RULES FOR CLASSIFICATION

Ships

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Part 3 Hull

Chapter 5 Hull girder strength
FOREWORD

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CHANGES – CURRENT

This is a new document.
The rules enter into force 1 January 2016.
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SECTION 1 STRENGTH CHARACTERISTICS OF HULL GIRDER TRANSVERSE SECTIONS

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

1 General

1.1 Scope
This section specifies the criteria for calculating the hull girder strength characteristics.

2 Hull girder transverse sections

2.1 General
Hull girder transverse sections shall be considered as being constituted by the members contributing to the hull girder longitudinal strength, i.e. all continuous longitudinal members.

2.2 Structural members not contributing to hull girder sectional area
The following members shall not be considered in the calculation as they are considered not contributing to the hull girder sectional area:
— superstructures extending less than 0.15 \( L \)
— deckhouses extending less than 0.15 \( L \)
— vertically corrugated bulkheads, according to [2.5]
— bulwarks and gutter plates
— bilge keels
— sniped or non-continuous longitudinal stiffeners
— non-continuous hatch coamings.

2.3 Continuous trunks and longitudinal continuous hatch coamings
Continuous trunks and longitudinal continuous hatch coamings may be included in the hull girder transverse sections, provided that they are effectively supported by longitudinal bulkheads or primary supporting members.

2.4 Longitudinal stiffeners or girders welded above the strength deck
Longitudinal stiffeners or girders welded above the strength deck, including the deck of any trunk fitted as specified in [2.3], shall be included in the hull girder transverse sections.

2.5 Longitudinal bulkheads with corrugations

2.5.1 For longitudinal bulkheads with vertical corrugations, the vertical corrugations shall not be included in the hull girder transverse section. Longitudinal bulkheads with vertical corrugations are not effective for hull girder bending, but they are effective for hull girder shear force.
2.5.2 For the purpose of calculating the unit shear flow for hull girder vertical shear force, \( q_{vi-gr} \), as defined in Sec.2 and \( q_{vi-n50} \), as defined in Sec.3 for vertical or horizontal corrugations, the following reduction factor shall be used to obtain the effective thickness of the corrugation:

\[
C_{shr} = \frac{\frac{s_c}{a}}{a + c}
\]

where \( s_c \), \( a \) and \( c \) are defined in Ch.3 Sec.6 [5.1].

For the thickness applied in the hull girder shear capacity as given in Sec.2 [2.1], \( t_{i-gr} \) and in the shear stress calculation as given in Sec.3 [4.2], \( t_{i-n50} \), this thickness reduction is not applicable.

2.6 Members in materials other than steel

Where a member contributing to the longitudinal strength is made of a material other than steel having a Young’s modulus, \( E \) different from \( 2.06 \times 10^5 \) N/mm², the steel equivalent sectional area that may be included in hull girder transverse section is obtained by applying the following factor:

\[
C_E = \frac{E}{2.06 \times 10^5}
\]

2.7 Definitions of openings

The following definitions of openings shall be applied:

a) Large openings are:
   — elliptical openings exceeding 2.5 m in length or 1.2 m in breadth
   — circular openings exceeding 0.9 m in diameter.

b) Small openings (i.e. manholes, lightening holes, etc.) are openings that are not large ones.

c) Isolated openings are openings spaced not less than 1 m apart in the ship’s transverse/vertical direction.

2.8 Large openings

Large openings shall be deducted from the sectional area used in hull girder moment of inertia and section modulus.

2.9 Isolated small openings

Smaller openings (manholes, lightening holes, single scallops in way of seams etc.) need not to be deducted provided that the sum of their breadths or shadow area breadths in one transverse section does not reduce the section modulus at deck or bottom by more than 3% and provided that the height of lightening holes, draining holes and single scallops in longitudinals or longitudinal girders does not exceed 25% of the web depth, for scallops maximum 75 mm.

A deduction-free sum of smaller openings breadths in one transverse section in the bottom or deck area equal to:

\[
0.06(B - \Sigma b)
\]

may be considered equivalent to the above reduction in section modulus.
$$\Sigma b = \text{total breadth of large openings, in m, at the transverse section being considered, determined as indicated in Figure 1. }$$

**Figure 1 Calculation of $$\Sigma b$$ and $$\Sigma b_s$$**

2.10 Lightening holes, draining holes and single scallops

Lightening holes, draining holes and single scallops in longitudinals need not be deducted if their height is less than 0.25 $h_w$, where $h_w$ is the web height of the longitudinals, in mm. Otherwise, the excess shall be deducted from the sectional area or compensated.

2.11 Non-continuous decks and longitudinal bulkheads

When calculating the effective area in way of non-continuous decks and longitudinal bulkheads, the effective area shall be taken as shown in Figure 2. The shadow areas, which are not effective for hull girder bending but effective for hull girder shear force, are obtained by drawing two tangent lines with an angle of 15 deg to the longitudinal axis of the ship.
2.12 Longitudinal members with reduced effectiveness

For hull girder cross sections where the beam theory is not applicable, the contribution of longitudinal members with reduced effectiveness, e.g. hatchway girders between the multi hatchways and upper decks of passenger ships, to the strength characteristics of the hull girder shall be determined by direct calculations.
SECTION 2 VERTICAL HULL GIRDER BENDING AND SHEAR STRENGTH

Symbols

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

\[ C_w \] = wave parameter as defined in Ch.4 Sec.4
\[ f_{har} \] = correction factor for harbour/ sheltered water conditions to be taken as:
\[ f_{har} = 0.5, \text{ unless otherwise defined in Pt.5} \]
\[ I_{y-gr} \] = gross moment of inertia, in m^4, of the hull transverse section about its horizontal neutral axis
\[ M_{sw} \] = permissible vertical still water bending moment, in kNm, for hogging and sagging, in seagoing condition at the hull transverse section being considered as defined in Ch.4 Sec.4 [2.2.2]
\[ M_{ww} \] = vertical wave bending moment, in kNm, for hogging and sagging, in seagoing condition at the hull transverse section being considered as defined in Ch.4 Sec.4 [3.1.1]
\[ Q_{ww} \] = positive and negative vertical wave shear force, in kN, for seagoing condition at the hull transverse section being considered as defined in Ch.4 Sec.4 [3.2.1]
\[ Q_R \] = total vertical hull girder shear capacity, in kN, at the hull transverse section being considered, as defined in [2.1]
\[ \Delta Q_{mdf} \] = shear force correction at the transverse section considered, in kN, if applicable as defined in [2.4]
\[ t_{i-gr} \] = gross thickness, in mm, for plate \( i \)
\[ V_D \] = vertical distance to the equivalent deck line, in m, as defined in [1.2.3]
\[ q_{vi-gr} \] = unit shear flow for hull girder vertical shear force, in mm^{-1}, for the plate \( i \) based on gross thickness \( t_{i-gr} \), in mm
\[ x \] = \( X \) coordinate, in m, of the calculation point with respect to the reference coordinate system defined in Ch.1 Sec.4 [3.6]
\[ z \] = \( Z \) coordinate, in m, of the calculation point with respect to the reference coordinate system defined in Ch.1 Sec.4 [3.6]
\[ z_D \] = \( Z \) coordinate, in m, of strength deck at ship side
\[ z_{n-gr} \] = \( Z \) coordinate, in m, of horizontal neutral axis of the hull transverse section with gross scantling defined in [1.2], with respect to the reference coordinate system defined in Ch.1 Sec.4 [3.6]
\[ Z_{B-gr} \] = gross section modulus, in m^3, at bottom, to be calculated according [1.2]
\[ Z_{D-gr} \] = gross section modulus, in m^3, at deck, to be calculated according [1.2]

1 Vertical hull girder bending strength

1.1 General

1.1.1 Scantlings of all continuous longitudinal members of the hull girder based on moment of inertia and section modulus requirement in [1.5] and [1.3], respectively, are generally to be maintained within 0.4 \( L \) amidships.

1.1.2 The \( k \) material factors shall be defined with respect to the materials used for the bottom and deck members contributing to the longitudinal strength according to Sec.1 [2.1] and [2.2]. When material factors for higher strength steels are used, the requirements in [1.6] apply.

1.2 Definition of hull girder section modulus

1.2.1 Section modulus at bottom

The gross section modulus at bottom is obtained, in m^3, from the following formula:
1.2.2 Section modulus at deck
The gross section modulus at equivalent deck line is obtained, in m³, from the following formula:

\[ Z_{D-gr} = \frac{I_{y-gr}}{V_D} \]

1.2.3 Equivalent deck line
When no effective longitudinal members specified in Sec.1 [2.3] and Sec.1 [2.4] are positioned above a line extending from strength deck at side to a position \((z_D - z_{n-gr})/0.9\) from the neutral axis at the centerline, the equivalent deck line is obtained from the following formula:

\[ V_D = z_D - z_{n-gr} \]

When effective longitudinal members as specified in Sec.1 [2.3] and Sec.1 [2.4] are positioned above a line extending from strength deck at side to a position \((z_D - z_{n-gr})/0.9\) from the neutral axis at the centerline, the equivalent deck line is obtained from the following formula:

\[ V_D = (z_T - z_{n-gr}) \left( 0.9 + 0.2 \frac{y_T}{B} \right) \geq z_D - z_{n-gr} \]

where:

\(y_T, z_T\) = Y and Z coordinates, in m, of the top of continuous trunk, hatch coaming, longitudinal stiffeners or girders, to be measured for the point which maximises the value of \(V_D\)

1.3 Minimum section modulus at midship part
The vertical hull girder gross section modulus, in m³, at equivalent deck line as defined in [1.2.3], and bottom at midship part shall not be less than the value obtained from the following formula:

\[ Z_{B-gr} = k \left( \frac{1+f_r}{2} \right) C_w L^2 \left( C_b + 0.7 \right) 10^{-6} \]

where:

\(f_r\) = reduction factor related to service restrictions, defined in Ch.4 Sec.3
1.4 Section modulus

1.4.1 The gross section modulus related to deck or bottom, along the full length of the hull girder, from AE to FE, in m$^3$, shall comply with the following formula:

\[
Z_{gr} = \frac{|M_{sw} + M_{wy}|}{\sigma_{perm}} 10^{-3}
\]

where:

\( \sigma_{perm} = \) permissible hull girder bending stress, in kN/m$^2$, to be taken as:

\[
\sigma_{perm} = \frac{125}{k} \text{ for } \frac{x}{L} \leq 0.1
\]

\[
\sigma_{perm} = \frac{175}{k} \text{ for } 0.3 \leq \frac{x}{L} \leq 0.7
\]

\[
\sigma_{perm} = \frac{125}{k} \text{ for } \frac{x}{L} \geq 0.9
\]

Intermediate values of \( \sigma_{perm} \) shall be obtained by linear interpolation.

1.5 Minimum moment of inertia at midship part

The gross moment of inertia about the horizontal axis in m$^4$ at midship part shall not be less than the value obtained from the following formula:

\[
l_{yR-gr} = 3 \cdot C_w \cdot L^3 \cdot B \cdot (C_b + 0.7) \cdot 10^{-8}
\]

1.6 Extent of high tensile steel

1.6.1 Vertical extent

The vertical extent of higher strength steel, in m, used in the deck zone or bottom zone and measured respectively from the equivalent deck line at side specified in [1.2.3], or the baseline shall not be taken less than the value obtained from the following formula, see Figure 1:

\[
z_{hts,i} = z_1 \left(1 - \frac{\sigma_{perm,i}}{\sigma_{L-gr}}\right)
\]
where:

\[ Z_1 = \text{distance from horizontal neutral axis to the equivalent deck line at side or baseline respectively, in m} \]

\[ \sigma_{perm,i} = \text{permissible hull girder bending stress of the considered steel, in N/mm}^2, \text{as given in [1.4.1] and Figure 1} \]

\[ \sigma_{L-gr} = \text{hull girder bending stress, at the equivalent deck line at side or at baseline respectively, in N/mm}^2, \text{to be taken as:} \]

\[ \sigma_{L-gr} = \frac{\max \left| M_{cw} + M_{ww} \right|}{I_{y-gr}}z_1 10^{-3} \]

based on the maximum absolute value of sagging and hogging vertical bending moment.

**Figure 1 Vertical extent of higher strength steel**

1.6.2 Longitudinal extent

Where used, the application of higher strength steel shall be continuous over the length of the ship to the location where the longitudinal stress levels are within the allowable range for mild steel structure as shown in Figure 2.
1.7 Permissible still water bending moments for harbour/sheltered water operations

The permissible still water bending moments, in kNm, for harbour/sheltered operations in hogging and sagging shall comply with the following criteria:

\[ |M_{SW-p}| \leq |M_{SW} + f_{hahr} M_{Wv}| \]

The bending moment \( M_{Wv} \) used above shall be taken with the same sign as the considered bending moment \( M_{SW-p} \).

2 Vertical hull girder shear strength

2.1 Total hull girder shear capacity

The total vertical hull girder shear capacity, in kN, is the minimum of the calculated values for all plates \( i \) contributing to the hull girder shear of the considered transverse section and shall be obtained by the following formula:

\[ Q_R = \min_i \left( \tau_{i-perm} \cdot t_{i-gr} \right) \frac{10^{-3}}{q_{vi-gr}} \]

where:

\( \tau_{i-perm} \) = permissible shear stress, in N/mm², for plate \( i \), to be taken as:
2.2 Seagoing condition

2.2.1 The positive and negative permissible vertical still water shear force, in kN, for seagoing condition shall comply with the following criteria:

\[ |Q_{sw}| \leq Q_R - |Q_{wv}| \]

The shear force \( Q_{wv} \) used above shall be taken with the same sign as the considered shear force \( Q_{sw} \).

2.2.2 The vertical still water shear forces, in kN, for all loading conditions for seagoing condition shall comply with the following criteria:

\[ |Q_{sw-Lcd} - \Delta Q_{mdf}| \leq |Q_{sw}| \]

The shear force \( Q_{sw} \) used above shall be taken with the same sign as the considered shear force \( Q_{sw-Lcd} \).

2.3 Harbour/sheltered water operations

2.3.1 The positive and negative permissible vertical still water shear force, in kN, for harbour/sheltered water operations shall comply with the following criteria:

\[ |Q_{sw-p}| \leq Q_R - f_{har} |Q_{wv}| \]

The shear force \( Q_{wv} \) used above shall be taken with the same sign as the considered shear force \( Q_{sw-p} \).

2.3.2 The vertical still water shear forces, in kN, for all loading conditions for harbour/sheltered water operations shall comply with the following criteria:

\[ |Q_{sw-Lcd-p} - \Delta Q_{mdf}| \leq |Q_{sw-p}| \]

The shear force \( Q_{sw-Lcd-p} \) used above shall be taken with the same sign as the considered shear force \( Q_{sw-p} \).

2.4 Shear force correction

Shear force correction, \( \Delta Q_{mdf} \) in kN, is defined as the difference between shear force on a shear panel determined from shear flow calculation and the actual shear force. Shear force correction results from shear force carrying longitudinal members and uneven transverse load distribution.

Shear force correction shall be taken into account where relevant. Procedures for calculation of shear force correction are given in Pt.5 for each ship type.
### SECTION 3 HULL GIRDER YIELD CHECK

**Symbols**

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

- $I_{y-n50}$ = net moment of inertia, in $m^4$, of the hull transverse section about its horizontal neutral axis
- $I_{z-n50}$ = net moment of inertia, in $m^4$, of the hull transverse section about its vertical neutral axis
- $I_{T-n50}$ = net torsional moment of inertia, in $m^4$, of the hull transverse section
- $I_{ω-n50}$ = net sectional moment of inertia, in $m^6$, of the hull transverse section
- $M_{SW-h}, M_{SW-s}$ = permissible vertical still water bending moment, in kNm, for hogging and sagging respectively, in seagoing condition at the hull transverse section being considered as defined in Ch.4 Sec.4 [2.2.2]
- $M_{st}$ = design still water torsional moment in seagoing condition, in kNm, at the hull transverse section being considered, as defined in Ch.4 Sec.4 [2.3.1], unless otherwise specified
- $M_{wh-LC}$ = horizontal wave bending moment, in kNm, for a dynamic load case at the hull transverse section being considered, as defined in Ch.4 Sec.4 [3.5.4]
- $M_{wt-LC}$ = wave torsional moment, in kNm, for a dynamic load case at the hull transverse section being considered, as defined in Ch.4 Sec.4 [3.5.5]
- $M_{wt-LC-max}$ = maximum absolute value of $M_{wt-LC}$ along the ship length
- $M_{wv-LC}$ = vertical wave bending moment, in kNm, for a dynamic load case at the hull transverse section being considered, as defined in Ch.4 Sec.4 [3.5.2]
- $q_{vi-n50}$ = unit shear flow for hull girder vertical shear force, in $mm^{-1}$, for the plate i based on $t_{i-n50}$
- $Q_{SW-pos}$, $Q_{SW-neg}$ = positive and negative permissible still water shear force for seagoing operation, in kN, at the hull transverse section being considered, as defined in Ch.4 Sec.4 [2.4.2]
- $Q_{wv-LC}$ = vertical wave shear force in seagoing condition, in kN, for a dynamic load case at the hull transverse section being considered, as defined in Ch.4 Sec.4 [3.5.3]
- $S_{ωi-n50}$ = net sectional moment of area, in $m^5$, of the hull transverse section
- $t_{i-n50}$ = net thickness of plate i, in mm
- $x$ = $X$ coordinate, in m, of the calculation point with respect to the reference coordinate system defined in Ch.1 Sec.4 [3.6]
- $y$ = $Y$ coordinate, in m, of the calculation point with respect to the reference coordinate system defined in Ch.1 Sec.4 [3.6]
- $z$ = $Z$ coordinate, in m, of the calculation point with respect to the reference coordinate system defined in Ch.1 Sec.4 [3.6]
- $z_{n-n50}$ = Z coordinate, in m, of horizontal neutral axis of the hull transverse section with net scantlings, with respect to the reference coordinate system defined in Ch.1 Sec.4 [3.6]

1 **General**

#### 1.1 Scope

This section provides the criteria for calculating the hull girder bending and shear strength in matters of the dynamic load cases as defined in Ch.4 Sec.2 [2]. The hull girder stresses as defined in [2] for ships without large deck openings and in [3] for ships with large deck openings are furthermore utilized for the following local assessments:

- hull local scantling assessment according to Ch.6
- buckling assessment according to Ch.8
- fatigue assessment according to Ch.9
- special requirements according to Ch.10.
2 Ships without large deck openings

2.1 Hull girder longitudinal stresses

2.1.1 Definition
For seagoing condition the longitudinal normal stress, in N/mm², induced by acting vertical and horizontal bending moments for a dynamic load case at the transverse section being considered is obtained from the following formula:

\[ \sigma_{hg} = \sigma_{hg-sw} + \sigma_{hg-dyn} \]

where:

\[ \sigma_{hg-sw} = \begin{cases} \sigma_{sw-h} \\ \sigma_{sw-s} \end{cases} \]

\[ \sigma_{hg-dyn} = \sigma_{wv-LC} + \sigma_{wh-LC} \]

2.1.2 Design criteria
Along the length \( L \), the longitudinal normal stress, in N/mm², at any point being considered shall comply with the following criteria:

\[ |\sigma_{hg}| \leq \sigma_{hg-perm} \]

where:

\[ \sigma_{hg-perm} = \text{permissible longitudinal normal stress, in N/mm}^2, \text{ to be taken as:} \]

\[ \sigma_{hg-perm} = 205/k \]

2.2 Hull girder shear stresses

2.2.1 Definition
For seagoing condition the shear stress, in N/mm², induced by acting vertical shear forces for a dynamic load case at the transverse section being considered is obtained from the following formula:

\[ \tau_{hg} = \tau_{hg-sw} + \tau_{hg-dyn} \]

where:
\[ \tau_{hg-dyn} = \tau_{wv-LC} \]

### 2.2.2 Design criteria
Along the length \( L \), the shear stress, in N/mm\(^2\), at any point being considered shall comply with the following formula:

\[ |\tau_{hg}| \leq \tau_{hg-perm} \]

where:

\( \tau_{hg-perm} = \) permissible shear stress, in N/mm\(^2\), to be taken as:

\[ \tau_{hg-perm} = \frac{120}{k} \]

### 3 Ships with large deck openings

#### 3.1 Hull girder longitudinal stresses

##### 3.1.1 Definition
For ships with large deck openings, as defined in Ch.1 Sec.4 Table 7, the additional longitudinal normal stresses induced by acting still water and wave torsional moments shall be considered. Hence, for the seagoing condition, the longitudinal normal stress, in N/mm\(^2\), for a dynamic load case at the transverse section being considered is obtained from the following formula:

\[ \sigma_{hg} = \sigma_{hg-sw} + \sigma_{hg-dyn} \]

where:

\[ \sigma_{hg-sw} = \begin{cases} \sigma_{sw-h} + |\sigma_{st}| \\ \sigma_{sw-h} - |\sigma_{st}| \\ \sigma_{sw-s} + |\sigma_{st}| \\ \sigma_{sw-s} - |\sigma_{st}| \end{cases} \]

\[ \sigma_{hg-dyn} = \sigma_{wv-LC} + \sigma_{wh-LC} + \sigma_{wt-LC} \]

##### 3.1.2 Design criteria
Along the length \( L \), the longitudinal normal stress, in N/mm\(^2\), at any point being considered shall comply with the following formula:
3.2 Hull girder shear stresses

3.2.1 Definition

For ships with large deck openings, as defined in Ch. 1 Sec. 4 Table 7, the additional shear stress induced by acting still water and wave torsional moments shall be considered. Hence, for the seagoing condition, the shear stress, in N/mm$^2$, for a dynamic load case at the transverse section being considered is obtained from the following formula:

\[
\tau_{hg} = \tau_{hg - sw} + \tau_{hg - dyn}
\]

where:

\[
\tau_{hg - sw} = \begin{cases} 
\tau_{sw - pos} + |\tau_{st}| \\
\tau_{sw - pos} - |\tau_{st}| \\
\tau_{sw - neg} + |\tau_{st}| \\
\tau_{sw - neg} - |\tau_{st}|
\end{cases}
\]

\[
\tau_{hg - dyn} = \tau_{wv - LC} + \tau_{wt - LC}
\]

3.2.2 Design criteria

Along the length $L$, the shear stress, in N/mm$^2$, at any point being considered shall comply with the following formula:

\[
\tau_{hg} \leq \tau_{hg - perm}
\]

where:

\[
\tau_{hg - perm} = \text{permissible shear stress, in N/mm}^2, \text{ as defined in [2.2.2]}
\]

3.3 Equivalent stress

3.3.1 Definition

The equivalent stress, in N/mm$^2$, related to the longitudinal normal and shear stresses, $\sigma_{hg}$ and $\tau_{hg}$ as defined in [3.1.1] and [3.2.1], ively, at any point being considered is obtained from the following formula:

\[
\sigma_v = \sqrt{\sigma_{hg}^2 + 3\tau_{hg}^2}
\]
### 3.3.2 Design criteria

Along the length $L$, the equivalent stress, in N/mm$^2$, at any point being considered shall comply with the following formula:

$$\sigma_k \leq \sigma_{v-perm}$$

where:

$$\sigma_{v-perm} = \text{permissible equivalent stress, in N/mm}^2, \text{to be taken as:}$$

$$\sigma_{v-perm} = \frac{220}{k}$$

### 4 Definitions of hull girder stress components

#### 4.1 Longitudinal normal stress

##### 4.1.1 Longitudinal stresses induced by still water vertical hull girder bending

The longitudinal stresses, in N/mm$^2$, induced by acting vertical still water bending moment in seagoing condition at the transverse section being considered, are obtained from the following formula:

$$\sigma_{sw-h} = \frac{M_{sw-h}}{I_{y-n50}} (z - z_{n-n50}) 10^{-3}$$

$$\sigma_{sw-s} = \frac{M_{sw-s}}{I_{y-n50}} (z - z_{n-n50}) 10^{-3}$$

##### 4.1.2 Longitudinal stresses induced by dynamic hull girder bending

The longitudinal stresses, in N/mm$^2$, induced by acting vertical and horizontal wave bending moment for a dynamic load case and at the transverse section being considered, are obtained from the following formula:

$$\sigma_{wv-LC} = \frac{M_{wv-LC}}{I_{y-n50}} (z - z_{n-n50}) 10^{-3}$$

$$\sigma_{wh-LC} = -\frac{M_{wh-LC}}{I_{z-n50}} y \cdot 10^{-3}$$

##### 4.1.3 Longitudinal warping normal stresses induced by wave and still water hull girder torsion

The longitudinal warping normal stresses, in N/mm$^2$, induced by acting still water torsional moment in seagoing condition at the transverse section being considered, are obtained from the following formula:
The longitudinal warping normal stress, in N/mm², induced by acting wave torsional moment for a dynamic load case and at the transverse section being considered, is obtained from the following formula:

\[
\sigma_{st} = \frac{M_{\sigma-st} \cdot \omega_{i-n50}}{I_{\omega-n50}} \cdot 10^{-3}
\]

where:

\[M_{\sigma-st} = c_d \cdot M_{st} \cdot \varepsilon_c \cdot \frac{-\pi + \lambda \cdot \varepsilon_c \cdot \sinh\left(\frac{\lambda \cdot \varepsilon_c}{2}\right)/\cosh\left(\lambda \cdot \varepsilon_c\right)}{\pi^2 + (\lambda \cdot \varepsilon_c)^2} \]

\[M_{\sigma-wt-LC} = \frac{0.85 \cdot c_{LC} \cdot c_d \cdot M_{wt-LC-max} \cdot \varepsilon_c \cdot -\pi + \lambda \cdot \varepsilon_c \cdot \sinh\left(\frac{\lambda \cdot \varepsilon_c}{2}\right)/\cosh\left(\lambda \cdot \varepsilon_c\right)}{\pi^2 + (\lambda \cdot \varepsilon_c)^2} \]

\[\omega_{i-n50} = \text{net sectorial coordinate, in m}^2, \text{of the point being considered} \]

\[\lambda = \frac{l_{T-n50}}{2.6 \cdot l_{\omega-n50}} \]

\[c_d = \text{distribution coefficient along the length L, to be taken as:} \]

\[c_d = \frac{x}{x_A} \quad \text{for} \quad 0 \leq \frac{x}{L} \leq \frac{x_A}{L} \]

\[c_d = 1 \quad \text{for} \quad \frac{x_A}{L} \leq \frac{x}{L} \leq 0.55 \]
\[ c_d = \frac{1}{0.45} \left(1 - \frac{x}{L}\right) \quad \text{for} \quad 0.55 \leq \frac{x}{L} \leq 0.65 \]

\[ c_d = \frac{1}{0.45 \cdot 0.35} \left(1 - \frac{x}{L}\right)^2 \quad \text{for} \quad \frac{x}{L} > 0.65 \]

\[ x_A = \text{longitudinal distance, in m, between the aft end of the length L and the engine room front bulkhead, to be taken neither less than 0.15 L nor more than 0.25 L, see also Figure 1} \]

\[ c_{LC} = \text{sign coefficient, to be taken as:} \]

\[ c_{LC} = -1 \text{ for OST-1S, OST-2P, OSA-1P and OSA-2S} \]

\[ c_{LC} = 1 \text{ for all other dynamic load cases} \]

\[ \ell_c = \text{characteristic torsion length, in m, to be taken as:} \]

\[ \ell_c = 0.71 \cdot \left(0.7 - \frac{x_A}{L}\right) L \]

The bi-moments, \( M_{\sigma-st} \) and \( M_{\sigma-wt-LC} \), are applicable to container ships with typical design. For other vessels (e.g. twin-island container ships and open hatch bulk carriers with wide cross decks) the bi-moments may be determined by direct calculations.

**Figure 1 Factor \( x_A \)**

### 4.2 Shear stresses

#### 4.2.1 Shear stresses induced by still water vertical hull girder shear force

The shear stresses, in N/mm², induced by vertical still water shear force in seagoing condition at the transverse section being considered, are obtained from the following formulae:

\[ \tau_{sw-pos} = \frac{Q_{sw-pos} \cdot q_{vi-n50}}{t_{l-n50} 10^3} \]
4.2.2 Shear stresses induced by dynamic vertical hull girder shear force
The shear stress, in N/mm², induced by dynamic vertical shear force for a dynamic load case at the transverse section being considered is obtained from the following formula:

\[ \tau_{sw-\text{neg}} = \frac{Q_{sw-\text{neg}} \cdot q_{vi-n50}}{t_{l-n50}} \cdot 10^3 \]

4.2.3 Warping shear stresses induced by wave and still water hull girder torsion
The warping shear stress, in N/mm², induced by still water torsional moment in seagoing condition at the transverse section being considered are obtained from the following formula:

\[ \tau_{st} = \frac{M_{\tau-st} \cdot S_{\omega l-n50}}{I_{\omega-n50} \cdot t_{l-n50}} \]

The warping shear stress, in N/mm², induced by wave torsional moment for a dynamic load case at the transverse section being considered is obtained from the following formula:

\[ \tau_{wt-\text{LC}} = \frac{0.85 M_{\tau-wt-\text{LC}} \cdot S_{\omega l-n50}}{I_{\omega-n50} \cdot t_{l-n50}} \]

where:

- \( M_{\tau-st} \) = warping component of still water torsional moment related to warping shear stresses induced by static torsion, in kNm, at the transverse section being considered, in seagoing condition, to be taken as:
  \[ M_{\tau-st} = M_{st} \]
- \( M_{\tau-wt-LC} \) = warping component of wave induced torsional moment related to warping shear stresses induced by wave torsion, in kNm, for a dynamic load case at the transverse section being considered, to be taken as:
  \[ M_{\tau-wt-LC} = c_h \cdot c_r \cdot M_{wt-\text{LC}} \]
  for \( 0 \leq \frac{x}{L} < 0.45 \)

  \[ M_{\tau-wt-LC} = c_h \cdot c_r \cdot M_{wt-\text{LC}-0.45L} \]
  for \( 0.45 \leq \frac{x}{L} \leq 0.53 \)
$$M_{T-wt-LC} = 0.85 \cdot c_h \cdot c_r \cdot M_{wt-LC-0.6L} \text{ for } 0.53 \leq \frac{x}{L} \leq 0.6$$

$$M_{T-wt-LC} = 0.85 \cdot c_h \cdot c_r \cdot M_{wt-LC} \quad 0.6 < \frac{x}{L} \leq 1$$

$c_r$ = reduction coefficient, to be taken as:

$$c_r = \min(0.7, \frac{2}{1 + \sqrt{1 + 4c}}, c = \frac{4D^2}{1.21T_{LC}L}$$

$c_h$ = reduction coefficient due to horizontal shear force, to be taken as,

$c_h = 0.7$

$M_{wt-LC-0.45L}$ = to be taken as: $M_{wt-LC}$ at $x = 0.45L$

$M_{wt-LC-0.6L}$ = to be taken as: $M_{wt-LC}$ at $x = 0.6L$

The warping components of torsional moments, $M_{T-st}$ and $M_{T-wt-LC}$, are applicable to container ships with typical design. For other vessels (e.g. twin-island container ships and open hatch bulk carriers with wide cross decks) the warping components of torsional moments may be determined by direct calculations.
SECTION 4 HULL GIRDER ULTIMATE STRENGTH CHECK

Symbols

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

\[ M_{SW-h}, M_{SW-s} = \text{permissible vertical still water bending moment in seagoing condition, in kNm, at the hull transverse section being considered in hogging and sagging, as defined in Ch.4 Sec.4 [2.2.2].} \]

\[ M_{wv} = \text{vertical wave bending moment in seagoing condition, in kNm, at the hull transverse section being considered in hogging and sagging, as defined in Ch.4 Sec.4 [3.1.1].} \]

1 Application

1.1 General

1.1.1 This section applies to ships with all of the following characteristics:

- unrestricted service
- \( L > 150 \text{ m} \)
- single deck or if required in Pt.5 for the considered ship type.

1.1.2 The hull girder ultimate strength requirements given in [2.1.2] applies to the cargo fold area in general and to the following locations:

- in way of the forward end of the engine room
- in way of the forward end of the foremost cargo hold
- at any locations where there are significant changes in hull cross-section
- at any locations where there are changes in the framing system
- for ships with large deck openings such as container ships, locations at or near 0.25 \( L \) and 0.75 \( L \).

1.1.3 The hull girder ultimate bending capacity shall be checked to ensure that it satisfies the criteria given in [2].

2 Checking criteria

2.1 General

2.1.1 The vertical hull girder ultimate bending capacity shall be checked for hogging and sagging conditions for load components as defined in Table 1:

<table>
<thead>
<tr>
<th>Load components</th>
<th>Permissible still water bending moment, ( M_{SW-U} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>S+D</td>
<td>( M_{SW-h} ) or ( M_{SW-s} )</td>
</tr>
</tbody>
</table>

2.1.2 The vertical hull girder ultimate bending capacity at any hull transverse section shall satisfy the following criteria:
where:

\[ M = \frac{M_U}{\gamma_R} \]

\[ M = \text{vertical bending moment, in kNm, to be obtained as specified in [2.2.1]} \]
\[ M_U = \text{vertical hull girder ultimate bending capacity, in kNm, to be obtained as specified in [2.3.1]} \]
\[ \gamma_R = \text{partial safety factor for the vertical hull girder ultimate bending capacity to be taken as:} \]
\[ \gamma_R = \gamma_M \gamma_{DB} \]
\[ \gamma_M = \text{partial safety factor for the vertical hull girder ultimate bending capacity, covering material, geometric and strength prediction uncertainties; in general, to be taken as:} \]
\[ \gamma_M = 1.1 \]
\[ \gamma_{DB} = \text{partial safety factor for the vertical hull girder ultimate bending capacity, covering the effect of double bottom bending, to be taken as:} \]

for hogging condition:
\[ \gamma_{DB} = 1.25 \text{ for vessels with empty cargo holds and class notation HC(A) or HC(B), or HC(M) if alternate loading conditions are included in the loading manual} \]
\[ \gamma_{DB} = 1.1 \text{ for all other cases.} \]

for sagging condition:
\[ \gamma_{DB} = 1.0 \]

2.2 Hull girder ultimate bending loads

2.2.1 The vertical hull girder bending moment in hogging and sagging conditions, in kNm, to be considered in the ultimate strength check shall be taken as:

\[ M = \gamma_S M_{SW-U} + \gamma_W M_{WV} \]

where:

\[ M_{SW-U} = \text{permissible still water bending moment, in kNm, in hogging and sagging conditions at the hull transverse section considered as defined in Table 1} \]
\[ \gamma_S = \text{partial safety factor for the still water bending moment, to be taken as:} \]
\[ \gamma_S = 1.0 \]
\[ \gamma_W = \text{partial safety factor for the vertical wave bending moment, to be taken as:} \]
\[ \gamma_W = 1.2 \]

2.3 Hull girder ultimate bending capacity

2.3.1 The ultimate bending moment capacities of a hull girder transverse section, in hogging and sagging conditions, are defined as the maximum values of the curve of bending moment capacity versus the curvature \( \chi \) of the transverse section considered (see Figure 1). The curvature \( \chi \) is positive for hogging condition and negative for sagging condition.
Figure 1 Bending moment capacity versus curvature $\chi$

The hull girder ultimate bending capacity, $M_{Ug}$ shall be assessed by prescriptive method given in the Society's document DNVGL-CG-0128, Buckling analysis, or by non-linear FE.
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