RULES FOR CLASSIFICATION

Ships

Part 3 Hull

Chapter 5 Hull girder strength

DNV GL AS

FOREWORD

DNV GL rules for classification contain procedural and technical requirements related to obtaining and retaining a class certificate. The rules represent all requirements adopted by the Society as basis for classification.

Any comments may be sent by e-mail to *rules@dnvgl.com*

CHANGES – CURRENT

This document supersedes the January 2018 edition.

Changes in this document are highlighted in red colour. However, if the changes involve a whole chapter, section or subsection, normally only the title will be in red colour.

Changes July 2019, entering into force 1 January 2020

Topic	Reference	Description
Clarification of rules	Previous Sec.1 [2.10]	Subsection about lightening holes, draining holes and scallops is deleted.
Tapering longitudinal strength	Sec.2 [1.3], Sec.2 [1.4], Sec.2 [1.5]	The minimum section modulus requirement and moment of inertia are applied to the midship section instead of midship part. The permissible stress outside 0.4L may be increased to the same as for midship region provide that specific strength criteria are fulfilled.

Editorial corrections

In addition to the above stated changes, editorial corrections may have been made.

CONTENTS

SECTION 1 STRENGTH CHARACTERISTICS OF HULL GIRDER TRANSVERSE SECTIONS

Symbols

For symbols not defined in this section, see 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 coaming.

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 flow, $q_{vi\text{-}gr}$, as defined in Sec.2 and $q_{vi\text{-}n50}$, as defined in Sec.3 for vertical corrugations, the following reduction factor shall be used to obtain the effective thickness of the corrugation:

$$C_{shr} = \frac{s_c}{a + c}$$

where s_c, a and c are defined in Ch.3 Sec.6 [6.1].

For the thickness applied in the hull girder shear capacity as given in Sec.2 [2.1], $t_{i\text{-}gr}$ and in the shear stress calculation as given in Sec.3 [4.2], $t_{i\text{-}n50}$, 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 $2.06 \cdot 10^5$ N/mm^2, the steel equivalent sectional area that may be included in hull girder transverse section is obtained by applying the following factor:

$$C_E = \frac{E}{2.06 \cdot 10^5}$$

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.

Σb = total breadth of large openings, in m, at the transverse section being considered, determined as indicated in Figure 1.

b_1 and b_2 included in Σb
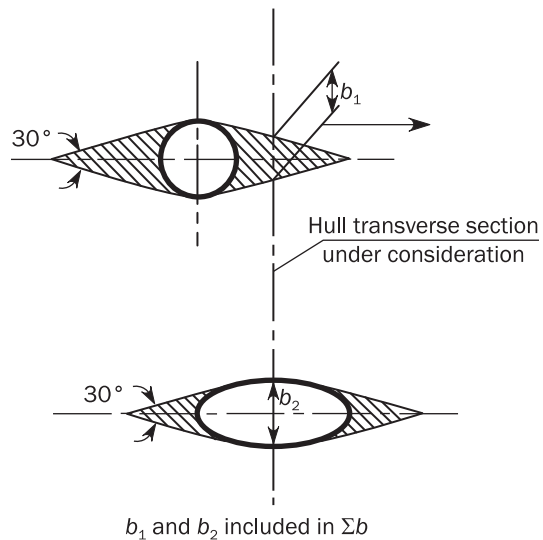
Figure 1 Calculation of Σb

2.10 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.
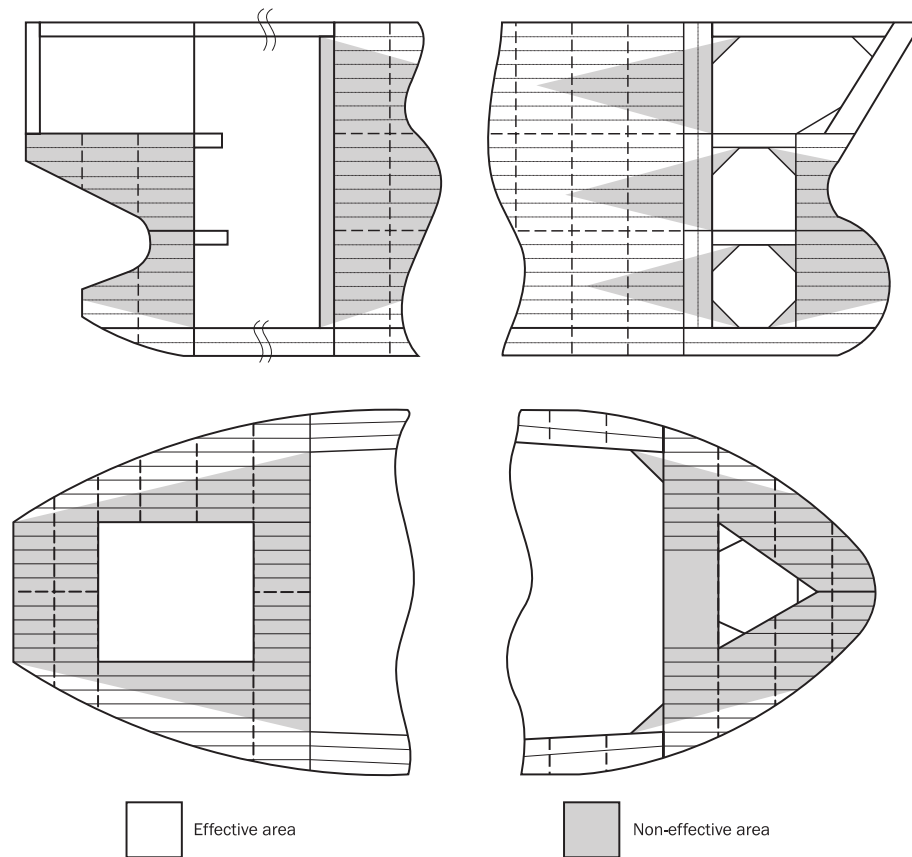
Figure 2 Effective area in way of non-continuous decks and bulkheads

2.11 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, see 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, unless otherwise defined in Pt.5
$I_{y\text{-}gr}$	=	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_{wv}	=	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_{sw}	=	permissible positive or negative still water shear force for seagoing operation, in kN, at the hull transverse section considered, as defined in Ch.4 Sec.4 [2.4.2]
$Q_{sw\text{-}p}$	=	permissible positive or negative still water shear force for harbour/sheltered operation, in kN, at the hull transverse section considered, as defined in Ch.4 Sec.4 [2.4.3]
$Q_{sw\text{-}Lcd}$	=	vertical still water shear force for considered loading condition in seagoing operation, in kN, at the hull transverse section considered
$Q_{sw\text{-}Lcd\text{-}p}$	=	vertical still water shear force for considered loading condition in harbour/sheltered operation, in kN, at the hull transverse section considered
Q_{wv}	=	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]
ΔQ_{mdf}	=	shear force correction at the transverse section considered, in kN, if applicable as defined in [2.4]
$t_{i\text{-}gr}$	=	gross thickness, in mm, for plate i
V_D	=	vertical distance to the equivalent deck line, in m, as defined in [1.2.3]
$q_{vi\text{-}gr}$	=	unit shear flow for hull girder vertical shear force, in mm^{-1}, for the plate i based on gross thickness $t_{i\text{-}gr}$, 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
$z_{n\text{-}gr}$	=	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]
$Z_{B\text{-}gr}$	=	gross section modulus, in m^3, at bottom, to be calculated according [1.2]
$Z_{D\text{-}gr}$	=	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 hull girder longitudinal strength members based on section modulus requirement in [1.3] and moment of inertia requirement in [1.5] shall generally be maintained within 0.4 L amidships. However, in special cases, based on consideration of type of ship, hull form and loading conditions, the scantlings may be gradually reduced towards the end of the 0.4 L part, bearing in mind the desire not to inhibit the vessel's loading flexibility.

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 hull girder longitudinal strength according to Sec.1 [2]. When material factors for higher strength steels are used, the requirements in [1.6] apply.

1.1.3 The shiptype rules for container ships substitute some of the paragraphs in this section. See Pt.5 Ch.2 (UR S11A).

1.2 Definition of hull girder section modulus

1.2.1 Section modulus at bottom
The gross section modulus at bottom is obtained, in m³, from the following formula:

$$Z_{B\text{-}gr} = \frac{I_{y\text{-}gr}}{z_{n\text{-}gr}}$$

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

$$Z_{D\text{-}gr} = \frac{I_{y\text{-}gr}}{V_D}$$

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 $(z_D - z_{n\text{-}gr})/0.9$ from the neutral axis at the centerline, the equivalent deck line is obtained, in m, from the following formula:

$$V_D = z_D - z_{n\text{-}gr}$$

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 $(z_D - z_{n\text{-}gr})/0.9$ from the neutral axis at the centerline, the equivalent deck line is obtained, in m, from the following formula:

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

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 midship

The gross midship section modulus, in m^3, at equivalent deck line as defined in [1.2.3], and bottom shall not be less than the value obtained from the following formula:

$$Z_{R\text{-}gr} = k\left(\frac{1+f_r}{2}\right)C_{w0}\,L^2\,B\left(C_B + 0.7\right)10^{-6}$$

where:

f_r = reduction factor related to service restrictions, defined in Ch.4 Sec.3.
C_{w0} = wave parameter taken as:
      = C_w for $L > 90$ m
      = $5.7 + 0.0222L$ for $L \leq 90$ m

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:

$$Z_{gr} = \frac{\left|M_{sw} + M_{wv}\right|}{\sigma_{perm}}10^{-3}$$

where:

σ_{perm} = permissible hull girder bending stress, in N/mm^2, to be taken as:

$$\sigma_{perm} = \frac{125}{k} \qquad\qquad\qquad \text{for } \frac{x}{L} \leq 0.1$$

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

$$\sigma_{perm} = \frac{125}{k} \qquad\qquad\qquad \text{for } \frac{x}{L} \geq 0.9$$

Intermediate values of σ_{perm} shall be obtained by linear interpolation.

Outside 0.4 L midship the permissible hull girder bending stress can be taken as 175/k provided the yielding and buckling strength of hull girder and primary supporting members is controlled to the same extent as the midship region. Possible inaccuracies related to distribution of hull girder bending moments, including effect of whipping, shall be accounted for.

1.5 Minimum moment of inertia midship

1.5.1 Application
The requirement in [1.5.2] applies to self propelled ships with length above 90 m.

1.5.2 Hull girder moment of inertia

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

$$I_{yR\text{-}gr} = 3f_r C_w L^3 B(C_B + 0.7)10^{-8}$$

where:

f_r = reduction factor related to service restrictions, defined in Ch.4 Sec.3.

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:

$$z_{hts,i} = z_1 \left| 1 - \frac{\sigma_{perm,\,i}}{\sigma_{L\text{-}gr}} \right|$$

where:

z_1 = distance from horizontal neutral axis to the equivalent deck line at side or baseline respectively, in m

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

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

$$\sigma_{L\text{-}gr} = \frac{\max \left| M_{sw} + M_{wv} \right|}{I_{y\text{-}gr}} z_1 10^{-3}$$

based on the maximum absolute value of sagging and hogging vertical bending moment.
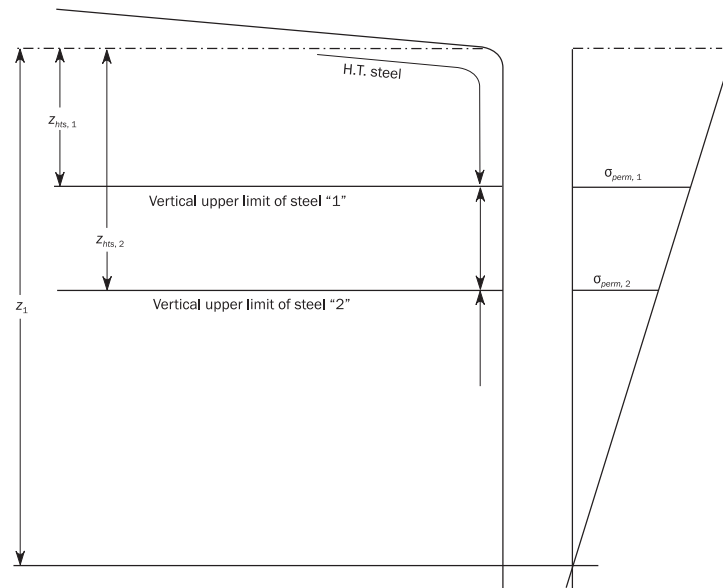
Figure 1 Vertical extent of higher strength steel

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.
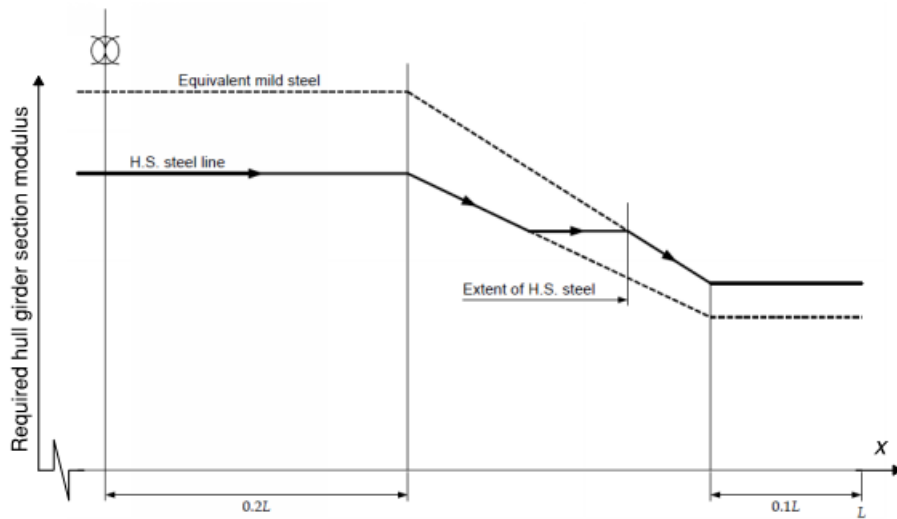
Figure 2 Longitudinal extent of higher strength steel

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:

$$\left| M_{sw\text{-}p} \right| \leq \left| M_{sw} + f_{har}\, M_{wv} \right|$$

The bending moment M_{wv} used above shall be taken with the same sign as the considered bending moment $M_{sw\text{-}p}$.

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:

$$Q_R = \frac{\min}{i}\left(\frac{\tau_{i\text{-}perm} \cdot t_{i\text{-}gr}}{q_{vi\text{-}gr}} \right) 10^{-3}$$

where:

$\tau_{i\text{-}perm}$ = permissible shear stress, in N/mm^2, for plate i, to be taken as:

$$\tau_{i\text{-}perm} = \frac{110}{k}$$

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:

$$\left| Q_{sw} \right| \leq Q_R - \left| Q_{wv} \right|$$

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:

$$\left| Q_{sw\text{-}Lcd} - \Delta Q_{mdf} \right| \leq \left| Q_{sw} \right|$$

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

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:

$$\left| Q_{sw\text{-}p} \right| \leq \left| Q_{sw} + f_{har} Q_{wv} \right|$$

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

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:

$$\left| Q_{sw\text{-}Lcd\text{-}p} - \Delta Q_{mdf} \right| \leq \left| Q_{sw\text{-}p} \right|$$

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

2.4 Shear force correction

Shear force correction, ΔQ_{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, see Ch.1 Sec.4.

$I_{y\text{-}n50}$	=	net moment of inertia, in m^4, of the hull transverse section about its horizontal neutral axis
$I_{z\text{-}n50}$	=	net moment of inertia, in m^4, of the hull transverse section about its vertical neutral axis
$I_{T\text{-}n50}$	=	net torsional moment of inertia, in m^4, of the hull transverse section
$I_{\omega\text{-}n50}$	=	net sectorial moment of inertia, in m^6, of the hull transverse section
$M_{sw\text{-}h}$, $M_{sw\text{-}s}$	=	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
$M_{wh\text{-}LC}$	=	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]
$M_{wt\text{-}LC}$	=	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]
$M_{wt\text{-}LC\text{-}max}$	=	maximum absolute value of $M_{wt\text{-}LC}$ along the ship length
$M_{wv\text{-}LC}$	=	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]
$q_{vi\text{-}n50}$	=	unit shear flow for hull girder vertical shear force, in mm^{-1}, for the plate i based on $t_{i\text{-}n50}$
$Q_{sw\text{-}pos}$, $Q_{sw\text{-}neg}$	=	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]
$Q_{wv\text{-}LC}$	=	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]
$S_{\omega i\text{-}n50}$	=	net sectorial static moment of area, in m^4, of the hull transverse section
$t_{i\text{-}n50}$	=	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]
$z_{n\text{-}n50}$	=	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 hull girder longitudinal stress σ_{hg}, in N/mm^2, 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:

$$\sigma_{hg} = \sigma_{hg\text{-}sw} + \sigma_{hg\text{-}dyn}$$

where:

$$\sigma_{hg\text{-}sw} = \begin{cases} \sigma_{sw\text{-}h} \\ \sigma_{sw\text{-}s} \end{cases}$$

$$\sigma_{hg\text{-}dyn} = \sigma_{wv\text{-}LC} + \sigma_{wh\text{-}LC}$$

2.1.2 Design criteria
Along the length L, the hull girder longitudinal stress σ_{hg}, in N/mm^2, at any point being considered shall comply with the following criteria:

$$\left| \sigma_{hg} \right| \leq \sigma_{hg\text{-}perm}$$

where:

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

$$\sigma_{hg\text{-}perm} = \frac{205}{k}$$

2.2 Hull girder shear stresses

2.2.1 Definition
For seagoing condition the hull girder shear stress τ_{hg}, in N/mm^2, induced by acting vertical shear forces for a dynamic load case at the transverse section being considered is obtained from the following formula:

$$\tau_{hg} = \tau_{hg\text{-}sw} + \tau_{hg\text{-}dyn}$$

where:

$$\tau_{hg\text{-}sw} = \begin{cases} \tau_{sw\text{-}pos} \\ \tau_{sw\text{-}neg} \end{cases}$$

$$\tau_{hg\text{-}dyn} = \tau_{wv\text{-}LC}$$

2.2.2 Design criteria

Along the length L, the hull girder shear stress τ_{hg}, in N/mm^2, at any point being considered shall comply with the following formula:

$$\left| \tau_{hg} \right| \le \tau_{hg\text{-}perm}$$

where:

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

$$\tau_{hg\text{-}perm} = \frac{120}{k}$$

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 stresses induced by acting still water and wave torsional moments shall be considered. Hence, for the seagoing condition, the hull girder longitudinal stress σ_{hg}, in N/mm^2, for a dynamic load case at the transverse section being considered is obtained from the following formula:

$$\sigma_{hg} = \sigma_{hg\text{-}sw} + \sigma_{hg\text{-}dyn}$$

where:

$$\sigma_{hg\text{-}sw} = \begin{cases} \sigma_{sw\text{-}h} + \left| \sigma_{st} \right| \\ \sigma_{sw\text{-}h} - \left| \sigma_{st} \right| \\ \sigma_{sw\text{-}s} + \left| \sigma_{st} \right| \\ \sigma_{sw\text{-}s} - \left| \sigma_{st} \right| \end{cases}$$

$\sigma_{hg\text{-}dyn}$ = $\sigma_{wv\text{-}LC} + C_{ht}\,\sigma_{wh\text{-}LC} + \sigma_{wt\text{-}LC}$

C_{ht} = reduction coefficient due to combination with warping stress

= 0.85

3.1.2 Design criteria

Along the length L, the hull girder longitudinal stress σ_{hg}, in N/mm^2, at any point being considered shall comply with the following formula:

$$\left| \sigma_{hg} \right| \le \sigma_{hg\text{-}perm}$$

where:

$\sigma_{hg\text{-}perm}$ = permissible longitudinal stress, in N/mm^2, as defined in [2.1.2].

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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 hull girder shear stress τ_{hg}, in N/mm^2, for a dynamic load case at the transverse section being considered is obtained from the following formula:

$$\tau_{hg} = \tau_{hg\text{-}sw} + \tau_{hg\text{-}dyn}$$

where:

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

$$\tau_{hg\text{-}dyn} = \tau_{wv\text{-}LC} + \tau_{wt\text{-}LC}$$

3.2.2 Design criteria

Along the length L, the hull girder shear stress τ_{hg}, in N/mm^2, at any point being considered shall comply with the following formula:

$$\tau_{hg} \leq \tau_{hg\text{-}perm}$$

where:

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

3.3 Equivalent stress

3.3.1 Definition

The equivalent stress, in N/mm^2, related to the hull girder longitudinal and shear stresses, σ_{hg} and τ_{hg} as defined in [3.1.1] and [3.2.1], respectively, 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:

$$\sigma_v \leq \sigma_{v\text{-}perm}$$

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where:

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

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

4 Definitions of hull girder stress components

4.1 Longitudinal 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:

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

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

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:

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

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

4.1.3 Longitudinal warping stresses induced by wave and still water hull girder torsion
The longitudinal warping stress, 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:

$$\sigma_{st} = \frac{M_{\sigma\text{-}st}\,\omega_{i\text{-}n50}}{I_{\omega\text{-}n50}}10^{-3}$$

The longitudinal warping stress, in N/mm^2, induced by acting wave torsional moment for a dynamic load case and at the transverse section being considered, is obtained from the following formula:

$$\sigma_{wtLC} = \frac{M_{\sigma\text{-}wt\text{-}LC}\,\omega_{i\text{-}n50}}{I_{\omega\text{-}n50}}10^{-3}$$

where:

$M_{\sigma\text{-}st}$ = still water bi-moment related to longitudinal warping stress, in kNm^2, at the transverse section being considered, in seagoing condition, to be taken as:

$$M_{\sigma\text{-}st} = 0.5c_d M_{st}\,\ell_c \frac{-\pi + \lambda\,\ell_c\,\sinh\left(\dfrac{\lambda\,\ell_c}{2}\right)/\cosh\left(\lambda\,\ell_c\right)}{\pi^2 + \left(\lambda\,\ell_c\right)^2}$$

$M_{\sigma\text{-}wt\text{-}LC}$ = dynamic bi-moment related to longitudinal warping stress, in kNm^2, for a dynamic load case and at the transverse section being considered, to be taken as:

$$M_{\sigma\text{-}wt\text{-}LC} = 0.85 c_{LC} c_d M_{wt\text{-}LC\text{-}max} \, \ell_c \, \frac{-\pi + \lambda \ell_c \sinh\left(\dfrac{\lambda \ell_c}{2}\right) / \cosh\left(\lambda \ell_c\right)}{\pi^2 + \left(\lambda \ell_c\right)^2}$$

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

λ = warping factor, in m^{-1}, to be taken as:

$$\lambda = \sqrt{\frac{I_{T\text{-}n50}}{2.6\, I_{\omega\text{-}n50}}}$$

c_d = distribution coefficient along the length L, to be taken as:

$$c_d = \frac{1}{0.45 \cdot 0.35}\left(\frac{x}{L}\right)^2 \qquad \text{for} \quad 0 \le \frac{x}{L} < 0.35$$

$$c_d = \frac{1}{0.45}\left(\frac{x}{L}\right) \qquad \text{for} \quad 0.35 \le \frac{x}{L} < 0.45$$

$$c_d = 1 \qquad \text{for} \quad 0.45 \le \frac{x}{L} < 0.55$$

$$c_d = \frac{1}{0.45}\left(1 - \frac{x}{L}\right) \qquad \text{for} \quad 0.55 \le \frac{x}{L} \le 0.65$$

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

x_A = 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} = sign coefficient, to be taken as:

C_{LC} = -1 for OST-1S, OST-2P, OSA-1P and OSA-2S

C_{LC} = 1 for all other dynamic load cases

ℓ_c = characteristic torsion length, in m, to be taken as:

$$\ell_c = 0.71\left(0.7 - \frac{x_A}{L}\right)L$$

The bi-moments, $M_{\sigma\text{-}st}$ and $M_{\sigma\text{-}wt\text{-}LC}$, 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.
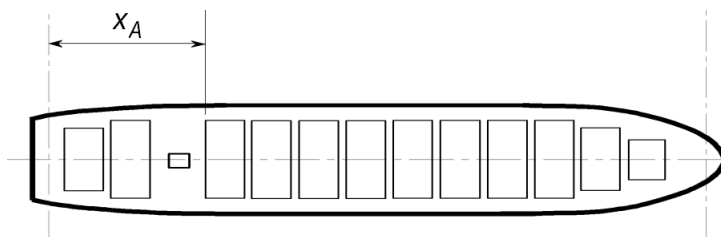

Figure 1 Factor x_A

4.2 Shear stresses

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

The shear stresses, in N/mm^2, induced by vertical still water shear force in seagoing condition at the transverse section being considered, are obtained from the following formulae:

$$\tau_{sw\text{-}pos} = \frac{Q_{sw\text{-}pos}\, q_{vi\text{-}n50}}{t_{i\text{-}n50}} 10^3$$

$$\tau_{sw\text{-}neg} = \frac{Q_{sw\text{-}neg}\, q_{vi\text{-}n50}}{t_{i\text{-}n50}} 10^3$$

4.2.2 Shear stresses induced by dynamic vertical hull girder shear force

The shear stress, in N/mm^2, induced by dynamic vertical shear force for a dynamic load case at the transverse section being considered is obtained from the following formula:

$$\tau_{wv\text{-}LC} = \frac{Q_{wv\text{-}LC}\, q_{vi\text{-}n50}}{t_{i\text{-}n50}} 10^3$$

4.2.3 Warping shear stresses induced by wave and still water hull girder torsion

The warping shear stress, in N/mm^2, induced by still water torsional moment in seagoing condition at the transverse section being considered are obtained from the following formula:

$$\tau_{st} = -\frac{M_{\tau\text{-}st}\, S_{\omega i\text{-}n50}}{I_{\omega\text{-}n50}\, t_{i\text{-}n50}}\, c_d$$

The warping shear stress, in N/mm^2, induced by wave torsional moment for a dynamic load case at the transverse section being considered is obtained from the following formula:

$$\tau_{wt\text{-}LC} = -\frac{0.85\, M_{\tau\text{-}wt\text{-}LC}\, S_{\omega i\text{-}n50}}{I_{\omega\text{-}n50}\, t_{i\text{-}n50}}$$

where:

$M_{\tau\text{-}st}$ = warping component of still water torsional moment related to warping shear stress induced by static torsion, in kNm, at the transverse section being considered, in seagoing condition, to be taken as:

$$M_{\tau\text{-}st} = M_{st}$$

$M_{\tau\text{-}wt\text{-}LC}$ = warping component of wave induced torsional moment related to warping shear stress induced by wave torsion, in kNm, for a dynamic load case at the transverse section being considered, to be taken as:

$$M_{\tau\text{-}wt\text{-}LC} = c_h\, c_r\, M_{wt\text{-}LC} \qquad \text{for} \quad 0 \leq \frac{x}{L} < 0.45$$

$$M_{\tau\text{-}wt\text{-}LC} = c_h\, c_r\, M_{wt\text{-}LC\text{-}0.45L} \qquad \text{for} \quad 0.45 \leq \frac{x}{L} \leq 0.53$$

$$M_{\tau\text{-}wt\text{-}LC} = 0.85\, c_h\, c_r\, M_{wt\text{-}LC\text{-}0.6L} \qquad \text{for} \quad 0.53 < \frac{x}{L} \leq 0.6$$

$$M_{\tau\text{-}wt\text{-}LC} = 0.85\, c_h\, c_r\, M_{wt\text{-}LC} \qquad \text{for} \quad 0.6 < \frac{x}{L} \leq 1$$

c_r =   reduction coefficient, to be taken as:

$$c_r = \min\left(0.7; \frac{2}{1+\sqrt{1+4c}}\right)$$

where:

$$c = \frac{4D^2}{1.21 T_{LC} L}$$

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

$$c_h = 0.7$$

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

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

The warping components of torsional moments, $M_{\tau\text{-}st}$ and $M_{\tau\text{-}wt\text{-}LC}$, 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, see Ch.1 Sec.4.

M_{sw-h}, M_{sw-s} =   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} =   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 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].

1.1.4 For container ships the requirements in this section are supplemented by particular shiptype requirements in Pt.5 Ch.2.

(UR S11A)

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 1 Load components

Load components	Permissible still water bending moment, M_{sw-U}
S+D	M_{sw-h} or M_{sw-s}

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

$$M \leq \frac{M_U}{\gamma_R}$$

where:

M = vertical bending moment, in kNm, to be obtained as specified in [2.2.1]

M_U = vertical hull girder ultimate bending capacity, in kNm, to be obtained as specified in [2.3.1]

γ_R = partial safety factor for the vertical hull girder ultimate bending capacity to be taken as:

   $\gamma_R = \gamma_M \gamma_{DB}$

γ_M = partial safety factor for the vertical hull girder ultimate bending capacity, covering material, geometric and strength prediction uncertainties; in general, to be taken as:

   $\gamma_M = 1.1$

γ_{DB} = 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:

   γ_{DB} = 1.25 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

   γ_{DB} = 1.1 for all other cases

   for sagging condition:

   γ_{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:

$$M = \gamma_S M_{sw\text{-}U} + \gamma_W M_{wv}$$

where:

$M_{sw\text{-}U}$ = permissible still water bending moment, in kNm, in hogging and sagging conditions at the hull transverse section considered as defined in Table 1

γ_S = partial safety factor for the still water bending moment, to be taken as:

   $\gamma_S = 1.0$

γ_W = 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 χ of the transverse section considered (see Figure 1). The curvature χ is positive for hogging condition and negative for sagging condition.
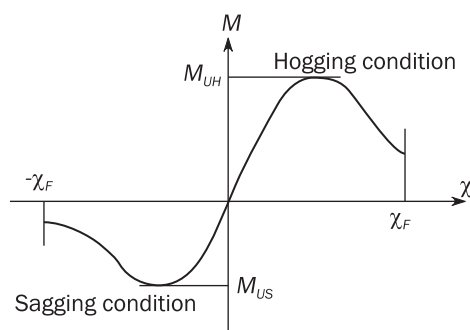

Figure 1 Bending moment capacity versus curvature χ

The hull girder ultimate bending capacity, M_U, shall be assessed by prescriptive method given in DNVGL-CG-0128 *Buckling* or by non-linear FE.

CHANGES – HISTORIC

January 2018 edition

Amendments July 2018

Only editorial corrections have been made.

Changes January 2018, entering into force 1 July 2018

Topic	Reference	Description
Minimum section modulus for small vessels.	Sec.2 [1.3]	The wave parameter for ships with $L \leq 90$ m has been modified.

January 2017 edition

Main changes January 2017, entering into force as from date of publication

• Sec.2 Vertical hull girder bending and shear strength

— Sec.2 [2.3.1]: Error correction.

• Sec.3 Hull girder yield check

— Sec.3 [3.1.1]: A new factor C_{ht} is introduced in connection with modified horizontal wave bending moment in Ch.4.

July 2016 edition

Main changes July 2016, entering into force as from date of publication

• Sec.2 Vertical hull girder bending and shear strength

— Sec.2: Q_{sw}, Q_{sw-p}, Q_{sw_Lcd} and $Q_{sw-Lcd-p}$ are added to the list of symbols.
— Sec.2 [1.1.1]: The tapering requirement has been aligned with IACS UR S7.
— Sec.2 [1.5.2]: The formula for gross moment of inertia is corrected.

• Sec.3 Hull girder yield check

— Sec.3 [4]: The still water bi-moment related to warping normal stresses, the longitudinal distribution of dynamic bi-moment related to warping normal stresses and the longitudinal distribution of dynamic warping shear stresses are updated.

October 2015 edition

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DNV GL AS

This is a new document.

The rules enter into force 1 January 2016.

Amendments January 2016

- Sec.1 Strength characteristics of hull girder transverse sections
— [2.5.2]: Clarification.