

$$F \leq 1 \quad \text{for } \frac{\sigma_{comb}}{F} \leq \frac{R_{eH}}{2\gamma_R\gamma_m}$$

$$F \leq \frac{4\sigma_{comb}}{R_{eH}/\gamma_R\gamma_m} \left(1 - \frac{\sigma_{comb}}{R_{eH}/\gamma_R\gamma_m}\right) \quad \text{for } \frac{\sigma_{comb}}{F} > \frac{R_{eH}}{2\gamma_R\gamma_m}$$

where:

$$\sigma_{comb} = \sqrt{\sigma_1^2 + 3\tau^2}$$

$$F = \gamma_R\gamma_m \left[ \frac{1+\psi|\sigma_1|}{4\sigma_E} + \sqrt{\left(\frac{3-\psi}{4}\right)^2 \left(\frac{\sigma_1}{\sigma_E}\right)^2 + \left(\frac{\tau}{\tau_E}\right)^2} \right]$$

$\sigma_E$  : Euler buckling stress, in N/mm<sup>2</sup>, defined in [5.3.1], [5.3.4] or [5.3.5] as the case may be

$\tau_E$  : Euler shear buckling stress, in N/mm<sup>2</sup>, defined in [5.3.2] or [5.3.4], as the case may be

$$\psi = \frac{\sigma_2}{\sigma_1}$$

$\sigma_1$ ,  $\sigma_2$  and  $\tau$  are defined in Fig 2 and are to be calculated, in N/mm<sup>2</sup>, as specified in [5.2].

### 5.4.5 Bi-axial compression, taking account of shear stress

For plate panels subjected to bi-axial compression and shear, the critical buckling stresses are to comply with the following formula:

$$\left| \frac{\gamma_R\gamma_m\sigma_a}{\sigma_{c,a}} \right|^{1.9} + \left| \frac{\gamma_R\gamma_m\sigma_b}{\sigma_{c,b}} \right|^{1.9} + \left| \frac{\gamma_R\gamma_m\tau}{\tau_c} \right|^{1.9} \leq 1$$

where:

$\sigma_{c,a}$  : Critical buckling stress for compression on side "a", in N/mm<sup>2</sup>, defined in [5.3.3]

$\sigma_{c,b}$  : Critical buckling stress for compression on side "b", in N/mm<sup>2</sup>, defined in [5.3.3]

$\sigma_a$  : Compression stress acting on side "a", in N/mm<sup>2</sup>, to be calculated as specified in [5.2.2] or [5.2.4], as the case may be

$\sigma_b$  : Compression stress acting on side "b", in N/mm<sup>2</sup>, to be calculated as specified in [5.2.2] or [5.2.4], as the case may be

$$\alpha = a / b$$

$\tau$  : Shear stress, in N/mm<sup>2</sup>, to be calculated as specified in [5.2.3] or [5.2.5], as the case may be

$\tau_c$  : Critical shear buckling stress, in N/mm<sup>2</sup>, defined in [5.3.2].

## SECTION 2

## ORDINARY STIFFENERS

## Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

- |                  |  |
|------------------|--|
| $p_s$            | : Still water pressure, in $\text{kN/m}^2$ , see [3.3.2] and [5.3.2]   |
| $p_w$            | : Wave pressure and, if necessary, dynamic pressures, according to the criteria in Ch 5, Sec 5, [2] and Ch 5, Sec 6, [2], in $\text{kN/m}^2$ (see [3.3.2] and [5.3.2])   |
| $p_{SF}, p_{WF}$ | : Still water and wave pressures, in $\text{kN/m}^2$ , in flooding conditions, defined in Ch 5, Sec 6, [9]   |
| $F_s$            | : Still water wheeled force, in $\text{kN}$ , see [3.3.5]  |
| $F_{WZ}$         | : Inertial wheeled force, in $\text{kN}$ , see [3.3.5]   |
| $\sigma_{x1}$    | : Hull girder normal stress, in $\text{N/mm}^2$ , defined in: <ul style="list-style-type: none"> <li>• [3.3.6] for the yielding check of ordinary stiffeners</li> <li>• [4.2.2] for the buckling check of ordinary stiffeners</li> <li>• [5.3.3] for the ultimate strength check of ordinary stiffeners</li> </ul> |
| $R_{eH,P}$       | : Minimum yield stress, in $\text{N/mm}^2$ , of the plating material, defined in Ch 4, Sec 1, [2]  |
| $R_{eH,S}$       | : Minimum yield stress, in $\text{N/mm}^2$ , of the stiffener material, defined in Ch 4, Sec 1, [2]  |
| $s$              | : Spacing, in $\text{m}$ , of ordinary stiffeners  |
| $\ell$           | : Span, in $\text{m}$ , of ordinary stiffeners, measured between the supporting members, see Ch 4, Sec 3, [3.2]  |
| $h_w$            | : Web height, in $\text{mm}$   |
| $t_w$            | : Net web thickness, in $\text{mm}$  |
| $b_f$            | : Face plate width, in $\text{mm}$   |
| $t_f$            | : Net face plate thickness, in $\text{mm}$   |
| $b_p$            | : Width, in $\text{m}$ , of the plating attached to the stiffener, for the yielding check, defined in Ch 4, Sec 3, [3.3.1]   |
| $b_e$            | : Width, in $\text{m}$ , of the plating attached to the stiffener, for the buckling check, defined in [4.1]  |
| $b_U$            | : Width, in $\text{m}$ , of the plating attached to the stiffener, for the ultimate strength check, defined in [5.2]   |
| $t_p$            | : Net thickness, in $\text{mm}$ , of the attached plating  |
| $w$              | : Net section modulus, in $\text{cm}^3$ , of the stiffener, with an attached plating of width $b_p$ , to be calculated as specified in Ch 4, Sec 3, [3.4]  |
| $A$              | : Net sectional area, in $\text{cm}^2$ , of the stiffener without attached plating   |
| $A_s$            | : Net sectional area, in $\text{cm}^2$ , of the stiffener with attached plating of width $s$   |

- $A_e$  : Net sectional area, in  $\text{cm}^2$ , of the stiffener with attached plating of width  $b_e$
- $A_U$  : Net sectional area, in  $\text{cm}^2$ , of the stiffener with attached plating of width  $b_U$
- $A_{sh}$  : Net shear sectional area, in  $\text{cm}^2$ , of the stiffener, to be calculated as specified in Ch 4, Sec 3, [3.4]
- $I$  : Net moment of inertia, in  $\text{cm}^4$ , of the stiffener without attached plating, about its neutral axis parallel to the plating (see Ch 4, Sec 3, Fig 4 and Ch 4, Sec 3, Fig 5)
- $I_s$  : Net moment of inertia, in  $\text{cm}^4$ , of the stiffener with attached shell plating of width  $s$ , about its neutral axis parallel to the plating
- $I_e$  : Net moment of inertia, in  $\text{cm}^4$ , of the stiffener with attached shell plating of width  $b_e$ , about its neutral axis parallel to the plating
- $I_U$  : Net moment of inertia, in  $\text{cm}^4$ , of the stiffener with attached shell plating of width  $b_U$ , about its neutral axis parallel to the plating
- $\rho_s$  : Radius of gyration, in cm, of the stiffener with attached plating of width  $s$
- $\rho_U$  : Radius of gyration, in cm, of the stiffener with attached plating of width  $b_U$ .

## 1 General

### 1.1 Net scantlings

**1.1.1** As specified in Ch 4, Sec 2, [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 Ch 4, Sec 2.

## 1.2 Partial safety factors

**1.2.1** The partial safety factors to be considered for the checking of ordinary stiffeners are specified in Tab 1.

### 1.3 Load point

### 1.3.1 Lateral pressure

Unless otherwise specified, lateral pressure is to be calculated at mid-span of the ordinary stiffener considered.

### 1.3.2 Hull girder stresses

For longitudinal ordinary stiffeners contributing to the hull girder longitudinal strength, the hull girder normal stresses are to be calculated in way of the attached plating of the stiffener considered.

Table 1 : Ordinary stiffeners - Partial safety factors

| Partial safety factors covering uncertainties regarding:  | Symbol        | Yielding check       |                   |                 |  |               | Buckling check | Ultimate strength check |
|---|---------------|----------------------|-------------------|-----------------|--|---------------|----------------|-------------------------|
|   |               | General              | Sloshing pressure | Impact pressure | Watertight bulk-head ordinary stiffeners (1) | Testing check |                |                         |
|   |               | (see [3.3] to [3.7]) |                   |                 | (see [3.8])                                  | (see [3.9])   |                |                         |
| Still water hull girder loads   | $\gamma_{S1}$ | 1,00                 | 0                 | 0               | 1,00   | N.A.          | 1,00           | 1,00                    |
| Wave hull girder loads  | $\gamma_{W1}$ | 1,15                 | 0                 | 0               | 1,15   | N.A.          | 1,15           | 1,30                    |
| Still water pressure  | $\gamma_{S2}$ | 1,00                 | 1,00              | 1,00            | 1,00   | 1,00          | N.A.           | 1,00                    |
| Wave pressure   | $\gamma_{W2}$ | 1,20                 | 1,10              | 1,00            | 1,05   | N.A.          | N.A.           | 1,40                    |
| Material  | $\gamma_m$    | 1,02                 | 1,02              | 1,02            | 1,02   | 1,02          | 1,02           | 1,02                    |
| Resistance  | $\gamma_R$    | 1,02                 | 1,02              | 1,02            | 1,02 (2)                                     | 1,20          | 1,10           | 1,02                    |
| (1) Applies also to ordinary stiffeners of bulkheads or inner side which constitute boundary of compartments not intended to carry liquids.<br>(2) For ordinary stiffeners of the collision bulkhead, $\gamma_R = 1,25$ .<br>Note 1: N.A. = Not applicable. |               |                      |                   |                 |  |               |                |                         |

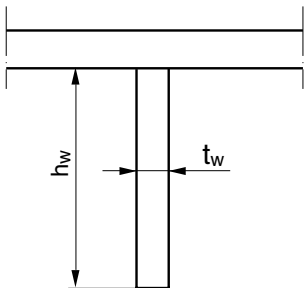
1.4 Net dimensions of ordinary stiffeners

1.4.1 Flat bar

The net dimensions of a flat bar ordinary stiffener (see Fig 1) are to comply with the following requirement:

$\frac{h_w}{t_w} \leq 20 \sqrt{k}$

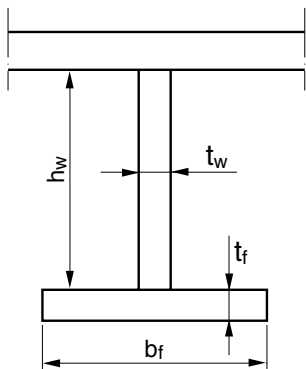
Figure 1 : Net dimensions of a flat bar



1.4.2 T-section

The net dimensions of a T-section ordinary stiffener (see Fig 2) are to comply with the following requirements:

Figure 2 : Net dimensions of a T-section



$\frac{h_w}{t_w} \leq 55 \sqrt{k}$

$\frac{b_f}{t_f} \leq 33 \sqrt{k}$

$b_f t_f \geq \frac{h_w t_w}{6}$

1.4.3 Angle

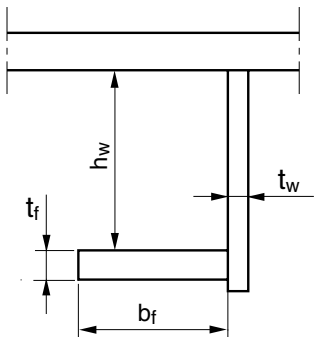
The net dimensions of an angle ordinary stiffener (see Fig 3) are to comply with the following requirements:

$\frac{h_w}{t_w} \leq 55 \sqrt{k}$

$\frac{b_f}{t_f} \leq 16,5 \sqrt{k}$

$b_f t_f \geq \frac{h_w t_w}{6}$

Figure 3 : Net dimensions of an angle



2 General requirements

2.1 General

2.1.1 The requirements in [2.2] and [2.3] are to be applied to ordinary stiffeners in addition of those in [3] to [5].

## 2.2 Minimum net thicknesses

**2.2.1** The net thickness of the web of ordinary stiffeners is to be not less than the lesser of:

- the value obtained, in mm, from the following formulae:

$$t_{\text{MIN}} = 0,8 + 0,004 L k^{1/2} + 4,5 s \quad \text{for } L < 120 \text{ m}$$

$$t_{\text{MIN}} = 1,6 + 2,2 k^{1/2} + s \quad \text{for } L \geq 120 \text{ m}$$

- the net as built thickness of the attached plating.

## 2.3 Struts connecting ordinary stiffeners

**2.3.1** The sectional area  $A_{\text{SR}}$ , in  $\text{cm}^2$ , and the moment of inertia  $I_{\text{SR}}$  about the main axes, in  $\text{cm}^4$ , of struts connecting ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$A_{\text{SR}} = \frac{p_{\text{SR}} s \ell}{20}$$

$$I_{\text{SR}} = \frac{0,75 s \ell (p_{\text{SR1}} + p_{\text{SR2}}) A_{\text{ASR}} \ell_{\text{SR}}^2}{47,2 A_{\text{ASR}} - s \ell (p_{\text{SR1}} + p_{\text{SR2}})}$$

where:

$p_{\text{SR}}$  : Pressure to be taken equal to the greater of the values obtained, in  $\text{kN/m}^2$ , from the following formulae:

$$p_{\text{SR}} = 0,5 (p_{\text{SR1}} + p_{\text{SR2}})$$

$$p_{\text{SR}} = p_{\text{SR3}}$$

$p_{\text{SR1}}$  : External pressure in way of the strut, in  $\text{kN/m}^2$ , acting on one side, outside the compartment in which the strut is located, equal to:

$$p_{\text{SR1}} = \gamma_{\text{S2}} p_{\text{S}} + \gamma_{\text{W2}} p_{\text{W}}$$

$p_{\text{SR2}}$  : External pressure in way of the strut, in  $\text{kN/m}^2$ , acting on the opposite side, outside the compartment in which the strut is located, equal to:

$$p_{\text{SR2}} = \gamma_{\text{S2}} p_{\text{S}} + \gamma_{\text{W2}} p_{\text{W}}$$

$p_{\text{SR3}}$  : Internal pressure at mid-span of the strut, in  $\text{kN/m}^2$ , in the compartment in which the strut is located, equal to:

$$p_{\text{SR3}} = \gamma_{\text{S2}} p_{\text{S}} + \gamma_{\text{W2}} p_{\text{W}}$$

$\ell$  : Span, in m, of ordinary stiffeners connected by the strut (see Ch 4, Sec 3, [3.2.2])

$\ell_{\text{SR}}$  : Length, in m, of the strut

$A_{\text{ASR}}$  : Actual net sectional area, in  $\text{cm}^2$ , of the strut.

## 2.4 Corrugated bulkhead

**2.4.1** Unless otherwise specified, the net section modulus and the net shear sectional area of a corrugation are to be not less than those obtained from [3] to [5] with  $s$  equal to the greater of  $(a + b)$ , where  $a$  and  $b$  are defined in Ch 4, Sec 7, Fig 3.

## 2.5 Deck ordinary stiffeners in way of launching appliances used for survival craft or rescue boat

**2.5.1** The scantlings of deck ordinary stiffeners are to be determined by direct calculations.

**2.5.2** The loads exerted by launching appliance are to correspond to the SWL of the launching appliance.

**2.5.3** The combined stress, in  $\text{N/mm}^2$ , is not to exceed the smaller of:

$$\frac{100}{235} R_{\text{eH}} \text{ and } \frac{54}{235} R_{\text{m}}$$

where  $R_{\text{m}}$  is the ultimate minimum tensile strength of the stiffener material, in  $\text{N/mm}^2$ .

## 3 Yielding check

### 3.1 General

**3.1.1** The requirements of this Article apply for the yielding check of ordinary stiffeners subjected to lateral pressure or to wheeled loads and, for ordinary stiffeners contributing to the hull girder longitudinal strength, to hull girder normal stresses.

**3.1.2** When tanks are partly filled and if a risk of resonance exists, the yielding check of vertical ordinary stiffeners of tank structures subjected to sloshing and impact pressures is to be carried out by direct calculation.

**3.1.3** The yielding check is also to be carried out for ordinary stiffeners subjected to specific loads, such as concentrated loads.

### 3.2 Structural model

#### 3.2.1 Boundary conditions

The requirements in [3.4], [3.7.3], [3.7.4] and [3.8] apply to stiffeners considered as clamped at both ends, whose end connections comply with the requirements in [3.2.2].

The requirements in [3.5] and [3.7.5] apply to stiffeners considered as simply supported at both ends. Other boundary conditions may be considered by the Society on a case by case basis, depending on the distribution of wheeled loads.

For other boundary conditions, the yielding check is to be considered on a case by case basis.

#### 3.2.2 Bracket arrangement

The requirements of this Article apply to ordinary stiffeners without end brackets, with a bracket at one end or with two end brackets, where the bracket length is not greater than  $0,2\ell$ .

In the case of ordinary stiffeners with end brackets of length greater than  $0,2\ell$ , the determination of normal and shear stresses due to design loads and the required section modulus and shear sectional area are considered by the Society on a case by case basis.

### 3.3 Load model

#### 3.3.1 General

The still water and wave lateral loads induced by the sea and the various types of cargoes and ballast in intact conditions are to be considered, depending on the location of the



ordinary stiffener under consideration and the type of compartments adjacent to it, in accordance with Ch 5, Sec 1, [2.4].

Ordinary stiffeners located on platings which constitute the boundary of compartments not intended to carry liquids (excluding those on bottom and side shell platings) are to be subjected to the lateral pressure in flooding conditions.

The wave lateral loads and hull girder loads are to be calculated in the mutually exclusive load cases "a", "b", "c" and "d" in Ch 5, Sec 4.

### 3.3.2 Lateral pressure in intact conditions

The lateral pressure in intact conditions is constituted by still water pressure and wave pressure.

Still water pressure ( $p_s$ ) includes:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water internal pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Wave pressure ( $p_w$ ) includes:

- the wave pressure, defined in Ch 5, Sec 5, [2] for each load case "a", "b", "c" and "d"
- the inertial pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast, and for each load case "a", "b", "c" and "d"
- the dynamic pressures, according to the criteria in Ch 5, Sec 6, [2].

Sloshing and impact pressures are to be applied to ordinary stiffeners of tank structures, when such tanks are partly filled and if a risk of resonance exists (see Ch 5, Sec 6, [2]).

### 3.3.3 Lateral pressure in flooding conditions

The lateral pressure in flooding conditions is constituted by the still water pressure  $p_{sf}$  and wave pressure  $p_{wf}$  defined in Ch 5, Sec 6, [9].

### 3.3.4 Lateral pressure in testing conditions

The lateral pressure in testing conditions is taken equal to:

- $p_{st} - p_s$  for bottom shell plating and side shell plating
- $p_{st}$  otherwise,

where  $p_s$  is the still water sea pressure defined in Ch 5, Sec 5, [1.1.1] for the draught  $T_1$  at which the testing is carried out.

If the draught  $T_1$  is not defined by the Designer, it may be taken equal to the light ballast draught  $T_B$  defined in Ch 5, Sec 1, [2.4.3].

### 3.3.5 Wheeled forces

The wheeled force applied by one wheel is constituted by still water force and inertial force:

- Still water force is the vertical force ( $F_s$ ) defined in Ch 5, Sec 6, [6.1]
- Inertial force is the vertical force ( $F_{wz}$ ) defined in Ch 5, Sec 6, [6.1], for load case "b".

### 3.3.6 Hull girder normal stresses

The hull girder normal stresses to be considered for the yielding check of ordinary stiffeners are obtained, in  $N/mm^2$ , from the following formulae:

- for longitudinal stiffeners contributing to the hull girder longitudinal strength and subjected to lateral pressure:

$$\sigma_{x1} = \gamma_{s1} \sigma_{s1} + \gamma_{w1} (C_{FV} \sigma_{WV1} + C_{FH} \sigma_{WH1} + C_{F\Omega} \sigma_{\Omega})$$

to be taken not less than 60/k

- for longitudinal stiffeners contributing to the hull girder longitudinal strength and subjected to wheeled loads:

$$\sigma_{x1,wh} = \max (\sigma_{x1H}; \sigma_{x1S})$$

to be taken not less than 60/k

- for longitudinal stiffeners not contributing to the hull girder longitudinal strength:

$$\sigma_{x1} = 0$$

- for transverse stiffeners:

$$\sigma_{x1} = 0$$

where:

$\sigma_{s1}$ ,  $\sigma_{WV1}$ ,  $\sigma_{WH1}$ : Hull girder normal stresses, in  $N/mm^2$ , defined in Tab 2

$\sigma_{\Omega}$ : Absolute value of the warping stress, in  $N/mm^2$ , induced by the torque 0,625  $M_{WT}$  and obtained through direct calculation analyses based on a structural model in accordance with Ch 6, Sec 1, [2.6]

$\sigma_{x1H}$ ,  $\sigma_{x1S}$ : Hull girder normal stresses, in  $N/mm^2$ , respectively in hogging and in sagging, defined in Tab 3

$C_{FV}$ ,  $C_{FH}$ ,  $C_{F\Omega}$ : Combination factors defined in Tab 4.

## 3.4 Normal and shear stresses due to lateral pressure in intact conditions

### 3.4.1 General

Normal and shear stresses, induced by lateral pressures, in ordinary stiffeners are to be obtained from the formulae in:

- [3.4.2] in the case of single span longitudinal and transverse stiffeners
- [3.4.3] in the case of single span vertical stiffeners
- [3.4.4] in the case of multispans stiffeners.

### 3.4.2 Single span longitudinal and transverse ordinary stiffeners

The maximum normal stress  $\sigma$  and shear stress  $\tau$  are to be obtained, in  $N/mm^2$ , from the following formulae:

$$\sigma = \beta_b \frac{\gamma_{s2} p_s + \gamma_{w2} p_w}{12 w} \left( 1 - \frac{s}{2\ell} \right) s \ell^2 10^3 + \sigma_{x1}$$

$$\tau = 5 \beta_s \frac{\gamma_{s2} p_s + \gamma_{w2} p_w}{A_{sh}} \left( 1 - \frac{s}{2\ell} \right) s \ell$$

where:

$\beta_b$ ;  $\beta_s$ : Coefficients defined in Tab 5.

Table 2 : Hull girder normal stresses - Ordinary stiffeners subjected to lateral pressure

| Condition  | $\sigma_{S1}$ , in N/mm <sup>2</sup> (1)  | $\sigma_{WV1}$ , in N/mm <sup>2</sup>   | $\sigma_{WH1}$ , in N/mm <sup>2</sup>               |
|--|---|---|---|
| Lateral pressure applied on the side opposite to the ordinary stiffener, with respect to the plating: <ul style="list-style-type: none"> <li><math>z \geq N</math></li> <li><math>z &lt; N</math></li> </ul> | $\left  \frac{M_{SW,S}}{I_Y} (z - N) \right  10^{-3}$ $\left  \frac{M_{SW,H}}{I_Y} (z - N) \right  10^{-3}$ | $\left  \frac{0,625 F_D M_{WV,S}}{I_Y} (z - N) \right  10^{-3}$ $\left  \frac{0,625 M_{WV,H}}{I_Y} (z - N) \right  10^{-3}$ | $\left  \frac{0,625 M_{WH}}{I_z} y \right  10^{-3}$ |
| Lateral pressure applied on the same side as the ordinary stiffener: <ul style="list-style-type: none"> <li><math>z \geq N</math></li> <li><math>z &lt; N</math></li> </ul>                                  | $\left  \frac{M_{SW,H}}{I_Y} (z - N) \right  10^{-3}$ $\left  \frac{M_{SW,S}}{I_Y} (z - N) \right  10^{-3}$ | $\left  \frac{0,625 M_{WV,H}}{I_Y} (z - N) \right  10^{-3}$ $\left  \frac{0,625 F_D M_{WV,S}}{I_Y} (z - N) \right  10^{-3}$ |   |
| (1) When the ship in still water is always in hogging condition, $M_{SW,S}$ is to be taken equal to 0.<br><b>Note 1:</b><br>$F_D$ : Coefficient defined in Ch 5, Sec 2, [4].                                 |   |   |   |

Table 3 : Hull girder normal stresses - Ordinary stiffeners subjected to wheeled loads

| Condition  | Hull girder normal stresses, in N/mm <sup>2</sup>   |
|--|---|
| • Hogging  | $\sigma_{X1H} = \left  \gamma_{S1} \frac{M_{SW,H}}{I_Y} (z - N) 10^{-3} + \gamma_{W1} \left( C_{FV} \frac{0,625 M_{WV,H}}{I_Y} (z - N) 10^{-3} + C_{FH} \frac{0,625 M_{WH}}{I_Z} y 10^{-3} + C_{F\Omega} \sigma_{\Omega} \right) \right $     |
| • Sagging (1)  | $\sigma_{X1S} = \left  \gamma_{S1} \frac{M_{SW,S}}{I_Y} (z - N) 10^{-3} + \gamma_{W1} \left( C_{FV} \frac{0,625 F_D M_{WV,S}}{I_Y} (z - N) 10^{-3} + C_{FH} \frac{0,625 M_{WH}}{I_Z} y 10^{-3} + C_{F\Omega} \sigma_{\Omega} \right) \right $ |
| (1) When the ship in still water is always in hogging condition, $M_{SW,S}$ is to be taken equal to 0.<br><b>Note 1:</b><br>$F_D$ : Coefficient defined in Ch 5, Sec 2, [4]. |   |

Table 5 : Coefficients  $\beta_b$  and  $\beta_s$

| Load case | $C_{FV}$ | $C_{FH}$ | $C_{F\Omega}$ |
|-----------|----------|----------|---------------|
| "a"       | 1,0      | 0        | 0             |
| "b"       | 1,0      | 0        | 0             |
| "c"       | 0,4      | 1,0      | 1,0           |
| "d"       | 0,4      | 1,0      | 0             |

| Brackets at ends | Bracket lengths         | $\beta_b$  | $\beta_s$   |
|------------------|-------------------------|--|---|
| 0                | —                       | 1  | 1   |
| 1                | $\ell_b$                | $\left( 1 - \frac{\ell_b}{2\ell} \right)^2$                              | $1 - \frac{\ell_b}{2\ell}$                              |
| 2                | $\ell_{b1} ; \ell_{b2}$ | $\left( 1 - \frac{\ell_{b1}}{2\ell} - \frac{\ell_{b2}}{2\ell} \right)^2$ | $1 - \frac{\ell_{b1}}{2\ell} - \frac{\ell_{b2}}{2\ell}$ |

3.4.3 Single span vertical ordinary stiffeners

The maximum normal stress  $\sigma$  and shear stress  $\tau$  are to be obtained, in N/mm<sup>2</sup>, from the following formulae:

$$\sigma = \lambda_b \beta_b \frac{\gamma_{S2} p_s + \gamma_{W2} p_w}{12 w} \left( 1 - \frac{s}{2\ell} \right) s \ell^2 10^3$$

$$\tau = 5 \lambda_s \beta_s \frac{\gamma_{S2} p_s + \gamma_{W2} p_w}{A_{Sh}} \left( 1 - \frac{s}{2\ell} \right) s \ell$$

where:

$\beta_b, \beta_s$  : Coefficients defined in [3.4.2]

$\lambda_b$  : Coefficient taken equal to the greater of the following values:

$$\lambda_b = 1 + 0,2 \frac{\gamma_{S2} (p_{sd} - p_{su}) + \gamma_{W2} (p_{wd} - p_{wu})}{\gamma_{S2} (p_{sd} + p_{su}) + \gamma_{W2} (p_{wd} + p_{wu})}$$

$$\lambda_b = 1 - 0,2 \frac{\gamma_{S2} (p_{sd} - p_{su}) + \gamma_{W2} (p_{wd} - p_{wu})}{\gamma_{S2} (p_{sd} + p_{su}) + \gamma_{W2} (p_{wd} + p_{wu})}$$

$\lambda_s$  : Coefficient taken equal to the greater of the following values:

$$\lambda_s = 1 + 0,4 \frac{\gamma_{S2} (p_{sd} - p_{su}) + \gamma_{W2} (p_{wd} - p_{wu})}{\gamma_{S2} (p_{sd} + p_{su}) + \gamma_{W2} (p_{wd} + p_{wu})}$$

$$\lambda_s = 1 - 0,4 \frac{\gamma_{S2} (p_{sd} - p_{su}) + \gamma_{W2} (p_{wd} - p_{wu})}{\gamma_{S2} (p_{sd} + p_{su}) + \gamma_{W2} (p_{wd} + p_{wu})}$$

- $p_{sd}$  : Still water pressure, in  $\text{kN/m}^2$ , at the lower end of the ordinary stiffener considered
- $p_{su}$  : Still water pressure, in  $\text{kN/m}^2$ , at the upper end of the ordinary stiffener considered
- $p_{wd}$  : Wave pressure, in  $\text{kN/m}^2$ , at the lower end of the ordinary stiffener considered
- $p_{wu}$  : Wave pressure, in  $\text{kN/m}^2$ , at the upper end of the ordinary stiffener considered.

3.4.4 Multispan ordinary stiffeners

The maximum normal stress  $\sigma$  and shear stress  $\tau$  in a multi-span ordinary stiffener are to be determined by a direct calculation taking into account:

- the distribution of still water and wave pressure and forces, to be determined on the basis of the criteria specified in Ch 5, Sec 5 and Ch 5, Sec 6
- the number and position of intermediate supports (decks, girders, etc.)
- the condition of fixity at the ends of the stiffener and at intermediate supports
- the geometrical characteristics of the stiffener on the intermediate spans.

3.5 Normal and shear stresses due to wheeled loads

3.5.1 General

Normal and shear stresses, induced by the wheeled loads, in ordinary stiffeners are to be obtained from the formulae in:

- [3.5.2] in the case of single span longitudinal and transverse stiffeners
- [3.5.3] in the case of multispan stiffeners.

3.5.2 Single span longitudinal and transverse ordinary stiffeners subjected to wheeled loads

The maximum normal stress  $\sigma$  and shear stress  $\tau$  are to be obtained, in  $\text{N/mm}^2$ , from the following formulae:

$$\sigma = \alpha_w K_s \frac{P_0 \ell}{6W} 10^3 + \sigma_{x1, wh}$$

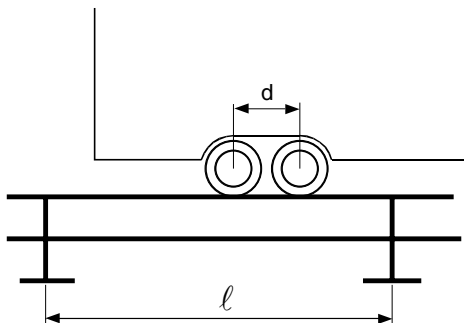
$$\tau = \alpha_w K_T \frac{10P_0}{A_{sh}}$$

where:

$P_0$  : Wheeled force, in  $\text{kN}$ , taken equal to:

$$P_0 = \gamma_{s2} F_s + \gamma_{w2} F_{w,z}$$

Figure 4 : Wheeled load on stiffeners - Double axles



- $\alpha_w$  : Coefficient taking account of the number of wheels per axle considered as acting on the stiffener, defined in Tab 6
- $K_s, K_T$  : Coefficients taking account of the number of axles considered as acting on the stiffener, defined in Tab 7.

Table 6 : Wheeled loads - Coefficient  $\alpha_w$

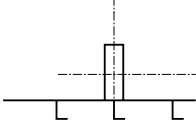
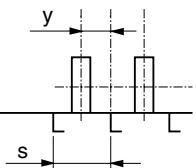
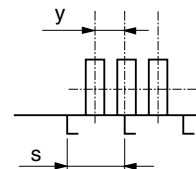
| Configuration   | $\alpha_w$                      |
|---|---------------------------------|
| Single wheel<br>  | 1                               |
| Double wheels<br>  | $2\left(1 - \frac{y}{s}\right)$ |
| Triple wheels<br>   | $3 - 2\frac{y}{s}$              |
| Note 1:<br>y : Distance, in m, from the external wheel of a group of wheels to the stiffener under consideration, to be taken equal to the distance from the external wheel to the centre of the group of wheels. |                                 |

Table 7 : Wheeled loads - Coefficients  $K_s$  and  $K_T$

| Configuration   |             |   |
|---|-------------|---|
|   | Single axle | Double axles  |
| $K_s$   | 1           | <ul style="list-style-type: none"><li>if <math>d &lt; 2\ell/3</math><br/><math display="block">\frac{43}{18} - \frac{7d}{4\ell} - \frac{1}{8} \frac{d^2}{\ell^2} + \frac{9}{16} \frac{d^3}{\ell^3}</math></li><li>if <math>d \geq 2\ell/3</math><br/><math display="block">\frac{9}{4} + \frac{3d}{8\ell} - \frac{3}{2} \frac{d^2}{\ell^2}</math></li></ul> |
| $K_T$   | 1           | $2 - 0,5 \frac{d}{\ell} - 1,5 \frac{d^2}{\ell^2} + \frac{d^3}{\ell^3}$  |
| Note 1:<br>d : Distance, in m, between two axles (see Fig 4). |             |   |

### 3.5.3 Multispan ordinary stiffeners subjected to wheeled loads

The maximum normal stress  $\sigma$  and shear stress  $\tau$  in a multi-span ordinary stiffener are to be determined by a direct calculation taking into account:

- the distribution of still water forces and inertial forces applying on the stiffener, to be determined according to [3.3.5]
- the number and position of intermediate supports (girders, bulkheads, etc)
- the condition of fixity at the ends of the stiffener and at intermediate supports
- the geometrical characteristics of the stiffener on the intermediate spans.

## 3.6 Checking criteria

### 3.6.1 General

It is to be checked that the normal stress  $\sigma$  and the shear stress  $\tau$ , calculated according to [3.4] and [3.5], are in compliance with the following formulae:

$$\frac{R_y}{\gamma_R \gamma_m} \geq \sigma$$

$$0,5 \frac{R_y}{\gamma_R \gamma_m} \geq \tau$$

## 3.7 Net section modulus and net shear sectional area of ordinary stiffeners, complying with the checking criteria

### 3.7.1 General

The requirements in [3.7.3] and [3.7.4] provide the minimum net section modulus and net shear sectional area of single span ordinary stiffeners subjected to lateral pressure in intact conditions, complying with the checking criteria indicated in [3.6].

The requirements in [3.7.5] provide the minimum net section modulus and net shear sectional area of single span ordinary stiffeners subjected to wheeled loads, complying with the checking criteria indicated in [3.6].

The requirements in [3.7.6] provide the minimum net section modulus and net shear sectional area of multispan ordinary stiffeners subjected to lateral pressure in intact condition or to wheeled loads, complying with the checking criteria indicated in [3.6].

### 3.7.2 Groups of equal ordinary stiffeners

Where a group of equal ordinary stiffeners is fitted, it is acceptable that the minimum net section modulus in [3.7.1] is calculated as the average of the values required for all the stiffeners of the same group, but this average is to be taken not less than 90% of the maximum required value.

The same applies for the minimum net shear sectional area.

### 3.7.3 Single span longitudinal and transverse ordinary stiffeners subjected to lateral pressure

The net section modulus  $w$ , in  $\text{cm}^3$ , and the net shear sectional area  $A_{sh}$ , in  $\text{cm}^2$ , of longitudinal or transverse ordi-

nary stiffeners subjected to lateral pressure are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{s2} P_s + \gamma_{w2} P_w}{12 (R_y - \gamma_R \gamma_m \sigma_{x1})} \left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{s2} P_s + \gamma_{w2} P_w}{R_y} \left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

$\beta_b, \beta_s$  : Coefficients defined in [3.4.2].

### 3.7.4 Single span vertical ordinary stiffeners subjected to lateral pressure

The net section modulus  $w$ , in  $\text{cm}^3$ , and the net shear sectional area  $A_{sh}$ , in  $\text{cm}^2$ , of vertical ordinary stiffeners subjected to lateral pressure are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \lambda_b \beta_b \frac{\gamma_{s2} P_s + \gamma_{w2} P_w}{12 R_y} \left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{sh} = 10 \gamma_R \gamma_m \lambda_s \beta_s \frac{\gamma_{s2} P_s + \gamma_{w2} P_w}{R_y} \left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

$\beta_b, \beta_s$  : Coefficients defined in [3.4.2]

$\lambda_b, \lambda_s$  : Coefficients defined in [3.4.3].

### 3.7.5 Single span ordinary stiffeners subjected to wheeled loads

The net section modulus  $w$ , in  $\text{cm}^3$ , and the net shear sectional area  $A_{sh}$ , in  $\text{cm}^2$ , of ordinary stiffeners subjected to wheeled loads are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \frac{\alpha_w K_s P_0 \ell}{6 (R_y - \gamma_R \gamma_m \sigma_{x1, wh})} 10^3$$

$$A_{sh} = 20 \gamma_R \gamma_m \frac{\alpha_w K_T P_0}{R_y}$$

where:

$P_0$  : Wheeled force, in kN, defined in [3.5.2]

$\alpha_w, K_s, K_T$ : Coefficients defined in [3.5.2].

### 3.7.6 Multispan ordinary stiffeners

The minimum net section modulus and the net shear sectional area of multispan ordinary stiffeners are to be obtained from [3.4.4] or [3.5.3], as applicable, taking account of the checking criteria indicated in [3.6].

## 3.8 Net section modulus and net shear sectional area of ordinary stiffeners subjected to lateral pressure in flooding conditions

### 3.8.1 General

The requirements in [3.8.3] to [3.8.5] provide the minimum net section modulus and net shear sectional area of ordinary stiffeners located on platings which constitute the boundary of compartments not intended to carry liquids (excluding stiffeners on bottom and side shell platings) in flooding conditions.

### 3.8.2 Groups of equal ordinary stiffeners

Where a group of equal ordinary stiffeners is fitted, it is acceptable that the minimum net section modulus in [3.8.1] is calculated as the average of the values required for all the stiffeners of the same group, but this average is to be taken not less than 90% of the maximum required value.

The same applies for the minimum net shear sectional area.

### 3.8.3 Single span longitudinal and transverse ordinary stiffeners

The net section modulus  $w$ , in  $\text{cm}^3$ , and the net shear sectional area  $A_{Sh}$ , in  $\text{cm}^2$ , of longitudinal or transverse ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{12(R_y - \gamma_R \gamma_m \sigma_{X1})} \left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{R_y} \left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

$\beta_b, \beta_s$  : Coefficients defined in [3.4.2].

### 3.8.4 Single span vertical ordinary stiffeners

The net section modulus  $w$ , in  $\text{cm}^3$ , and the net shear sectional area  $A_{Sh}$ , in  $\text{cm}^2$ , of vertical ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \lambda_b \beta_b \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{12 R_y} \left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \lambda_s \beta_s \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{R_y} \left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

$\beta_b, \beta_s$  : Coefficients defined in [3.4.2]

$\lambda_b$  : Coefficient taken equal to the greater of the following values:

$$\lambda_b = 1 + 0,2 \frac{\gamma_{S2}(p_{SFd} - p_{SFu}) + \gamma_{W2}(p_{WFd} - p_{WFu})}{\gamma_{S2}(p_{SFd} + p_{SFu}) + \gamma_{W2}(p_{WFd} + p_{WFu})}$$

$$\lambda_b = 1 - 0,2 \frac{\gamma_{S2}(p_{SFd} - p_{SFu}) + \gamma_{W2}(p_{WFd} - p_{WFu})}{\gamma_{S2}(p_{SFd} + p_{SFu}) + \gamma_{W2}(p_{WFd} + p_{WFu})}$$

$\lambda_s$  : Coefficient taken equal to the greater of the following values:

$$\lambda_s = 1 + 0,4 \frac{\gamma_{S2}(p_{SFd} - p_{SFu}) + \gamma_{W2}(p_{WFd} - p_{WFu})}{\gamma_{S2}(p_{SFd} + p_{SFu}) + \gamma_{W2}(p_{WFd} + p_{WFu})}$$

$$\lambda_s = 1 - 0,4 \frac{\gamma_{S2}(p_{SFd} - p_{SFu}) + \gamma_{W2}(p_{WFd} - p_{WFu})}{\gamma_{S2}(p_{SFd} + p_{SFu}) + \gamma_{W2}(p_{WFd} + p_{WFu})}$$

$p_{SFd}$  : Still water pressure, in  $\text{kN/m}^2$ , in flooding conditions, at the lower end of the ordinary stiffener considered

$p_{SFu}$  : Still water pressure, in  $\text{kN/m}^2$ , in flooding conditions, at the upper end of the ordinary stiffener considered

$p_{WFd}$  : Wave pressure, in  $\text{kN/m}^2$ , in flooding conditions, at the lower end of the ordinary stiffener considered

$p_{WFu}$  : Wave pressure, in  $\text{kN/m}^2$ , in flooding conditions, at the upper end of the ordinary stiffener considered.

### 3.8.5 Multispan ordinary stiffeners

The minimum net section modulus and the net shear sectional area of multispan ordinary stiffeners are to be obtained from [3.4.4], considering the still water pressure  $p_{SF}$  and the wave pressure  $p_{WF}$  in flooding conditions, and taking account of the checking criteria indicated in [3.6].

## 3.9 Net section modulus and net shear sectional area of ordinary stiffeners subjected to lateral pressure in testing conditions

### 3.9.1 General

The requirements in [3.9.3] to [3.9.5] provide the minimum net section modulus and net shear sectional area of ordinary stiffeners of compartments subject to testing conditions.

### 3.9.2 Groups of equal ordinary stiffeners

Where a group of equal ordinary stiffeners is fitted, it is acceptable that the minimum net section modulus in [3.9.1] is calculated as the average of the values required for all the stiffeners of the same group, but this average is to be taken not less than 90% of the maximum required value.

The same applies for the minimum net shear sectional area.

### 3.9.3 Single span longitudinal and transverse ordinary stiffeners

The net section modulus  $w$ , in  $\text{cm}^3$ , and the net shear sectional area  $A_{Sh}$ , in  $\text{cm}^2$ , of longitudinal or transverse ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{S2} p_{ST}}{12 R_y} \left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2} p_{ST}}{R_y} \left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

$\beta_b, \beta_s$  : Coefficients defined in [3.4.2].

### 3.9.4 Single span vertical ordinary stiffeners

The net section modulus  $w$ , in  $\text{cm}^3$ , and the net shear sectional area  $A_{Sh}$ , in  $\text{cm}^2$ , of vertical ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \lambda_b \beta_b \frac{\gamma_{S2} p_{ST}}{12 R_y} \left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \lambda_s \beta_s \frac{\gamma_{S2} p_{ST}}{R_y} \left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

$\beta_b, \beta_s$  : Coefficients defined in [3.4.2]

$\lambda_b$  : Coefficient taken equal to the greater of the following values:

$$\lambda_b = 1 + 0,2 \frac{p_{STd} - p_{STu}}{p_{STd} + p_{STu}}$$

$$\lambda_b = 1 - 0,2 \frac{p_{STd} - p_{STu}}{p_{STd} + p_{STu}}$$

$\lambda_s$  : Coefficient taken equal to the greater of the following values:

$$\lambda_s = 1 + 0,4 \frac{p_{STd} - p_{STu}}{p_{STd} + p_{STu}}$$

$$\lambda_s = 1 - 0,4 \frac{p_{STd} - p_{STu}}{p_{STd} + p_{STu}}$$

$p_{STd}$  : Still water pressure, in kN/m<sup>2</sup>, in testing conditions, at the lower end of the ordinary stiffener considered

$p_{STu}$  : Still water pressure, in kN/m<sup>2</sup>, in testing conditions, at the upper end of the ordinary stiffener considered.

3.9.5 Multispan ordinary stiffeners

The minimum net section modulus and the net shear sectional area of multispan ordinary stiffeners are to be obtained from [3.4.4], considering the pressure in testing conditions and taking account of the checking criteria indicated in [3.6].

4 Buckling check

4.1 Width of attached plating

4.1.1 The width of the attached plating to be considered for the buckling check of ordinary stiffeners is to be obtained, in m, from the following formulae:

- where no local buckling occurs on the attached plating (see Ch 7, Sec 1, [5.4.1]):  
 $b_e = s$
- where local buckling occurs on the attached plating (see Ch 7, Sec 1, [5.4.1]):

$$b_e = \left( \frac{2,25}{\beta_e} - \frac{1,25}{\beta_e^2} \right) s$$

to be taken not greater than s

where:

$$\beta_e = \frac{s}{t_p} \sqrt{\frac{\sigma_b}{E}} 10^3$$

$\sigma_b$  : Compression stress  $\sigma_x$  or  $\sigma_y$ , in N/mm<sup>2</sup>, acting on the plate panel, defined in Ch 7, Sec 1, [5.2.4], according to the direction x or y considered.

4.2 Load model

4.2.1 Sign convention for normal stresses

The sign convention for normal stresses is as follows:

- tension: positive
- compression: negative.

4.2.2 Hull girder compression normal stresses

The hull girder compression normal stresses to be considered for the buckling check of ordinary stiffeners contributing to the hull girder longitudinal strength are obtained, in N/mm<sup>2</sup>, from the following formula:

$$\sigma_{x1} = \gamma_{s1} \sigma_{s1} + \gamma_{w1} (C_{FV} \sigma_{WV1} + C_{FH} \sigma_{WH1} + C_{F\Omega} \sigma_{\Omega})$$

where:

$\sigma_{s1}$ ,  $\sigma_{WV1}$ ,  $\sigma_{WH1}$  : Hull girder normal stresses, in N/mm<sup>2</sup>, defined in Tab 8

$\sigma_{\Omega}$  : Compression warping stress, in N/mm<sup>2</sup>, induced by the torque 0,625M<sub>WT</sub> and obtained through direct calculation analyses based on a structural model in accordance with Ch 6, Sec 1, [2.6]

$C_{FV}$ ,  $C_{FH}$ ,  $C_{F\Omega}$  : Combination factors defined in Tab 4.

For longitudinal stiffeners,  $\sigma_{x1}$  is to be taken as the maximum compression stress on the stiffener considered.

In no case may  $\sigma_{x1}$  be taken less than 30/k N/mm<sup>2</sup>.

When the ship in still water is always in hogging condition,  $\sigma_{x1}$  may be evaluated by means of direct calculations when justified on the basis of the ship's characteristics and intended service. The calculations are to be submitted to the Society for approval.

Where deemed necessary, the buckling check is to be carried out in harbour conditions by considering a reduced wave bending moment equal to 0,1M<sub>WV</sub> given in Ch 5, Sec 2, [3.1]

4.2.3 Combined hull girder and local compression normal stresses

The combined compression normal stresses to be considered for the buckling check of ordinary stiffeners are to take into account the hull girder stresses and the local stresses resulting from the bending of the primary supporting members. These local stresses are to be obtained from a direct structural analysis using the design loads as given in Part B, Chapter 5.

Table 8 : Hull girder normal compression stresses

| Condition   | $\sigma_{s1}$ in N/mm <sup>2</sup> (1) | $\sigma_{WV1}$ in N/mm <sup>2</sup>           | $\sigma_{WH1}$ in N/mm <sup>2</sup>             |
|---|--|---|---|
| $z \geq N$  | $\frac{M_{SW,S}}{I_y}(z - N)10^{-3}$   | $\frac{0,625F_D M_{WV,S}}{I_y}(z - N)10^{-3}$ | $-\left \frac{0,625M_{WH}}{I_z}y\right 10^{-3}$ |
| $z < N$   | $\frac{M_{SW,H}}{I_y}(z - N)10^{-3}$   | $\frac{0,625M_{WV,H}}{I_y}(z - N)10^{-3}$     |   |
| (1) When the ship in still water is always in hogging condition, $\sigma_{s1}$ for $z \geq N$ is to be obtained, in N/mm <sup>2</sup> , from the following formula, unless $\sigma_{x1}$ is evaluated by means of direct calculations (see [4.2.2]):<br>$\sigma_{s1} = \frac{M_{SW,Hmin}}{I_y}(z - N)10^{-3}$ |  |   |   |
| <b>Note 1:</b><br>$F_D$ : Coefficient defined in Ch 5, Sec 2, [4].  |  |   |   |

With respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4.1], the combined stresses in x and y direction are obtained, in N/mm<sup>2</sup>, from the following formulae:

$$\sigma_x = \sigma_{x1} + \gamma_{s2} \sigma_{x2, s} + \gamma_{w2} \sigma_{x2, w}$$

$$\sigma_y = \gamma_{s2} \sigma_{y2, s} + \gamma_{w2} \sigma_{y2, w}$$

where:

$\sigma_{x1}$  : Compression normal stress, in N/mm<sup>2</sup>, induced by the hull girder still water and wave loads, defined in [4.2.2]

$\sigma_{x2, s}, \sigma_{y2, s}$ : Compression normal stress in x and y direction, respectively, in N/mm<sup>2</sup>, induced by the local bending of the primary supporting members and obtained from a direct structural analysis using the still water design loads as given in Part B, Chapter 5

$\sigma_{x2, w}, \sigma_{y2, w}$ : Compression normal stress in x and y direction, respectively, in N/mm<sup>2</sup>, induced by the local bending of the primary supporting members and obtained from a direct structural analysis using the wave design loads as given in Part B, Chapter 5.

### 4.3 Critical stress

#### 4.3.1 General

The critical buckling stress is to be obtained, in N/mm<sup>2</sup>, from the following formulae:

$$\sigma_c = \sigma_E \quad \text{for } \sigma_E \leq \frac{R_{eH,S}}{2}$$

$$\sigma_c = R_{eH,S} \left( 1 - \frac{R_{eH,S}}{4\sigma_E} \right) \quad \text{for } \sigma_E > \frac{R_{eH,S}}{2}$$

where:

$$\sigma_E = \min(\sigma_{E1}, \sigma_{E2}, \sigma_{E3})$$

$\sigma_{E1}$  : Euler column buckling stress, in N/mm<sup>2</sup>, given in [4.3.2]

$\sigma_{E2}$  : Euler torsional buckling stress, in N/mm<sup>2</sup>, given in [4.3.3]

$\sigma_{E3}$  : Euler web buckling stress, in N/mm<sup>2</sup>, given in [4.3.4].

#### 4.3.2 Column buckling of axially loaded stiffeners

The Euler column buckling stress is obtained, in N/mm<sup>2</sup>, from the following formula:

$$\sigma_E = \pi^2 E \frac{I_e}{A_e \ell^2} 10^{-4}$$

#### 4.3.3 Torsional buckling of axially loaded stiffeners

The Euler torsional buckling stresses is obtained, in N/mm<sup>2</sup>, from the following formula:

$$\sigma_E = \frac{\pi^2 E I_w}{10^4 I_p \ell^2} \left( \frac{K_C}{m^2} + m^2 \right) + 0,385 E \frac{I}{I_p}$$

where:

$I_w$  : Net sectorial moment of inertia, in cm<sup>6</sup>, of the stiffener about its connection to the attached plating:

- for flat bars:

$$I_w = \frac{h_w^3 t_w^3}{36} 10^{-6}$$

- for T-sections:

$$I_w = \frac{t_f b_f^3 h_w^2}{12} 10^{-6}$$

- for angles and bulb sections:

$$I_w = \frac{b_f^3 h_w^2}{12(b_f + h_w)^2} [t_f b_f^2 + 2b_f h_w + 4h_w^2 + 3t_w b_f h_w] 10^{-6}$$

$I_p$  : Net polar moment of inertia, in cm<sup>4</sup>, of the stiffener about its connection to the attached plating:

- for flat bars:

$$I_p = \frac{h_w^3 t_w^3}{3} 10^{-4}$$

- for stiffeners with face plate:

$$I_p = \left( \frac{h_w^3 t_w^3}{3} + h_w^2 b_f t_f \right) 10^{-4}$$

$I_t$  : St. Venant's net moment of inertia, in cm<sup>4</sup>, of the stiffener without attached plating:

- for flat bars:

$$I_t = \frac{h_w t_w^3}{3} 10^{-4}$$

- for stiffeners with face plate:

$$I_t = \frac{1}{3} \left[ h_w t_w^3 + b_f t_f^3 \left( 1 - 0,63 \frac{t_f}{b_f} \right) \right] 10^{-4}$$

$m$  : Number of half waves, to be taken equal to the integer number such that (see also Tab 9):

$$m^2(m-1)^2 \leq K_C < m^2(m+1)^2$$

$$K_C = \frac{C_0 \ell^4}{\pi^4 E I_w} 10^6$$

$C_0$  : Spring stiffness of the attached plating:

$$C_0 = \frac{E t_p^3}{2,73 s} 10^{-3}$$

**Table 9 : Torsional buckling of axially loaded stiffeners - Number m of half waves**

|       |                  |                   |                     |
|-------|------------------|-------------------|---------------------|
| $K_C$ | $0 \leq K_C < 4$ | $4 \leq K_C < 36$ | $36 \leq K_C < 144$ |
| $m$   | 1                | 2                 | 3                   |

#### 4.3.4 Web buckling of axially loaded stiffeners

The Euler buckling stress of the stiffener web is obtained, in N/mm<sup>2</sup>, from the following formulae:

- for flat bars:

$$\sigma_E = 16 \left( \frac{t_w}{h_w} \right)^2 10^4$$

- for stiffeners with face plate:

$$\sigma_E = 78 \left( \frac{t_w}{h_w} \right)^2 10^4$$

## 4.4 Checking criteria

### 4.4.1 Stiffeners parallel to the direction of compression

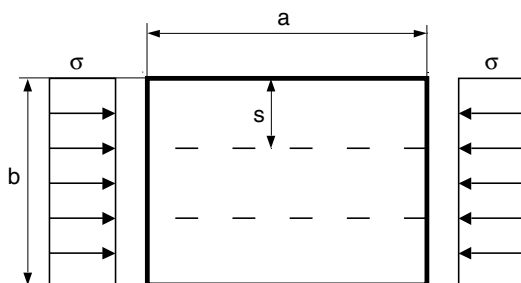
The critical buckling stress of the ordinary stiffener is to comply with the following formula:

$$\frac{\sigma_c}{\gamma_R \gamma_m} \geq |\sigma_b|$$

where:

- $\sigma_c$  : Critical buckling stress, in N/mm<sup>2</sup>, as calculated in [4.3.1]
- $\sigma_b$  : Compression stress  $\sigma_{xb}$  or  $\sigma_{yb}$ , in N/mm<sup>2</sup>, in the stiffener, as calculated in [4.2.2] or [4.2.3].

**Figure 5 : Buckling of stiffeners parallel to the direction of compression**



### 4.4.2 Stiffeners perpendicular to the direction of compression

The net moment of inertia of stiffeners, in cm<sup>4</sup>, is to be not less than the greatest value obtained from the following formulae:

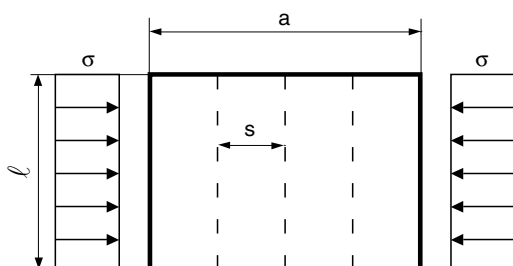
- $I = 360 \ell^2$
- for  $\sigma \leq R_{eH,P} / 2$ :

$$I = \frac{s t_p^3}{485} \left[ \left( \frac{\ell}{s} \right)^4 - 4 \right] (\sigma - \sigma_{E,0})$$

- for  $\sigma > R_{eH,P} / 2$ :

$$I = \frac{s t_p^3}{485} \left[ \left( \frac{\ell}{s} \right)^4 - 4 \right] \left[ \frac{R_{eH,P}}{4 \left( 1 - \frac{\sigma}{R_{eH,P}} \right)} - \sigma_{E,0} \right]$$

**Figure 6 : Buckling of stiffeners perpendicular to the direction of compression**



where:

- $\ell/s$  : Ratio to be taken not less than 1,41
- $\sigma_{E,0}$  : Euler buckling stress, in N/mm<sup>2</sup>, of the unstiffened plate taken equal to:

$$\sigma_{E,0} = \frac{\pi^2 E}{12(1 - \nu^2)} \left( \frac{t_p}{\ell} \right)^2 \epsilon K_{1,0} 10^{-6}$$

- $K_{1,0}$  : Coefficient defined in Ch 7, Sec 1, Tab 8 for:  
 $0 \leq \Psi \leq 1$  and  $\alpha = a / \ell$

- $\epsilon$  : Coefficient defined in Ch 7, Sec 1, [5.3.1]

- $\sigma_{E,1}$  : Euler buckling stress, in N/mm<sup>2</sup>, of the plate panel taken equal to:

$$\sigma_{E,1} = \frac{\pi^2 E}{12(1 - \nu^2)} \left( \frac{t_p}{\ell} \right)^2 \epsilon K_{1,1} 10^{-6}$$

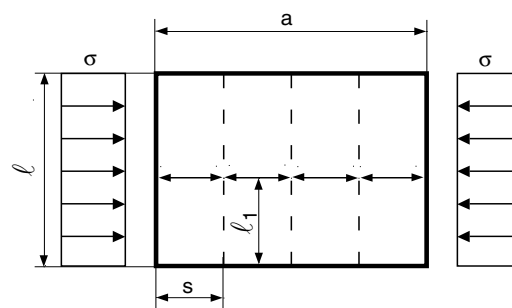
- $K_{1,1}$  : Coefficient defined in Ch 7, Sec 1, Tab 8 for:  
 $0 \leq \Psi \leq 1$  and  $\alpha = s / \ell$ .

Where intercostal stiffeners are fitted, as shown in Fig 7, the check of the moment of inertia of stiffeners perpendicular to the direction of compression is to be carried out with the equivalent net thickness  $t_{eq,net}$ , in mm, obtained from the following formula:

$$t_{eq,net} = \frac{1 + \left( \frac{s}{\ell_1} \right)^2}{1 + \left( \frac{s}{\ell} \right)^2} t_{net}$$

where  $\ell_1$  is to be taken not less than  $s$ .

**Figure 7 : Buckling of stiffeners perpendicular to the direction of compression (intercostal stiffeners)**



## 5 Ultimate strength check of ordinary stiffeners contributing to the hull girder longitudinal strength

### 5.1 Application

**5.1.1** The requirements of this Article apply to ships equal to or greater than 170 m in length. For such ships, the ultimate strength of stiffeners subjected to lateral pressure and to hull girder normal stresses is to be checked.

### 5.2 Width of attached plating

**5.2.1** The width of the attached plating to be considered for the ultimate strength check of ordinary stiffeners is to be obtained, in m, from the following formulae:



- if  $\beta_U \leq 1,25$ :

$b_U = s$

- if  $\beta_U > 1,25$ :

$b_U = \left(\frac{2,25}{\beta_U} - \frac{1,25}{\beta_U^2}\right)s$

where:

$\beta_U = \frac{s}{t_p} \sqrt{\frac{\sigma_{X1E}}{E}} 10^3$

$\sigma_{X1E}$  : Stress defined in [5.4].

Table 10 : Ultimate strength stress

| Symbol      | Resultant load pressure acting on the side opposite to the ordinary stiffener, with respect to the plating, in N/mm <sup>2</sup> | Resultant load pressure acting on the same side as the ordinary stiffener, in N/mm <sup>2</sup> |
|-------------|--|---|
| $\sigma_U$  | $f \frac{A_U}{A_S} \left(1 - \frac{s}{10b_U}\right) R_{eH,P}$  | $R_{eH,S} f$  |
| $f$         | $\frac{\zeta}{2} - \sqrt{\frac{\zeta^2}{4} - \frac{1-\mu}{(1+\eta_p)\lambda_U^2}}$   |   |
| $\zeta$     | $\frac{1-\mu}{1+\eta_p} + \frac{1+\eta_p+\eta}{(1+\eta_p)\lambda_U^2}$   |   |
| $\mu$       | $\frac{125ps\ell^2 d_{p,U}}{R_{eH,P} I_U \left(1 - \frac{s}{10b_U}\right)}$  | $\frac{41,7ps\ell^2 d_{F,S}}{R_{eH,S} I_S}$   |
| $\eta$      | $\left(\delta_0 + \frac{13ps\ell^4}{E_T I_S} 10^4\right) \frac{d_{p,U}}{\rho_U^2}$   | $\left(0,577\delta_0 + \frac{1,5ps\ell^4}{E_T I_S} 10^4\right) \frac{d_{F,S}}{\rho_S^2}$        |
| $\eta_P$    | $d_P A \left(\frac{1}{A_U} - \frac{1}{A_S}\right) \frac{d_{p,U}}{\rho_U^2}$  | 0   |
| $\lambda_U$ | $\frac{31,8\ell}{\rho_U} \sqrt{\frac{R_{eH,P}}{E_T} \left(1 - \frac{s}{10b_U}\right)}$   | $\frac{18,4\ell}{\rho_S} \sqrt{\frac{R_{eH,S}}{E_T}}$   |

**Note 1:**

- $\sigma_{C2}$  : Critical torsional buckling stress, in N/mm<sup>2</sup>, defined in [4.3.1]  
 $d_{p,U}$  : Distance, in cm, between the neutral axis of the cross-section of the stiffener with attached plating of width  $b_U$  and the fibre at half-thickness of the plating  
 $d_{F,S}$  : Distance, in cm, between the neutral axis of the cross-section of the stiffener with attached plating of width  $s$  and the fibre at half-thickness of the face plate of the stiffener  
 $d_P$  : Distance, in cm, between the neutral axis of the ordinary stiffener without attached plating and the fibre at half-thickness of the attached plating  
 $p$  : Lateral pressure acting on the stiffener, equal to:  $p = \gamma_{S2} p_S + \gamma_{W2U} p_W$   
 $\delta_0$  : Pre-deformation, in cm, of the ordinary stiffener, to be assumed, in the absence of more accurate evaluation:  $\delta_0 = 0,2 \ell$   
 $E_T$  : Structural tangent modulus, equal to:

$$E_T = 4E \frac{\sigma_{X1E}}{R_{eH,P}} \left(1 - \frac{\sigma_{X1E}}{R_{eH,P}}\right) \text{ for } \sigma_{X1E} > 0,5 R_{eH,P}$$

$$E_T = E \text{ for } \sigma_{X1E} \leq 0,5 R_{eH,P}$$

- $\sigma_{X1E}$  : Stress to be obtained, in N/mm<sup>2</sup>, from the following formulae:

$$\sigma_{X1E} = \left\{ \frac{-\frac{22,5st_p}{\alpha} + \sqrt{\left(\frac{22,5st_p}{\alpha}\right)^2 + 4A \left[ (A + 10st_p)\sigma_{X1} + \frac{12,5st_p}{\alpha^2} \right]}}{2A} \right\}^2 \text{ if } \alpha > \frac{1,25}{\sqrt{|\sigma_{X1}|}}$$

$$\sigma_{X1E} = \sigma_{X1} \text{ if } \alpha \leq \frac{1,25}{\sqrt{|\sigma_{X1}|}}$$

$\alpha = 1000 \frac{s}{t_p \sqrt{E}}$

- $\sigma_{X1}$  : Compression stress, in N/mm<sup>2</sup>, acting on the stiffener, as defined in [5.3.3].

5.3 Load model

5.3.1 General

The still water and wave lateral pressures induced by the sea and the various types of cargoes and ballast in intact conditions are to be considered, depending on the location of the ordinary stiffener under consideration and the type of compartments adjacent to it, in accordance with Ch 5, Sec 1, [2.4].

The wave lateral pressures and hull girder loads are to be calculated in the mutually exclusive load cases “a”, “b”, “c” and “d” in Ch 5, Sec 4.

5.3.2 Lateral pressure

Lateral pressure is constituted by still water pressure and wave pressure.

Still water pressure ( $p_s$ ) includes:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water internal pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Wave induced pressure ( $p_w$ ) includes:

- the wave pressure, defined in Ch 5, Sec 5, [2] for each load case “a”, “b”, “c” and “d”
- the inertial pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast, and for each load case “a”, “b”, “c” and “d”.

5.3.3 Hull girder compression normal stresses

The hull girder compression normal stresses  $\sigma_{x1}$  to be considered for the ultimate strength check of stiffeners contributing to the longitudinal strength are those given in [4.2.2], where the partial safety factors are those specified in Tab 1 for the ultimate strength check.

5.4 Ultimate strength stress

5.4.1 The ultimate strength stress  $\sigma_U$  is to be obtained, in N/mm<sup>2</sup>, from the formulae in Tab 10, for resultant lateral pressure acting either on the side opposite to the ordinary stiffener, with respect to the plating, or on the same side as the ordinary stiffener.

5.5 Checking criteria

5.5.1 The ultimate strength stress of the ordinary stiffener is to comply with the following formula:

$$\frac{\sigma_U}{\gamma_R \gamma_m} \geq |\sigma_{x1}|$$

where:

- $\sigma_U$  : Ultimate strength stress, in N/mm<sup>2</sup>, as calculated in [5.4.1]
- $\sigma_{x1}$  : Compression stress, in N/mm<sup>2</sup>, as calculated in [5.3.3].

SECTION 3

PRIMARY SUPPORTING MEMBERS

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

- $p_s$

:

Still water pressure, in kN/m<sup>2</sup>, see [3.4.2] and [3.4.4]
- $p_w$

:

Wave pressure, in kN/m<sup>2</sup>, see [3.4.2] and [3.4.4]
- $p_{SF}, p_{WF}$

:

Still water and wave pressures, in kN/m<sup>2</sup>, in flooding conditions, defined in Ch 5, Sec 6, [9]
- $\sigma_{x1}$

:

Hull girder normal stress, in N/mm<sup>2</sup>, defined in [3.4.5]
- $s$

:

Spacing, in m, of primary supporting members
- $\ell$

:

Span, in m, of primary supporting members, measured between the supporting elements, see Ch 4, Sec 3, [4.1]
- $b_p$

:

Width, in m, of the plating attached to the primary supporting member, for the yielding check, defined in Ch 4, Sec 3, [4.2]
- $w$

:

Net section modulus, in cm<sup>3</sup>, of the primary supporting member, with an attached plating of width  $b_p$ , to be calculated as specified in Ch 4, Sec 3, [4.3]
- $A_{sh}$

:

Net shear sectional area, in cm<sup>2</sup>, of the primary supporting member, to be calculated as specified in Ch 4, Sec 3, [4.3]
- $m$

:

Boundary coefficient, to be taken equal to:
  - $m = 10$  in general
  - $m = 12$  for bottom and side primary supporting members
- $I$

:

Net moment of inertia, in cm<sup>4</sup>, of the primary supporting member without attached plating, about its neutral axis parallel to the plating.

1 General

1.1 Application

1.1.1 Analysis criteria

The requirements of this Section apply for the yielding and buckling checks of primary supporting members.

1.1.2 Structural models

Depending on the service notation and structural arrangement, primary structural models are to be modelled as specified in Tab 1.

Table 1 : Selection of structural models

| Service notation   | Ship length, in m  | Calculation model  |
|--|--------------------|--|
| <b>Ro-ro cargo ship</b><br><b>Ro-ro passenger ship</b>   | $L \leq 120$       | Isolated beam model, or three dimensional beam model for grillage or complex arrangement |
|  | $120 < L \leq 200$ | Three dimensional beam model   |
|  | $L > 200$          | Complete ship model  |
| <b>Passenger ship</b><br><b>Container ship</b><br><b>General cargo ship</b> with large deck openings | $L \leq 120$       | Isolated beam model, or three dimensional beam model for grillage or complex arrangement |
|  | $120 < L \leq 170$ | Three dimensional beam model   |
|  | $L > 170$          | Complete ship model  |
| Other ships  | $L \leq 120$       | Isolated beam model, or three dimensional beam model for grillage or complex arrangement |
|  | $120 < L \leq 170$ | Three dimensional beam model   |
|  | $L > 170$          | Three dimensional finite element model   |

1.1.3 Yielding check

The yielding check is to be carried out according to:

- [3] for primary supporting members analysed through isolated beam models
- [4] for primary supporting members analysed through three dimensional beam or finite element models
- [5] for primary supporting members analysed through complete ship models.

1.1.4 Buckling check

The buckling check is to be carried out according to [6], on the basis of the stresses in primary supporting members calculated according to [3], [4] or [5], depending on the structural model adopted.

1.1.5 Minimum net thicknesses

In addition to the above, the scantlings of primary supporting members are to comply with the requirements in [2].

1.2 Analysis documentation

1.2.1 The following documents are to be submitted to the Society for review of the three dimensional beam or finite element structural analyses:

- reference to the calculation program used with identification of the version number and results of the validation text, 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 as required in [6]
- fatigue checks of structural details, as required in Ch 7, Sec 4

- identification of the critical areas, where the results of the checkings exceed 97,5% of the permissible rule criteria in [4.3] or [5.3] and [6].

1.2.2 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.

1.3 Net scantlings

1.3.1 As specified in Ch 4, Sec 2, [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 Ch 4, Sec 2.

1.4 Partial safety factors

1.4.1 The partial safety factors to be considered for checking primary supporting members are specified in:

- Tab 2 for analyses based on isolated beam models
- Tab 3 for analyses based on three dimensional models
- Tab 4 for analyses based on complete ship models.

Table 2 : Primary supporting members analysed through isolated beam models - Partial safety factors

| Partial safety factors covering uncertainties regarding:   | Symbol        | Yielding check                                      |  | Buckling check           |  |
|--|---------------|---|--|--------------------------|--|
|  |               | General (see [3.4] to [3.7])                        | Watertight bulkhead primary supporting members (1) (see [3.8]) | Plate panels (see [6.1]) | Pillars (see [6.2] and [6.3])            |
| Still water hull girder loads  | $\gamma_{s1}$ | 1,00  | 1,00   | 1,00                     | 1,00                                     |
| Wave hull girder loads   | $\gamma_{w1}$ | 1,15  | 1,15   | 1,15                     | 1,15                                     |
| Still water pressure   | $\gamma_{s2}$ | 1,00  | 1,00   | 1,00                     | 1,00                                     |
| Wave pressure  | $\gamma_{w2}$ | 1,20  | 1,05   | 1,20                     | 1,20                                     |
| Material   | $\gamma_m$    | 1,02  | 1,02   | 1,02                     | 1,02                                     |
| Resistance   | $\gamma_R$    | 1,02 in general<br>1,15 for bottom and side girders | 1,02 (2)   | 1,10                     | for [6.2]: see Tab 13<br>for [6.3]: 1,15 |
| (1) Applies also to primary supporting members of bulkheads or inner side which constitute boundary of compartments not intended to carry liquids. |               |   |  |                          |  |
| (2) For primary supporting members of the collision bulkhead, $\gamma_R = 1,25$  |               |   |  |                          |  |

Table 3 : Primary supporting members analysed through three dimensional models - Partial safety factors

| Partial safety factors covering uncertainties regarding:   | Symbol        | Yielding check (see [4]) |  | Buckling check           |  |
|--|---------------|--------------------------|--|--------------------------|--|
|  |               | General                  | Watertight bulkhead primary supporting members (1) | Plate panels (see [6.1]) | Pillars (see [6.2] and [6.3])            |
| Still water hull girder loads  | $\gamma_{s1}$ | 1,00                     | 1,00   | 1,00                     | 1,00                                     |
| Wave hull girder loads   | $\gamma_{w1}$ | 1,05                     | 1,05   | 1,05                     | 1,05                                     |
| Still water pressure   | $\gamma_{s2}$ | 1,00                     | 1,00   | 1,00                     | 1,00                                     |
| Wave pressure  | $\gamma_{w2}$ | 1,10                     | 1,10   | 1,10                     | 1,10                                     |
| Material   | $\gamma_m$    | 1,02                     | 1,02   | 1,02                     | 1,02                                     |
| Resistance   | $\gamma_R$    | defined in Tab 5         | defined in Tab 5                                   | 1,02                     | for [6.2]: see Tab 13<br>for [6.3]: 1,15 |
| (1) Applies also to primary supporting members of bulkheads or inner side which constitute boundary of compartments not intended to carry liquids. |               |                          |  |                          |  |
| Note 1: For primary supporting members of the collision bulkhead, $\gamma_R = 1,25$  |               |                          |  |                          |  |

Table 4 : Primary supporting members analysed through complete ship models - Partial safety factors

| Partial safety factors covering uncertainties regarding: | Symbol        | Yielding check<br>(see [5]) | Buckling check           |  |
|--|---------------|-----------------------------|--------------------------|--|
|  |               |                             | Plate panels (see [6.1]) | Pillars (see [6.2] and [6.3])            |
| Still water hull girder loads                            | $\gamma_{S1}$ | 1,00                        | 1,00                     | 1,00                                     |
| Wave hull girder loads                                   | $\gamma_{W1}$ | 1,10                        | 1,10                     | 1,10                                     |
| Still water pressure                                     | $\gamma_{S2}$ | 1,00                        | 1,00                     | 1,00                                     |
| Wave pressure  | $\gamma_{W2}$ | 1,10                        | 1,10                     | 1,10                                     |
| Material   | $\gamma_m$    | 1,02                        | 1,02                     | 1,02                                     |
| Resistance   | $\gamma_R$    | defined in Tab 5            | 1,02                     | for [6.2]: see Tab 13<br>for [6.3]: 1,15 |

Table 5 : Primary supporting members analysed through three dimensional or complete ship models  
Resistance partial safety factor

| Type of three dimensional model<br>(see Ch 7, App 1) | Resistance partial safety factor $\gamma_R$<br>(see [4.3] and [5.3]) |  |
|--|--|--|
|  | General  | Watertight bulkhead primary supporting members |
| Beam model   | 1,20   | 1,02   |
| Coarse mesh finite element model                     | 1,20   | 1,02   |
| Fine mesh finite element model                       | 1,05   | 1,02   |

Table 6 : Minimum net thicknesses of webs of double bottom primary supporting members

| Primary supporting member   | Minimum net thickness, in mm |                             |
|---|------------------------------|-----------------------------|
|   | Area within 0,4L amidships   | Area outside 0,4L amidships |
| Centre girder   | $2,0 L^{1/3} k^{1/6}$        | $1,7 L^{1/3} k^{1/6}$       |
| Side girders  | $1,4 L^{1/3} k^{1/6}$        | $1,4 L^{1/3} k^{1/6}$       |
| Floors  | $1,5 L^{1/3} k^{1/6}$        | $1,5 L^{1/3} k^{1/6}$       |
| Girder bounding a duct keel (1)   | $1,5 + 0,8 L^{1/2} k^{1/4}$  | $1,5 + 0,8 L^{1/2} k^{1/4}$ |
| Margin plate  | $L^{1/2} k^{1/4}$            | $0,9 L^{1/2} k^{1/4}$       |
| (1) The minimum net thickness is to be taken not less than that required for the centre girder. |                              |                             |

Table 7 : Minimum net thicknesses of webs and flanges of single bottom primary supporting members

| Primary supporting member | Minimum net thickness, in mm |                             |
|---------------------------|------------------------------|-----------------------------|
|                           | Area within 0,4L amidships   | Area outside 0,4L amidships |
| Centre girder             | $6,0 + 0,05 L_2 k^{1/2}$     | $4,5 + 0,05 L_2 k^{1/2}$    |
| Floors and side girders   | $5,0 + 0,05 L_2 k^{1/2}$     | $3,5 + 0,05 L_2 k^{1/2}$    |

2 Minimum net thicknesses

2.1 General

2.1.1 The net thickness of plating which forms the webs of primary supporting members is to be not less than the value obtained, in mm, from the following formulae:

$t_{MIN} = 3,7 + 0,015 L k^{1/2}$  for  $L < 120$  m

$t_{MIN} = 3,7 + 1,8 k^{1/2}$  for  $L \geq 120$  m

2.2 Double bottom

2.2.1 In addition to the requirements in [2.1], the net thickness of plating which forms the webs of primary supporting members of the double bottom is to be not less than the values given in Tab 6.

2.3 Single bottom

2.3.1 In addition to the requirements in [2.1], the net thickness of plating which forms the webs and the flanges of primary supporting members of the single bottom is to be not less than the values given in Tab 7.

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

3.1 General

3.1.1 The requirements of this Article apply for the yielding check of primary supporting members subjected to lateral pressure or to wheeled loads and, for those contributing to the hull girder longitudinal strength, to hull girder normal stresses, which may be analysed through an isolated beam model, according to [1.1.2].

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

3.2 Bracket arrangement

3.2.1 The requirements of this Article apply to primary supporting members with brackets at both ends of length not greater than 0,2  $\ell$ .

In the case of a significantly different bracket arrangement, the determination of normal and shear stresses due to design loads and the required section modulus and shear sectional area are considered by the Society on a case by case basis.

3.3 Load point

3.3.1 Lateral pressure

Unless otherwise specified, lateral pressure is to be calculated at mid-span of the primary supporting member considered.

3.3.2 Hull girder normal stresses

For longitudinal primary supporting 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 primary supporting member with attached plating.

3.4 Load model

3.4.1 General

The still water and wave lateral pressures induced by the sea and the various types of cargoes and ballast in intact conditions are to be considered, depending on the location of the primary supporting member under consideration and the type of compartments adjacent to it, in accordance with Ch 5, Sec 1, [2.4].

Primary supporting members of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids are to be subjected to the lateral pressure in flooding conditions.

The wave lateral pressures and hull girder loads are to be calculated in the mutually exclusive load cases “a”, “b”, “c” and “d” in Ch 5, Sec 4.

3.4.2 Lateral pressure in intact conditions

The lateral pressure in intact conditions is constituted by still water pressure and wave pressure.

Still water pressure ( $p_s$ ) includes:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water internal pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Wave pressure ( $p_w$ ) includes:

- the wave pressure, defined in Ch 5, Sec 5, [2] for each load case “a”, “b”, “c” and “d”
- the inertial pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast, and for each load case “a”, “b”, “c” and “d”.

3.4.3 Lateral pressure in flooding conditions

The lateral pressure in flooding conditions is constituted by the still water pressure  $p_{sf}$  and the wave pressure  $p_{wf}$  defined in Ch 5, Sec 6, [9].

3.4.4 Wheeled loads

For primary supporting members subjected to wheeled loads, the yielding check may be carried out according to [3.5] to [3.7] considering uniform pressures equivalent to the distribution of vertical concentrated forces, when such forces are closely located.

For the determination of the equivalent uniform pressures, the most unfavourable case, i.e. where the maximum number of axles is located on the same primary supporting member according to Fig 1 to Fig 3, is to be considered.

The equivalent still water pressure and inertial pressure are indicated in Tab 8.

For arrangements different from those shown in Fig 1 to Fig 3, the yielding check of primary supporting members is to be carried out by a direct calculation, taking into account the distribution of concentrated loads induced by vehicle wheels.

Figure 1 : Wheeled loads - Distribution of vehicles on a primary supporting member

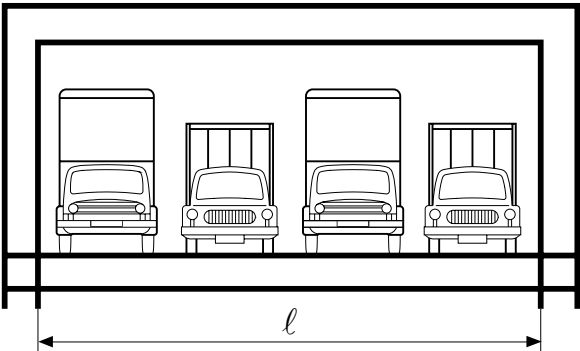


Table 8 : Wheeled loads  
Equivalent uniform still water and inertial pressures

| Ship condition  | Load case | Still water pressure $p_s$ and inertial pressure $p_w$ , in kN/m <sup>2</sup> |
|---|-----------|---|
| Still water condition   |           | $p_s = p_{eq}$  |
| Upright condition   | “a”       | No inertial pressure  |
|   | “b”       | $p_w = \alpha \, p_{eq} \, a_{z1} / g$  |
| Inclined condition  | “c”       | The inertial pressure may be disregarded                                      |
|   | “d”       | $p_w = \alpha \, p_{eq} \, a_{z2} / g$  |
| <b>Note 1:</b><br>$p_{eq} = 10 \frac{n_v Q_A}{\ell_s} \left( 3 - \frac{X_1 + X_2}{s} \right)$<br>$n_v$ : Maximum number of vehicles possible located on the primary supporting member<br>$Q_A$ : Maximum axle load, in t, defined in Ch 5, Sec 6, Tab 9<br>$X_1$ : Minimum distance, in m, between two consecutive axles (see Fig 2 and Fig 3)<br>$X_2$ : Minimum distance, in m, between axles of two consecutive vehicles (see Fig 3)<br>$\alpha$ : Coefficient taken equal to 0,4. |           |   |

Figure 2 : Wheeled loads  
Distance between two consecutive axles

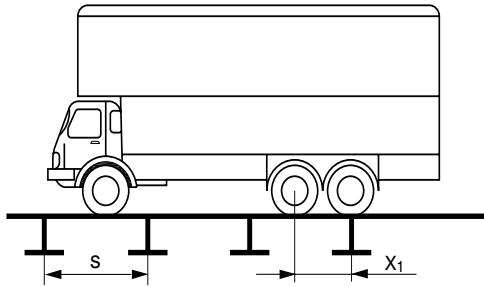
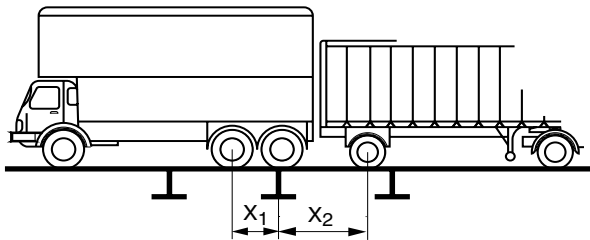


Figure 3 : Wheeled loads  
Distance between axles of two consecutive vehicles



3.4.5 Hull girder normal stresses

The hull girder normal stresses to be considered for the yielding check of primary supporting members are obtained, in N/mm<sup>2</sup>, from the following formulae:

- for longitudinal primary supporting members contributing to the hull girder longitudinal strength:  
$$\sigma_{X1} = \gamma_{S1} \sigma_{S1} + \gamma_{W1} (C_{FV} \sigma_{WV1} + C_{FH} \sigma_{WH1} + C_{F\Omega} \sigma_{\Omega})$$
- for longitudinal primary supporting members not contributing to the hull girder longitudinal strength:  
$$\sigma_{X1} = 0$$
- for transverse primary supporting members:  
$$\sigma_{X1} = 0$$

where:

$\sigma_{S1}$ ,  $\sigma_{WV1}$ ,  $\sigma_{WH1}$  : Hull girder normal stresses, in N/mm<sup>2</sup>, defined in:

- Tab 9 for primary supporting members subjected to lateral pressure
- Tab 10 for primary supporting members subjected to wheeled loads

$\sigma_{\Omega}$  : absolute value of the warping stress, in N/mm<sup>2</sup>, induced by the torque 0,625M<sub>WT</sub> and obtained in accordance with Ch 6, Sec 1, [2.6]

$C_{FV}$ ,  $C_{FH}$ ,  $C_{F\Omega}$  : Combination factors defined in Tab 11.

Table 9 : Hull girder normal stresses - Primary supporting members subjected to lateral pressure

| Condition  |            | $\sigma_{S1}$ , in N/mm <sup>2</sup> (1)              | $\sigma_{WV1}$ , in N/mm <sup>2</sup>                           | $\sigma_{WH1}$ , in N/mm <sup>2</sup>               |
|--|------------|---|---|---|
| Lateral pressure applied on the side opposite to the primary supporting member, with respect to the plating: | $z \geq N$ | $\left  \frac{M_{SW,S}}{I_Y} (z - N) \right  10^{-3}$ | $\left  \frac{0,625 F_D M_{WV,S}}{I_Y} (z - N) \right  10^{-3}$ | $\left  \frac{0,625 M_{WH}}{I_z} y \right  10^{-3}$ |
|  | $z < N$    | $\left  \frac{M_{SW,H}}{I_Y} (z - N) \right  10^{-3}$ | $\left  \frac{0,625 M_{WV,H}}{I_Y} (z - N) \right  10^{-3}$     |   |
| Lateral pressure applied on the same side as the primary supporting member:                                  | $z \geq N$ | $\left  \frac{M_{SW,H}}{I_Y} (z - N) \right  10^{-3}$ | $\left  \frac{0,625 M_{WV,H}}{I_Y} (z - N) \right  10^{-3}$     |   |
|  | $z < N$    | $\left  \frac{M_{SW,S}}{I_Y} (z - N) \right  10^{-3}$ | $\left  \frac{0,625 F_D M_{WV,S}}{I_Y} (z - N) \right  10^{-3}$ |   |
| (1) When the ship in still water is always in hogging condition, $M_{SW,S}$ is to be taken equal to 0.       |            |   |   |   |
| <b>Note 1:</b>   |            |   |   |   |
| $F_D$ : Coefficient defined in Ch 5, Sec 2, [4].   |            |   |   |   |

Table 10 : Hull girder normal stresses - Primary supporting members subjected to wheeled loads

| Condition   | $\sigma_{S1}$ in N/mm <sup>2</sup> (1)                | $\sigma_{WV1}$ in N/mm <sup>2</sup>                             | $\sigma_{WH1}$ in N/mm <sup>2</sup>                 |
|---|---|---|---|
| $z \geq N$  | $\left  \frac{M_{SW,H}}{I_Y} (z - N) \right  10^{-3}$ | $\left  \frac{0,625 M_{WV,H}}{I_Y} (z - N) \right  10^{-3}$     | $\left  \frac{0,625 M_{WH}}{I_z} y \right  10^{-3}$ |
| $z < N$   | $\left  \frac{M_{SW,S}}{I_Y} (z - N) \right  10^{-3}$ | $\left  \frac{0,625 F_D M_{WV,S}}{I_Y} (z - N) \right  10^{-3}$ |   |
| <p>(1) When the ship in still water is always in hogging condition, <math>M_{SW,S}</math> is to be taken equal to 0.</p> <p><b>Note 1:</b></p> <p><math>F_D</math> : Coefficient defined in Ch 5, Sec 2, [4].</p> |   |   |   |

Table 11 : Combination factors  $C_{FV}$ ,  $C_{FH}$  and  $C_{F\Omega}$

| Load case | $C_{FV}$ | $C_{FH}$ | $C_{F\Omega}$ |
|-----------|----------|----------|---------------|
| "a"       | 1,0      | 0        | 0             |
| "b"       | 1,0      | 0        | 0             |
| "c"       | 0,4      | 1,0      | 1,0           |
| "d"       | 0,4      | 1,0      | 0             |

3.5 Normal and shear stresses due to lateral pressure in intact conditions

3.5.1 General

Normal and shear stresses, induced by lateral pressures, in primary supporting members are to be determined from the formulae given in:

- [3.5.2] in the case of longitudinal and transverse stiffeners
- [3.5.3] in the case of vertical stiffeners.

3.5.2 Longitudinal and transverse primary supporting members

The maximum normal stress  $\sigma$  and shear stress  $\tau$  are to be obtained, in N/mm<sup>2</sup>, from the following formulae:

$$\sigma = \beta_b \frac{\gamma_{S2} p_s + \gamma_{W2} p_w}{m w} s \ell^2 10^3 + \sigma_{x1}$$

$$\tau = 5 \beta_s \frac{\gamma_{S2} p_s + \gamma_{W2} p_w}{A_{sh}} s \ell$$

where:

$$\beta_b = \left(1 - \frac{\ell_{b1}}{2 \ell} - \frac{\ell_{b2}}{2 \ell}\right)^2$$

$$\beta_s = 1 - \frac{\ell_{b1}}{2 \ell} - \frac{\ell_{b2}}{2 \ell}$$

$\ell_{b1}$ ;  $\ell_{b2}$  : Lengths of the brackets at ends, in m.

3.5.3 Vertical primary supporting members

The maximum normal stress  $\sigma$  and shear stress  $\tau$  are to be obtained, in N/mm<sup>2</sup>, from the following formulae:

$$\sigma = \lambda_b \beta_b \frac{\gamma_{S2} p_s + \gamma_{W2} p_w}{m w} s \ell^2 10^3 + \sigma_A$$

$$\tau = 5 \lambda_s \beta_s \frac{\gamma_{S2} p_s + \gamma_{W2} p_w}{A_{sh}} s \ell$$

where:

$\beta_b$ ,  $\beta_s$  : Coefficients defined in [3.5.2]

$\lambda_b$  : Coefficient taken equal to the greater of the following values:

$$\lambda_b = 1 + 0,2 \frac{\gamma_{S2}(p_{sd} - p_{su}) + \gamma_{W2}(p_{wd} - p_{wu})}{\gamma_{S2}(p_{sd} + p_{su}) + \gamma_{W2}(p_{wd} + p_{wu})}$$

$$\lambda_b = 1 - 0,2 \frac{\gamma_{S2}(p_{sd} - p_{su}) + \gamma_{W2}(p_{wd} - p_{wu})}{\gamma_{S2}(p_{sd} + p_{su}) + \gamma_{W2}(p_{wd} + p_{wu})}$$

$\lambda_s$  : Coefficient taken equal to the greater of the following values:

$$\lambda_s = 1 + 0,4 \frac{\gamma_{S2}(p_{sd} - p_{su}) + \gamma_{W2}(p_{wd} - p_{wu})}{\gamma_{S2}(p_{sd} + p_{su}) + \gamma_{W2}(p_{wd} + p_{wu})}$$

$$\lambda_s = 1 - 0,4 \frac{\gamma_{S2}(p_{sd} - p_{su}) + \gamma_{W2}(p_{wd} - p_{wu})}{\gamma_{S2}(p_{sd} + p_{su}) + \gamma_{W2}(p_{wd} + p_{wu})}$$

$p_{sd}$  : Still water pressure, in kN/m<sup>2</sup>, at the lower end of the primary supporting member considered

$p_{su}$  : Still water pressure, in kN/m<sup>2</sup>, at the upper end of the primary supporting member considered

$p_{wd}$  : Wave pressure, in kN/m<sup>2</sup>, at the lower end of the primary supporting member considered

$p_{wu}$  : Wave pressure, in kN/m<sup>2</sup>, at the upper end of the primary supporting member considered

$\sigma_A$  : Axial stress, to be obtained, in N/mm<sup>2</sup>, from the following formula:

$$\sigma_A = 10 \frac{F_A}{A}$$

$F_A$  : Axial load (still water and wave) transmitted to the vertical primary supporting members by the structures above. For multideck ships, the criteria in [6.2.1] for pillars are to be adopted

$A$  : Net sectional area, in cm<sup>2</sup>, of the vertical primary supporting members with attached plating of width  $b_p$ .

3.6 Checking criteria

3.6.1 General

It is to be checked that the normal stress  $\sigma$  and the shear stress  $\tau$ , calculated according to [3.5], are in compliance with the following formulae:

$$\frac{R_y}{\gamma_R \gamma_m} \geq \sigma$$

$$0,5 \frac{R_y}{\gamma_R \gamma_m} \geq \tau$$

3.7 Net section modulus and net sectional shear area complying with the checking criteria

3.7.1 General

The requirements in [3.7.2] and [3.7.3] provide the minimum net section modulus and net shear sectional area of primary supporting members subjected to lateral pressure in intact conditions, complying with the checking criteria indicated in [3.6].

3.7.2 Longitudinal and transverse primary supporting members

The net section modulus  $w$ , in cm<sup>3</sup>, and the net shear sectional area  $A_{sh}$ , in cm<sup>2</sup>, of longitudinal or transverse primary supporting members are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{S2} p_s + \gamma_{W2} p_w}{m (R_y - \gamma_R \gamma_m \sigma_{x1})} s \ell^2 10^3$$

$$A_{sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2} p_s + \gamma_{W2} p_w}{R_y} s \ell$$

where  $\beta_b$  and  $\beta_s$  are the coefficients defined in [3.5.2].

3.7.3 Vertical primary supporting members

The net section modulus  $w$ , in cm<sup>3</sup>, and the net shear sectional area  $A_{sh}$ , in cm<sup>2</sup>, of vertical primary supporting mem-



bers are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \lambda_b \beta_b \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{m(R_y - \gamma_R \gamma_m \sigma_A)} s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \lambda_s \beta_s \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{R_y} s \ell$$

where:

$\beta_b, \beta_s$  : Coefficients defined in [3.5.2]

$\lambda_b, \lambda_s$  : Coefficients defined in [3.5.3]

$\sigma_A$  : Defined in [3.5.3].

### 3.8 Net section modulus and net shear sectional area of primary supporting members subjected to lateral pressure in flooding conditions

#### 3.8.1 General

The requirements in [3.8.2] and [3.8.3] provide the minimum net section modulus and net shear sectional area of primary supporting members of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids, in flooding conditions.

#### 3.8.2 Longitudinal and transverse primary supporting members

The net section modulus  $w$ , in  $\text{cm}^3$ , and the net shear sectional area  $A_{Sh}$ , in  $\text{cm}^2$ , of longitudinal or transverse primary supporting members are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{m(R_y - \gamma_m \sigma_{X1})} s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{R_y} s \ell$$

where:

$\beta_b, \beta_s$  : Coefficients defined in [3.5.2].

#### 3.8.3 Vertical primary supporting members

The net section modulus  $w$ , in  $\text{cm}^3$ , and the net shear sectional area  $A_{Sh}$ , in  $\text{cm}^2$ , of vertical primary supporting members are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \lambda_b \beta_b \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{m R_y} s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \lambda_s \beta_s \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{R_y} s \ell$$

where:

$\beta_b, \beta_s$  : Coefficients defined in [3.5.2]

$\lambda_b$  : Coefficient taken equal to the greater of the following values:

$$\lambda_b = 1 + 0,2 \frac{\gamma_{S2}(p_{SFd} - p_{SFu}) + \gamma_{W2}(p_{WFd} - p_{WFu})}{\gamma_{S2}(p_{SFd} + p_{SFu}) + \gamma_{W2}(p_{WFd} + p_{WFu})}$$

$$\lambda_b = 1 - 0,2 \frac{\gamma_{S2}(p_{SFd} - p_{SFu}) + \gamma_{W2}(p_{WFd} - p_{WFu})}{\gamma_{S2}(p_{SFd} + p_{SFu}) + \gamma_{W2}(p_{WFd} + p_{WFu})}$$

$\lambda_s$  : Coefficient taken equal to the greater of the following values:

$$\lambda_s = 1 + 0,4 \frac{\gamma_{S2}(p_{SFd} - p_{SFu}) + \gamma_{W2}(p_{WFd} - p_{WFu})}{\gamma_{S2}(p_{SFd} + p_{SFu}) + \gamma_{W2}(p_{WFd} + p_{WFu})}$$

$$\lambda_s = 1 - 0,4 \frac{\gamma_{S2}(p_{SFd} - p_{SFu}) + \gamma_{W2}(p_{WFd} - p_{WFu})}{\gamma_{S2}(p_{SFd} + p_{SFu}) + \gamma_{W2}(p_{WFd} + p_{WFu})}$$

$p_{SFd}$  : Still water pressure, in  $\text{kN/m}^2$ , in flooding conditions, at the lower end of the primary supporting member considered

$p_{SFu}$  : Still water pressure, in  $\text{kN/m}^2$ , in flooding conditions, at the upper end of the primary supporting member considered

$p_{WFd}$  : Wave pressure, in  $\text{kN/m}^2$ , in flooding conditions, at the lower end of the primary supporting member considered

$p_{WFu}$  : Wave pressure, in  $\text{kN/m}^2$ , in flooding conditions, at the upper end of the primary supporting member considered.

## 4 Yielding check of primary supporting members analysed through a three dimensional structural model

### 4.1 General

**4.1.1** The requirements of this Article apply for the yielding check of primary supporting members subjected to lateral pressure or to wheeled loads and, for those contributing to the hull girder longitudinal strength, to hull girder normal stresses, which are to be analysed through a three dimensional structural model.

**4.1.2** The yielding check is also to be carried out for primary supporting members subjected to specific loads, such as concentrated loads.

### 4.2 Analysis criteria

**4.2.1** The analysis of primary supporting members based on three dimensional models is to be carried out according to:

- the requirements in Ch 7, App 1 for primary supporting members subjected to lateral pressure
- the requirements in Ch 7, App 2 for primary supporting members subjected to wheeled loads.

These requirements apply for:

- the structural modelling
- the load modelling
- the stress calculation.

### 4.3 Checking criteria

#### 4.3.1 General

For all types of analysis (see Ch 7, App 1, [2]), it is to be checked that the equivalent stress  $\sigma_{VM}$ , calculated according to Ch 7, App 1, [5] is in compliance with the following formula:

$$\frac{R_y}{\gamma_R \gamma_m} \geq \sigma_{VM}$$

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

Fine mesh finite element models are defined with reference to Ch 7, App 1, [3.4].

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 Ch 7, App 1, [5], are in compliance with the following formulae:

$$\frac{R_y}{\gamma_R \gamma_m} \geq \max(|\sigma_1|, |\sigma_2|)$$

$$0,5 \frac{R_y}{\gamma_R \gamma_m} \geq \tau_{12}$$

**4.3.3 Specific case of primary supporting members subjected to wheeled loads**

For all types of analysis (see Ch 7, App 2, [2] ), it is to be checked that the equivalent stress  $\sigma_{VM}$ , calculated according to Ch 7, App 2, [5] is in compliance with the following formula:

$$\frac{R_y}{\gamma_R \gamma_m} \geq \sigma_{VM}$$

**5 Yielding check of primary supporting members analysed through a complete ship structural model**

**5.1 General**

**5.1.1** The requirements of this Article apply for the yielding check of primary supporting members which are to be analysed through a complete ship structural model.

**5.1.2** A complete ship structural model is to be carried out, when deemed necessary by the Society, to analyse primary supporting members of ships with one or more of the following characteristics:

- ships having large deck openings
- ships having large space arrangements
- multideck ships having series of openings in side or longitudinal bulkheads, when the stresses due to the different contribution of each deck to the hull girder strength are to be taken into account.

**5.1.3** Based on the criteria in [5.1.2], analyses based on complete ship models may be required, in general, for the following ship types:

- ships with the service notation **general cargo ship**, having large deck openings
- ships with the service notation **container ship**
- ships with the service notation **ro-ro cargo ship**
- ships with the service notation **passenger ship**
- ships with the service notation **ro-ro passenger ship**.

**5.2 Analysis criteria**

**5.2.1** The analysis of primary supporting members based on complete ship models is to be carried out according to Ch 7, App 3.

These requirements apply for:

- the structural modelling
- the load modelling
- the stress calculation.

**5.3 Checking criteria**

**5.3.1 General**

It is to be checked that the equivalent stress  $\sigma_{VM}$ , calculated according to Ch 7, App 3, [4] is in compliance with the following formula:

$$\frac{R_y}{\gamma_R \gamma_m} \geq \sigma_{VM}$$

**5.3.2 Additional criteria for elements modelled with fine meshes**

Fine meshes are defined with reference to Ch 7, App 3, [2.4].

For all the elements modelled with fine meshes, it is to be checked that the normal stresses  $\sigma_1$  and  $\sigma_2$  and the shear stress  $\tau_{12}$ , calculated according to Ch 7, App 3, [4], are in compliance with the following formulae:

$$\frac{R_y}{\gamma_R \gamma_m} \geq \max(\sigma_1, \sigma_2)$$

$$0,5 \frac{R_y}{\gamma_R \gamma_m} \geq \tau_{12}$$

**6 Buckling check**

**6.1 Local buckling of plate panels**

**6.1.1** A local buckling check is to be carried out, according to Ch 7, Sec 1, [5], for plate panels which constitute primary supporting members.

In carrying out this check, the stresses in the plate panels are to be calculated according to [3], [4] or [5], depending on the structural model adopted for the analysis of primary supporting members.

**6.2 Buckling of pillars subjected to compression axial load**

**6.2.1 Compression axial load**

Where pillars are in line, the compression axial load in a pillar is obtained, in kN, from the following formula:

$$F_A = A_D (\gamma_{S2} P_S + \gamma_{W2} P_W) + \sum_{i=1}^N r_i (\gamma_{S2} Q_{i,S} + \gamma_{W2} Q_{i,W})$$

where:

$A_D$  : Area, in m<sup>2</sup>, of the portion of the deck or platform supported by the pillar considered

- $r_i$  : Coefficient which depends on the relative position of each pillar above the one considered, to be taken equal to:
- $r_i = 0,9$  for the pillar immediately above that considered ( $i = 1$ )
  - $r_i = 0,9^i$  for the  $i^{\text{th}}$  pillar of the line above the pillar considered, to be taken not less than 0,478
- $Q_{i,S}, Q_{i,W}$  : Still water and wave loads, respectively, in kN, from the  $i^{\text{th}}$  pillar of the line above the pillar considered.

6.2.2 Critical column buckling stress of pillars

The critical column buckling stress of pillars is to be obtained, in N/mm<sup>2</sup>, from the following formulae:

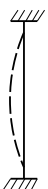
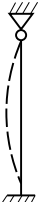
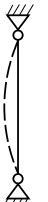
$\sigma_{cB} = \sigma_{E1}$  for  $\sigma_{E1} \leq \frac{R_{eH}}{2}$

$\sigma_{cB} = R_{eH} \left(1 - \frac{R_{eH}}{4\sigma_{E1}}\right)$  for  $\sigma_{E1} > \frac{R_{eH}}{2}$

where:

- $\sigma_{E1}$  : Euler column buckling stress, to be obtained, in N/mm<sup>2</sup>, from the following formula:
- $\sigma_{E1} = \pi^2 E \frac{I}{A(f\ell)^2} 10^{-4}$
- $I$  : Minimum net moment of inertia, in cm<sup>4</sup>, of the pillar

Table 12 : Coefficient f

| Boundary conditions of the pillar   | f                    |
|---|----------------------|
| <b>Both ends fixed</b><br>               | 0,5                  |
| <b>One end fixed, one end pinned</b><br> | $\frac{\sqrt{2}}{2}$ |
| <b>Both ends pinned</b><br>              | 1                    |

- $A$  : Net cross-sectional area, in cm<sup>2</sup>, of the pillar
- $\ell$  : Span, in m, of the pillar
- $f$  : Coefficient, to be obtained from Tab 12.

6.2.3 Critical torsional buckling stress of built-up pillars

The critical torsional buckling stress of built-up pillars is to be obtained, in N/mm<sup>2</sup>, from the following formulae:

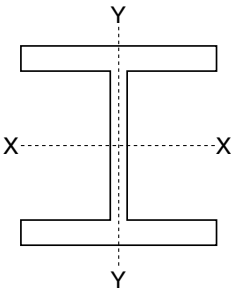
$\sigma_{cT} = \sigma_{E2}$  for  $\sigma_{E2} \leq \frac{R_{eH}}{2}$

$\sigma_{cT} = R_{eH} \left(1 - \frac{R_{eH}}{4\sigma_{E2}}\right)$  for  $\sigma_{E2} > \frac{R_{eH}}{2}$

where:

- $\sigma_{E2}$  : Euler torsional buckling stress, to be obtained, in N/mm<sup>2</sup>, from the following formula:
- $\sigma_{E2} = \frac{\pi^2 E I_w}{10^4 I_p \ell^2} + 0,41 E \frac{I_t}{I_p}$
- $I_w$  : Net sectorial moment of inertia of the pillar, to be obtained, in cm<sup>6</sup>, from the following formula:
- $I_w = \frac{t_f b_f^3 h_w^2}{24} 10^{-6}$
- $h_w$  : Web height of built-up section, in mm
- $t_w$  : Net web thickness of built-up section, in mm
- $b_f$  : Face plate width of built-up section, in mm
- $t_f$  : Net face plate thickness of built-up section, in mm
- $I_p$  : Net polar moment of inertia of the pillar, to be obtained, in cm<sup>4</sup>, from the following formula:
- $I_p = I_{XX} + I_{YY}$
- $I_{XX}$  : Net moment of inertia about the XX axis of the pillar section (see Fig 4)
- $I_{YY}$  : Net moment of inertia about the YY axis of the pillar section (see Fig 4)
- $I_t$  : St. Venant's net moment of inertia of the pillar, to be obtained, in cm<sup>4</sup>, from the following formula:
- $I_t = \frac{1}{3} [h_w t_w^3 + 2 b_f t_f^3] 10^{-4}$

Figure 4 : Reference axes for the calculation of the moments of inertia of a built-up section



6.2.4 Critical local buckling stress of built-up pillars

The critical local buckling stress of built-up pillars is to be obtained, in N/mm², from the following formulae:

$$\sigma_{cL} = \sigma_{E3} \quad \text{for } \sigma_{E3} \leq \frac{R_{eH}}{2}$$
$$\sigma_{cL} = R_{eH} \left( 1 - \frac{R_{eH}}{4\sigma_{E3}} \right) \quad \text{for } \sigma_{E3} > \frac{R_{eH}}{2}$$

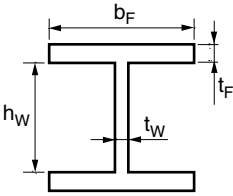
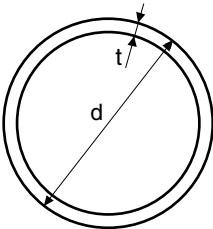
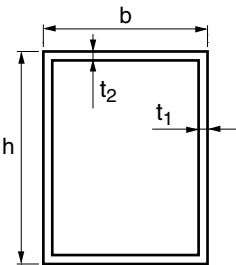
where:

$\sigma_{E3}$  : Euler local buckling stress, to be taken equal to the lesser of the values obtained, in N/mm², from the following formulae:

- $$\sigma_{E3} = 78 \left( \frac{t_W}{h_W} \right)^2 10^4$$
- $$\sigma_{E3} = 32 \left( \frac{t_F}{b_F} \right)^2 10^4$$

$t_W, h_W, t_F, b_F$  : Dimensions, in mm, of the built-up section, defined in [6.2.3].

Table 13 : Buckling check of pillars subject to compression axial load

| Pillar cross-section   | Column buckling check   | Torsional buckling check                                      | Local buckling check  | Geometric condition   |
|--|---|---|---|---|
| <b>Built-up</b><br>             | $\frac{\sigma_{cB}}{\gamma_R \gamma_m} \geq 10 \frac{F_A}{A}$ | $\frac{\sigma_{cT}}{\gamma_R \gamma_m} \geq 10 \frac{F_A}{A}$ | $\frac{\sigma_{cL}}{\gamma_R \gamma_m} \geq 10 \frac{F_A}{A}$ | <ul style="list-style-type: none"><li><math>\frac{b_F}{t_F} \leq 40</math></li></ul>  |
| <b>Hollow tubular</b><br>     | $\frac{\sigma_{cB}}{\gamma_R \gamma_m} \geq 10 \frac{F_A}{A}$ | Not required  | Not required  | <ul style="list-style-type: none"><li><math>\frac{d}{t} \leq 55</math></li><li><math>t \geq 5,5 \text{ mm}</math></li></ul>   |
| <b>Hollow rectangular</b><br> | $\frac{\sigma_{cB}}{\gamma_R \gamma_m} \geq 10 \frac{F_A}{A}$ | Not required  | $\frac{\sigma_{cL}}{\gamma_R \gamma_m} \geq 10 \frac{F_A}{A}$ | <ul style="list-style-type: none"><li><math>\frac{b}{t_2} \leq 55</math></li><li><math>\frac{h}{t_1} \leq 55</math></li><li><math>t_1 \geq 5,5 \text{ mm}</math></li><li><math>t_2 \geq 5,5 \text{ mm}</math></li></ul> |

Note 1:

- $\sigma_{cB}$  : Critical column buckling stress, in N/mm², defined in [6.2.2]
- $\sigma_{cT}$  : Critical torsional buckling stress, in N/mm², defined in [6.2.3]
- $\sigma_{cL}$  : Critical local buckling stress, in N/mm², defined in [6.2.4] for built-up section or in [6.2.5] for hollow rectangular section
- $\gamma_R$  : Resistance partial safety factor, equal to:
  - 2,00 for column buckling
  - 1,05 for torsional and local buckling
- $F_A$  : compression axial load in the pillar, in kN, defined in [6.2.1]
- $A$  : Net sectional area, in cm², of the pillar.

### 6.2.5 Critical local buckling stress of pillars having hollow rectangular section

The critical local buckling stress of pillars having hollow rectangular section is to be obtained, in N/mm<sup>2</sup>, from the following formulae:

$$\sigma_{CL} = \sigma_{E4} \quad \text{for } \sigma_{E4} \leq \frac{R_{eH}}{2}$$

$$\sigma_{CL} = R_{eH} \left( 1 - \frac{R_{eH}}{4\sigma_{E4}} \right) \quad \text{for } \sigma_{E4} > \frac{R_{eH}}{2}$$

where:

$\sigma_{E4}$  : Euler local buckling stress, to be taken equal to the lesser of the values obtained, in N/mm<sup>2</sup>, from the following formulae:

$$\bullet \quad \sigma_{E4} = 78 \left( \frac{t_2}{b} \right)^2 10^4$$

$$\bullet \quad \sigma_{E4} = 78 \left( \frac{t_1}{h} \right)^2 10^4$$

$b$  : Length, in mm, of the shorter side of the section  
 $t_2$  : Net web thickness, in mm, of the shorter side of the section  
 $h$  : Length, in mm, of the longer side of the section  
 $t_1$  : Net web thickness, in mm, of the longer side of the section.

### 6.2.6 Checking criteria

The net scantlings of the pillar loaded by the compression axial stress  $F_A$  defined in [6.2.1] are to comply with the formulae in Tab 13.

### 6.3 Buckling of pillars subjected to compression axial load and bending moments

#### 6.3.1 Checking criteria

In addition to the requirements in [6.2], the net scantlings of the pillar loaded by the compression axial load and bending moments are to comply with the following formula:

$$10F \left( \frac{1}{A} + \frac{\Phi e}{w_p} \right) + \left( 10^3 \frac{M_{max}}{w_p} \right) \leq \frac{R_{eH}}{\gamma_R \gamma_m}$$

where:

$F$  : Compression load, in kN, acting on the pillar  
 $A$  : Net cross-sectional area, in cm<sup>2</sup>, of the pillar  
 $e$  : Eccentricity, in cm, of the compression load with respect to the centre of gravity of the cross-section

$$\Phi = \frac{1}{1 - \frac{10F}{\sigma_{E1} A}}$$

$\sigma_{E1}$  : Euler column buckling stress, in N/mm<sup>2</sup>, defined in [6.2.2]  
 $w_p$  : Minimum net section modulus, in cm<sup>3</sup>, of the cross-section of the pillar  
 $M_{max}$  : Max ( $M_1$ ,  $M_2$ ,  $M_0$ )  
 $M_1$  : Bending moment, in kN.m, at the upper end of the pillar  
 $M_2$  : Bending moment, in kN.m, at the lower end of the pillar

$$M_0 = \frac{0.5(\sqrt{1+t^2})(M_1 + M_2)}{\cos(u)}$$

$$u = 0.5\pi \sqrt{\frac{10F}{\sigma_{E1} A}}$$

$$t = \frac{1}{\tan(u)} \left( \frac{M_2 - M_1}{M_2 + M_1} \right)$$

## SECTION 4

## FATIGUE CHECK OF STRUCTURAL DETAILS

### Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

- $p_s$  : Still water pressure, in  $\text{kN/m}^2$ , see [2.2]  
 $p_w$  : Wave pressure, in  $\text{kN/m}^2$ , see [2.2]  
 $i$  : Index which denotes the load case "a", "b", "c" or "d"  
 $j$  : Index which denotes the loading condition "Full load" or "Ballast"  
 $K_h, K_\ell$  : Stress concentration factors, defined in Ch 12, Sec 2 for the special structural details there specified  
 $K_F$  : Fatigue notch factor, defined in [4.3.1]  
 $K_m$  : Stress concentration factor, taking account of misalignment, defined in [4.3.1]  
 $K_S$  : Coefficient taking account of the stiffener section geometry, defined in [6.2.2].

### 1 General

#### 1.1 Application

##### 1.1.1 General

The requirements of this Section apply to ships equal to or greater than 170 m in length.

##### 1.1.2 Structural details to be checked

The requirements of this Section apply for the fatigue check of special structural details defined in Ch 12, Sec 2, depending on the ship type and on the hull area where the detail are located.

The Society may require other details to be checked, when deemed necessary on the basis of the detail geometry and stress level.

In case of a hot spot located in a plate edge without any welded joint, the SN curve to be used is to be considered on a case by case basis by the Society.

##### 1.1.3 Categorisation of details

With respect to the method to be adopted to calculate the stresses acting on structural members, the details for which the fatigue check is to be carried out may be grouped as follows:

- details where the stresses are to be calculated through a three dimensional structural model (e.g. connections between primary supporting members)
- details located at ends of ordinary stiffeners, for which an isolated structural model can be adopted.

##### 1.1.4 Details where the stresses are to be calculated through a three dimensional structural model

The requirements of Ch 7, App 1, [6] apply, in addition of those of [1] to [5] of this Section.

##### 1.1.5 Details located at ends of ordinary stiffeners

The requirements of [1] to [6] of this Section apply.

##### 1.1.6 Other details

In general, for details other than those in [1.1.3], the stresses are to be calculated through a method agreed by the Society on a case by case basis, using the load model defined in [2].

The checking criteria in [5] is generally to be applied.

### 1.2 Net scantlings

**1.2.1** As specified in Ch 4, Sec 2, [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 Ch 4, Sec 2.

### 1.3 Sign conventions

#### 1.3.1 Bending moments

The sign conventions of bending moments at any ship transverse section are the following ones:

- the vertical bending moment is positive when it induces tensile stresses in the strength deck (hogging bending moment); it is negative in the opposite case (sagging bending moment)
- the horizontal bending moment is positive.

#### 1.3.2 Stresses

The sign conventions of stresses are the following ones:

- tensile stresses are positive
- compressive stresses are negative.

### 1.4 Definitions

#### 1.4.1 Hot spots

Hot spots are the locations where fatigue cracking may occur. They are indicated in the relevant figures of special structural details in Ch 12, Sec 2 (see [1.1.2]).

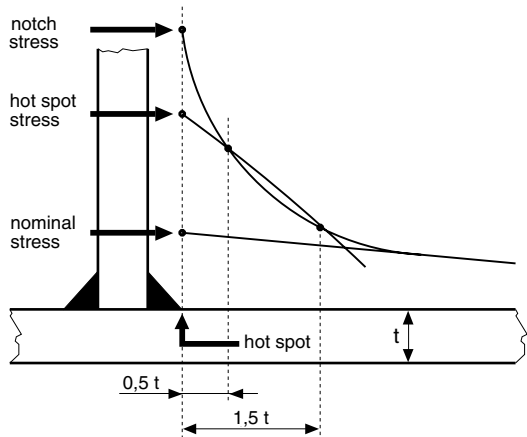
#### 1.4.2 Nominal stress

Nominal stress is the stress in a structural component taking into account macro-geometric effects but disregarding the stress concentration due to structural discontinuities and to the presence of welds (see Fig 1).

1.4.3 Hot spot stress

Hot spot stress is a local stress at the hot spot taking into account the influence of structural discontinuities due to the geometry of the detail, but excluding the effects of welds (see Fig 1).

Figure 1 : Nominal, hot spot and notch stresses



1.4.4 Notch stress

Notch stress is a peak stress in a notch such as the root of a weld or the edge of a cut-out. This peak stress takes into account the stress concentrations due to the presence of notches (see Fig 1).

1.4.5 Elementary stress range

Elementary stress range is the stress range determined for one of the load cases “a”, “b”, “c” or “d” (see Ch 5, Sec 4, [2]) and for either of the loading conditions (see Ch 5, Sec 1, [2.4] and Ch 5, Sec 1, [2.5]).

1.5 Partial safety factors

1.5.1 The partial safety factors to be considered for the fatigue check of structural details are specified in Tab 1.

Table 1 : Fatigue check - Partial safety factors

| Partial safety factors covering uncertainties regarding: | Symbol        | Value   |  |
|--|---------------|---------|--|
|  |               | General | Details at ends of ordinary stiffeners |
| Still water hull girder loads                            | $\gamma_{s1}$ | 1,00    | 1,00                                   |
| Wave hull girder loads                                   | $\gamma_{w1}$ | 1,05    | 1,15                                   |
| Still water pressure                                     | $\gamma_{s2}$ | 1,00    | 1,00                                   |
| Wave pressure  | $\gamma_{w2}$ | 1,10    | 1,20                                   |
| Resistance   | $\gamma_R$    | 1,02    | 1,02                                   |

2 Load model

2.1 General

2.1.1 Load point

Unless otherwise specified, design loads are to be determined at points defined in:

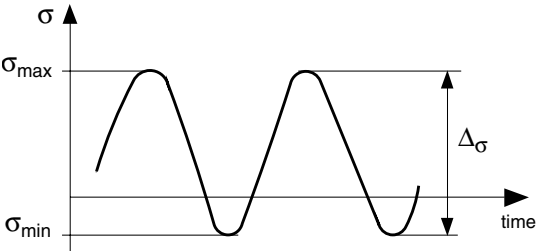
- Ch 7, Sec 2, [1.3] for ordinary stiffeners
- Ch 7, Sec 3, [1] for primary supporting members.

2.1.2 Local and hull girder loads

The fatigue check is based on the stress range induced at the hot spot by the time variation of the local pressures and hull girder loads in each load case “a”, “b”, “c” and “d” defined in [2.2] for the loading conditions defined in [2.1.4] and [2.1.3] (see Fig 2).

For the purpose of fatigue check, each load case “a”, “b”, “c” and “d” is divided in two cases “-max” and “-min” for which the local pressures and corresponding hull girder loads are defined in [2.2] and [2.3] respectively.

Figure 2 : Stress range



2.1.3 Loading conditions for details where the stresses are to be calculated through a three dimensional structural model

The most severe full load and ballast conditions for the detail concerned are to be considered in accordance with Ch 5, Sec 1, [2.5].

2.1.4 Loading conditions for details located at ends of ordinary stiffeners

The cargo and ballast distribution is to be considered in accordance with Ch 5, Sec 1, [2.4].

2.1.5 Spectral fatigue analysis

For ships with non-conventional shapes or with restricted navigation, the Society may require a spectral fatigue analysis to be carried out.

In this analysis, the loads and stresses are to be evaluated through long-term stochastic analysis taking into account the characteristics of the ship and the navigation notation.

The load calculations and fatigue analysis are to be submitted to the Society for approval.

2.2 Local lateral pressures

2.2.1 General

The still water and wave lateral pressures induced by the sea and various types of cargoes and ballast are to be considered.

Lateral pressure is constituted by still water pressure and wave pressure.

2.2.2 Load cases “a-max” and “a-min”, in upright ship condition

The still water sea pressure (p<sub>s</sub>) is defined in Ch 5, Sec 5, [1.1.1].

The wave pressure (p<sub>w</sub>) is defined in Tab 2.

No internal inertial pressures are considered.

2.2.3 Load cases “b-max” and “b-min”, in upright ship condition

Still water pressure (p<sub>s</sub>) includes:

- the still water sea pressure defined in Ch 5, Sec 5, [1]
- the still water internal pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Dynamic pressure (p<sub>w</sub>) is constituted by internal inertial pressures defined in Tab 4.

No sea wave dynamic pressures are considered.

2.2.4 Load cases “c-max” and “c-min”, in inclined ship condition

Still water pressure (p<sub>s</sub>) includes:

- the still water sea pressure defined in Ch 5, Sec 5, [1]
- the still water internal pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Wave pressure (p<sub>w</sub>) includes:

- the wave pressure obtained from Tab 3
- the inertial pressure obtained from Tab 4 for the various types of cargoes and ballast.

2.2.5 Load cases “d-max” and “d-min”, in inclined ship condition

Still water pressure (p<sub>s</sub>) includes:

- the still water sea pressure defined in Ch 5, Sec 5, [1]
- the still water internal pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Wave pressure (p<sub>w</sub>) includes:

- the wave pressure obtained from Tab 3
- the inertial pressure obtained from Tab 4 for the various types of cargoes and ballast.

Table 2 : Wave pressure in load case a

| Location  | Wave pressure p <sub>w</sub> , in kN/m <sup>2</sup>                    |   |
|---|--|---|
|   | a-max  | a-min   |
| Bottom and sides below the waterline<br>(z ≤ T <sub>1</sub> ) | $\alpha^{1/4} \frac{\rho g h_1}{2} \left[ \frac{T_1 + z}{T_1} \right]$ | $-\alpha^{1/4} \frac{\rho g h_1}{2} \left[ \frac{T_1 + z}{T_1} \right]$<br>without being taken less than $\frac{\gamma_s}{\gamma_w} \rho g (z - T_1)$ |
| Sides above the waterline<br>(z > T <sub>1</sub> )            | $\rho g (T_1 + \alpha^{1/4} h_1 - z)$                                  | 0,0   |

Table 3 : Wave pressure in inclined ship conditions (load cases “c” and “d”)

| Location   | Wave pressure p <sub>w</sub> , in kN/m <sup>2</sup> (negative roll angle)         |  |
|--|---|--|
|  | c-max / d-max   | c-min / d-min  |
| Bottom and sides below the waterline<br>(z ≤ T <sub>1</sub> )  | $C_{F2} \alpha^{1/4} \rho g h_2 \frac{Y}{B_w} \left[ \frac{T_1 + z}{T_1} \right]$ | $-C_{F2} \alpha^{1/4} \rho g h_2 \frac{Y}{B_w} \left[ \frac{T_1 + z}{T_1} \right]$<br>without being taken less than $\frac{\gamma_s}{\gamma_w} \rho g (z - T_1)$ |
| Sides above the waterline<br>(z > T <sub>1</sub> )   | $\rho g \left[ T_1 + 2 C_{F2} \alpha^{1/4} \frac{Y}{B_w} h_2 - z \right]$         | 0,0  |
| <b>Note 1:</b><br>C <sub>F2</sub> : Combination factor, to be taken equal to: <ul style="list-style-type: none"><li>C<sub>F2</sub> = 1,0 for load case “c”</li><li>C<sub>F2</sub> = 0,5 for load case “d”</li></ul><br>B <sub>w</sub> : Moulded breadth, in m, measured at the waterline at draught T <sub>1</sub> , at the hull transverse section considered<br>h <sub>2</sub> : Reference value, in m, of the relative motion in the inclined ship condition, defined in Ch 5, Sec 3, [3.3.2] and not to be taken greater than the minimum of T <sub>1</sub> and D − 0,9 T <sub>1</sub> . |   |  |



Table 4 : Inertial pressures

| Cargo  | Load case                          | Inertial pressures, in kN/m <sup>2</sup> (1)   |
|--|------------------------------------|--|
| Liquids  | b-max                              | $p_W = \rho_L [-0,5 a_{X1} \ell_B - a_{Z1} (z_{TOP} - z)]$   |
|  | b-min                              | $p_W = \rho_L [0,5 a_{X1} \ell_B + a_{Z1} (z_{TOP} - z)]$  |
|  | c-max<br>d-max                     | $p_W = \rho_L [0,7 C_{FA} a_{Y2} (y - y_H) + (-0,7 C_{FA} a_{Z2} - g)(z - z_H) + g(z - z_{TOP})]$  |
|  | c-min<br>d-min                     | $p_W = \rho_L [-0,7 C_{FA} a_{Y2} (y - y_H) + (0,7 C_{FA} a_{Z2} - g)(z - z_H) + g(z - z_{TOP})]$  |
| Dry bulk cargoes   | b-max                              | $p_W = -\rho_B a_{Z1} (z_B - z) \left\{ (\sin \alpha)^2 \left[ \tan \left( 45^\circ - \frac{\Phi}{2} \right) \right]^2 + (\cos \alpha)^2 \right\}$   |
|  | b-min                              | $p_W = \rho_B a_{Z1} (z_B - z) \left\{ (\sin \alpha)^2 \left[ \tan \left( 45^\circ - \frac{\Phi}{2} \right) \right]^2 + (\cos \alpha)^2 \right\}$  |
|  | c-max and c-min<br>d-max and d-min | The inertial pressure transmitted to the hull structures in inclined condition may generally be disregarded. Specific cases in which this simplification is not deemed permissible by the Society are considered individually. |
| <b>(1)</b> The symbols used in the formulae of inertial pressures are defined in Ch 5, Sec 6.<br><b>Note 1:</b><br>$C_{FA}$ : Combination factor, to be taken equal to: <ul style="list-style-type: none"><li><math>C_{FA} = 0,7</math> for load case “c”</li><li><math>C_{FA} = 1,0</math> for load case “d”.</li></ul> |                                    |  |

2.3 Nominal hull girder normal stresses

2.3.1 The nominal hull girder normal stresses are obtained, in N/mm<sup>2</sup>, from the following formulae:

- for members contributing to the hull girder longitudinal strength:  
 $\sigma_h = \gamma_{S1} \sigma_{SW} + \gamma_{W1} (C_{FV} \sigma_{WV} + C_{FH} \sigma_{WH} + C_{F\Omega} \sigma_{\Omega})$
- for members not contributing to the hull girder longitudinal strength:  
 $\sigma_h = 0$

where:

$\sigma_{SW}$  : Still water hull girder normal stresses, in N/mm<sup>2</sup>, taken equal to:

$$\sigma_{SW} = \frac{M_{SW}}{I_Y} (z - N) 10^{-3}$$

Table 5 : Nominal hull girder normal stresses

| Load case      | $\sigma_{WV}$ , in N/mm <sup>2</sup>         | $\sigma_{WH}$ , in N/mm <sup>2</sup>  |
|----------------|--|---------------------------------------|
| a-max          | $\frac{0,625 M_{WV,H}}{I_Y} (z - N) 10^{-3}$ | 0                                     |
| a-min          | $\frac{0,625 M_{WV,S}}{I_Y} (z - N) 10^{-3}$ | 0                                     |
| b-max<br>b-min | 0  | 0                                     |
| c-max<br>d-max | 0  | $-\frac{0,625 M_{WH}}{I_Z} y 10^{-3}$ |
| c-min<br>d-min | 0  | $\frac{0,625 M_{WH}}{I_Z} y 10^{-3}$  |

$M_{SW}$  : Still water bending moment for the loading condition considered

$\sigma_{WV}$ ,  $\sigma_{WH}$ ,  $\sigma_{\Omega}$ : Hull girder normal stresses, in N/mm<sup>2</sup>, defined in Tab 5

$\sigma_{\Omega}$  : Warping stresses, in N/mm<sup>2</sup>, induced by the torque  $0,625 M_{WT}$  and obtained through direct calculation analyses based on a structural model in accordance with Ch 6, Sec 1, [2.6]

$C_{FV}$ ,  $C_{FH}$ ,  $C_{F\Omega}$ : Combination factors defined in Tab 6.

Table 6 : Combination factors  $C_{FV}$ ,  $C_{FH}$  and  $C_{F\Omega}$

| Load case | $C_{FV}$ | $C_{FH}$ | $C_{F\Omega}$ |
|-----------|----------|----------|---------------|
| “a”       | 1,0      | 0        | 0             |
| “b”       | 1,0      | 0        | 0             |
| “c”       | 0,4      | 1,0      | 1,0           |
| “d”       | 0,4      | 1,0      | 0             |

3 Fatigue damage ratio

3.1 General

3.1.1 Elementary fatigue damage ratio

The elementary fatigue damage ratio is to be obtained from the following formula:

$$D_{ij} = \frac{N_t (\Delta \sigma_{N,ij})^3}{K_p (-\ln p_R)^{3/\xi}} \mu_{ij} \Gamma_c \left[ \frac{3}{\xi} + 1 \right]$$

where:

$\Delta \sigma_{N,ij}$  : Elementary notch stress range, in N/mm<sup>2</sup>, defined in [4.3.1]

Table 7 : Function  $\Gamma_N [X+1, v_{ij}]$

| X   | Value of $v_{ij}$ |      |       |       |       |       |       |       |       |       |       |        |        |        |
|-----|-------------------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--------|--------|
|     | 1,5               | 2,0  | 2,5   | 3,0   | 3,5   | 4,0   | 4,5   | 5,0   | 5,5   | 6,0   | 6,5   | 7,0    | 7,5    | 8,0    |
| 2,5 | 0,38              | 0,73 | 1,13  | 1,53  | 1,90  | 2,22  | 2,48  | 2,70  | 2,86  | 2,99  | 3,08  | 3,15   | 3,20   | 3,24   |
| 2,6 | 0,38              | 0,75 | 1,19  | 1,63  | 2,04  | 2,41  | 2,71  | 2,96  | 3,16  | 3,31  | 3,42  | 3,51   | 3,57   | 3,61   |
| 2,7 | 0,39              | 0,78 | 1,25  | 1,73  | 2,20  | 2,62  | 2,97  | 3,26  | 3,49  | 3,67  | 3,81  | 3,91   | 3,99   | 4,04   |
| 2,8 | 0,39              | 0,80 | 1,31  | 1,85  | 2,38  | 2,85  | 3,26  | 3,60  | 3,87  | 4,09  | 4,25  | 4,37   | 4,46   | 4,53   |
| 2,9 | 0,39              | 0,83 | 1,38  | 1,98  | 2,57  | 3,11  | 3,58  | 3,98  | 4,30  | 4,56  | 4,75  | 4,90   | 5,01   | 5,10   |
| 3,0 | 0,39              | 0,86 | 1,45  | 2,12  | 2,78  | 3,40  | 3,95  | 4,41  | 4,79  | 5,09  | 5,33  | 5,51   | 5,65   | 5,75   |
| 3,1 | 0,40              | 0,89 | 1,54  | 2,27  | 3,01  | 3,72  | 4,35  | 4,89  | 5,34  | 5,70  | 5,99  | 6,21   | 6,37   | 6,49   |
| 3,2 | 0,40              | 0,92 | 1,62  | 2,43  | 3,27  | 4,08  | 4,81  | 5,44  | 5,97  | 6,40  | 6,74  | 7,01   | 7,21   | 7,36   |
| 3,3 | 0,41              | 0,95 | 1,72  | 2,61  | 3,56  | 4,48  | 5,32  | 6,06  | 6,68  | 7,20  | 7,61  | 7,93   | 8,17   | 8,36   |
| 3,4 | 0,41              | 0,99 | 1,82  | 2,81  | 3,87  | 4,92  | 5,90  | 6,76  | 7,50  | 8,11  | 8,60  | 8,99   | 9,29   | 9,51   |
| 3,5 | 0,42              | 1,03 | 1,93  | 3,03  | 4,22  | 5,42  | 6,55  | 7,55  | 8,42  | 9,15  | 9,74  | 10,21  | 10,57  | 10,85  |
| 3,6 | 0,42              | 1,07 | 2,04  | 3,26  | 4,60  | 5,97  | 7,27  | 8,45  | 9,48  | 10,34 | 11,05 | 11,62  | 12,06  | 12,41  |
| 3,7 | 0,43              | 1,12 | 2,17  | 3,52  | 5,03  | 6,59  | 8,09  | 9,47  | 10,68 | 11,71 | 12,56 | 13,25  | 13,79  | 14,21  |
| 3,8 | 0,43              | 1,16 | 2,31  | 3,80  | 5,50  | 7,28  | 9,02  | 10,63 | 12,06 | 13,28 | 14,30 | 15,13  | 15,80  | 16,31  |
| 3,9 | 0,44              | 1,21 | 2,45  | 4,10  | 6,02  | 8,05  | 10,06 | 11,94 | 13,63 | 15,09 | 16,31 | 17,32  | 18,12  | 18,76  |
| 4,0 | 0,45              | 1,26 | 2,61  | 4,43  | 6,59  | 8,91  | 11,23 | 13,43 | 15,42 | 17,16 | 18,63 | 19,85  | 20,83  | 21,61  |
| 4,1 | 0,45              | 1,32 | 2,78  | 4,80  | 7,22  | 9,87  | 12,55 | 15,12 | 17,47 | 19,54 | 21,31 | 22,78  | 22,98  | 24,94  |
| 4,2 | 0,46              | 1,38 | 2,96  | 5,20  | 7,93  | 10,95 | 14,05 | 17,05 | 19,82 | 22,29 | 24,41 | 26,19  | 27,65  | 28,83  |
| 4,3 | 0,47              | 1,44 | 3,16  | 5,63  | 8,70  | 12,15 | 15,73 | 19,24 | 22,51 | 25,45 | 28,00 | 30,16  | 31,93  | 33,38  |
| 4,4 | 0,48              | 1,51 | 3,37  | 6,11  | 9,56  | 13,50 | 17,64 | 21,74 | 25,60 | 29,10 | 32,16 | 34,77  | 36,94  | 38,71  |
| 4,5 | 0,49              | 1,57 | 3,60  | 6,63  | 10,52 | 15,01 | 19,79 | 24,58 | 29,14 | 33,31 | 36,99 | 40,15  | 42,79  | 44,96  |
| 4,6 | 0,49              | 1,65 | 3,85  | 7,20  | 11,57 | 16,70 | 22,23 | 27,82 | 33,20 | 38,17 | 42,59 | 46,41  | 49,63  | 52,29  |
| 4,7 | 0,50              | 1,73 | 4,12  | 7,82  | 12,75 | 18,59 | 24,98 | 31,53 | 37,88 | 43,79 | 49,10 | 53,72  | 57,65  | 60,91  |
| 4,8 | 0,52              | 1,81 | 4,40  | 8,50  | 14,04 | 20,72 | 28,11 | 35,75 | 43,25 | 50,29 | 56,66 | 62,26  | 67,05  | 71,05  |
| 4,9 | 0,52              | 1,90 | 4,71  | 9,25  | 15,49 | 23,11 | 31,64 | 40,57 | 49,42 | 57,81 | 65,47 | 72,24  | 78,08  | 82,98  |
| 5,0 | 0,53              | 1,99 | 5,04  | 10,07 | 17,09 | 25,78 | 35,65 | 46,08 | 56,53 | 66,52 | 75,72 | 83,92  | 91,03  | 97,05  |
| 5,1 | 0,55              | 2,09 | 5,40  | 10,97 | 18,86 | 28,79 | 40,19 | 52,39 | 64,71 | 76,61 | 87,66 | 97,58  | 106,3  | 113,6  |
| 5,2 | 0,56              | 2,19 | 5,79  | 11,95 | 20,84 | 32,17 | 45,34 | 59,60 | 74,15 | 88,32 | 101,6 | 113,6  | 124,2  | 133,2  |
| 5,3 | 0,57              | 2,30 | 6,21  | 13,03 | 23,03 | 35,96 | 51,19 | 67,85 | 85,02 | 101,9 | 117,8 | 132,4  | 145,3  | 156,4  |
| 5,4 | 0,58              | 2,41 | 6,66  | 14,21 | 25,46 | 40,23 | 57,83 | 77,29 | 97,56 | 117,7 | 136,8 | 154,4  | 170,1  | 183,8  |
| 5,5 | 0,59              | 2,54 | 7,14  | 15,50 | 28,17 | 45,03 | 65,37 | 88,11 | 112,0 | 136,0 | 159,0 | 180,3  | 199,4  | 216,2  |
| 5,6 | 0,61              | 2,67 | 7,67  | 16,92 | 31,18 | 50,42 | 73,93 | 100,5 | 128,8 | 157,3 | 184,9 | 210,7  | 234,0  | 254,6  |
| 5,7 | 0,62              | 2,80 | 8,23  | 18,48 | 34,53 | 56,49 | 83,66 | 114,7 | 148,1 | 182,0 | 215,2 | 246,4  | 274,8  | 300,1  |
| 5,8 | 0,64              | 2,95 | 8,84  | 20,19 | 38,25 | 63,33 | 94,73 | 131,0 | 170,4 | 210,9 | 250,7 | 288,4  | 323,1  | 354,1  |
| 5,9 | 0,65              | 3,10 | 9,50  | 22,07 | 42,39 | 71,02 | 107,3 | 149,8 | 196,2 | 244,4 | 292,2 | 337,9  | 380,2  | 418,2  |
| 6,0 | 0,67              | 3,26 | 10,21 | 24,13 | 47,00 | 79,69 | 121,6 | 171,2 | 226,1 | 283,5 | 340,9 | 396,2  | 447,7  | 494,4  |
| 6,1 | 0,68              | 3,44 | 10,98 | 26,39 | 52,14 | 89,45 | 138,0 | 195,9 | 260,6 | 329,0 | 398,0 | 464,9  | 527,7  | 585,0  |
| 6,2 | 0,70              | 3,62 | 11,82 | 28,87 | 57,86 | 100,5 | 156,5 | 224,2 | 300,6 | 382,1 | 464,9 | 546,0  | 622,5  | 692,8  |
| 6,3 | 0,72              | 3,81 | 12,71 | 31,60 | 64,24 | 112,9 | 177,7 | 256,8 | 347,0 | 444,0 | 543,5 | 641,6  | 734,9  | 821,1  |
| 6,4 | 0,73              | 4,02 | 13,68 | 34,60 | 71,34 | 126,9 | 201,7 | 294,3 | 400,7 | 516,3 | 635,8 | 754,5  | 868,3  | 974,0  |
| 6,5 | 0,75              | 4,23 | 14,73 | 37,90 | 79,25 | 142,6 | 229,2 | 337,3 | 463,0 | 600,6 | 744,2 | 887,9  | 1026,6 | 1156,3 |
| 6,6 | 0,77              | 4,46 | 15,87 | 41,52 | 88,07 | 160,4 | 260,5 | 386,9 | 535,2 | 699,2 | 871,6 | 1045,5 | 1214,6 | 1373,8 |

$$\mu_{ij} = 1 - \frac{\Gamma_N\left[\frac{3}{\xi} + 1, v_{ij}\right] - \Gamma_N\left[\frac{5}{\xi} + 1, v_{ij}\right] v_{ij}^{-2/\xi}}{\Gamma_C\left[\frac{3}{\xi} + 1\right]}$$

$$\xi = \xi_0 \left(1, 04 - 0, 14 \frac{|z - T_1|}{D - T_1}\right)$$
 without being less than 0,9  $\xi_0$

$$\xi_0 = \frac{73 - 0,07 L}{60} C_{FL}$$
 without being less than 0,85

$T_1$  : Draught, in m, corresponding to the loading condition “Full load” or “Ballast”

$C_{FL}$  : • in general:  $C_{FL} = 1$   
• when the additional class notation **VeriSTAR-HULL DFL xx years** is assigned, xx being equal to  $T_{FL}$ :

$$C_{FL} = \frac{\log[0, 2 \log(N_{tFL})]}{\log[0, 2 \log(N_t)]}$$

$$v_{ij} = -\left(\frac{S_q}{\Delta \sigma_{N,ij}}\right)^\xi \ln p_R$$

$$S_q = (K_p 10^{-7})^{1/3}$$

$$K_p = 5,802 \left(\frac{22}{t}\right)^{0,9} 10^{12}$$

$t$  : Net thickness, in mm, of the element under consideration not being taken less than 22 mm

$N_t$  : Number of cycles, to be taken equal to:

$$N_t = \frac{631 \alpha_0}{T_A} 10^6$$

$$N_{tFL} = \frac{31,55 \alpha_0 T_{FL}}{T_A} 10^6$$

$\alpha_0$  : Sailing factor, taken equal to 0,85

$T_A$  : Average period, in seconds, to be taken equal to:  
 $T_A = 4 \log L$

$T_{FL}$  : Increased design fatigue life, in years, having a value between 25 and 40

$$p_R = 10^{-5}$$

$\Gamma_N[X+1, v_{ij}]$ : Incomplete Gamma function, calculated for  $X = 3 / \xi$  or  $X = 5 / \xi$  and equal to:

$$\Gamma_N[X + 1, v_{ij}] = \int_0^{v_{ij}} t^X e^{-t} dt$$

Values of  $\Gamma_N[X+1, v_{ij}]$  are also indicated in Tab 7. For intermediate values of  $X$  and  $v_{ij}$ ,  $\Gamma_N$  may be obtained by linear interpolation

$\Gamma_C[X+1]$  : Complete Gamma function, calculated for  $X = 3 / \xi$ , equal to:

$$\Gamma_C[X + 1] = \int_0^{500} t^X e^{-t} dt$$

Values of  $\Gamma_C[X+1]$  are also indicated in Tab 8. For intermediate values of  $X$ ,  $\Gamma_C$  may be obtained by linear interpolation.

Table 8 : Function  $\Gamma_C [X+1]$

| X   | $\Gamma_C [X+1]$ | X   | $\Gamma_C [X+1]$ |
|-----|------------------|-----|------------------|
| 2,5 | 3,323            | 3,3 | 8,855            |
| 2,6 | 3,717            | 3,4 | 10,136           |
| 2,7 | 4,171            | 3,5 | 11,632           |
| 2,8 | 4,694            | 3,6 | 13,381           |
| 2,9 | 5,299            | 3,7 | 15,431           |
| 3,0 | 6,000            | 3,8 | 17,838           |
| 3,1 | 6,813            | 3,9 | 20,667           |
| 3,2 | 7,757            | 4,0 | 24,000           |

3.1.2 Cumulative damage ratio

The cumulative damage ratio is to be obtained from the following formula:

$$D = K_{cor} [\alpha D_F + (1 - \alpha) D_B]$$

where:

$\alpha$  : Part of the ship's life in full load condition, given in Tab 9 for various ship types

Table 9 : Part of the ship's life in full load condition

| Service notation  | Coefficient $\alpha$ |
|---|----------------------|
| <b>Oil tanker ESP</b><br><b>Chemical tanker ESP</b><br><b>Liquefied gas carrier</b><br><b>Tanker</b><br><b>Bulk carrier ESP</b><br><b>Ore carrier ESP</b><br><b>Combination carrier ESP</b> | 0,6                  |
| Others  | 0,75                 |

$D_F$  : Cumulative damage ratio for ship in “Full load” condition, taken equal to:

$$D_F = \frac{1}{6} D_{aF} + \frac{1}{6} D_{bF} + \frac{1}{3} D_{cF} + \frac{1}{3} D_{dF}$$

$D_B$  : Cumulative damage ratio for ship in “Ballast” condition, taken equal to:

$$D_B = \frac{1}{3} D_{aB} + \frac{1}{3} D_{bB} + \frac{1}{3} D_{cB}$$

$D_{aF}$ ,  $D_{bF}$ ,  $D_{cF}$ ,  $D_{dF}$ : Elementary damage ratios for load cases “a”, “b”, “c” and “d”, respectively, in “Full load” condition, defined in [3.1.1]

$D_{aB}$ ,  $D_{bB}$ ,  $D_{cB}$ : Elementary damage ratios for load cases “a”, “b”, and “c”, respectively, in “Ballast” condition, defined in [3.1.1]

$K_{cor}$  : Corrosion factor, taken equal to:

- $K_{cor} = 1,5$  for cargo oil tanks
- $K_{cor} = 1,1$  for ballast tanks having an effective coating protection.

## 4 Stress range

### 4.1 General

#### 4.1.1 Calculation point

Unless otherwise specified, stresses are to be determined at the hot spots indicated, for each detail, in the relevant figures in Ch 12, Sec 2.

#### 4.1.2 Stress components

For the details in [1.1.3], the stresses to be used in the fatigue check are the normal stresses in the directions indicated, for each detail, in the relevant figures in Ch 12, Sec 2.

Where the fatigue check is required for details other than those in [1.1.3], the stresses to be used are the principal stresses at the hot spots which form the smallest angle with the crack rising surface.

### 4.2 Hot spot stress range

#### 4.2.1 Elementary hot spot stress range

The elementary hot spot stress range  $\Delta\sigma_{G,ij}$  is to be obtained, in N/mm<sup>2</sup>, in accordance with:

- Ch 7, App 1, [6] for details where the stresses are to be calculated through a three dimensional structural models
- [6.2] for details located at ends of ordinary stiffeners.

### 4.3 Notch stress range

#### 4.3.1 Elementary notch stress range

The elementary notch stress range is to be obtained, in N/mm<sup>2</sup>, from the following formula:

$$\Delta\sigma_{N,ij} = K_{C,ij} \Delta\sigma_{N0,ij}$$

with:

$$\Delta\sigma_{N0,ij} = 0,7 K_F K_m \Delta\sigma_{G,ij}$$

where:

$K_F$  : Fatigue notch factor, equal to:

$$K_F = \lambda \sqrt{\frac{\theta}{30}}$$

for flame-cut edges,  $K_F$  may be taken equal to 2,0

$\lambda$  : Coefficient depending on the weld configuration, and given in Tab 10

$\theta$  : Mean weld toe angle, in degrees, without being taken less than 30°. Unless otherwise specified,  $\theta$  may be taken equal to:

- 30° for butt joints
- 45° for T joints or cruciform joints

$K_m$  : Stress concentration factor, taking account of misalignment, defined in Tab 11, and to be taken not less than 1,0

$\Delta\sigma_{G,ij}$  : Elementary hot spot stress range, defined in [4.2.1]

$$K_{C,ij} = \frac{0,4R_{eH}}{\Delta\sigma_{N0,ij}} + 0,6 \text{ with } 0,8 \leq K_{C,ij} \leq 1$$

## 5 Checking criteria

### 5.1 Damage ratio

**5.1.1** The cumulative damage ratio  $D$  calculated according to [3.1.2], is to comply with the following formula:

$$D \leq \frac{1}{\gamma_R}$$

## 6 Structural details located at ends of ordinary stiffeners

### 6.1 General

**6.1.1** For the fatigue check of connections located at ends of ordinary stiffeners, the elementary hot spot stress range  $\Delta\sigma_{G,ij}$  may be calculated as indicated in [6.2].

### 6.2 Determination of elementary hot spot stress range

#### 6.2.1 Nominal local stress

For each load case "a", "b", "c" and "d", "-max" and "-min", the nominal local stress  $\sigma_\ell$  applied to the ordinary stiffener, is to be obtained, in N/mm<sup>2</sup>, from the following formula:

$$\sigma_\ell = \frac{\gamma_{s2} p_s + \gamma_{w2} p_w}{12 w} \left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

where:

$w$  : Net section modulus, in cm<sup>3</sup>, of the stiffener, with an attached plating of width  $b_p$ , to be calculated as specified in Ch 4, Sec 3, [3.4]

$s$  : Spacing, in m, of ordinary stiffeners

$\ell$  : Span, in m, of ordinary stiffeners, measured between the supporting members, see Ch 4, Sec 3, [3.2].

#### 6.2.2 Elementary hot spot stress range

For each load case "a", "b", "c" and "d", the elementary hot spot stress range  $\Delta\sigma_{G,ij}$  is to be obtained, in N/mm<sup>2</sup>, from the following formula:

$$\Delta\sigma_{G,ij} = | \sigma_{G(i-max)} - \sigma_{G(i-min)} | + K_\ell \Delta\sigma_{DEF,ij}$$

where:

$$\sigma_{G(i-max)} = K_N (K_h \sigma_h + K_\ell K_s \sigma_\ell)_{(i-max)}$$

$$\sigma_{G(i-min)} = K_N (K_h \sigma_h + K_\ell K_s \sigma_\ell)_{(i-min)}$$

$\Delta\sigma_{DEF,ij}$  : Nominal stress range due to the local deflection of the ordinary stiffener to be obtained, in N/mm<sup>2</sup>, from the following formula:

$$\Delta\sigma_{DEF,ij} = \frac{4(\Delta\delta)EI}{w\ell^2} 10^{-5}$$

$\sigma_h$  : Nominal hull girder stress for the load case "i-max" or "i-min" considered, to be determined as indicated in [2.3.1]

$\sigma_\ell$  : Nominal local stress for the load case "i-max" or "i-min" considered, to be determined as indicated in [6.2.1]

Table 10 : Weld coefficient  $\lambda$

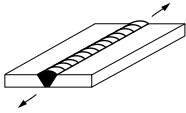
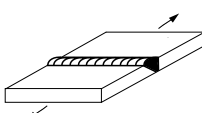
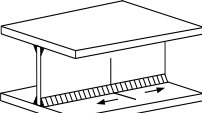
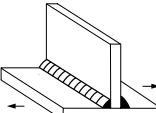
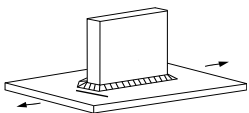
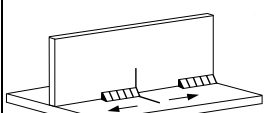
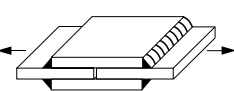
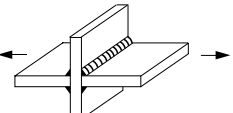
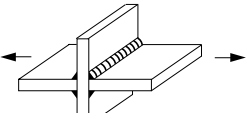
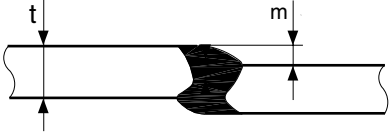
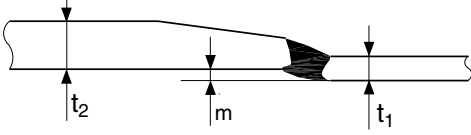
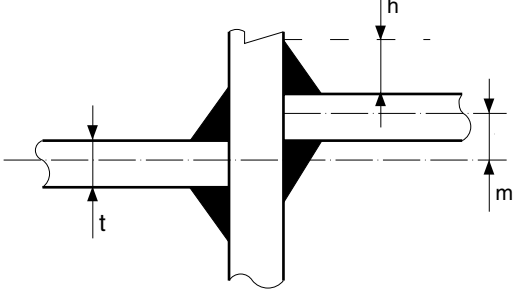
| Weld configuration   |   |  |  | Coefficient $\lambda$ |              |
|--|---|--|--|-----------------------|--------------|
| Type   | Description   | Stress direction   | Figure   | Not grinded weld      | Grinded weld |
| Butt weld  |   | Parallel to the weld                                     |    | 2,10                  | 1,85         |
|  |   | Perpendicular to the weld                                |    | 2,40                  | 2,10         |
| Fillet weld  | Continuous  | Parallel to the weld                                     |    | 1,80                  | 1,60         |
|  |   | Perpendicular to the weld (1)                            |   | 2,15                  | 1,90         |
|  | Well contoured end  | Perpendicular to the weld                                |  | 2,15                  | 1,90         |
|  | Not continuous  | Parallel to the weld                                     |  | 2,90                  | 2,55         |
|  | Lap weld  | Axial loading out of plane and perpendicular to the weld |  | 4,50                  | 3,95         |
| Cruciform Joint  | Full penetration or partial penetration with toe cracking | Perpendicular to the weld                                |  | 2,10                  | 1,85         |
|  | Partial penetration with root cracking                    | Perpendicular to the weld                                |  | 4,50                  | N.A.         |
| <p>(1) This case includes the hot spots indicated in the sheets of special structural details in Ch 12, Sec 2 relevant to the connections of longitudinal ordinary stiffeners with transverse primary supporting members.</p> <p><b>Note 1:</b> N.A. = Not applicable.</p> |   |  |  |                       |              |

Table 11 : Stress concentration factor  $K_m$  for misalignment

| Geometry  | $K_m$ (1)  |
|---|--|
| <b>Axial misalignment between flat plates</b><br>  | $1 + \frac{3(m - m_0)}{t}$   |
| <b>Axial misalignment between flat plates of different thicknesses</b><br>   | $1 + \frac{6(m - m_0)}{t_1} \frac{t_1^{3/2}}{t_1^{3/2} + t_2^{3/2}}$ |
| <b>Axial misalignment in fillet welded cruciform joints</b><br>   | $1 + \frac{m - m_0}{t + h}$  |
| <b>(1)</b> When the actual misalignment $m$ is lower than the permissible misalignment $m_0$ , $K_m$ is to be taken equal to 1.<br><b>Note 1:</b><br>$m$ : Actual misalignment between two abutting members<br>$m_0$ : Permissible misalignment for the detail considered, given in Ch 12, Sec 2. |  |

$K_N$  : Coefficient taking account of North Atlantic navigation, taken equal to 1,0

$K_S$  : Coefficient taking account of the stiffener section geometry, equal to:

$$K_S = 1 + \left[ \frac{t_f(a^2 - b^2)}{2w_B} \right] \left[ 1 - \frac{b}{a + b} \left( 1 + \frac{w_B}{w_A} \right) \right] 10^{-3}$$

without being taken less than 1,0

$a, b$  : Eccentricities of the stiffener, in mm, defined in Fig 3

Bulb sections are to be taken as equivalent to an angle profile, as defined in Ch 4, Sec 3, [3.1.2] with  $a = 0,75 b_f$  and  $b = 0,25 b_f$

$t_f$  : Face plate net thickness, in mm

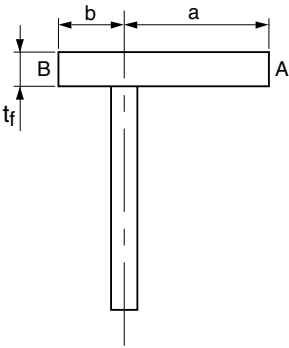
$b_f$  : Face plate width, in mm

$w_A, w_B$  : Net section moduli of the stiffener without attached plating, in  $cm^3$ , respectively in A and B (see Fig 3), about its neutral axis parallel to the stiffener web

$\Delta\delta$  : Local range of deflection, in mm, of the ordinary stiffener

$I$  : Net moment of inertia, in  $cm^4$ , of the ordinary stiffener with an attached plating of width  $b_p$ , to be calculated as specified in Ch 4, Sec 3, [3.4].

Figure 3 : Geometry of a stiffener section



# APPENDIX 1

# ANALYSES BASED ON THREE DIMENSIONAL MODELS

## Symbols

For symbols not defined in this Appendix, refer to the list at the beginning of this Chapter.

$\rho$  : Sea water density, taken equal to 1,025 t/m<sup>3</sup>

$g$  : Gravity acceleration, in m/s<sup>2</sup>:

$$g = 9,81 \text{ m/s}^2$$

$h_1$  : Reference values of the ship relative motions in the upright ship condition, defined in Ch 5, Sec 3, [3.3]

$h_2$  : Reference values of the ship relative motions in the inclined ship conditions, defined in Ch 5, Sec 3, [3.3]

$$\alpha = \frac{T_1}{T}$$

$T_1$  : Draught, in m, corresponding to the loading condition considered

$M_{SW}$  : Still water bending moment, in kN.m, at the hull transverse section considered

$M_{WV}$  : Vertical wave bending moment, in kN.m, at the hull transverse section considered, defined in Ch 5, Sec 2, [3.1], having the same sign as  $M_{SW}$

$Q_{SW}$  : Still water shear force, in kN, at the hull transverse section considered

$Q_{WV}$  : Vertical wave shear force, in kN, at the hull transverse section considered, defined in Ch 5, Sec 2, [3.4], having sign:

- where  $M_{WV}$  is positive (hogging condition):  
positive for  $x < 0,5L$   
negative for  $x \geq 0,5L$
- where  $M_{WV}$  is negative (sagging condition):  
negative for  $x < 0,5L$   
positive for  $x \geq 0,5L$

$\gamma_{S1}, \gamma_{W1}$  : Partial safety factors, defined in Ch 7, Sec 3.

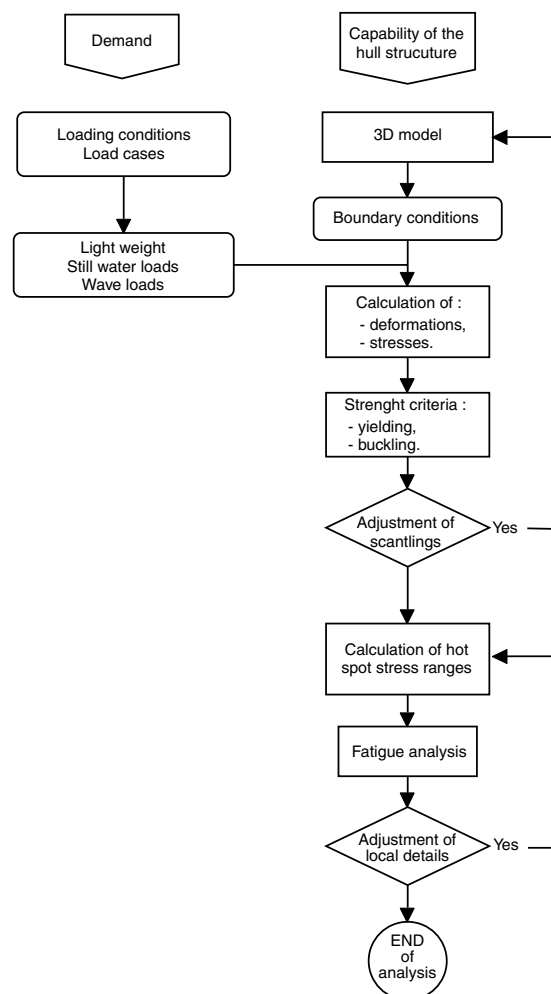
## 1 General

### 1.1 Application

**1.1.1** The requirements of this Appendix 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 Ch 7, Sec 3.

The analysis application procedure is shown graphically in Fig 1.

**Figure 1 : Application procedure of the analyses based on three dimensional models**



**1.1.2** This Appendix 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
- calculating the hot spot stress ranges in the structural details which are to be used in the fatigue check.

**1.1.3** The yielding and buckling checks of primary supporting members are to be carried out according to Ch 7, Sec 3. The fatigue check of structural details is to be carried out according to Ch 7, Sec 4.

2 Analysis criteria

2.1 General

2.1.1 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 on 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

2.3.1 Beam models may be adopted in cases specified in Ch 7, Sec 3, [1.1.2], 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, finite element models are to be adopted when deemed necessary by the Society on the basis of the ship's structural arrangement.

2.4 Structural detail analysis

2.4.1 Structural details in Ch 7, Sec 4, [1.1.4], for which a fatigue analysis is to be carried out, are to be modelled as specified in [6].

3 Primary supporting members structural modelling

3.1 Model construction

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 finite 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 Ch 4, Sec 2. 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

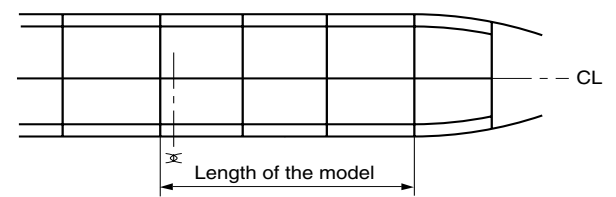
3.2.1 The longitudinal extension of the structural model is to be such that:

- 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 In general, for multitank/hold ships more than 170 m in length, the conditions in [3.2.1] are considered as being satisfied when the model is extended over at least three cargo tank/hold lengths.

For the analysis of the midship area, this model is to be such that its aft end corresponds to the first transverse bulkhead aft of the midship, as shown in Fig 2. The structure of the fore and aft transverse bulkheads located within the model, including the bulkhead plating, is to be modelled.

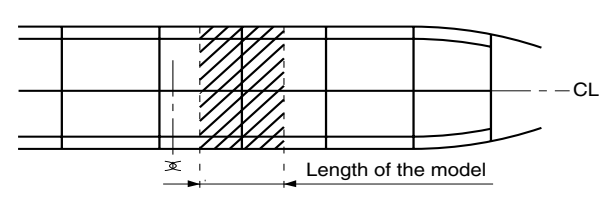
Figure 2 : Model longitudinal extension  
Ships more than 170 m in length



3.2.3 For ships less than 170 m in length, 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 Fig 3).

However, larger models may need to be adopted when deemed necessary by the Society on the basis of the ship's structural arrangement.

Figure 3 : Model longitudinal extension  
Ships less than 170 m in length



3.2.4 In the case of structural symmetry with respect to the ship's centreline longitudinal plane, the hull structures may be modelled over half the ship's breadth.



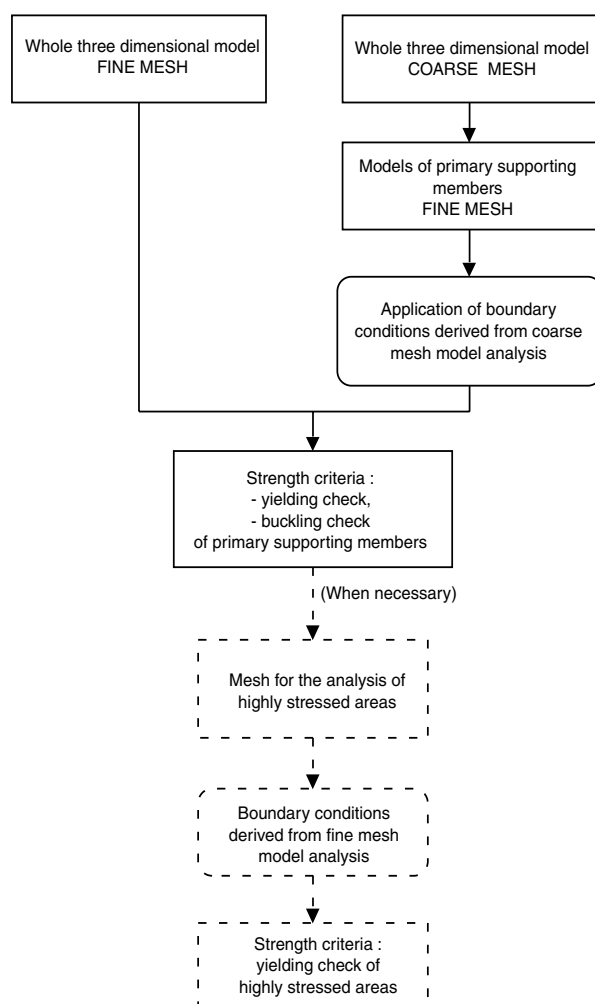
### 3.3 Finite element modelling criteria

#### 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 Fig 4), 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 4 : Finite element modelling criteria**



#### 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 Finite element models

#### 3.4.1 General

Finite 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.

Most of quadrilateral elements are to be such that the ratio between the longer side length and the shorter side length does not exceed 2. Some of them may have a ratio not exceeding 4. 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 on 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 stripe
- 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.

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.

#### 3.4.3 Fine mesh

The ship's structure may be considered as finely meshed when each longitudinal ordinary stiffener is modelled; as a consequence, the standard size of finite 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 with general behaviour 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 strain, positioned on their neutral axes, whose inertia characteristics are to be calculated as specified in Ch 4, Sec 3, [4].

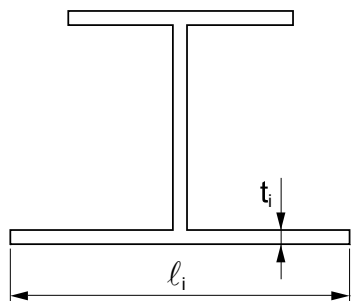
3.5.2 Torsional moments of inertia

Whenever the torsional effects of the modelling beams are to be taken into account (e.g. for modelling the double bottom, hopper tanks and lower stools), their net torsional moments of inertia are obtained, in cm<sup>4</sup>, from the following formulae:

- for open section beams (see Fig 5):

$$I_T = \frac{1}{3} \sum_i (t_i^3 \ell_i) 10^{-4}$$

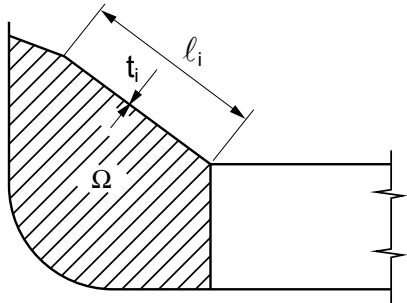
Figure 5 : Open section beams



- for box-type section beams, e.g. those with which hopper tanks and lower stools are modelled (see Fig 6):

$$I_T = \frac{4\Omega^2}{\sum_i \frac{\ell_i}{t_i}} 10^{-4}$$

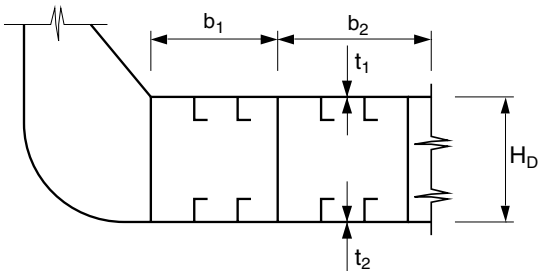
Figure 6 : Box-type section beams



- for beams of double skin structures (see Fig 7):

$$I_T = \frac{t_1 t_2 (b_1 + b_2) H_D^2}{2(t_1 + t_2)} 10^{-4}$$

Figure 7 : Beams of double skin structures



where:

- $\sum_i$  : Sum of all the profile segments that constitute the beam section
- $t_i, \ell_i$  : Net thickness and length, respectively, in mm, of the i-th profile segment of the beam section (see Fig 5 and Fig 6)
- $\Omega$  : Area, in mm<sup>2</sup>, of the section enclosed by the beam box profile (see Fig 6)
- $t_1, t_2$  : Net thickness, in mm, of the inner and outer plating, respectively, (see Fig 7)
- $b_1, b_2$  : Distances, in mm, from the beam considered to the two adjacent beams (see Fig 7)
- $H_D$  : Height, in mm, of the double skin (see Fig 7).

3.5.3 Variable cross-section primary supporting members

In the case of variable cross-section primary supporting members, the inertia characteristics of the modelling beams may be assumed as a constant and equal to their average value along the length of the elements themselves.

3.5.4 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.

3.5.5 Beams representing hull girder characteristics

The stiffness and inertia of the hull girder are 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 of the whole 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 ship's breadth (see [3.2.4]), in way of the ship's centreline longitudinal plane, symmetry or anti-symmetry boundary conditions as specified in Tab 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 ship's centreline longitudinal plane

| Boundary conditions | DISPLACEMENTS in directions (1) |       |       |
|---------------------|---------------------------------|-------|-------|
|                     | X                               | Y     | Z     |
| Symmetry            | free                            | fixed | free  |
| Anti-symmetry       | fixed                           | free  | fixed |

| Boundary conditions | ROTATION around axes (1) |       |       |
|---------------------|--------------------------|-------|-------|
|                     | X                        | Y     | Z     |
| Symmetry            | fixed                    | free  | fixed |
| Anti-symmetry       | free                     | fixed | free  |

(1) X, Y and Z directions and axes are defined with respect to the reference co-ordinate system in Ch 1, Sec 2, [4].

3.6.2 Structural models 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 Tab 2.

When the hull structure is modelled over half the ship's breadth (see [3.2.4]), in way of the ship's centreline longitudinal plane, symmetry or anti-symmetry boundary conditions as specified in Tab 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

| DISPLACEMENTS in directions (1):   |      |      | ROTATION around axes (1): |       |       |
|--|------|------|---------------------------|-------|-------|
| X  | Y    | Z    | X                         | Y     | Z     |
| fixed  | free | free | free                      | fixed | fixed |
| (1) X, Y and Z directions and axes are defined with respect to the reference co-ordinate system in Ch 1, Sec 2, [4]. |      |      |                           |       |       |

4 Primary supporting members load model

4.1 General

4.1.1 Loading conditions and load cases in intact conditions

The still water and wave loads are to be calculated for the most severe loading conditions as given in the loading manual, 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.

The wave local and hull girder loads are to be calculated in the mutually exclusive load cases "a", "b", "c" and "d" in Ch 5, Sec 4.

4.1.2 Loading conditions and load cases in flooding conditions

When applicable, the pressures in flooding conditions are to be calculated according to Ch 5, Sec 6, [9].

4.1.3 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.

4.1.4 Models extended over half ship’s breadth

When the ship is symmetrical with respect to her centreline longitudinal plane and the hull structure is modelled over half the ship’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 ship’s centreline longitudinal plane (see [3.6]).

4.2 Local loads

4.2.1 General

Still water loads include:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water internal loads, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Wave loads include:

- the wave pressure, defined in [4.2.2] for each load case “a”, “b”, “c” and “d”

- the inertial loads, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast, and for each load case “a”, “b”, “c” and “d”.

4.2.2 Wave loads

The wave pressure at any point of the model is obtained from the formulae in Tab 3 for upright ship conditions (load cases “a” and “b”) and in Tab 4 for inclined ship conditions (load cases “c” and “d”).

4.2.3 Distributed loads

Distributed loads are to be applied to the plating panels.

In the analyses carried out on the basis of membrane finite 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.

Table 3 : Wave pressure in upright ship conditions (load cases “a” and “b”)

| Location  | Wave pressure $p_w$ , in kN/m <sup>2</sup>  |   |
|---|---|---|
|   | crest   | trough (1)  |
| Bottom and sides below the waterline<br>( $z \leq T_1$ )  | $C_{F1} \alpha^{1/4} \rho g h_1 e^{\frac{-2\pi(T_1-z)}{\alpha L}}$                                      | $-C_{F1} \alpha^{1/4} \rho g h_1 e^{\frac{-2\pi(T_1-z)}{\alpha L}}$<br>without being taken less than $\rho g (z - T_1)$ |
| Sides above the waterline<br>( $z > T_1$ )  | $\rho g (T_1 + C_{F1} \alpha^{1/4} h_1 - z)$<br>without being taken, for case “a” only, less than 0,15L | 0,0   |
| (1) The wave pressure for load case “b, trough” is to be used only for the fatigue check of structural details (see Ch 7, Sec 4).   |   |   |
| <b>Note 1:</b><br>$C_{F1}$ : Combination factor, to be taken equal to: <ul style="list-style-type: none"><li><math>C_{F1} = 1,0</math> for load case “a”</li><li><math>C_{F1} = 0,5</math> for load case “b”.</li></ul> |   |   |

Table 4 : Wave pressure in inclined ship conditions (load cases “c” and “d”)

| Location  | Wave pressure $p_w$ , in kN/m <sup>2</sup> (negative roll angle)  |  |
|---|---|--|
|   | $y \geq 0$  | $y < 0$  |
| Bottom and sides below the waterline<br>( $z \leq T_1$ )  | $C_{F2} \alpha^{1/4} \rho g \left[ \frac{y}{B_W} h_1 e^{\frac{-2\pi(T_1-z)}{\alpha L}} + A_R y e^{\frac{-\pi(T_1-z)}{\alpha L}} \right]$                  | $C_{F2} \alpha^{1/4} \rho g \left[ \frac{y}{B_W} h_1 e^{\frac{-2\pi(T_1-z)}{\alpha L}} + A_R y e^{\frac{-\pi(T_1-z)}{\alpha L}} \right]$<br>without being taken less than $\rho g (z - T_1)$ |
| Sides above the waterline<br>( $z > T_1$ )  | $\rho g \left[ T_1 + C_{F2} \alpha^{1/4} \left( \frac{y}{B_W} h_1 + A_R y \right) - z \right]$<br>without being taken, for case “c” only, less than 0,15L | 0,0  |
| <b>Note 1:</b><br>$C_{F2}$ : Combination factor, to be taken equal to: <ul style="list-style-type: none"><li><math>C_{F2} = 1,0</math> for load case “c”</li><li><math>C_{F2} = 0,5</math> for load case “d”</li></ul><br>$B_W$ : Moulded breadth, in m, measured at the waterline at draught $T_1$ , at the hull transverse section considered<br>$A_R$ : Roll amplitude, defined in Ch 5, Sec 3, [2.4.1]. |   |  |

4.2.4 Concentrated loads

When the elements directly supporting the concentrated loads are not represented in the structural model, the loads are to be distributed on the adjacent structures according to the actual stiffness of the structures which transmit them.

In the analyses carried out on the basis of coarse mesh finite 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.

4.2.5 Cargo in sacks, bales and similar packages

The vertical loads are comparable to distributed loads. The loads on vertical walls may be disregarded.

4.2.6 Other cargoes

The modelling of cargoes other than those mentioned under [4.2.3] to [4.2.5] 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 horizontal wave bending moment
  - 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 on 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: the hull girder loads applied at the free end section are to be such that the values of the hull girder loads in Tab 5 are obtained
  - maximal shear forces in way of the aft transverse bulkhead of the central tank/hold: the hull girder loads applied at the free end section are to be such that the values of the hull girder loads in Tab 6 are obtained.

4.3.2 Structural model extended over one cargo tank/hold length

The normal and shear stresses induced by the hull girder loads in Tab 7 are to be added to the stresses induced in the primary supporting members by local loads.

Table 5 : Hull girder loads - Maximal bending moments at the middle of the central tank/hold

| Ship condition   | Load case  | Vertical bending moments at the middle of the central tank/hold |                              | Horizontal wave bending moment at the middle of the central tank/hold | Vertical shear forces at the middle of the central tank/hold |      |
|--|------------|---|------------------------------|---|--|------|
|  |            | Still water   | Wave                         |   | Still water  | Wave |
| Upright  | “a” crest  | $\gamma_{S1} M_{SW}$  | $0,625 \gamma_{W1} M_{WV,H}$ | 0   | 0  | 0    |
|  | “a” trough | $\gamma_{S1} M_{SW}$  | $0,625 \gamma_{W1} M_{WV,S}$ | 0   | 0  | 0    |
|  | “b”        | $\gamma_{S1} M_{SW}$  | $0,625 \gamma_{W1} M_{WV,S}$ | 0   | 0  | 0    |
| Inclined   | “c”        | $\gamma_{S1} M_{SW}$  | $0,250 \gamma_{W1} M_{WV}$   | $0,625 \gamma_{W1} M_{WH}$  | 0  | 0    |
|  | “d”        | $\gamma_{S1} M_{SW}$  | $0,250 \gamma_{W1} M_{WV}$   | $0,625 \gamma_{W1} M_{WH}$  | 0  | 0    |
| Note 1: Hull girder loads are to be calculated at the middle of the central tank/hold. |            |   |                              |   |  |      |

Table 6 : Hull girder loads - Maximal shear forces in way of the aft bulkhead of the central tank/hold

| Ship condition  | Load case  | Vertical bending moments in way of the aft bulkhead of the central tank/hold |                           | Vertical shear forces in way of the aft bulkhead of the central tank/hold |                            |
|---|------------|--|---------------------------|---|----------------------------|
|   |            | Still water  | Wave                      | Still water   | Wave                       |
| Upright   | “a” crest  | $\gamma_{S1} M_{SW}$   | $0,40 \gamma_{W1} M_{WV}$ | $\gamma_{S1} Q_{SW}$  | $0,625 \gamma_{W1} Q_{WV}$ |
|   | “a” trough | $\gamma_{S1} M_{SW}$   | $0,40 \gamma_{W1} M_{WV}$ | $\gamma_{S1} Q_{SW}$  | $0,625 \gamma_{W1} Q_{WV}$ |
|   | “b”        | $\gamma_{S1} M_{SW}$   | $0,40 \gamma_{W1} M_{WV}$ | $\gamma_{S1} Q_{SW}$  | $0,625 \gamma_{W1} Q_{WV}$ |
| Inclined  | “c”        | $\gamma_{S1} M_{SW}$   | $0,25 \gamma_{W1} M_{WV}$ | $\gamma_{S1} Q_{SW}$  | $0,250 \gamma_{W1} Q_{WV}$ |
|   | “d”        | $\gamma_{S1} M_{SW}$   | $0,25 \gamma_{W1} M_{WV}$ | $\gamma_{S1} Q_{SW}$  | $0,250 \gamma_{W1} Q_{WV}$ |
| Note 1: Hull girder loads are to be calculated in way of the aft bulkhead of the central tank/hold. |            |  |                           |   |                            |

Table 7 : Hull girder loads for a structural model extended over one cargo tank/hold length

| Ship condition | Load case  | Vertical bending moments at the middle of the model |                              | Horizontal wave bending moment at the middle of the model | Vertical shear forces at the middle of the model |                            |
|----------------|------------|---|------------------------------|---|--|----------------------------|
|                |            | Still water   | Wave                         |   | Still water                                      | Wave                       |
| Upright        | "a" crest  | $\gamma_{S1} M_{SW}$                                | $0,625 \gamma_{W1} M_{WV,H}$ | 0   | $\gamma_{S1} Q_{SW}$                             | $0,625 \gamma_{W1} Q_{WV}$ |
|                | "a" trough | $\gamma_{S1} M_{SW}$                                | $0,625 \gamma_{W1} M_{WV,S}$ | 0   | $\gamma_{S1} Q_{SW}$                             | $0,625 \gamma_{W1} Q_{WV}$ |
|                | "b"        | $\gamma_{S1} M_{SW}$                                | $0,625 \gamma_{W1} M_{WV,S}$ | 0   | $\gamma_{S1} Q_{SW}$                             | $0,625 \gamma_{W1} Q_{WV}$ |
| Inclined       | "c"        | $\gamma_{S1} M_{SW}$                                | $0,250 \gamma_{W1} M_{WV}$   | $0,625 \gamma_{W1} M_{WH}$                                | $\gamma_{S1} Q_{SW}$                             | $0,250 \gamma_{W1} Q_{WV}$ |
|                | "d"        | $\gamma_{S1} M_{SW}$                                | $0,250 \gamma_{W1} M_{WV}$   | $0,625 \gamma_{W1} M_{WH}$                                | $\gamma_{S1} Q_{SW}$                             | $0,250 \gamma_{W1} Q_{WV}$ |

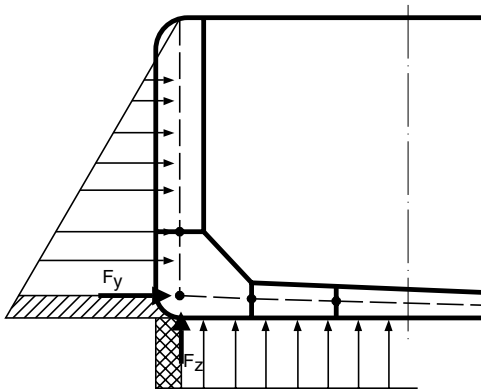
**Note 1:** Hull girder loads are to be calculated at the middle of the model.

4.4 Additional requirements for the load assignment to beam models

4.4.1 Vertical and transverse concentrated loads are to be applied to the model, as shown in Fig 8, 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.

Figure 8 : Concentrated loads equivalent to non-modelled distributed loads



5 Stress calculation

5.1 Analyses based on finite 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 finite element program include the contribution of both local and hull girder loads.

When finite 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 added to the stresses induced by local loads.

5.1.2 Stress components

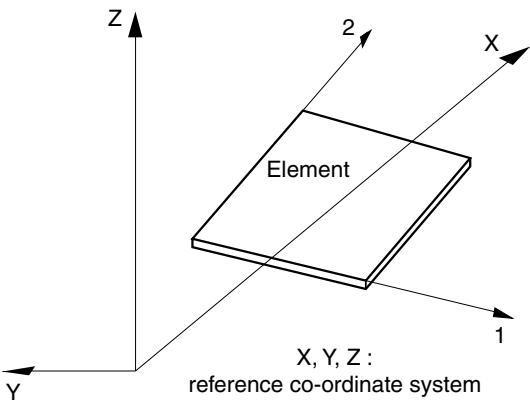
Stress components are generally identified with respect to the element co-ordinate system, as shown, by way of example, in Fig 9. The orientation of the element co-ordinate system may or may not coincide with that of the reference co-ordinate system in Ch 1, Sec 2, [4].

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:

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

Figure 9 : Reference and element co-ordinate systems



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 [3.2.3]), 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 added 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:

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

### 5.2.3 Stress calculation points

Stresses are to be calculated at least in the following points of each primary supporting member:

- in 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 are to be used for carrying out the checks required.

## 6 Fatigue analysis

### 6.1 Elementary hot spot stress range calculation

#### 6.1.1 General

The requirements of this Article apply for calculating the elementary hot spot stress range for the fatigue check of structural details at the connections of primary supporting members analysed through a three dimensional structural model. The fatigue check of these details is to be carried out in accordance with the general requirements of Ch 7, Sec 4, [1] to Ch 7, Sec 4, [5].

The definitions in Ch 7, Sec 4, [1.4] apply.

#### 6.1.2 Net scantlings

The three dimensional structural model is to be built considering all the structures with their net scantlings according to Ch 4, Sec 2.

### 6.1.3 Hot spot stresses directly obtained through finite element analyses

Where the structural detail is analysed through a finite element analysis based on a very fine mesh, the elementary hot spot stress range may be obtained as the difference between the maximum and minimum stresses induced by the wave loads in the hot spot considered.

The requirements for:

- the finite element modelling, and
- the calculation of the hot spot stresses and the hot spot stress range

are specified in [6.2].

### 6.1.4 Hot spot stresses directly obtained through the calculation of nominal stresses

Where the structural detail is analysed through a finite element analysis based on a mesh less fine than that in [6.1.3], the elementary hot spot stress range may be obtained by multiplying the nominal stress range, obtained as the difference between the maximum and minimum nominal stresses induced by the wave loads in the vicinity of the hot spot considered, by the appropriate stress concentration factors.

The requirements for:

- the finite element modelling
- the calculation of the nominal stresses and the nominal stress range
- the stress concentration factors
- the calculation of the hot spot stresses and the hot spot stress range

are specified in [6.3].

## 6.2 Hot spot stresses directly obtained through finite element analyses

### 6.2.1 Finite element model

In general, the determination of hot spot stresses necessitates carrying out a very fine mesh finite element analysis, further to a coarser mesh finite element analysis. The boundary nodal displacements or forces obtained from the coarser mesh model are applied to the very fine mesh model as boundary conditions.

The model extension is to be such as to enable a faithful representation of the stress gradient in the vicinity of the hot spot and to avoid it being incorrectly affected by the application of the boundary conditions.

### 6.2.2 Finite element modelling criteria

The finite element model is to be built according to the following requirements:

- the detail may be considered as being realised with no misalignment
- the size of finite elements located in the vicinity of the hot spot is to be about once to twice the thickness of the structural member. Where the details is the connection between two or more members of different thickness, the thickness to be considered is that of the thinnest member

- the centre of the first element adjacent to a weld toe is to be located between the weld toe and 0,4 times the thickness of the thinnest structural member connected by the weld
- plating, webs and face plates of primary and secondary members are to be modelled by 4-node thin shell or 8-node solid elements. In the case of a steep stress gradient, 8-node thin shell elements or 20-node solid elements are recommended
- when thin shell elements are used, the structure is to be modelled at mid-face of the plates
- the aspect ratio of elements is to be not greater than 2

**6.2.3 Calculation of hot spot stresses**

When the detail is located at a structural discontinuity where a large stress gradient is expected the hot spot stresses are normally obtained by linear extrapolation. The stress components must be evaluated at a distance of 0,5 and 1,5 times the thickness of the plating from the weld toe and linearly extrapolated to the weld toe. The two evaluation points must be located in two different finite elements.

In other cases or when extrapolation can not be used the hot spot stresses are to be calculated at the centroid of the first element adjacent to the hot spot. The size of this element has to be determined according to the requirements in [6.2.2].

Where the detail is the free edge of an opening (e.g. a cut-out for the passage of an ordinary stiffener through a primary supporting member), the hot spot stresses have to be calculated at the free edge. The stresses can be obtained by linear extrapolation or using fictitious truss elements with minimal stiffness fitted along the edge.

The stress components to be considered are those specified in Ch 7, Sec 4, [4.1.2]. They are to be calculated at the surface of the plate in order to take into account the plate bending moment, where relevant.

**6.2.4 Calculation of the elementary hot spot stress range**

The elementary hot spot stress range is to be obtained, in N/mm<sup>2</sup>, from the following formula:

$$\Delta\sigma_{s,ij} = |\sigma_{s,ij,max} - \sigma_{s,ij,min}|$$

where:

$\sigma_{s,ij,max}$ ,  $\sigma_{s,ij,min}$ : Maximum and minimum values of the hot spot stress, induced by the maximum and minimum loads, defined in Ch 7, Sec 4, [2.2] and Ch 7, Sec 4, [2.3]

i : Denotes the load case

j : Denotes the loading condition.

**6.3 Hot spot stresses obtained through the calculation of nominal stresses**

**6.3.1 Finite element model**

A finite element is to be adopted, to be built according to the requirements in [3.3] and [3.4]. The areas in the vicinity of the structural details are to be modelled with fine mesh models, as defined in [3.4.3].

**6.3.2 Calculation of the elementary nominal stress range**

The elementary nominal stress range is to be obtained, in N/mm<sup>2</sup>, from the following formula:

$$\Delta\sigma_{n,ij} = |\sigma_{n,ij,max} - \sigma_{n,ij,min}|$$

where:

$\sigma_{n,ij,max}$ ,  $\sigma_{n,ij,min}$ : Maximum and minimum values of the nominal stress, induced by the maximum and minimum loads, defined in Ch 7, Sec 4, [2.2] and Ch 7, Sec 4, [2.3]

i : Denotes the load case

j : Denotes the loading condition.

**6.3.3 Calculation of the elementary hot spot stress range**

The elementary hot spot stress range is to be obtained, in N/mm<sup>2</sup>, from the following formula:

$$\Delta\sigma_{s,ij} = K_s \Delta\sigma_{n,ij}$$

where:

$K_s$  : Stress concentration factor, defined in Ch 12, Sec 2, [2], for the relevant detail configuration

$\Delta\sigma_{n,ij}$  : Elementary nominal stress range, defined in [6.3.2].



## APPENDIX 2

## ANALYSES OF PRIMARY SUPPORTING MEMBERS SUBJECTED TO WHEELED LOADS

### 1 General

#### 1.1 Scope

**1.1.1** The requirements of this Appendix 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 Ch 7, Sec 3.

**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 are 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 Ch 7, Sec 3, [4.3].

#### 1.2 Application

**1.2.1** The requirements of this Appendix apply to ships whose 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 ship ends; their effect on the ship 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 ship's structural arrangement and loading conditions. In such cases, the analysis is generally to be carried out on the basis of a finite element model of the whole ship, built according to the requirements in Ch 7, App 1, as far as applicable.

#### 1.3 Information required

**1.3.1** To perform these structural analyses, the following characteristics of vehicles loaded are necessary:

- load per axle
- arrangement of wheels on axles
- tyre dimensions.

#### 1.4 Lashing of vehicles

**1.4.1** 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 interested parties.

### 2 Analysis criteria

#### 2.1 Finite element model analyses

**2.1.1** For ships greater than 200 m in length, finite element models, built according to Ch 7, App 1, [3.4], are generally to be adopted.

The analysis of primary supporting members is to be carried out on fine mesh models, as defined in Ch 7, App 1, [3.4.3].

**2.1.2** 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 Ch 7, App 1, [3.4.4].

#### 2.2 Beam model analyses

**2.2.1** For ships less than 200 m in length, beam models, built according to Ch 7, App 1, [3.5], may be adopted in lieu of the finite element models in [2.1], 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.

**2.2.2** In any case, finite element models may need to be adopted when deemed necessary by the Society on the basis of the ship's structural arrangement.

**3 Primary supporting members structural modelling**

**3.1 Model construction**

**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 Ch 4, Sec 2, [1].

**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 repeated 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 of 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 Tab 1.

**Table 1 : Symmetry conditions at the model fore and aft ends**

| DISPLACEMENTS in directions (1):   |      |      | ROTATION around axes (1): |       |       |
|--|------|------|---------------------------|-------|-------|
| X  | Y    | Z    | X                         | Y     | Z     |
| fixed  | free | free | free                      | fixed | fixed |
| (1) X, Y and Z directions and axes are defined with respect to the reference co-ordinate system in Ch 1, Sec 2, [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 ship conditions (as defined in Ch 5, Sec 4) 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.

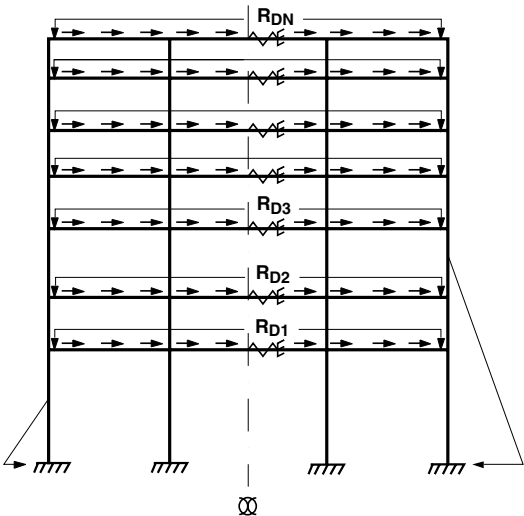
For ships with a traditional arrangement of fore and aft parts, a simplified approximation may be adopted, when deemed acceptable by the Society, defining the boundary conditions without taking into account the racking calculation and introducing springs, acting in the transverse direction, at the fore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

$$R_D = \frac{24EJ_D s_a 10^3}{2x^4 - 4L_D x^3 + L_D^2 \left( x^2 + 15,6 \frac{J_D}{A_D} \right) + L_D^3 x}$$

where:

- $J_D$  : Net moment of inertia, in  $m^4$ , of the average cross-section of the deck, with the attached side shell plating
- $A_D$  : Net area, in  $m^2$ , of the average cross-section of deck plating

**Figure 1 : Springs at the fore and aft ends of models subjected to transverse loads**



- $s_a$  : Spacing of side vertical primary supporting members, in m
- $x$  : Longitudinal distance, in m, measured from the transverse section at mid-length of the model to any deck end
- $L_D$  : Length of the deck, in m, to be taken equal to the ship'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 model

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 added to the stresses induced by local loads.

4.1.2 Loading conditions and load cases: wheeled cargoes

The still water and wave loads are to be calculated for the most severe loading conditions as given in the loading manual, 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 ship structures.

The wave local loads and hull girder loads are to be calculated in the mutually exclusive load cases "b" and "d" in Ch 5, Sec 4. Load cases "a" and "c" may be disregarded for the purposes of the structural analyses dealt with in this Appendix.

4.1.3 Loading conditions and load cases: dry uniform cargoes

When the ship'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.

The wave local loads and hull girder loads are to be calculated in the mutually exclusive load cases "b" and "d" in Ch 5, Sec 4. Load cases "a" and "c" may be disregarded for the purposes of the structural analyses dealt with in this Appendix.

4.2 Local loads

4.2.1 General

Still water loads include:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water forces induced by wheeled cargoes, defined in Ch 5, Sec 6, Tab 9.

Wave induced loads include:

- the wave pressure, defined in Ch 5, Sec 5, [2] for load cases "b" and "d"
- the inertial forces defined in Ch 5, Sec 6, Tab 9 for load cases "b" and "d".

When the ship's decks are also designed to carry dry uniform cargoes, local loads also include the still water and inertial pressures defined in Ch 5, Sec 6, [4]. Inertial pressures are to be calculated for load cases "b" and "d".

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 finite 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

4.3.1 The normal stresses induced by the hull girder loads in Tab 2 are to be added to the stresses induced in the primary supporting members by local loads.

Table 2 : Hull girder loads

| Ship condition | Load case | Vertical bending moments at the middle of the model  |                  | Horizontal wave bending moment at the middle of the model |
|----------------|-----------|--|------------------|---|
|                |           | Still water  | Wave             |   |
| Upright        | "b"       | $M_{SW}$   | $0,625 M_{WV,S}$ | 0   |
| Inclined       | "d"       | $M_{SW}$   | $0,25 M_{WV}$    | $0,625 M_{WH}$  |
| <b>Note 1:</b> |           |  |                  |   |
| $M_{SW}$       |           | Still water bending moment at the middle of the model, for the loading condition considered              |                  |   |
| $M_{WV,S}$     |           | Sagging wave bending moments at the middle of the model, defined in Ch 5, Sec 2                          |                  |   |
| $M_{WV}$       |           | Wave bending moment at the middle of the model, defined in Ch 5, Sec 2, having the same sign as $M_{SW}$ |                  |   |
| $M_{WH}$       |           | Horizontal wave bending moment at the middle of the model, defined in Ch 5, Sec 2.                       |                  |   |

5 Stress calculation

5.1 Stresses induced by local and hull girder loads

5.1.1 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 added to the stresses induced by local loads.

5.2 Analyses based on finite element models

5.2.1 Stress components

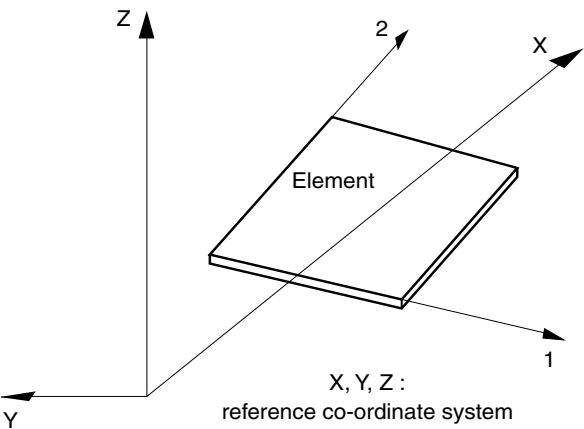
Stress components are generally identified with respect to the element co-ordinate system, as shown, by way of example, in Fig 2. The orientation of the element co-ordinate system may or may not coincide with that of the reference co-ordinate system in Ch 1, Sec 2, [4].

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:

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

Figure 2 : Reference and element co-ordinate systems



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:

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

5.3.2 Stress calculation points

Stresses are to be calculated at least in the following points of each primary supporting member:

- in 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

6.1.1 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 model

The structural model used to represent the deck primary supporting members is a beam grillage model.

6.2.2 Model extension

The structural model is to represent a hull portion which includes the zone under examination and which is repeated 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 Tab 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, in kN.m/rad, from the following formulae:

- for intermediate decks:

$$R_F = \frac{3E(J_1 + J_2)(\ell_1 + \ell_2)}{\ell_1^2 + \ell_2^2 - \ell_1 \ell_2} 10^{-5}$$

- for the uppermost deck:

$$R_F = \frac{6EJ_1}{\ell_1} 10^{-5}$$

where:

$\ell_1, \ell_2$  : Height, in m, of the 'tweendecks, respectively below and above the deck under examination (see Fig 3)

$J_1, J_2$  : Net moments of inertia, in cm<sup>4</sup>, of side primary supporting members with attached shell plating, relevant to the 'tweendecks, respectively below and above the deck under examination.

## 6.4 Load model

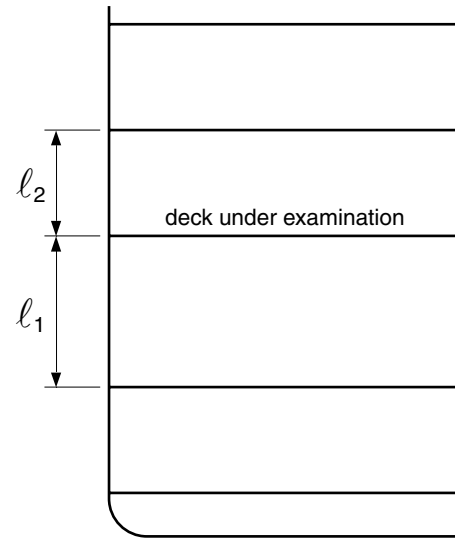
**6.4.1** Hull girder and local loads are to be calculated and applied to the model according to [4].

Wave loads are to be calculated considering load case "b" only.

## 6.5 Stress calculation

**6.5.1** Stress components are to be calculated according to [5.1] and [5.3].

**Figure 3 : Heights of tween-decks for grillage analysis of deck primary supporting members**



## APPENDIX 3

## ANALYSES BASED ON COMPLETE SHIP MODELS

### Symbols

|  |  |
|--|--|
| $g$  | : Gravity acceleration, equal to $9,81 \text{ m/s}^2$                                    |
| $\Delta$   | : Moulded displacement in seawater, in t   |
| $B$  | : Moulded breadth, in m  |
| $L$  | : Rule length, in m  |
| $T_R$  | : Roll period, in s, defined in Ch 5, Sec 3, [2.4.1]                                     |
| $F$  | : Froude's number, defined in Part B, Chapter 5, calculated at the maximum service speed |
| $\gamma_{S1}, \gamma_{W1}, \gamma_{S2}, \gamma_{W2}$ | : Partial safety factors defined in Ch 7, Sec 3  |
| $\lambda$  | : Wave length, in m.   |

### 1 General

#### 1.1 Application

**1.1.1** The requirements of this Appendix apply for the analysis criteria, structural modelling, load modelling and stress calculation of primary supporting members which are to be analysed through a complete ship model, according to Ch 7, Sec 3.

**1.1.2** This Appendix deals with that part of the structural analysis which aims at calculating the stresses in the primary supporting members and also in the hull plating, to be used for yielding and buckling checks.

**1.1.3** The yielding and buckling checks of primary supporting members are to be carried out according to Ch 7, Sec 3.

### 2 Structural modelling

#### 2.1 Model construction

##### 2.1.1 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 the inertia of the actual hull girder structure.

##### 2.1.2 Net scantlings

All the elements in [2.1.1] are to be modelled with their net scantlings according to Ch 4, Sec 2. 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.

#### 2.2 Model extension

**2.2.1** The complete ship is to be modelled so that the coupling between torsion and horizontal bending is properly taken into account in the structural analysis.

Superstructures are to be modelled in order to reproduce the correct lightweight distribution.

Long superstructures of ships with one of the service notations **passenger ship** or **ro-ro passenger ship** are to be modelled in order to also reproduce the correct hull global strength, in particular the contribution of each superstructure deck to the hull girder longitudinal strength.

**2.2.2** In the case of structural symmetry with respect to the ship's centreline longitudinal plane, the hull structures may be modelled over half the ship's breadth.

#### 2.3 Finite element modelling criteria

##### 2.3.1 Modelling of primary supporting members

The analyses of primary supporting members are to be based on fine mesh models, as defined in Ch 7, App 1, [3.4.3].

Such analyses may be carried out deriving the nodal displacements or forces, to be used as boundary conditions, from analyses of the complete ship based on coarse meshes, as defined in Ch 7, App 1, [3.4.2].

The areas for which analyses based on fine mesh models are to be carried out are listed in Tab 1 for various types of ships.

Other areas may be required to be analysed through fine mesh models, where deemed necessary by the Society, depending on the ship's structural arrangement and loading conditions as well as the results of the coarse mesh analysis.

.

##### 2.3.2 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 Ch 7, App 1, [3.4.4].

#### 2.4 Finite element models

##### 2.4.1 General

Finite 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, for some of the most common elements, 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 [2.4.2] to [2.4.4].

**Table 1 : Areas to be analysed through fine mesh models**

| Service notation            | Areas   |
|-----------------------------|---|
| <b>Container ship</b>       | <ul style="list-style-type: none"><li>• typical transverse reinforced frames</li><li>• hatch corners and hatch coamings of the strength deck</li><li>• connection of the cross-deck box beams to the longitudinal bulkheads and hatch coamings</li><li>• connection of the longitudinal deck girders to the transverse bulkheads</li><li>• end connections of hatch coamings including connection with the fore front of the superstructures, if any</li><li>• cut-outs in the longitudinal bulkheads, longitudinal deck girders, hatch coamings, and cross-deck box beams.</li></ul> |
| <b>Ro-ro cargo ship</b>     | <ul style="list-style-type: none"><li>• typical reinforced transverse rings</li><li>• typical deck girders</li><li>• areas of structural discontinuity (e.g. ramp areas).</li></ul>   |
| <b>Passenger ship</b>       | <ul style="list-style-type: none"><li>• areas in way of typical side and deck openings</li><li>• areas of significant discontinuity in primary supporting member arrangements (e.g. in way of lounges, large public spaces, theatres).</li></ul>  |
| <b>Ro-ro passenger ship</b> | <ul style="list-style-type: none"><li>• typical reinforced transverse rings</li><li>• typical deck girders</li><li>• areas of structural discontinuity (e.g. ramp areas)</li><li>• areas in way of typical side and deck openings</li><li>• areas of significant discontinuity in primary supporting member arrangements (e.g. in way of lounges, large public spaces).</li></ul>   |

**2.4.2 Coarse mesh**

The number of nodes and elements is to be such that the stiffness and the inertia of the model represent properly 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 on 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 stripe
- 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.

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.

**2.4.3 Fine mesh**

The ship's structure may be considered as finely meshed when each longitudinal secondary stiffener is modelled; as a consequence, the standard size of finite 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.

**2.4.4 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 with bending behaviour are to be used.

**2.5 Boundary conditions of the model**

**2.5.1** In order to prevent rigid body motions of the overall model, the constraints specified in Tab 2 are to be applied.

**2.5.2** When the hull structure is modelled over half the ship's breadth (see [2.2.2]), in way of the ship's centreline longitudinal plane, symmetry or anti-symmetry boundary conditions as specified in Tab 3 are to be applied, depending on the loads applied to the model (respectively symmetrical or anti-symmetrical).

Table 2 : Boundary conditions to prevent rigid body motion of the model

| Boundary conditions   | DISPLACEMENTS in directions (1) |       |       |
|---|---------------------------------|-------|-------|
|   | X                               | Y     | Z     |
| One node on the fore end of the ship                            | free                            | fixed | fixed |
| One node on the port side shell at aft end of the ship (2)      | fixed                           | free  | fixed |
| One node on the starboard side shell at aft end of the ship (2) | free                            | fixed | fixed |

| Boundary conditions  | ROTATION around axes (1) |      |      |
|--|--------------------------|------|------|
|  | X                        | Y    | Z    |
| One node on the fore end of the ship   | free                     | free | free |
| One node on the port side shell at aft end of the ship (2)   | free                     | free | free |
| One node on the starboard side shell at aft end of the ship (2)  | free                     | free | free |
| (1) X, Y and Z directions and axes are defined with respect to the reference co-ordinate system in Ch 1, Sec 2, [4].                                       |                          |      |      |
| (2) The nodes on the port side shell and that on the starboard side shell are to be symmetrical with respect to the ship's longitudinal plane of symmetry. |                          |      |      |

Table 3 : Symmetry and anti-symmetry conditions in way of the ship's centreline longitudinal plane

| Boundary conditions | DISPLACEMENTS in directions (1) |       |       |
|---------------------|---------------------------------|-------|-------|
|                     | X                               | Y     | Z     |
| Symmetry            | free                            | fixed | free  |
| Anti-symmetry       | fixed                           | free  | fixed |

| Boundary conditions  | ROTATION around axes (1) |       |       |
|--|--------------------------|-------|-------|
|  | X                        | Y     | Z     |
| Symmetry   | fixed                    | free  | fixed |
| Anti-symmetry  | free                     | fixed | free  |
| (1) X, Y and Z directions and axes are defined with respect to the reference co-ordinate system in Ch 1, Sec 2, [4]. |                          |       |       |

3 Load model

3.1 General

3.1.1 Design wave method

The various load components which occur simultaneously may be combined by setting the characteristics of regular waves that maximise the dominant load parameters given in Ch 5.

Any other method may be used provided that relevant documentation is submitted to the Society for review.

A recommended procedure to compute the characteristics of the design wave is provided in [3.2].

3.1.2 Loads

Still water loads include:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water internal loads, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Wave loads, determined by mean of hydrodynamic calculations according to [3.2], include:

- the wave pressure
- the inertial loads.

3.1.3 Lightweight

The lightweight of the ship is to be distributed over the model length, in order to obtain the actual longitudinal distribution of the still water bending moment.

3.1.4 Models extended over half ship's breadth

When the ship is symmetrical with respect to her centreline longitudinal plane and the hull structure is modelled over half the ship'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 ship's centreline longitudinal plane (see [2.5.2]).

3.2 Procedure for the selection of design waves

3.2.1 Summary of the loading procedure

Applicable cargo loading conditions given in Part D are analysed through:

- the computation of the characteristics of the finite element model under still water loads (see [3.3.1])
- the selection of the load cases critical for the strength of the resistant structural members (see [3.3.2]).

The determination of the design wave characteristics for each load case includes the following steps:

- computation of the response operators (amplitude and phase) of the dominant load effect
- selection of the wave length and heading according to the guidelines in [3.3]
- determination of the wave phase such that the dominant load effect reaches its maximum
- computation of the wave amplitude corresponding to the design value of the dominant load effect.

3.2.2 Dominant load effects

Each critical load case maximises the value of one of the nine following load effects having a dominant influence on the strength of some parts of the structure:

- vertical wave bending moment in hogging condition at midship section
- vertical wave bending moment in sagging condition at midship section
- vertical wave shear force on transverse bulkheads
- horizontal wave bending moment at midship section
- wave torque within cargo area of ships with large deck openings
- vertical acceleration in midship and fore body sections



- transverse acceleration at deck at sides at midship section
- wave pressure at bottom at centreline in upright ship condition, at midship section
- wave pressure at bottom at side in inclined ship condition, at midship section.

### 3.2.3 Response Amplitude Operators

The Response Amplitude Operators (RAO's) and associated phase characteristics are to be computed for wave periods between 4 and 22 seconds, using a seakeeping program, for the following motions and load effects:

- heave, sway, pitch, roll and yaw motions
- vertical wave bending moment at 0,50L or at the longitudinal position where the bending moment RAO is maximum
- vertical wave shear force at 0,25L and 0,50L
- horizontal wave bending moment at 0,50L
- wave torque at 0,25L, 0,50L and 0,75L (for ships with large deck openings).

The response amplitude operators are to be calculated for wave headings ranging from following seas (0 degree) to head seas (180 degrees) by increment of 15 degrees, using a ship speed of 60% of the maximum service speed.

The amplitude and phase of other dominant load effects may be computed at relevant wave period, using the RAO's listed above.

### 3.2.4 Design waves

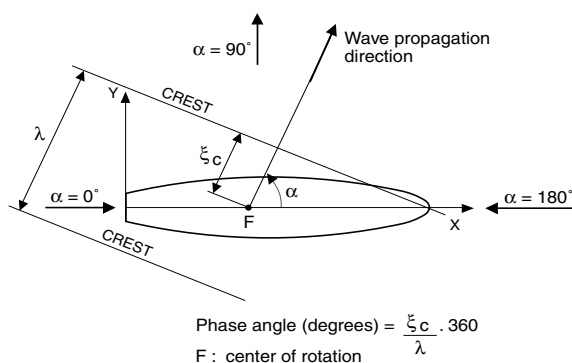
For each load case, the ship is considered to encounter a regular wave, defined by its parameters:

- wave length  $\lambda$  or period  $T$
- heading angle  $\alpha$  (see Fig 1)
- wave height (double amplitude)
- wave phase (see Fig 1).

The wave length  $\lambda$  and the wave period  $T$  are linked by the following relation:

$$\lambda = g T^2 / 2 \pi$$

Figure 1 : Wave heading



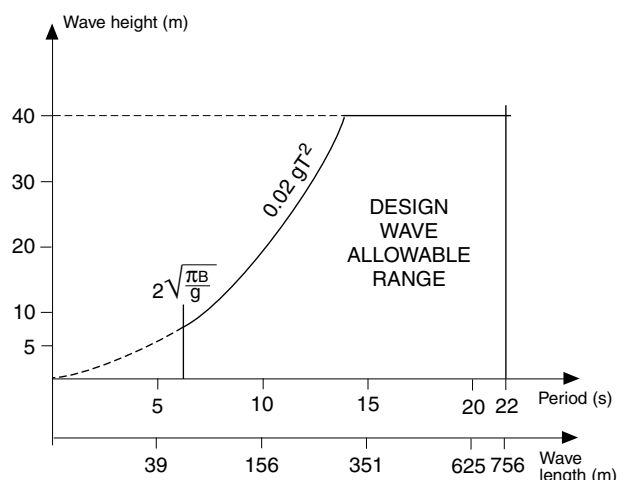
The range of variation of design wave period is between  $T_1$  and 22 seconds, where  $T_1$  is equal to:

$$T_1 = 2 \sqrt{\frac{\pi B}{g}}$$

The possible wave height  $H$ , in m, is limited by the maximum wave steepness according to the relation (see Fig 2):

$$H = 0,02 g T^2$$

Figure 2 : Allowable range of design waves



### 3.2.5 Design wave amplitude

The amplitude of the design wave is obtained by dividing the design value of the dominant load effect by the value of the response amplitude operator of this effect computed for the relevant heading and wave length.

The design values of load effect, heading and wave length are given for each load case in [3.3.2].

When positioning the finite element model of the ship on the design wave, the amplitude of the wave is to be corrected to obtain the design value of the dominant load effect in order to take into account the non linear effects due to the hull shape and to the pressure distribution above the mean water line given in [3.2.7].

The design wave phase is the phase of the dominant load effect.

### 3.2.6 Combined load cases

For the wave characteristics and crest position selected according to [3.2.5], the value of the wave-induced motions, accelerations and other load effects is obtained by the following formula:

$$E_i = RAO_i a \cos(\varphi_d - \varphi_i)$$

where:

- $E_i$  : Value of amplitude of the load component  $i$
- $RAO_i$  : Response amplitude operator of the load component  $i$  computed for the design heading and wave length
- $a$  : Design wave amplitude
- $\varphi_d$  : Phase of the dominant load effect
- $\varphi_i$  : Phase of the load component  $i$ .

As a rule, the amplitude of the load components computed above are not to exceed their rule reference value by a factor  $C_{max}$  given in Tab 4.

Table 4 : Values of factor  $C_{max}$

| Load component  | $C_{max}$ |
|---|-----------|
| Wave bending moments and wave torque<br>(see Ch 5, Sec 2, [3])              | 1,10      |
| Wave shear forces<br>(see Ch 5, Sec 2, [3])                                 | 1,40      |
| Roll angle, vertical and horizontal accelerations<br>(see Ch 5, Sec 3, [2]) | 1,10      |
| Wave pressure<br>(see Ch 7, App 1, [4.2.2])                                 | 1,20      |

3.2.7 Finite element model loading

The loads are applied to the finite element model according to the following indications:

- a) For fatigue analysis of structural members located in the vicinity of the mean waterline, the sum of the wave and hydrostatic parts of the pressure is zero above the deformed wave profile and varies linearly between the mean waterline and the wave crest levels.
- b) The fluid pressure in tanks is affected by the change of direction of the total acceleration vector defined in Ch 5, Sec 6, [1.1.3].
- c) For dry unit cargoes, the inertial forces are computed at the centre of mass, taking into account the mass moment of inertia.
- d) Inertial loads for structure weight and dry uniform cargo are computed using local accelerations calculated at their location.

3.2.8 Equilibrium check

The finite element model is to be in equilibrium condition with all the still water and wave loads applied.

The unbalanced forces in the three axes are not to exceed 2% of the displacement.

The unbalanced moments are not to exceed 2% of  $\Delta.B$  around y and z axes and 0,2% of  $\Delta.B$  around x axis.

3.3 Load cases

3.3.1 Hydrostatic calculation

For each cargo loading condition given in the relevant chapter of Part E, the longitudinal distribution of still water shear force and bending moment is to be computed and checked by reference to the approved loading manual (see Ch 11, Sec 2).

The convergence of the displacement, trim and vertical bending moment is deemed satisfactory if within the following tolerances:

- 2% of the displacement
- 0,1 degrees of the trim angle
- 10% of the still water wave bending moment.

3.3.2 Value of load effects

The wave length and heading which maximise each dominant load effect are specified in Tab 5. Where two values of heading angle are indicated in the table, the angle which corresponds to the highest peak value of the load effect's RAO is to be considered. The wave length and heading may have to be adjusted in order to fulfil the requirements given in [3.3.2].

The design value of dominant load effects is specified in Tab 6.

4 Stress calculation

4.1 Stress components

4.1.1 Stress components are generally identified with respect to the element co-ordinate system, as shown, by way of example, in Fig 3. The orientation of the element co-ordinate system may or may not coincide with that of the reference co-ordinate system in Ch 1, Sec 2, [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:

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

Figure 3 : Reference and element co-ordinate systems

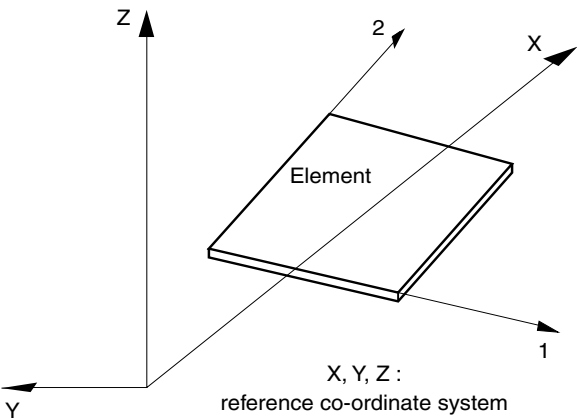


Table 5 : Load cases and load effect values

| Load case   | Dominant load effect  | Wave parameters (1)   |               | Location(s)                            | Notes   |
|---|---|---|---------------|--|---|
|   |   | $\lambda$   | Heading angle |  |   |
| 1   | Vertical wave bending moment in hogging condition               | peak value of vertical wave bending moment RAO without being less than 0,9L   | 180°          | Midship section                        |   |
| 2   | Vertical wave bending moment in sagging condition               | same as load case 1   | 180°          | Midship section                        |   |
| 3   | Vertical wave shear force                                       | peak value of vertical wave shear force RAO:<br>at 0,5L for $0,35L < x < 0,65L$<br>at 0,25L elsewhere   | 0° or 180°    | Each transverse bulkhead               |   |
| 4   | Horizontal wave bending moment                                  | peak value of horizontal wave bending moment RAO or 0,5L  | 120° or 135°  | Midship section                        | Select the heading such that the value of $C_{max}$ for vertical wave bending moment is not exceeded  |
| 5   | Wave torque   | peak value of wave torque RAO or 0,5L   | 60° or 75°    | Vicinity of 0,25 L Midship section     | Select the heading such that the value of $C_{max}$ for vertical wave bending moment is not exceeded  |
| 6   | Wave torque   | peak value of wave torque RAO within the allowable range  | 90°           | Midship section                        | Wave amplitude may have to be limited such that the value of $C_{max}$ for transverse acceleration and vertical relative motion at sides are not exceeded |
| 7   | Wave torque   | same as load case 5   | 105° or 120 ° | Vicinity of 0,75 L Midship section     | Select the heading such that the value of $C_{max}$ for vertical wave bending moment is not exceeded  |
| 8   | Vertical acceleration in inclined ship condition                | $\lambda = \frac{12,3C_{\beta}\Delta}{BLC_w}$<br><br>where:<br>$C_{\beta} = 1,0$ for 90° heading<br>1,15 for 105° heading<br>$C_w$ : Waterplane coefficient at load waterline | 90° or 105°   | Midship section                        |   |
| 9   | Vertical acceleration in upright ship condition                 | $\lambda = 1,6 L (0,575 + 0,8 F)^2$   | 180°          | From forward end of cargo area to F.P. |   |
| 10  | Transverse acceleration   | $\lambda = 1,35 g T_R^2 / (2\pi)$<br>without being taken greater than 756 m   | 90°           | Midship section                        |   |
| 11  | Wave pressure at bottom at centreline in upright ship condition | 0,7 L   | 180° or 0°    | Midship section                        | $\lambda$ may have to be increased to keep the wave steepness below wave breaking limit   |
| 12  | Wave pressure at bottom at side in inclined ship condition      | $\lambda = 0,35 g T_R^2 / (2\pi)$<br>without being taken less than 2,0B   | 90°           | Midship section                        |   |
| (1) The forward ship speed is to be taken equal to 0,6 V. |   |   |               |  |   |

Table 6 : Dominant load effect values

| Dominant load effect  | Design value                     | Combined load components                  | References  |
|---|----------------------------------|---|---|
| Vertical wave bending moment in hogging condition                                 | $0,625 \gamma_{W1} M_{WV,H}$     | –   | $M_{WV,H}$ defined in Ch 5, Sec 2, [3.1.1]  |
| Vertical wave bending moment in sagging condition                                 | $0,625 \gamma_{W1} F_D M_{WV,S}$ |   | $M_{WV,S}$ defined in Ch 5, Sec 2, [3.1.1]<br>$F_D$ defined in Ch 5, Sec 2, [4.2.1] |
| Vertical wave shear force   | $0,625 \gamma_{W1} Q_{WV}$       | –   | $Q_{WV}$ defined in Ch 5, Sec 2, [3.4]  |
| Horizontal wave bending moment  | $0,625 \gamma_{W1} M_{WH}$       | –   | $M_{WH}$ defined in Ch 5, Sec 2, [3.2.1]  |
| Wave torque (1)   | $0,625 \gamma_{W1} M_{WT}$       | Horizontal wave bending moment            | $M_T$ defined in Ch 5, Sec 2, [3.3]   |
| Vertical acceleration at centreline in upright ship condition                     | $\gamma_{W2} a_{Z1}$             | Vertical relative motion at sides at F.E. | $a_{Z1}$ defined in Ch 5, Sec 3, [3.4.1]  |
| Vertical acceleration at deck at sides in inclined ship condition                 | $\gamma_{W2} a_{Z2}$             | –   | $a_{Z2}$ defined in Ch 5, Sec 3, [3.4.1]  |
| Transverse acceleration at deck at sides  | $\gamma_{W2} a_{Y2}$             | Roll angle                                | $a_{Y2}$ defined in Ch 5, Sec 3, [3.4.1]  |
| Wave pressure at bottom at centreline in upright ship condition                   | $\gamma_{W2} p_W$                | Vertical wave bending moment at midship   | $p_W$ defined in Ch 7, App 1, Tab 3 for case “a”                                    |
| Wave pressure at bottom at side in inclined ship condition                        | $\gamma_{W2} p_W$                | –   | $p_W$ defined in Ch 7, App 1, Tab 4 for case “c”                                    |
| (1) This load effect is to be considered for ships with large deck openings only. |                                  |   |   |