Chapter 6 HULL SCANTLINGS

Section 1 PLATING

Symbols

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

I_Y : Net moment of inertia, in m^4, of the hull transverse section about its horizontal neutral axis, to be calculated according to **Ch 5, Sec 1, 1.5**, on gross offered thickness reduced by $0.5t_C$ for all structural members

I_Z : Net moment of inertia, in m^4, of the hull transverse section about its vertical neutral axis, to be calculated according to **Ch 5, Sec 1, 1.5**, on gross offered thickness reduced by $0.5t_C$ for all structural members

N : Z co-ordinate with respect to the reference co-ordinate system defined in **Ch 1, Sec 4, 4**, in *m*, of the centre of gravity of the hull net transverse section, defined in **Ch 5, Sec 1, 1.2**, considering gross offered thickness reduced by $0.5t_C$ for all structural members

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

p_S, p_W : Still water and wave pressure, in kN/m^2, in intact conditions, defined in **3.1.2**

p_F : Pressure, in kN/m^2, in flooded conditions, defined in **3.1.3**

p_T : Pressure, in kN/m^2, in testing conditions, defined in **3.1.4**

σ_X : Normal stress, in N/mm^2, defined in **3.1.5**

ℓ : Length, in *m*, of the longer side of the elementary plate panel, measured along the chord

s : Length, in *m*, of the shorter side of the elementary plate panel, measured along the chord at mid-span of ℓ

c_a : Coefficient of 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:

$$c_r = 1 - 0.5\frac{s}{r}$$, to be taken not less than 0.4

r : Radius of curvature, in *m*.

1. General

1.1 Application

1.1.1

The requirements of this Section 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 stress.

In addition, the buckling check of platings and stiffened panels is to be carried out according to **Ch 6, Sec 3**.

1.2 Net thicknesses

1.2.1

As specified in **Ch 3, Sec 2**, all thicknesses referred to in this Section are net, i.e. they do not include any corrosion addition.

The gross thicknesses are obtained as specified in **Ch 3, Sec 2, 3**.

1.2.2

The net thickness, in mm, of each plating is given by the greatest of the net thicknesses calculated for each load calculation point, as defined in **0**, representative of the considered plating (see **Table 1**). The geometry to be considered is that of the elementary plate panel related to the load calculation point.

1.3 Pressure combination

1.3.1 Elements of the outer shell

The still water and wave lateral pressures are to be calculated considering independently the following cases:

- the still water and wave external sea pressures
- the static and dynamic internal pressure considering the compartment adjacent to the outer shell as being loaded.

If the compartment adjacent to the outer shell is intended to carry liquids, this static and dynamic pressures may be reduced from the corresponding still water and wave external sea pressures.

1.3.2 Elements other than those of the outer shell

The static and dynamic lateral pressures to be considered as acting on an element which separates two adjacent compartments are those obtained considering the two compartments individually loaded.

1.4 Elementary plate panel

1.4.1

The elementary plate panel (*EPP*) is the smallest unstiffened part of plating between stiffeners.

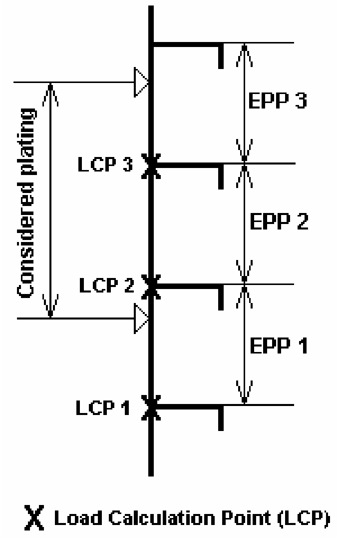
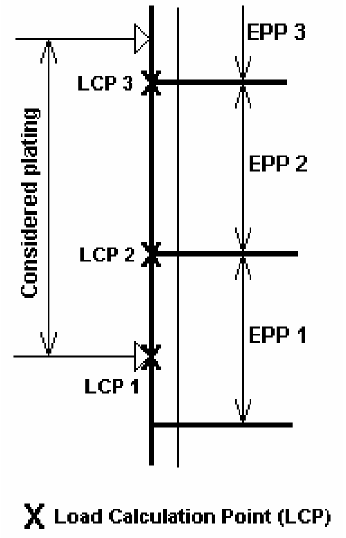
1.5 Load calculation point

1.5.1

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 (see **Table 1**) or, in the case of horizontal plating, at the point of minimum y-value among those of the elementary plate panel considered, as the case may be
- for transverse framing, at the lower edge of the elementary plate panel or at the lower edge of the strake (see **Table 1**) or, in the case of horizontal plating, at the point of minimum y-value among those of the elementary plate panel considered, as the case may be.

Table 1 Load calculation points

Longitudinally stiffened plating	Transversely stiffened plating
	

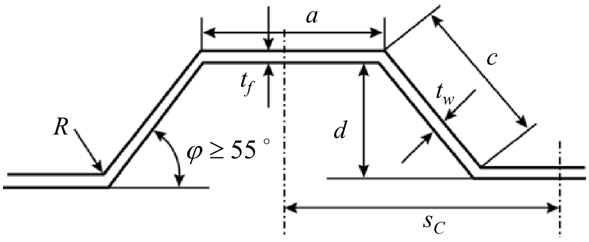
2. General requirements

2.1 Corrugated bulkhead

2.1.1

Unless otherwise specified, the net plating thickness of a corrugated bulkhead is to be not less than that obtained for a plate panel with *s* equal to the greater of *a* and *c*, where *a* and *c* are defined in **Fig 1**.

Fig. 1 Corrugated bulkhead



2.2 Minimum net thicknesses

2.2.1

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

In addition, in the cargo area, the net thickness of side shell plating, from the normal ballast draught to 0.25T (minimum 2.2 *m*) above T, is to be not less than the value obtained, in *mm*, from the following formula:

$$t = 28(s + 0.7)\frac{(BT)^{0.25}}{\sqrt{R_{eH}}}$$

Table 2 Minimum net thickness of plating

Plating	Minimum net thickness, in *mm*
Keel	$7.5 + 0.03L$
Bottom, inner bottom	$5.5 + 0.03L$
Weather strength deck and trunk deck, if any	$4.5 + 0.02L$
Side shell, bilge	$0.85L^{1/2}$
Inner side, hopper sloping plate and topside sloping plate	$0.7L^{1/2}$
Transverse and longitudinal watertight bulkheads	$0.6L^{1/2}$
Wash bulkheads	6.5
Accommodation deck	5.0

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 value obtained from **3.2**.

2.3.2

The net thickness of the transversely framed bilge plating, in *mm*, is to be not less than the value obtained from the following formula:

$$t = 0.76\left[(p_S + p_W)s_b\right]^{0.4} R^{0.6} k^{0.5}$$

where :

R : Bilge radius, in *m*

s_b : Spacing of floors or transverse bilge brackets, in *m*.

2.3.3

The net thickness of the bilge plating is to be not less than the actual net thicknesses of the adjacent 2 *m* width bottom or side plating, whichever is the greater.

2.4 Keel plating

2.4.1

The net thickness of the keel plating is to be not less than the actual net thicknesses of the adjacent 2 *m* width bottom plating.

2.5 Sheerstrake

2.5.1 Welded sheerstrake

The net thickness of a welded sheerstrake is to be not less than the actual thicknesses of the adjacent 2 *m* width side plating, taking into account higher strength steel corrections if needed.

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 0.5*L* 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 not to be less than 40% of the net thickness of sheerstrake other than those in way of such breaks, but need not exceed 4.5 *mm*.

Where the breaks of superstructures occur outside 0.5*L* 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 0.6*L* 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 0.5*L* 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 not to be less than 40% of the net thickness of sheerstrake other than those in way of such breaks, but need not exceed 4.5 *mm*.

Where the breaks of superstructures occur outside 0.5*L* 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 0.6*L* 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 Inner bottom loaded by steel coils on a wooden support

2.7.1 General

The net thickness of inner bottom, bilge hopper sloping plate and inner hull for ships intended to carry steel coils is to comply with **2.7.2** to **2.7.4**.

The provision is determined by assuming **Fig 2** as the standard means of securing steel coils. In case where steel coils are lined up two or more tier, formulae in **2.7.2** and **2.7.3** can be applied to the case that only lowest tier of steel coils is in contact with hopper sloping plate or inner hull plate. In other cases, scantlings of plate thickness are calculated by direct strength analysis or other procedures deemed as appropriate by the Society.

2.7.2 Inner bottom plating

The net thickness of plating of longitudinally framed inner bottom is to be not less than the value obtained, in *mm*, from the following formula:

$$t = K_1 \sqrt{\frac{(g + a_Z)F}{\lambda_P R_Y}}$$

where:

K_1 : Coefficient taken equal to:

$$K_1 = \sqrt{\frac{1.7 s \ell K_2 - 0.73 s^2 K_2^2 - (\ell - \ell')^2}{2\ell'(2s + 2\ell K_2)}}$$

a_Z : Vertical acceleration, in *m/s*^{2}, defined in **Ch 4, Sec2, 3.2**,

F : Force, in *kg*, taken equal to:

$$F = K_S \frac{W n_1 n_2}{n_3}$$

λ_P : Coefficient defined in **Table 6**

K_S : Coefficient taken equal to:

$K_S = 1.4$ when steel coils are lined up in one tier with a key coil
$K_S = 1.0$ in other cases

W : Mass of one steel coil, in *kg*

n_1 : Number of tiers of steel coils

n_2 : Number of load points per elementary plate panel of inner bottom, taken equal to:

- in case of steel coils loaded as shown in **Fig 3**, n_2 is obtained from **Table 3** according to the values of n_3 and ℓ / ℓ_S
- in case of steel coils loaded as shown in **Fig 4**, $n_2 = n_3$

n_3 : Number of dunnages supporting one steel coil

ℓ_S : Length of a steel coil, in *m*

K_2 : Coefficient taken equal to:

$$K_2 = -\frac{s}{\ell} + \sqrt{\left(\frac{s}{\ell}\right)^2 + 1.37\left(\frac{\ell}{s}\right)^2\left(1 - \frac{\ell'}{\ell}\right)^2 + 2.33}$$

ℓ' : Distance, in *m*, between load points per elementary plate panel of inner bottom plate in ship length, taken equal to:

- in case of steel coils loaded as shown in **Fig 3**, ℓ' is obtained from **Table 4** according to the values of ℓ, ℓ_S, n_2 and n_3
- in case of steel coils loaded as shown in **Fig 4**, ℓ' is the actual value.

2.7.3 Hopper sloping plate and inner hull plating

The net thickness of plating of longitudinally framed hopper sloping plate and inner hull is to be not less than the value obtained, in *mm*, from the following formula:

$$t = K_1 \sqrt{\frac{\left[g \cos(\theta_1 - \theta_2) + a_Y \sin\theta_1\right] F'}{\lambda_P R_Y}}$$

where:

K_1 : Coefficient defined in **2.7.2**

θ_1 : Angle, in *deg*, between inner bottom plate and hopper sloping plate or inner hull plating

θ_2 : Single roll amplitude, in *deg*, defined in **Ch 4, Sec 2, 2.1**

a_Y : Transverse acceleration, in *m/s*^{2}, defined in **Ch 4, Sec2, 3.2**

F' : Force, in *kg*, taken equal to:

$$F' = \frac{W n_2 C_k}{n_3}$$

λ_P : Coefficient defined in **Table 6**

W, n_2, n_3 : As defined in **2.7.2**

C_k : Coefficient taken equal to:

$C_k = 4.0$ when steel coils are lined up two or more tier, or when steel coils are lined up one tier and key coil is located second from hopper sloping plate or inner hull plate
$C_k = 2.5$ for other cases

Fig. 2 Inner bottom loaded by steel coils

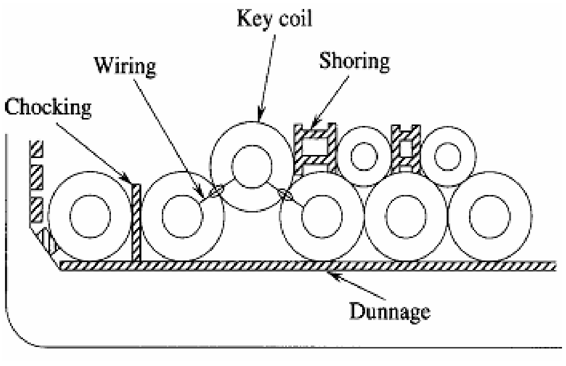


Fig. 3 Loading condition of steel coils

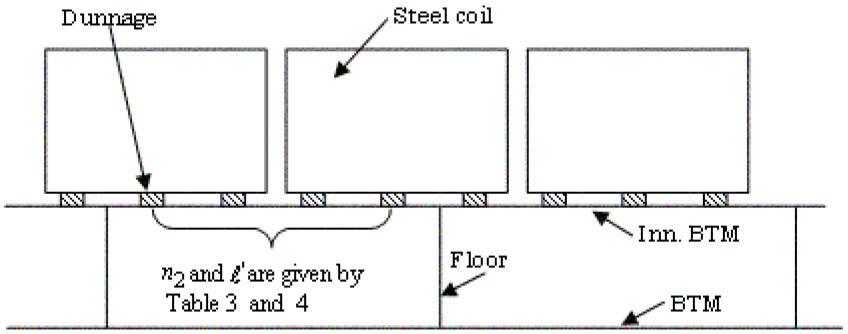


Fig. 4 Loading condition of steel coils

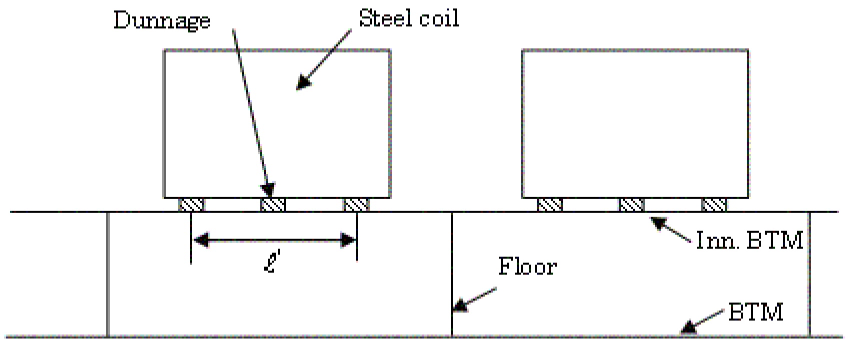


Table 3 Number n_2 of load points per elementary plate panel

n_2	$n_3 = 2$	$n_3 = 3$	$n_3 = 4$	$n_3 = 5$
1	$0 < \frac{\ell}{\ell_s} \le 0.5$	$0 < \frac{\ell}{\ell_s} \le 0.33$	$0 < \frac{\ell}{\ell_s} \le 0.25$	$0 < \frac{\ell}{\ell_s} \le 0.2$
2	$0.5 < \frac{\ell}{\ell_s} \le 1.2$	$0.33 < \frac{\ell}{\ell_s} \le 0.67$	$0.25 < \frac{\ell}{\ell_s} \le 0.5$	$0.2 < \frac{\ell}{\ell_s} \le 0.4$
3	$1.2 < \frac{\ell}{\ell_s} \le 1.7$	$0.67 < \frac{\ell}{\ell_s} \le 1.2$	$0.5 < \frac{\ell}{\ell_s} \le 0.75$	$0.4 < \frac{\ell}{\ell_s} \le 0.6$
4	$1.7 < \frac{\ell}{\ell_s} \le 2.4$	$1.2 < \frac{\ell}{\ell_s} \le 1.53$	$0.75 < \frac{\ell}{\ell_s} \le 1.2$	$0.6 < \frac{\ell}{\ell_s} \le 0.8$
5	$2.4 < \frac{\ell}{\ell_s} \le 2.9$	$1.53 < \frac{\ell}{\ell_s} \le 1.87$	$1.2 < \frac{\ell}{\ell_s} \le 1.45$	$0.8 < \frac{\ell}{\ell_s} \le 1.2$
6	$2.9 < \frac{\ell}{\ell_s} \le 3.6$	$1.87 < \frac{\ell}{\ell_s} \le 2.4$	$1.45 < \frac{\ell}{\ell_s} \le 1.7$	$1.2 < \frac{\ell}{\ell_s} \le 1.4$
7	$3.6 < \frac{\ell}{\ell_s} \le 4.1$	$2.4 < \frac{\ell}{\ell_s} \le 2.73$	$1.7 < \frac{\ell}{\ell_s} \le 1.95$	$1.4 < \frac{\ell}{\ell_s} \le 1.6$
8	$4.1 < \frac{\ell}{\ell_s} \le 4.8$	$2.73 < \frac{\ell}{\ell_s} \le 3.07$	$1.95 < \frac{\ell}{\ell_s} \le 2.4$	$1.6 < \frac{\ell}{\ell_s} \le 1.8$
9	$4.8 < \frac{\ell}{\ell_s} \le 5.3$	$3.07 < \frac{\ell}{\ell_s} \le 3.6$	$2.4 < \frac{\ell}{\ell_s} \le 2.65$	$1.8 < \frac{\ell}{\ell_s} \le 2.0$
10	$5.3 < \frac{\ell}{\ell_s} \le 6.0$	$3.6 < \frac{\ell}{\ell_s} \le 3.93$	$2.65 < \frac{\ell}{\ell_s} \le 2.9$	$2.0 < \frac{\ell}{\ell_s} \le 2.4$

Table 4 Distance between load points in ship length direction per elementary plate panel of inner bottom

n_2	n_3			
	2	3	4	5
1	Actual breadth of dunnage			
2	$0.5\ell_s$	$0.33\ell_s$	$0.25\ell_s$	$0.2\ell_s$
3	$1.2\ell_s$	$0.67\ell_s$	$0.50\ell_s$	$0.4\ell_s$
4	$1.7\ell_s$	$1.20\ell_s$	$0.75\ell_s$	$0.6\ell_s$
5	$2.4\ell_s$	$1.53\ell_s$	$1.20\ell_s$	$0.8\ell_s$
6	$2.9\ell_s$	$1.87\ell_s$	$1.45\ell_s$	$1.2\ell_s$
7	$3.6\ell_s$	$2.40\ell_s$	$1.70\ell_s$	$1.4\ell_s$
8	$4.1\ell_s$	$2.73\ell_s$	$1.95\ell_s$	$1.6\ell_s$
9	$4.8\ell_s$	$3.07\ell_s$	$2.40\ell_s$	$1.8\ell_s$
10	$5.3\ell_s$	$3.60\ell_s$	$2.65\ell_s$	$2.0\ell_s$

2.7.4

Where the number of load points per elementary plate panel n_2 is greater than 10 and/or the number of dunnages n_3 is greater than 5, the inner bottom may be considered as loaded by a uniform distributed load. In such a case, the thickness of the inner bottom plating is to be obtained according to **3.2.1**.

3. Strength check of plating subjected to lateral pressure

3.1 Load model

3.1.1 General

The static and dynamic 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.

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

The wave lateral pressures and hull girder loads are to be calculated, for the probability level of 10^{-8}, in the mutually exclusive load cases H1, H2, F1, F2, R1, R2, P1 and P2, as defined in **Ch 4, Sec 4**.

3.1.2 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 hydrostatic pressure, defined in **Ch 4, Sec 5, 1**
- the still water internal pressure, defined in **Ch 4, Sec 6** for the various types of cargoes and for ballast.

Wave pressure p_W includes for each load case H1, H2, F1, F2, R1, R2, P1 and P2:

- the hydrodynamic pressure, defined in **Ch 4, Sec 5, 1**
- the inertial pressure, defined in **Ch 4, Sec 6** for the various types of cargoes and for ballast.

3.1.3 Lateral pressure in flooded conditions

The lateral pressure in flooded conditions p_F is defined in **Ch 4, Sec 6, 3**.

3.1.4 Lateral pressure in testing conditions

The lateral pressure p_T in testing conditions is taken equal to:

- $p_T = p_{ST} - p_S$ for bottom shell plating and side shell plating
- $p_T = p_{ST}$ otherwise,

where:

p_{ST} : Testing pressure defined in **Ch 4, Sec 6, 4**

p_S : Pressure taken equal to:

- if the testing is carried out afloat: hydrostatic pressure defined in **Ch 4, Sec 5, 1** for the draught T_1, defined by the Designer, at which the testing is carried out. If T_1 is not defined, the testing is considered as being not carried out afloat
- if the testing is not carried out afloat: $p_S = 0$

3.1.5 Normal stresses

The normal stress to be considered for the strength check of plating contributing to the hull girder longitudinal strength is the maximum value of σ_X between sagging and hogging conditions, when applicable, obtained, in *N/mm*^{2}, from the following formula:

$$\sigma_X = \left[C_{SW} \left| \frac{M_{SW}}{I_Y} \right| (z - N) + C_{WV} \left| \frac{M_{WV}}{I_Y} \right| (z - N) - C_{WH} \left| \frac{M_{WH}}{I_Z} \right| y \right] 10^{-3}$$

where:

M_{SW} : Permissible still water bending moments, in *kN-m*, in hogging or sagging as the case may be

M_{WV} : Vertical wave bending moment, in *kN-m*, in hogging or sagging as the case may be, as defined in **Ch 4**, **Sec 3**

M_{WH} : Horizontal wave bending moment, in *kN-m*, as defined in **Ch 4, Sec 3**

C_{SW} : Combination factor for each load case H1, H2, F1, F2, R1, R2, P1 and P2 and defined in **Table 5**

C_{WV}, C_{WH} : Combination factors defined in **Ch 4, Sec 4, 2.2** for each load case H1, H2, F1, F2, R1, R2, P1 and P2 and given in **Table 5**.

Table 5 Combination factors C_{SW}, C_{WV} and C_{WH}

LC	Hogging			Sagging		
	C_{SW}	C_{WV}	C_{WH}	C_{SW}	C_{WV}	C_{WH}
H1	Not Applicable			-1	-1	0
H2	1	1	0	Not Applicable		
F1	Not Applicable			-1	-1	0
F2	1	1	0	Not Applicable		
R1	1	0	$1.2-\frac{T_{LC}}{T_S}$	-1	0	$1.2-\frac{T_{LC}}{T_S}$
R2	1	0	$\frac{T_{LC}}{T_S}-1.2$	-1	0	$\frac{T_{LC}}{T_S}-1.2$
P1	1	$0.4-\frac{T_{LC}}{T_S}$	0	-1	$0.4-\frac{T_{LC}}{T_S}$	0
P2	1	$\frac{T_{LC}}{T_S}-0.4$	0	-1	$\frac{T_{LC}}{T_S}-0.4$	0

3.2 Plating thickness

3.2.1 Intact conditions

The net thickness of laterally loaded plate panels is to be not less than the value obtained, in *mm*, from the following formula:

$$t = 15.8 c_a c_r s \sqrt{\frac{p_S + p_W}{\lambda_P R_Y}}$$

where:

λ_P : Coefficient defined in **Table 6**

Table 6 Coefficient λ_P

Plating		Coefficient λ_P
Contributing to the hull girder longitudinal strength	Longitudinally framed plating	$0.95-0.45\left\|\frac{\sigma_X}{R_Y}\right\|$, without being taken greater than 0.9
	Transversely framed plating	$0.95-0.90\left\|\frac{\sigma_X}{R_Y}\right\|$, without being taken greater than 0.9
Not contributing to the hull girder longitudinal strength		0.9

3.2.2 Net thickness under flooded conditions excluding corrugations of transverse vertically corrugated bulkhead separating cargo holds

The plating which constitutes the boundary of compartments not intended to carry liquids (excluding bottom plating and side shell plating), and excluding corrugations of transverse vertically corrugated bulkhead separating cargo holds is to be checked in flooded conditions. To this end, its net thickness is to be not less than the value obtained, in *mm*, from the following formula:

$$t = 15.8 c_a c_r s \sqrt{\frac{p_F}{\alpha \lambda_P R_Y}}$$

where:

λ_P : Coefficient defined in **Table 6**, determined by considering σ_X in flooded condition

α : Coefficient taken equal to:

$\alpha = 0.95$ for the plating of collision bulkhead

$\alpha = 1.15$ for the plating of other watertight boundaries of compartments.

3.2.3 Net thickness of the corrugations of transverse vertically corrugated watertight bulkheads separating cargo holds for flooded conditions

The net plate thickness t, in *mm*, of transverse vertically corrugated watertight bulkheads separating cargo holds is to be not less than that obtained from the following formula:

$$t = 14.9s\sqrt{\frac{1.05p}{R_{eH}}}$$

p : Resultant pressure, in *kN/m*^{2}, as defined in **Ch 4, Sec 6, 3.3.7**

For built-up corrugation bulkheads, when the thicknesses of the flange and web are different:

- the net thickness of the narrower plating is to be not less than that obtained, in *mm*, from the following formula:

$$t_N = 14.9s\sqrt{\frac{1.05p}{R_{eH}}}$$

- the net thickness of the wider plating is not to be less than the greater of those obtained, in *mm*, from the following formulae:

$$t_W = 14.9s\sqrt{\frac{1.05p}{R_{eH}}}$$

$$t_W = \sqrt{\frac{462s^2p}{R_{eH}} - t_{NP}^2}$$

where:

t_{NP} : Actual net thickness of the narrower plating, in *mm*, to be not taken greater than:

$$t_{NP} = 14.9s\sqrt{\frac{1.05p}{R_{eH}}}$$

3.2.4 Testing conditions

The plating of compartments or structures as defined in **Ch 4, Sec 6, 4** 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:

$$t = 15.8c_a c_r s\sqrt{\frac{p_T}{1.05R_Y}}$$

Section 2 ORDINARY STIFFENERS

Symbols

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

L_2 : Rule length L, but to be taken not greater than 300 *m*

I_Y : Net moment of inertia, in m^4, of the hull transverse section about its horizontal neutral axis, to be calculated according to **Ch 5**, **Sec 1**, **1.5**, on gross offered thickness reduced by $0.5t_C$ for all structural members

I_Z : Net moment of inertia, in m^4, of the hull transverse section about its vertical neutral axis, to be calculated according to **Ch 5**, **Sec 1**, **1.5**, on gross offered thickness reduced by $0.5t_C$ for all structural members

N : Z co-ordinate with respect to the reference co-ordinate system defined in **Ch 1**, **Sec 4**, **4**, in *m*, of the centre of gravity of the hull net transverse section defined in **Ch 5**, **Sec 1**, **1.2**, considering gross offered thickness reduced by $0.5t_C$ for all structural members

p_S, p_W : Still water and wave pressure, in kN/m^2, in intact conditions, defined in **3.1.2**

p_F : Pressure, in kN/m^2, in flooded conditions, defined in **3.1.3**

p_T : Pressure, in kN/m^2, in testing conditions, defined in **3.1.4**

σ_X : Normal stress, in N/mm^2, defined in **3.1.5**

s : Spacing, in *m*, of ordinary stiffeners, measured at mid-span along the chord

ℓ : Span, in *m*, of ordinary stiffeners, measured along the chord between the supporting members, see **Ch 3**, **Sec 6**, **4.2**

h_w : Web height, in *mm*

t_w : Net web thickness, in *mm*

b_f : Face plate width, in *mm*

t_f : Net face plate thickness, in *mm*

b_p : Width, in *m*, of the plating attached to the stiffener, for the yielding check, defined in **Ch 3**, **Sec 6**, **4.3**

w : Net section modulus, in cm^3, of the stiffener, with an attached plating of width b_p, to be calculated as specified in **Ch 3**, **Sec 6**, **4.4**

A_{sh} : Net shear sectional area, in cm^2, of the stiffener, to be calculated as specified in **Ch 3**, **Sec 6**, **4.4**

m : Coefficient taken equal to:

$m = 10$ for vertical stiffeners

$m = 12$ for other stiffeners

τ_α : Allowable shear stress, in N/mm^2, taken equal to:

$$\tau_a = \frac{R_Y}{\sqrt{3}}$$

1. General

1.1 Application

1.1.1

The requirements of this Section apply for the yielding check of ordinary stiffeners subjected to lateral pressure and, for ordinary stiffeners contributing to the hull girder longitudinal strength, to hull girder normal stresses.

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

In addition, the buckling check of ordinary stiffeners is to be carried out according to **Ch 6**, **Sec 3**.

1.2 Net scantlings

1.2.1

As specified in **Ch 3**, **Sec 2**, all scantlings referred to in this Section are net, i.e. they do not include any corrosion addition.

The gross scantlings are obtained as specified in **Ch 3**, **Sec 2**, **3**.

1.3 Pressure combination

1.3.1 Elements of the outer shell

The still water and wave lateral pressures are to be calculated considering independently the following cases:

- the still water and wave external sea pressures
- the still water and wave internal pressure considering the compartment adjacent to the outer shell as being loaded. If the compartment adjacent to the outer shell is intended to carry liquids, this still water and wave internal pressures are to be reduced from the corresponding still water and wave external sea pressures.

1.3.2 Elements other than those of the outer shell

The still water and wave lateral pressures to be considered as acting on an element which separates two adjacent compartments are those obtained considering the two compartments individually loaded.

1.4 Load calculation point

1.4.1 Horizontal stiffeners

Unless otherwise specified, lateral pressure and hull girder stress, if any, are to be calculated at mid-span of the ordinary stiffener considered.

1.4.2 Vertical stiffeners

The lateral pressure p is to be calculated as the maximum between the value obtained at mid-span and the value obtained from the following formula:

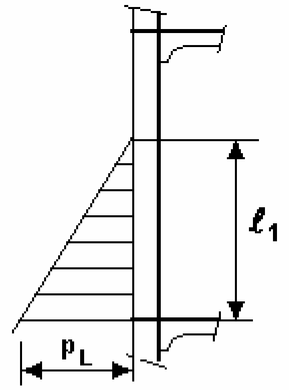
- $p = \frac{p_U + p_L}{2}$, when the upper end of the vertical stiffener is below the lowest zero pressure level
- $p = \frac{\ell_1}{\ell} \frac{p_L}{2}$, when the upper end of the vertical stiffener is at or above the lowest zero pressure level (see **Fig. 1**)

where:

ℓ_1 : Distance, in m, between the lower end of vertical stiffener and the lowest zero pressure level

p_U, p_L : Lateral pressures at the upper and lower end of the vertical stiffener span ℓ, respectively.

Fig. 1 Definition of pressure for vertical stiffeners



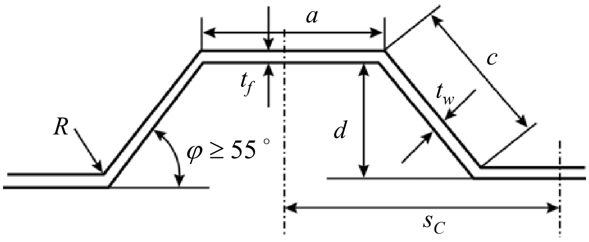
2. General requirements

2.1 Corrugated bulkhead

2.1.1

Unless otherwise specified, the net section modulus and the net shear sectional area of a corrugation are to be not less than those obtained for an ordinary stiffener with s equal s_C, as defined in **Fig. 2**.

Fig. 2 Corrugated bulkhead



2.2 Minimum net thicknesses of webs of ordinary stiffeners

2.2.1 Ordinary stiffeners other than side frames of single side bulk carriers

The net thickness of the web of ordinary stiffeners, in *mm*, is to be not less than the greater of:

- $t = 3.0 + 0.015L_2$
- 40% of the net offered thickness of the attached plating

and is to be less than 2 *times* the net offered thickness of the attached plating

2.2.2 Side frames of single side bulk carriers

The net thickness of side frame webs within the cargo area, in *mm*, is to be not less than the value obtained from the following formula:

$$t_{MIN} = 0.75\alpha(7 + 0.03L)$$

where:

α : Coefficient taken equal to:

$\alpha = 1.15$	for the frame webs in way of the foremost hold
$\alpha = 1.00$	for the frame webs in way of other holds.

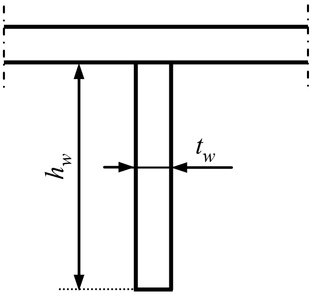
2.3 Net dimensions of ordinary stiffeners

2.3.1 Flat bar

The net dimensions of a flat bar ordinary stiffener (see **Fig. 3**) are to comply with the following requirement:

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

Fig. 3 Net dimensions of a flat bar



2.3.2 T-section

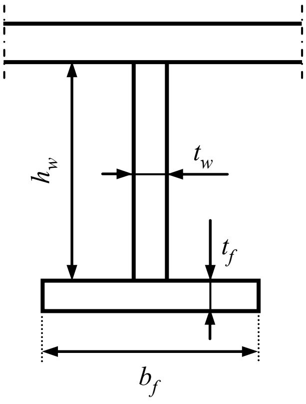
The net dimensions of a *T*-section ordinary stiffener (see **Fig. 4**) are to comply with the following requirements:

$$\frac{h_w}{t_w} \leq 65\sqrt{k}$$

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

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

Fig. 4 Net dimensions of a *T*-section



2.3.3 Angle

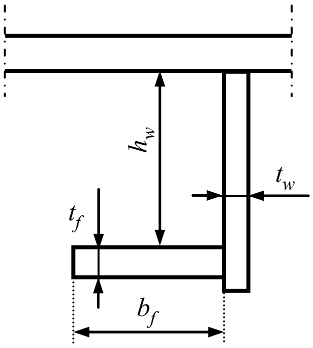
The net dimensions of an angle ordinary stiffener (see **Fig. 5**) are to comply with the following requirements:

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

$$\frac{b_f}{t_f} \le 16.5\sqrt{k}$$

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

Fig. 5 Net dimensions of an angle



2.4 Struts connecting ordinary stiffeners

2.4.1

The net sectional area A_{SR}, in cm^2, and the minimum net moment of inertia I_{SR} about the axes perpendicular to the strut, in cm^4, of struts connecting ordinary stiffeners are to be not less than the values obtained from the following formulae:

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

$$I_{SR} = \frac{0.75 s\ell(p_{SR1} + p_{SR2})A_{ASR}\ \ell_{SR}^2}{47.2A_{ASR} - s\ell(p_{SR1} + p_{SR2})}$$

where:

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

$$p_{SR} = 0.5(p_{SR1} + p_{SR2})$$

$$p_{SR} = p_{SR3}$$

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

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

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

ℓ : Span, in *m*, of ordinary stiffeners connected by the strut (see **Ch 3**, **Sec 6**, **4.2.3**)

ℓ_{SR} : Length, in *m*, of the strut

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

2.5 Ordinary stiffeners of inner bottom loaded by steel coils on a wooden support

2.5.1 General

The requirements of this sub-article apply to the ordinary stiffeners located on inner bottom, hopper sloping plate and inner hull when loaded by steel coils on a wooden support (dunnage), as indicated in **Fig 2** of **Ch 6**, **Sec 1**.

In case where steel coils are lined up two or more tier, formulae in **2.5.2** and **2.5.3** can be applied to the case that only lowest tier of steel coils is in contact with hopper sloping plate or inner hull plate. In other cases, scantlings of net section modulus and net shear section area are calculated by direct strength analysis or other procedures.

2.5.2 Ordinary stiffeners located on inner bottom plating

The net section modulus w, in *cm*^{3}, and the net shear sectional area A_{sh}, in *cm*^{2}, of single span ordinary stiffeners located on inner bottom plating are to be not less than the values obtained from the following formulae:

$$w = K_3 \frac{(g + a_Z)F}{8\lambda_S R_Y}$$

$$A_{sh} = \frac{5(g + a_Z)F}{\tau_a \sin\phi} 10^{-3}$$

where:

K_3 : Coefficient defined in **Table 1**

a_Z : Vertical acceleration, in *m/s*^{2}, defined in **Ch 4**, **Sec2**, **3.2**

F : Force, in *kg*, defined in **Ch 6**, **Sec 1**, **2.7.2**

λ_S : Coefficient defined in **Table 3**

ϕ : Angle, in *deg*, defined in **3.2.3**.

2.5.3 Ordinary stiffeners located on hopper sloping plate or inner hull plating

The net section modulus w, in *cm*^{3}, and the net shear sectional area A_{sh}, in *cm*^{2}, of single span ordinary stiffeners located on hopper sloping plate and inner hull plate are to be not less than the values obtained from the following formulae:

$$w = K_3 \frac{[g\cos(\theta_1 - \theta_2) + a_Y \sin\theta_1]F'}{8\lambda_S R_Y}$$

$$A_{sh} = \frac{5a_Y F'}{\tau_a \sin\varphi \sin\phi} 10^{-3}$$

where:

K_3 : Coefficient defined in **Table 1**

θ_1, θ_2 : Angles, in *deg*, defined in **Ch 6**, **Sec 1**, **2.7.3**

a_Y : Transverse acceleration, in *m/s*^{2}, defined in **Ch 4, Sec 2, 3.2**

F' : Force, in *kg*, defined in **Ch 6**, **Sec 1**, **2.7.3**

λ_S : Coefficient defined in **Table 3**

ϕ : Angle, in *deg*, defined in **3.2.3**

φ : Angle, in *deg*, between inner bottom plating and hopper sloping plate or inner hull plating.

ℓ' : Distance, in *m*, between load points per elementary plate panel of inner bottom plate in ship length, sloping plate or inner hull plating, as defined in **Ch 6, Sec 1, 2.7.2**.

Table 1 Coefficient K_3

n_2	1	2	3	4	5	6	7	8	9	10
K_3	ℓ	$\ell - \frac{\ell'^2}{\ell}$	$\ell - \frac{2\ell'^2}{3\ell}$	$\ell - \frac{5\ell'^2}{9\ell}$	$\ell - \frac{\ell'^2}{2\ell}$	$\ell - \frac{7\ell'^2}{15\ell}$	$\ell - \frac{4\ell'^2}{9\ell}$	$\ell - \frac{3\ell'^2}{7\ell}$	$\ell - \frac{5\ell'^2}{12\ell}$	$\ell - \frac{11\ell'^2}{27\ell}$

2.5.4

Where the number of load points per elementary plate panel n_2 is greater than 10 and/or the number of dunnages n_3 is greater than 5, the inner bottom may be considered as loaded by a uniform distributed load. In such a case, the scantling of the inner bottom ordinary stiffeners is to be obtained according to **3.2.3**.

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

2.6.1

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

2.6.2

The loads exerted by launching appliance are to correspond to the Safe Working Load of the launching appliance.

2.6.3

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

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

where R_m is the ultimate tensile strength of the stiffener material, in *N/mm*^{2}.

3. Yielding check

3.1 Load model

3.1.1 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 the compartments adjacent to it.

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

The wave lateral loads and hull girder loads are to be calculated, for the probability level of 10^{-8}, in the mutually exclusive load cases H1, H2, F1, F2, R1, R2, P1 and P2, as defined in **Ch 4**, **Sec 4**.

3.1.2 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 hydrostatic pressure, defined in **Ch 4**, **Sec 5**, **1**
- the still water internal pressure, defined in **Ch 4**, **Sec 6** for the various types of cargoes and for ballast.

Wave pressure p_W includes for each load case H1, H2, F1, F2, R1, R2, P1 and P2:

- the hydrodynamic pressure, defined in **Ch 4**, **Sec 5**, **1**
- the inertial pressure, defined in **Ch 4**, **Sec 6** for the various types of cargoes and for ballast.

3.1.3 Lateral pressure in flooded conditions

The lateral pressure in flooded conditions p_F is defined in **Ch 4**, **Sec 6**, **3**.

3.1.4 Lateral pressure in testing conditions

The lateral pressure p_T in testing conditions is taken equal to:

- $p_T = p_{ST} - p_S$ for bottom shell plating and side shell plating
- $p_T = p_{ST}$ otherwise,

where:

p_{ST} : Testing pressure defined in **Ch 4**, **Sec 6**, **4**

p_S : Pressure taken equal to:

- if the testing is carried out afloat: hydrostatic pressure defined in **Ch 4**, **Sec 5**, **1** for the draught T_1, defined by the Designer, at which the testing is carried out. If T_1 is not defined, the testing is considered as being not carried out afloat
- if the testing is not carried out afloat: $p_S = 0$

3.1.5 Normal stresses

The normal stress to be considered for the strength check of ordinary stiffeners contributing to the hull girder longitudinal strength is the maximum value of σ_X between sagging and hogging conditions, when applicable, obtained , in *N/mm*^{2}, from the following formula:

$$\sigma_X = \left[C_{SW} \left| \frac{M_{SW}}{I_Y} \right| (z-N) + C_{WV} \left| \frac{M_{WV}}{I_Y} \right| (z-N) - C_{WH} \left| \frac{M_{WH}}{I_Z} \right| y \right] 10^{-3}$$

where:

M_{SW} : Permissible still water bending moments, in *kN-m*, in hogging or sagging as the case may be
M_{WV} : Vertical wave bending moment, in *kN-m*, in hogging or sagging as the case may be, as defined in **Ch 4**, **Sec 3**
M_{WH} : Horizontal wave bending moment, in *kN-m*, as defined in **Ch 4**, **Sec 3**
C_{SW} : Combination factor for each load case H1, H2, F1, F2, R1, R2, P1 and P2 and defined in **Table 2**
C_{WV}, C_{WH} : Combination factors defined in **Ch 4**, **Sec 4**, **2.2** for each load case H1, H2, F1, F2, R1, R2, P1 and P2 and given in **Table 2**.

Table 2 Combination factors C_{SW}, C_{WV} and C_{WH}

LC	Hogging			Sagging		
	C_{SW}	C_{WV}	C_{WH}	C_{SW}	C_{WV}	C_{WH}
H1	Not Applicable			-1	-1	0
H2	1	1	0	Not Applicable		
F1	Not Applicable			-1	-1	0
F2	1	1	0	Not Applicable		
R1	1	0	$1.2-\frac{T_{LC}}{T_S}$	-1	0	$1.2-\frac{T_{LC}}{T_S}$
R2	1	0	$\frac{T_{LC}}{T_S}-1.2$	-1	0	$\frac{T_{LC}}{T_S}-1.2$
P1	1	$0.4-\frac{T_{LC}}{T_S}$	0	-1	$0.4-\frac{T_{LC}}{T_S}$	0
P2	1	$\frac{T_{LC}}{T_S}-0.4$	0	-1	$\frac{T_{LC}}{T_S}-0.4$	0

3.2 Strength criteria for single span ordinary stiffeners other than side frames of single side bulk carriers

3.2.1 Boundary conditions

The requirements of this sub-article apply to ordinary stiffeners considered as clamped at both ends.

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

3.2.2 Groups of equal ordinary stiffeners

Where a group of equal ordinary stiffeners is fitted, it is acceptable that the minimum net section modulus in **3.2.3** to **3.2.7** 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.

3.2.3 Net section modulus and net shear sectional area of single span ordinary stiffeners under intact conditions

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

$$w = \frac{(p_S + p_W)s\ell^2}{m\lambda_S R_Y} 10^3$$

$$A_{sh} = \frac{5(p_S + p_W)s\ell}{\tau_a \sin\phi}$$

where:

λ_S : Coefficient defined in **Table 3**.

ϕ : Angle, in *deg*, between the stiffener web and the shell plate, measured at the middle of the stiffener span; the correction is to be applied when ϕ is less than 75 *deg*.

Table 3 Coefficient λ_S

Ordinary stiffener	Coefficient λ_S
Longitudinal stiffener ccontributing to the hull girder longitudinal strength	$1.2\left(1.0-0.85\left\|\frac{\sigma_X}{R_Y}\right\|\right)$, without being taken greater than 0.9
Other stiffeners	0.9

3.2.4 Net section modulus of corrugated bulkhead of ballast hold for ships having a length (L) less than 150*m*

The net section modulus w, in cm^3, of corrugated bulkhead of ballast hold for ships having a length (L) less than 150*m* subjected to lateral pressure are to be not less than the values obtained from the following formula:

$$w = K\frac{(p_S + p_W)s_C\ell^2}{m\lambda_S R_Y}10^3$$

where:

K : Coefficient given in **Table 4** and **5**, according to the type of end connection. When $d_H < 2.5d_0$, both section modulus per half pitch of corrugated bulkhead and section modulus of lower stool at inner bottom are to be calculated.

s_C : Half pitch length, in *m*, of the corrugation, defined in **2.1.1**

ℓ : Length, in *m*, between the supports, as indicated in **Fig. 6**

λ_S : Coefficient defined in **Table 3**.

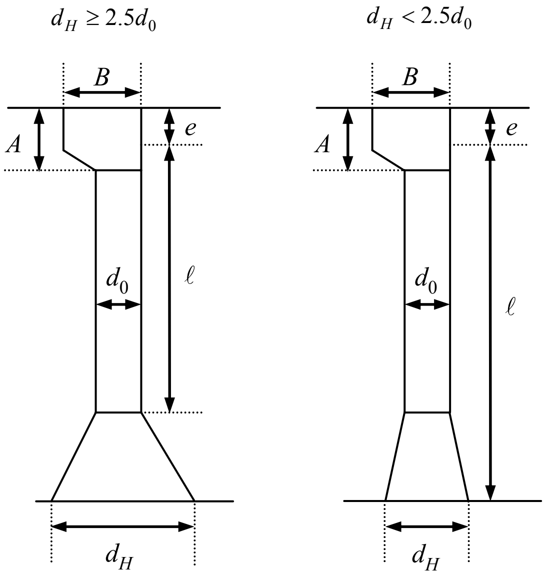
Table 4 Values of K, in case $d_H \geq 2.5d_0$

Lower end	Upper end		
	Supported by girders	Welded directly to deck	Welded to stool efficiently supported by ship structure
Supported by girders or welded directly to decks or inner bottoms	0.83	1.25	1.25
Welded to stool efficiently supported by ship structure	1.25	1.00	0.83

Table 5 Values of K, in case $d_H < 2.5d_0$

Upper end support	Supported by girders	Connected to deck	Connected to stool
Section modulus of corrugated bulkhead	0.83	0.71	0.65
Section modulus of stool at bottom	0.83	1.25	1.13

Fig. 6 Measurement of ℓ



$$e = A\left(1 - d_0 / 2B\right)$$

3.2.5 Net section modulus and net shear sectional area of single span ordinary stiffeners under flooded conditions excluding corrugations of transverse vertically corrugated bulkhead separating cargo holds

The net section modulus w, in cm^3, and the net shear sectional area A_{sh}, in cm^2, of single span ordinary stiffeners excluding corrugations of transverse vertically corrugated bulkhead separating cargo holds subjected to flooding are to be not less than the values obtained from the following formulae:

$$w = \frac{p_F s \ell^2}{16 \alpha \lambda_S R_Y} 10^3$$

$$A_{sh} = \frac{5 p_F s \ell}{\alpha \tau_a \sin \phi}$$

where:

λ_S, ϕ : Coefficient and angle defined in **3.2.3**, λ_S being determined by considering σ_X in flooded condition.

α : Coefficient taken equal to:

$\alpha = 0.95$ for the ordinary stiffeners of collision bulkhead,

$\alpha = 1.15$ for the ordinary stiffeners of other watertight boundaries of compartments.

without taken $\alpha \lambda_S$ greater than 1.0

3.2.6 Bending capacity and shear capacity of the corrugations of transverse vertically corrugated watertight bulkheads separating cargo holds for flooded conditions

The bending capacity and the shear capacity of the corrugations of watertight bulkheads between separating cargo holds are to comply with the following formulae:

$$0.5 W_{LE} + W_M \geq \frac{M}{0.95 R_{eH}} 10^3$$

$$\tau \leq \frac{R_{eH}}{2}$$

where:

M : Bending moment in a corrugation, to be obtained, in $kN\text{-}m$, from the following formula:

$M = F \ell_C / 8$

F : Resultant force, in kN, to be calculated according to **Ch 4**, **Sec 6**, **3.3.7**

ℓ_C : Span of the corrugations, in m, to be obtained according to **Ch 3**, **Sec 6**, **10.4.4**

W_{LE} : Net section modulus, in cm^3, of one half pitch corrugation, to be calculated at the lower end of the corrugations according to **Ch 3**, **Sec 6**, **10.4.13**, without being taken greater than the value obtained from the following formula:

$$W_{LE,M} = W_G + \left(\frac{Q\, h_G - 0.5 h_G^2\, s_C\, p_G}{R_{eH}} \right) 10^3$$

W_G : Net section modulus, in *cm*^{3}, of one half pitch corrugation, to be calculated in way of the upper end of shedder or gusset plates, as applicable, according to **Ch 3**, **Sec 6**, **10.4.14**

Q : Shear force in a corrugation, to be obtained, in *kN*, from the following formula:
$Q = 0.8F$

h_G : Height, in *m*, of shedders or gusset plates, as applicable (see **Ch 3**, **Sec 6**, **Fig 31** to **Fig 35**)

p_G : Resultant pressure, in *kN/m*^{2}, to be calculated in way of the middle of the shedders or gusset plates, as applicable, according to **Ch 4**, **Sec 6**, **3.3.7**

s_C : Spacing of the corrugations, in *m*, to be taken according to **Fig. 2**

W_M : Net section modulus, in *cm*^{3}, of one half pitch corrugation, to be calculated at the mid-span of corrugations according to **Ch 3**, **Sec 6**, **10.4.14**, without being taken greater than $1.15 W_{LE}$

τ : Shear stress in the corrugation, in *N/mm*^{2}, to be obtained from the following formula:

$$\tau = 10 \frac{Q}{A_{sh}}$$

A_{sh} : Shear area, in *cm*^{2}, calculated according to **Ch 3**, **Sec 6**, **10.4.15**.

3.2.7 Net section modulus and net shear sectional area of single span ordinary stiffeners under testing conditions

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

$$w = \frac{p_T s \ell^2}{1.05 m R_Y} 10^3$$

$$A_{sh} = \frac{5 p_T s \ell}{1.05 \tau_a \sin\phi}$$

where:

ϕ : Angle, in *deg*, defined in **3.2.3**.

3.3 Strength criteria for side frames of single side bulk carriers

3.3.1 Net section modulus and net shear sectional area of side frames

The net section modulus *w*, in *cm*^{3}, and the net shear sectional area A_{sh}, in *cm*^{2}, of side frames subjected to lateral pressure are to be not less, in the mid-span area, than the values obtained from the following formulae:

$$w = 1.125 \alpha_m \frac{(p_S + p_W) s \ell^2}{m \lambda_S R_Y} 10^3$$

$$A_{sh} = 1.1 \alpha_S \frac{5 (p_S + p_W) s \ell}{\tau_a \sin\phi} \left(\frac{\ell - 2\ell_B}{\ell} \right)$$

where:

α_m : Coefficient taken equal to:

$\alpha_m = 0.42$	for *BC-A* ships
$\alpha_m = 0.36$	for other ships

λ_S : Coefficient taken equal to 0.9

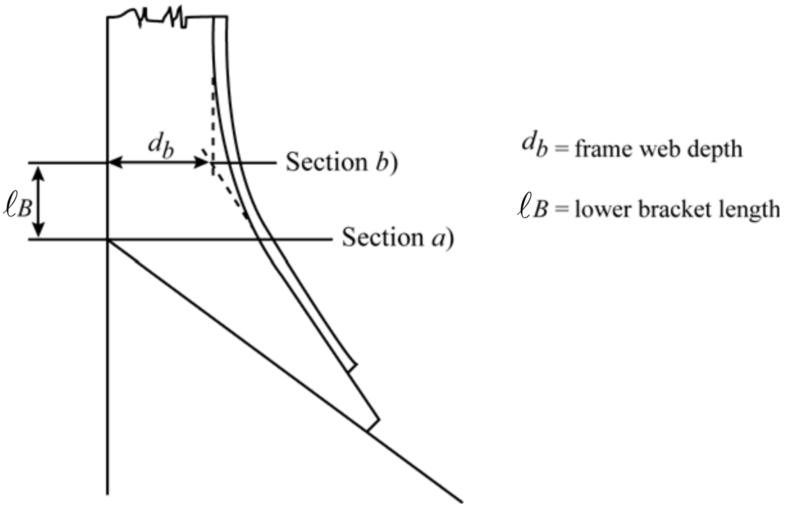
ℓ : Side frame span, in m, defined in **Ch 3**, **Sec 6**, **Fig. 19**, to be taken not less than $0.25D$

α_S : Coefficient taken equal to:

$\alpha_S = 1.1$	for side frames of holds specified to be empty in *BC-A* ships
$\alpha_S = 1.0$	for other side frames

ℓ_B : Lower bracket length, in *m*, defined in **Fig 7**

Fig. 7 Side frame lower bracket length



In addition to the above provision, the net section modulus w, in cm^3, and the net shear sectional area A_{sh}, in cm^2, of side frames subjected to lateral pressure in holds intended to carry ballast water are to be in accordance with **3.2.3**.

3.3.2 Supplementary strength requirements

In addition to **3.3.1**, the net moment of inertia, in cm^4, of the 3 side frames located immediately abaft the collision bulkhead is to be not less than the value obtained from the following formula:

$$I = 0.18 \frac{(p_S + p_W)\ell^4}{n}$$

where:

ℓ : Side frame span, in m

n : Number of frames from the bulkhead to the frame in question, taken equal to 1, 2 or 3

s : Frame spacing, in m.

As an alternative, supporting structures, such as horizontal stringers, are to be fitted between the collision bulkhead and a side frame which is in line with transverse webs fitted in both the topside tank and hopper tank, maintaining the continuity of forepeak stringers within the foremost hold.

3.3.3 Lower bracket of side frame

In addition, at the level of lower bracket as shown in **Ch 3**, **Sec 6**, **Fig. 19**, the net section modulus of the frame and bracket, or integral bracket, with associated shell plating, is to be not less than twice the net section modulus w required for the frame mid-span area obtained from **3.3.1**.

The net thickness t_{LB} of the frame lower bracket, in mm, is to be not less than the net thickness of the side frame web plus 1.5 mm.

Moreover, the net thickness t_{LB} of the frame lower bracket is to comply with the following formula:

- for symmetrically flanged frames: $\frac{h_{LB}}{t_{LB}} \le 87\sqrt{k}$
- for asymmetrically flanged frames : $\frac{h_{LB}}{t_{LB}} \le 73\sqrt{k}$

The web depth h_{LB} of lower bracket may be measured from the intersection between the sloped bulkhead of the hopper tank and the side shell plate, perpendicularly to the face plate of the lower bracket (see **Ch 3, Sec 6, Fig. 22**).

For the 3 side frames located immediately abaft the collision bulkhead, whose scantlings are increased according to **3.3.2**, when t_{LB} is greater than $1.73 t_w$, the thickness t_{LB} may be taken as the value t'_{LB} obtained from the following formula:

$$t'_{LB} = \left(t_{LB}^2 \cdot t_w\right)^{1/3}$$

where t_w is the net thickness of the side frame web, in mm, corresponding to A_{sh} determined in accordance to **3.3.1**.

The flange outstand is not to exceed $12k^{0.5}$ *times* the net flange thickness.

3.3.4 Upper bracket of side frame

In addition, at the level of upper bracket as shown in **Ch 3**, **Sec 6**, **Fig 19**, the net section modulus of the frame and bracket, or integral bracket, with associated shell plating, is to be not less than twice the net section modulus *w* required for the frame mid-span area obtained from **3.3.1**.

The net thickness t_{UB} of the frame upper bracket, in *mm*, is to be not less than the net thickness of the side frame web.

3.4 Upper and lower connections of side frames of single side bulk carriers

3.4.1

The section moduli of the:

- side shell and hopper tank longitudinals that support the lower connecting brackets,
- side shell and topside tank longitudinals that support the upper connecting brackets

are to be such that the following relationship is separately satisfied for each lower and upper connecting bracket (see also **Ch 3**, **Sec 6**, **Fig 22**):

$$\sum_n w_i d_i \ge \alpha_T \frac{(p_S + p_W)\ell^2 \ell_1^2}{16 R_Y}$$

where:

n : Number of the longitudinal stiffeners of side shell and hopper / topside tank that support the lower / upper end connecting bracket of the side frame, as applicable

w_i : Net section modulus, in cm^3, of the *i*-th longitudinal stiffener of the side shell or hopper / topside tank that support the lower / upper end connecting bracket of the side frame, as applicable

d_i : Distance, in *m*, of the above *i*-th longitudinal stiffener from the intersection point of the side shell and hopper /topside tank

ℓ_1 : Spacing, in *m*, of transverse supporting webs in hopper / topside tank, as applicable

R_y : Lowest value of equivalent yield stress, in N/mm^2, among the materials of the longitudinal stiffeners of side shell and hopper / topside tanks that support the lower / upper end connecting bracket of the side frame

α_T : Coefficient taken equal to:

$\alpha_T = 150$ for the longitudinal stiffeners supporting the lower connecting brackets

$\alpha_T = 75$ for the longitudinal stiffeners supporting the upper connecting brackets

ℓ : Side frame span, in *m*, as defined in **3.3.1**.

3.4.2

The net connection area, A_i, in cm^2, of the bracket to the *i*-th longitudinal stiffener supporting the bracket is to be obtained from the following formula:

$$A_i = 0.4 \frac{w_i s}{\ell_1^2} \frac{k_{bkt}}{k_{lg,i}}$$

where:

w_i : Net section modulus, in cm^3, of the *i*-th longitudinal stiffener of the side or sloped bulkheads that support the lower or the upper end connecting bracket of the side frame, as applicable

ℓ_1 : As defined in **3.4.1**

k_{bkt} : Material factor for the bracket

$k_{lg,i}$: Material factor for the *i*-th longitudinal stiffener.

3.5 Strength criteria for multi-span ordinary stiffeners

3.5.1 Checking criteria

The maximum normal stress σ and shear stress τ in a multi-span ordinary stiffener, calculated according to **3.5.2**, are to comply with the formulae in **Table 6**.

Table 6 Checking criteria for multi-span ordinary stiffeners

Condition	Intact	Flooded	Testing
Normal stress	$\sigma \le \lambda_S R_Y$	$\sigma \le \alpha \lambda_S R_Y$	$\sigma \le 1.05 R_Y$
Shear stress	$\tau \le \tau_a$	$\tau \le \alpha \tau_a$	$\tau \le 1.05 \tau_a$

where:

λ_S : Coefficient defined in **3.2.3**

α : Coefficient defined in **3.2.5**

3.5.2 Multi-span ordinary stiffeners

The maximum normal stress σ and shear stress τ 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, if any
- 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.

4. Web stiffeners of primary supporting members

4.1 Net scantlings

4.1.1

Where primary supporting member web stiffeners are welded to ordinary stiffener face plates, their net sectional area at the web stiffener mid-height is to be not less than the value obtained, in *cm*^{2}, from the following formula:

$$A = 0.1 k_1 p s \ell$$

where:

k_1 : Coefficient depending on the web connection with the ordinary stiffener, to be taken as:

$k_1 = 0.30$ for connections without collar plate (see **Ch 3**, **Sec 6**, **Fig 8**)

$k_1 = 0.225$ for connections with a collar plate (see **Ch 3**, **Sec 6**, **Fig 9**)

$k_1 = 0.20$ for connections with one or two large collar plates (see **Ch 3**, **Sec 6**, **Fig 10** and **11**)

p : Pressure, in *kN/m*^{2}, acting on the ordinary stiffener.

4.1.2

The net section modulus of web stiffeners of non-watertight primary supporting members is to be not less than the value obtained, in *cm*^{3}, from the following formula:

$$w = 2.5 s^2 t S_S^2$$

where:

s : Length, in *m*, of web stiffeners

t : Web net thickness, in *mm*, of the primary supporting member

S_S : Spacing, in *m*, of web stiffeners.

4.1.3 Connection ends of web stiffeners

The stress at ends of web stiffeners of primary supporting members in water ballast tanks, in *N/mm*^{2}, is to comply with the following formula when no bracket is fitted:

$$\sigma \le 175$$

where:

$$\sigma = 1.1 K_{con} K_{longi} K_{stiff} \frac{\Delta\sigma}{\cos\theta}$$

K_{con} : Coefficient considering stress concentration, taken equal to:

$K_{con} = 3.5$ for stiffeners in the double bottom or double side space (see **Fig. 8**)

$K_{con} = 4.0$ for other cases (e.g. hopper tank, top side tank, etc.) (see **Fig. 8**)

K_{longi} : Coefficient considering shape of cross section of the longitudinal, taken equal to:

$K_{longi} = 1.0$ for symmetrical profile of stiffener (e.g. *T*-section, flat bar)

$K_{longi} = 1.3$ for asymmetrical profile of stiffener (e.g. angle section, bulb profile)

K_{stiff} : Coefficient considering the shape of the end of the stiffener, taken equal to:

$K_{stiff} = 1.0$ for standard shape of the end of the stiffener (see **Fig. 9**)

$K_{stiff} = 0.8$ for the improved shape of the end of the stiffener (see **Fig. 9)**

θ : As given in **Fig. 10**

$\Delta\sigma$: Stress range, in *N/mm*^{2}, transferred from longitudinals into the end of web stiffener, as obtained from the following formula:

$$\Delta\sigma = \frac{2W}{0.322h'\left[\left(A_{w1}/\ell_1\right)+\left(A_{w2}/\ell_2\right)\right]+A_{s0}}$$

W : Dynamic load, in *N*, as obtained from the following formula:

$$W = 1000(\ell - 0.5s)sp$$

p : Maximum inertial pressure due to liquid according to **Ch 4**, **Sec 6**, **2**, in *kN/m*^{2}, of the probability level of 10^{-4}

ℓ : Span of the longitudinal, in *m*

s : Spacing of the longitudinal, in *m*

A_{s0} , A_{w1} , A_{w2} : Geometric parameters as given in **Fig. 10**, in *mm*^{2}

ℓ_1 , ℓ_2 : Geometric parameters as given in **Fig. 10**, in *mm*

h' : As obtained from following formula, in *mm*:

$$h' = h_s + h_0'$$

h_s : As given in **Fig. 10**, in *mm*

h_0' : As obtained from the following formula, in *mm*

$h_0' = 0.636b'$ for $b' \le 150$

$h_0' = 0.216b' + 63$ for $150 < b'$

b' : Smallest breadth at the end of the web stiffener, in *mm*, as shown in **Fig. 10**

Fig.8 Web stiffeners fitted on primary supporting members

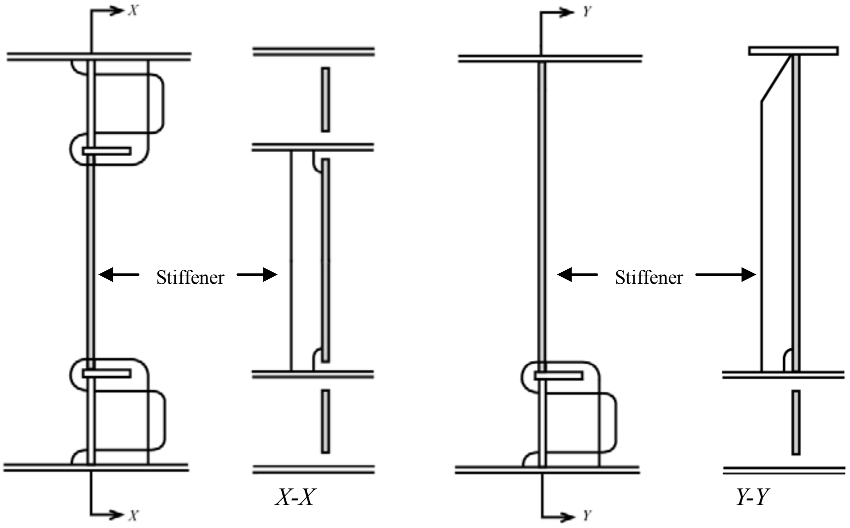


Fig. 9 Shape of the end of the web stiffener

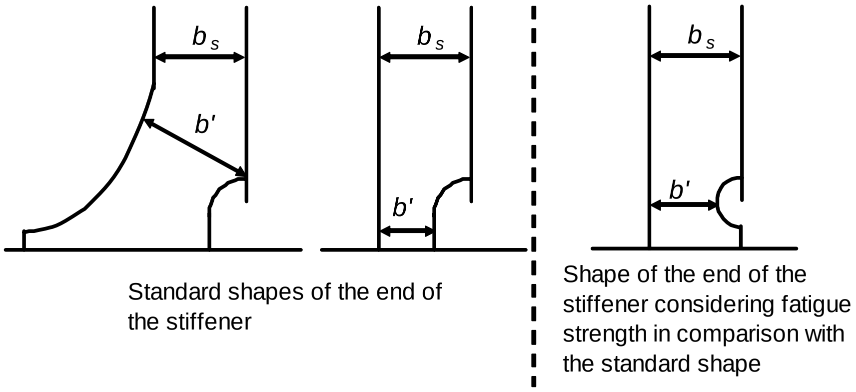
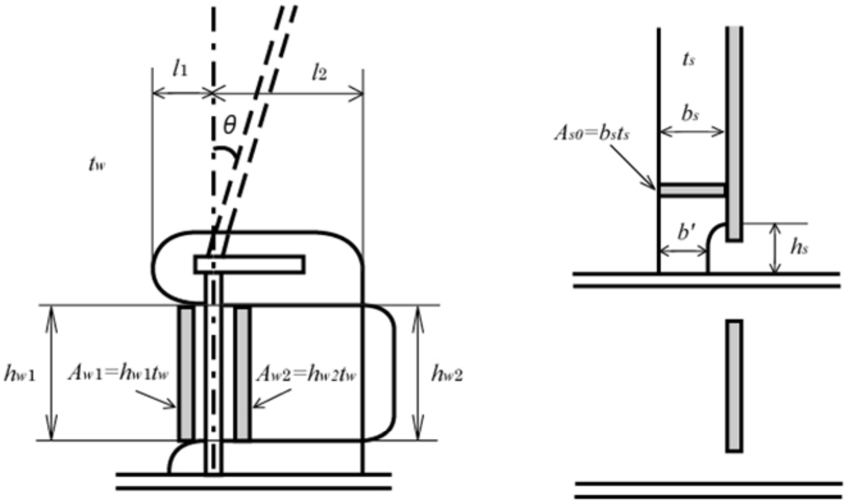


Fig. 10 Definitions of geometric parameters



Section 3 BUCKLING & ULTIMATE STRENGTH OF ORDINARY STIFFENERS AND STIFFENED PANELS

Symbols

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

In this section, compressive and shear stresses are to be taken positive, tension stresses are to be taken negative.

a : Length of single or partial plate panel, in *mm*

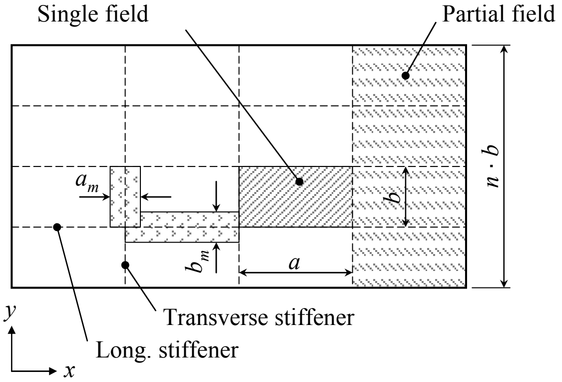
b : Breadth of elementary plate panel, in *mm*

α : Aspect ratio of elementary plate panel, taken equal to:

$$\alpha = \frac{a}{b}$$

n : Number of elementary plate panel breadths within the partial or total plate panel

Fig. 1 General arrangement of panel



Longitudinal : stiffener in the direction of the length *a*

Transverse : stiffener in the direction of the breath *b*

t : Net plate thickness, in *mm*

σ_n : Normal stress resulting from hull girder bending, in *N/mm*^{2}

τ_{SF} : Shear stress induced by the shear forces as defined in **2.1.3**, in *N/mm*^{2}

σ_x : Membrane stress in *x*-direction, in *N/mm*^{2}

σ_y : Membrane stress in *y*-direction, in *N/mm*^{2}

τ : Shear stress in the *x-y* plane, in *N/mm*^{2}

λ : Reference degree of slenderness, taken equal to:

$$\lambda = \sqrt{\frac{R_{eH}}{K\sigma_e}}$$

K : Buckling factor according to **Table 2** and **Table 3**

σ_e : Reference stress, taken equal to:

$$\sigma_e = 0.9E\left(\frac{t}{b'}\right)^2$$

b' : Shorter side of elementary plate oanel

ψ : Edge stress ratio taken equal to:

$$\psi = \sigma_2 / \sigma_1$$

where:

σ_1 : maximum compressive stress

σ_2 : minimum compressive stress or tensile stress

S : Safety factor, taken equal to:

$S = 1.0$ except for the case mentioned below

$S = 1.1$ for structures which are exclusively exposed to local loads (e.g. hatch covers, foundations)

$S = 1.15$ for the ultimate strength in lateral buckling mode of longitudinal and transverse ordinary stiffeners of the hatchway coamings, sloping plating of the topside tanks and hopper tanks, inner bottom, inner side if any, side shell of single side skin construction and top and bottom stools of transverse bulkheads, assessed according to **4.2**.

For constructions of aluminium alloys the safety factors are to be increased in each case by 0.1

F_1 : Correction factor for boundary condition of stiffeners on the longer side of elementary plate panels according to **Table 1**. If the clamping is unequal on the longitudinal sides of the panel, the minimum value of the appropriate F_1-parameter has to be used.

Table 1 Correction factor F_1

	$F_1^{(2)}$	Edge stiffener
Stiffeners sniped at both ends	1.00	
Guidance values where both ends are effectively connected to adjacent structures(1)	1.05	Flat bar
	1.10	Bulb section
	1.20	Angle and tee-sections
	1.30	Girders of high rigidity (e.g. bottom transverses)

(1) Exact values may be determined by direct calculations.

(2) An average value of F_1 is to be used for plate panels having different edge stiffeners.

1. General

1.1

1.1.1

The requirements of this Section apply for the buckling check of structural members subjected to compressive stresses, shear stresses and lateral pressure.

1.1.2

The buckling checks have to be performed for the following elements:

(a) according to requirements of **2**, **3** and **4** and for all load cases as defined in **Ch 4**, **Sec 4** in intact condition:
  - elementary plate panels and ordinary stiffeners in a hull transverse section analysis,
  - elementary plate panels modeled in *FEM* as requested in **Ch 7**.

(b) according to requirements of **6** and only in flooded condition:
  - transverse vertically corrugated watertight bulkheads for *BC-A* and *BC-B* ships.

1.1.3

The boundary condition for elementary plate panels are to be considered as simply supported. If the boundary condition differs significantly from simple support, more appropriate boundary condition can be applied according to cases 3, 4 and 7 to 10 of **Table 2**.

2. Application

2.1 Load model for hull transverse section analysis

2.1.1 General

The structural members at a considered hull transverse section are to be checked for buckling criteria under the combination of:

- the normal stress σ_n resulting from hull girder bending, as defined in **2.1.2**
- the shear stress τ_{SF} as defined in **2.1.3**

- the lateral pressure in intact condition applied on the members as the case may be.

The lateral pressures and hull girder loads are to be calculated, for the probability level of 10^{-8}, in the mutually exclusive load cases H1, H2, F1, F2, R1, R2, P1 and P2, as defined in **Ch 4**, **Sec 4**.

2.1.2 Normal stress σ_n

The normal stress σ_n to be considered for each of the mutually exclusive load cases as referred in **2.1.1** is the maximum compressive stress on the considered structural member according to the formulas given in **Ch 6**, **Sec 1**, **3.1.5** and **Ch 6**, **Sec 2**, **3.1.5**, respectively for elementary plate panels and ordinary stiffeners.

For transverse ordinary stiffeners, the normal stress σ_n for each of the mutually exclusive load cases is the maximum compressive stress calculated at each end.

2.1.3 Shear stress

The shear stress τ_{SF} to be considered for each of the mutually exclusive load cases as referred in **2.1.1** is the shear stress induced by the shear forces, in *kN*, equal to:

$$Q = Q_{SW} + C_{QW}\, Q_{WV}$$

where:

Q_{SW} : Design still water shear force in intact condition, in *kN*, at the hull transverse section considered, defined in **Ch 4**, **Sec 3**, **2.3**

Q_{WV} : Vertical wave shear force in intact condition, in *kN*, at the hull transverse section considered, defined in **Ch 4**, **Sec 3**, **3.2**

C_{QW} : Load combination factor as defined in **Ch 4**, **Sec 4**, **Table 3**

If the design still water shear force is not available at preliminary design stage, the following default value, in *kN*, may be used:

$$Q_{SW0} = 30\, CLB\left(C_B + 0.7\right)10^{-2}$$

2.1.4 Lateral pressure

The lateral pressure to be considered for the buckling check is defined in **Ch 6**, **Sec 1**, **3.1** for curved plate panel and in **Ch 6**, **Sec 2**, **3.1** for ordinary stiffeners.

The load calculation point for the curved plate panel is located at mid distance of the curved plate panel extremities along the curve.

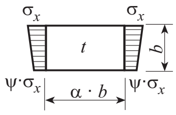
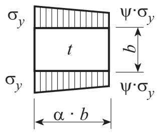
The load calculation point of ordinary stiffeners is defined in **Ch 6**, **Sec 2**, **1.4**

2.2 Application

2.2.1

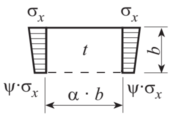
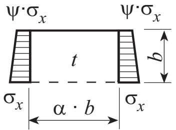
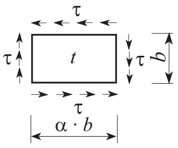
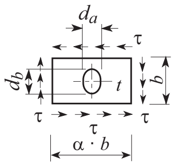
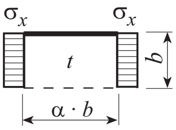
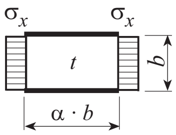
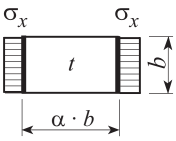
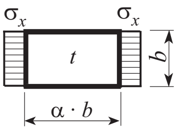
Application of the buckling and ultimate strength criterion is described in **App 1**.

Table 2 Buckling and reduction factors for plane elementary plate panels

Buckling-Load Case	Edge stress ratio ψ	Asp. ratio $\alpha = a/b$	Buckling factor K	Reduction factor κ
1 	$1 \geq \psi \geq 0$	$\alpha \geq 1$	$K = \frac{8.4}{\psi + 1.1}$	$\kappa_x = 1$ for $\lambda \leq \lambda_c$ $\kappa_x = c\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > \lambda_c$ $c = (1.25 - 0.12\psi) \leq 1.25$ $\lambda_c = \frac{c}{2}\left(1 + \sqrt{1 - \frac{0.88}{c}}\right)$
	$0 > \psi > -1$		$K = 7.63 - \psi(6.26 - 10\psi)$	
	$\psi \leq -1$		$K = (1 - \psi)^2 \cdot 5.975$	
2 	$1 \geq \psi \geq 0$	$\alpha \geq 1$	$K = F_1\left(1 + \frac{1}{\alpha^2}\right)^2 \frac{2.1}{(\psi + 1.1)}$	$\kappa_y = c\left(\frac{1}{\lambda} - \frac{R + F^2(H - R)}{\lambda^2}\right)$ $c = (1.25 - 0.12\psi) \leq 1.25$ $R = \lambda\left(1 - \frac{\lambda}{c}\right)$ for $\lambda < \lambda_c$ $R = 0.22$ for $\lambda \geq \lambda_c$ $\lambda_c = \frac{c}{2}\left(1 + \sqrt{1 - \frac{0.88}{c}}\right)$ $F = \left(1 - \frac{\frac{K}{0.91} - 1}{\lambda_p^{\ 2}}\right) \cdot c_1 \geq 0$ $\lambda_p^{\ 2} = \lambda^2 - 0.5$ for $1 \leq \lambda_p^{\ 2} \leq 3$ $c_1 = 1$, for σ_y due to direct loads $c_1 = \left(1 - \frac{F_1}{\alpha}\right) \geq 0$, for σ_y due to bending (in general) $c_1 = 0$, for σ_y due to bending in extreme load cases (e.g. wt. bulkheads) $H = \lambda - \frac{2\lambda}{c\left(T + \sqrt{T^2 - 4}\right)} \geq R$ $T = \lambda + \frac{14}{15\lambda} + \frac{1}{3}$
	$0 > \psi > -1$	$1 \leq \alpha \leq 1.5$	$K = F_1\left[\left(1 + \frac{1}{\alpha^2}\right)^2 \frac{2.1(1 + \psi)}{1.1} - \frac{\psi}{\alpha^2}(13.9 - 10\psi)\right]$	
		$\alpha > 1.5$	$K = F_1\left[\left(1 + \frac{1}{\alpha^2}\right)^2 \frac{2.1(1 + \psi)}{1.1} - \frac{\psi}{\alpha^2}(5.87 + 1.87\alpha^2 + \frac{8.6}{\alpha^2} - 10\psi)\right]$	
	$\psi \leq -1$	$1 \leq \alpha \leq \frac{3(1 - \psi)}{4}$	$K = F_1\left(\frac{1 - \psi}{\alpha}\right)^2 \cdot 5.975$	
		$\alpha > \frac{3(1 - \psi)}{4}$	$K = F_1\left[\left(\frac{1 - \psi}{\alpha}\right)^2 \cdot 3.9675 + 0.5375\left(\frac{1 - \psi}{\alpha}\right)^4 + 1.87\right]$	

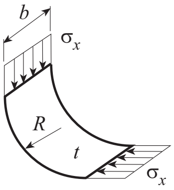
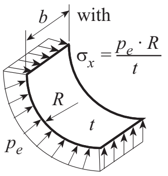
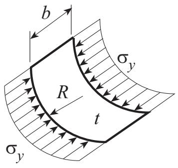
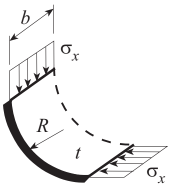
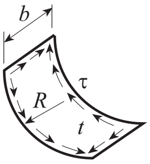
Explanations for boundary conditions		
	- - - - -	plate edge free
	———	plate edge simply supported
	▬▬▬	plate edge clamped

Note: The load cases as listed in **Table 2** are general cases. Each stress component (σ_x, σ_y) is to be understood in a local coordinates.

3 	$1 \geq \psi \geq 0$	$\alpha > 0$	$K = \dfrac{4\left(0.425 + \dfrac{1}{\alpha^2}\right)}{3\psi + 1}$	$\kappa_x = 1$ for $\lambda \leq 0.7$ $\kappa_x = \dfrac{1}{\lambda^2 + 0{,}51}$ for $\lambda > 0.7$
	$0 > \psi \geq -1$		$K = 4\left(0.425 + \dfrac{1}{\alpha^2}\right)(1+\psi) - 5\psi(1 - 3.42\psi)$	
4 	$1 \geq \psi \geq -1$	$\alpha > 0$	$K = \left(0.425 + \dfrac{1}{\alpha^2}\right)\dfrac{3-\psi}{2}$	
5 	===		$K = K_\tau \sqrt{3}$	$\kappa_\tau = 1$ for $\lambda \leq 0.84$ $\kappa_\tau = \dfrac{0.84}{\lambda}$ for $\lambda > 0.84$
		$\alpha \geq 1$	$K_\tau = \left[5.34 + \dfrac{4}{\alpha^2}\right]$	
		$0 < \alpha < 1$	$K_\tau = \left[4 + \dfrac{5.34}{\alpha^2}\right]$	
6 	===		$K = K'r$ $K' = K$ according to load case 5 r = Reductions factor $r = \left(1 - \dfrac{d_a}{a}\right)\left(1 - \dfrac{d_b}{b}\right)$ with $\dfrac{d_a}{a} \leq 0.7$ and $\dfrac{d_b}{b} \leq 0.7$	
7 	===	$\alpha \geq 1.64$	$K = 1.28$	$\kappa_x = 1$ for $\lambda \leq 0.7$ $\kappa_x = \dfrac{1}{\lambda^2 + 0.51}$ for $\lambda > 0.7$
		$\alpha < 1.64$	$K = \dfrac{1}{\alpha^2} + 0.56 + 0.13\alpha^2$	
8 	===	$\alpha \geq \dfrac{2}{3}$	$K = 6.97$	$\kappa_x = 1$ for $\lambda \leq 0.83$ $\kappa_x = 1.13\left[\dfrac{1}{\lambda} - \dfrac{0.22}{\lambda^2}\right]$ for $\lambda > 0.83$
		$\alpha < \dfrac{2}{3}$	$K = \dfrac{1}{\alpha^2} + 2.5 + 5\alpha^2$	
9 	===	$\alpha \geq 4$	$K = 4$	
		$4 > \alpha > 1$	$K = 4 + \left[\dfrac{4-\alpha}{3}\right]^4 \cdot 2.74$	
		$\alpha \leq 1$	$K = \dfrac{4}{\alpha^2} + 2.07 + 0.67\alpha^2$	
10 	===	$\alpha \geq 4$	$K = 6.97$	
		$4 > \alpha > 1$	$K = 6.97 + \left[\dfrac{4-\alpha}{3}\right]^4 \cdot 3.1$	
		$\alpha \leq 1$	$K = \dfrac{4}{\alpha^2} + 2.07 + 4\alpha^2$	
Explanations for boundary conditions			- - - - - plate edge free ——— plate edge simply supported ▬▬▬ plate edge clamped	

Note: The load cases as listed in **Table 2** are general cases. Each stress component (σ_x, σ_y) is to be understood in a local coordinates.

Table 3 Buckling and reduction factor for curved plate panel with $R/t \le 2500$[1]

Buckling-Load Case	Aspect ratio b/R	Buckling factor K	Reduction factor κ
1a 	$\frac{b}{R} \le 1.63\sqrt{\frac{R}{t}}$	$K = \frac{b}{\sqrt{Rt}} + 3\frac{(Rt)^{0.175}}{b^{0.35}}$	$\kappa_x = 1$ for $\lambda \le 0.4$ [2] $\kappa_x = 1.274 - 0.686 \cdot \lambda$ for $0.4 < \lambda \le 1.2$ $\kappa_x = \frac{0.65}{\lambda^2}$ for $\lambda > 1.2$
1b  p_e = external pressure in [N/mm²]	$\frac{b}{R} > 1.63\sqrt{\frac{R}{t}}$	$K = 0.3\frac{b^2}{R^2} + 2.25\left(\frac{R^2}{b\,t}\right)^2$	
2 	$\frac{b}{R} \le 0.5\sqrt{\frac{R}{t}}$	$K = 1 + \frac{2}{3}\frac{b^2}{R\,t}$	$\kappa_y = 1$ for $\lambda \le 0.25$ [2] $\kappa_y = 1.233 - 0.933 \cdot \lambda$ for $0.25 < \lambda \le 1$ $\kappa_y = 0.3 / \lambda^3$ for $1 < \lambda \le 1.5$ $\kappa_y = 0.2 / \lambda^2$ for $\lambda > 1.5$
	$\frac{b}{R} > 0.5\sqrt{\frac{R}{t}}$	$K = 0.267\frac{b^2}{R\,t}\left[3 - \frac{b}{R}\sqrt{\frac{t}{R}}\right]$ $\ge 0.4\frac{b^2}{R\,t}$	
3 	$\frac{b}{R} \le \sqrt{\frac{R}{t}}$	$K = \frac{0.6 \cdot b}{\sqrt{Rt}} + \frac{\sqrt{Rt}}{b} - 0.3\frac{Rt}{b^2}$	as in load case 1a
	$\frac{b}{R} > \sqrt{\frac{R}{t}}$	$K = 0.3\frac{b^2}{R^2} + 0.291\left(\frac{R^2}{b\,t}\right)^2$	
4 	$\frac{b}{R} \le 8.7\sqrt{\frac{R}{t}}$	$K = K_\tau\sqrt{3}$ $K_\tau = \left[28.3 + \frac{0.67\,b^3}{R^{1.5}\,t^{1.5}}\right]^{0.5}$	$\kappa_\tau = 1$ for $\lambda \le 0.4$ $\kappa_\tau = 1.274 - 0.686 \cdot \lambda$ for $0.4 < \lambda \le 1.2$ $\kappa_\tau = \frac{0.65}{\lambda^2}$ for $\lambda > 1.2$
	$\frac{b}{R} > 8.7\sqrt{\frac{R}{t}}$	$K_\tau = 0.28\frac{b^2}{R\sqrt{Rt}}$	

Explanations for boundary conditions
- - - - - plate edge free
——— plate edge simply supported
━━━ plate edge clamped

[1] For curved plate fields with a very large radius the κ-value need not to be taken less than for the expanded plane field

[2] For curved single fields, e.g. bilge strake, which are located within plane partial or total fields, the reduction factor κ may taken as follow:

Load case 1b: $\kappa_x = \frac{0.8}{\lambda^2} \le 1.0$ Load case 2: $\kappa_y = \frac{0.65}{\lambda^2} \le 1.0$

3. Buckling criteria of elementary plate panels

3.1 Plates

3.1.1 General

The net thickness of the elementary plate panel is to comply with the following:

$$t \geq b/100$$

The verification of an elementary plate panel in a transverse section analysis is to be carried out according to **3.1.2**. It is to be performed for the two different following combinations of stresses:

- stress combination 1: 100% of the normal stress as defined in **2.1.2** and 70% of the shear stress as defined in **2.1.3**
- stress combination 2: 70% of the normal stress as defined in **2.1.2** and 100% of the shear stress as defined in **2.1.3**.

The verification of elementary plate panel in a *FEM* analysis is to be carried out according to **3.2**.

3.1.2 Verification of elementary plate panel in a transverse section analysis

Each elementary plate panel is to comply with the following criteria, taking into account the loads defined in **2.1**:

- longitudinally framed plating

$$\left(\frac{|\sigma_x|S}{\kappa_x R_{eH}}\right)^{e1} + \left(\frac{|\tau|S\sqrt{3}}{\kappa_\tau R_{eH}}\right)^{e3} \leq 1.0 \quad \text{for stress combination 1 with } \sigma_x = \sigma_n \text{ and } \tau = 0.7\tau_{SF}$$

$$\left(\frac{|\sigma_x|S}{\kappa_x R_{eH}}\right)^{e1} + \left(\frac{|\tau|S\sqrt{3}}{\kappa_\tau R_{eH}}\right)^{e3} \leq 1.0 \quad \text{for stress combination 2 with } \sigma_x = 0.7\sigma_n \text{ and } \tau = \tau_{SF}$$

- transversely framed plating

$$\left(\frac{|\sigma_y|S}{\kappa_y R_{eH}}\right)^{e2} + \left(\frac{|\tau|S\sqrt{3}}{\kappa_\tau R_{eH}}\right)^{e3} \leq 1.0 \quad \text{for stress combination 1 with } \sigma_x = \sigma_n \text{ and } \tau = 0.7\tau_{SF}$$

$$\left(\frac{|\sigma_y|S}{\kappa_y R_{eH}}\right)^{e2} + \left(\frac{|\tau|S\sqrt{3}}{\kappa_\tau R_{eH}}\right)^{e3} \leq 1.0 \quad \text{for stress combination 2 with } \sigma_x = 0.7\sigma_n \text{ and } \tau = \tau_{SF}$$

Each term of the above conditions must be less than 1.0.

The reduction factors κ_x and κ_y are given in **Table 2** and/or **Table 3**.

The coefficients $e1$, $e2$ and $e3$ are defined in **Table 4**. For the determination of $e3$, κ_y is to be taken equal to 1 in case of longitudinally framed plating and κ_x is to be taken equal to 1 in case of transversely framed plating.

3.2 Verification of elementary plate panel within *FEM* analysis

3.2.1 General

The buckling check of the elementary plate panel is to be performed under the loads defined in **3.2.2**, according to the requirements of **3**.

The determination of the buckling and reduction factors is made for each relevant case of **Table 2** according to the stresses calculated in **3.2.2** loading the considered elementary plate panel.

3.2.2 Stresses

For the buckling check, the buckling stresses are to be determined according to **Table 2** and **Table 3** including their stress ratio Ψ for the loading conditions required in **Ch 4**, **Sec 7** and according to the requirements of **Ch 7**.

3.2.3 Poisson effect

Stresses derived with superimposed or direct method have to be reduced for buckling assessment because of the Poisson effect, which is taken into consideration in both analysis methods. The correction has to be carried out after summation of stresses due to local and global loads.

Both stresses σ_x^* and σ_y^* are to be compressive stresses, in order to apply the stress reduction according to the following formulae:

$$\sigma_x = (\sigma_x^* - 0.3\sigma_y^*)/0.91$$

$$\sigma_y = (\sigma_y^* - 0.3\sigma_x^*)/0.91$$

where:

σ_x^*, σ_y^* : Stresses containing the Poisson effect

Where compressive stress fulfils the condition $\sigma_y^* < 0.3\sigma_x^*$, then $\sigma_y = 0$ and $\sigma_x = \sigma_x^*$

Where compressive stress fulfils the condition $\sigma_x^* < 0.3\sigma_y^*$, then $\sigma_x = 0$ and $\sigma_y = \sigma_y^*$

3.2.4 Checking Criteria

Each elementary plate panel is to comply with the following criteria, taking into account the loads defined in **2.1**:

$$\left(\frac{|\sigma_x|S}{\kappa_x R_{eH}}\right)^{e1} + \left(\frac{|\sigma_y|S}{\kappa_y R_{eH}}\right)^{e2} - B\left(\frac{\sigma_x \sigma_y S^2}{R_{eH}^2}\right) + \left(\frac{|\tau| S\sqrt{3}}{\kappa_\tau R_{eH}}\right)^{e3} \le 1.0$$

In addition, each compressive stress σ_x and σ_y, and the shear stress τ are to comply with the following formulae:

$$\left(\frac{|\sigma_x|S}{\kappa_x\ R_{eH}}\right)^{e1} \le 1.0$$

$$\left(\frac{|\sigma_y|S}{\kappa_y\ R_{eH}}\right)^{e2} \le 1.0$$

$$\left(\frac{|\tau| S\sqrt{3}}{\kappa_\tau\ R_{eH}}\right)^{e3} \le 1,0$$

The reduction factors κ_x, κ_y and κ_τ are given in **Table 2** and/or **Table 3**.

- where $\sigma_x \le 0$ (tensile stress), $\kappa_x = 1.0$.
- where $\sigma_y \le 0$ (tensile stress), $\kappa_y = 1.0$.

The coefficients $e1$, $e2$ and $e3$ as well as the factor B are defined in **Table 4**.

Table 4 Coefficients $e1$, $e2$, $e3$ and factor B

Exponents $e1 - e3$ and factor B	Plate panel plane	 curved
$e1$	$1+\kappa_x^4$	1.25
$e2$	$1+\kappa_y^4$	1.25
$e3$	$1+\kappa_x\kappa_y\kappa_\tau^2$	2.0
B σ_x and σ_y positive (compressive stress)	$(\kappa_x\kappa_y)^5$	0
B σ_x or σ_y negative (tensile stress)	1	-

3.3 Webs and flanges

3.3.1

For non-stiffened webs and flanges of sections and girders proof of sufficient buckling strength as for elementary plate panels is to be provided according to **3.1**.

4. Buckling criteria of partial and total panels

4.1 Longitudinal and transverse stiffeners

4.1.1

In a hull transverse section analysis, the longitudinal and transverse ordinary stiffeners of partial and total plate panels are to comply with the requirements of **4.2** and **4.3**.

4.2 Ultimate strength in lateral buckling mode

4.2.1 Checking criteria

The longitudinal and transverse ordinary stiffeners are to comply with the following criteria:

$$\frac{\sigma_a + \sigma_b}{R_{eH}} S \le 1$$

σ_a : Uniformly distributed compressive stress, in *N/mm*^{2} in the direction of the stiffener axis.

$\sigma_a = \sigma_n$ for longitudinal stiffeners

$\sigma_a = 0$ for transverse stiffeners

σ_b : Bending stress, in *N/mm*^{2}, in the stiffener.

σ_b calculated as in **4.2.2** with $\sigma_x = \sigma_n$ and $\tau = \tau_{SF}$

4.2.2 Evaluation of the bending stress σ_b

The bending stress σ_b, in *N/mm*^{2}, in the stiffeners is equal to:

$$\sigma_b = \frac{M_0 + M_1}{W_{st}\, 10^3}$$

with:

M_0 : Bending moment, in *N-mm*, due to the deformation *w* of stiffener, taken equal to:

$$M_0 = F_{Ki} \frac{p_z w}{c_f - p_z}$$

with $(c_f - p_z) > 0$

M_1 : Bending moment, in *N-mm*, due to the lateral load *p*, taken equal to:

$$M_1 = \frac{pba^2}{24 \cdot 10^3}$$ for longitudinal stiffeners

$$M_1 = \frac{pa(n \cdot b)^2}{8c_S\, 10^3}$$ for transverse stiffeners, with *n* equal to 1 for ordinary transverse stiffeners.

W_{st} : Net section modulus of stiffener (longitudinal or transverse), in *cm*^{3}, including effective width of plating according to **5**, taken equal to:

- if a lateral pressure is applied on the stiffener:

  W_{st} is the net section modulus calculated at flange if the lateral pressure is applied on the same side as the stiffener.

  W_{st} is the net section modulus calculated at attached plate if the lateral pressure is applied on the side opposite to the stiffener.

- if no lateral pressure is applied on the stiffener:

  W_{st} is the minimum net section modulus among those calculated at flange and attached plate

c_S : Factor accounting for the boundary conditions of the transverse stiffener

$c_S = 1.0$ for simply supported stiffeners

$c_S = 2.0$ for partially constraint stiffeners

p : Lateral load in *kN/m*^{2}, as defined in **Ch 4**, **Sec5** and **Ch 4**, **Sec 6** calculated at the load point as defined in **Ch 6**, **Sec 2**, **1.4.2**

F_{Ki} : Ideal buckling force, in *N*, of the stiffener, taken equal to:

$$F_{Kix} = \frac{\pi^2}{a^2} EI_x\, 10^4$$ for longitudinal stiffeners

$$F_{Kiy} = \frac{\pi^2}{(nb)^2} EI_y\, 10^4$$ for transverse stiffeners

I_x, I_y : Net moments of inertia, in *cm*^{4}, of the longitudinal or transverse stiffener including effective width of attached plating according to **5**. I_x and I_y are to comply with the following criteria:

$$I_x \ge \frac{bt^3}{12 \cdot 10^4}$$

$$I_y \ge \frac{at^3}{12 \cdot 10^4}$$

p_z : Nominal lateral load, in *N/mm*^{2}, of the stiffener due to σ_x, σ_y and τ

$$p_{zx} = \frac{t_a}{b}\left(\sigma_{xl}\left(\frac{\pi\, b}{a}\right)^2 + 2c_y\sigma_y + \tau_1\sqrt{2}\right) \qquad \text{for longitudinal stiffeners}$$

$$p_{zy} = \frac{t_a}{a}\left(2c_x\sigma_{xl} + \sigma_y\left(\frac{\pi\, a}{nb}\right)^2\left(1+\frac{A_y}{at_a}\right) + \tau_1\sqrt{2}\right) \qquad \text{for transverse stiffeners}$$

$$\sigma_{xl} = \sigma_x\left(1+\frac{A_x}{b\cdot t_a}\right)$$

t_a : Net thickness offered of attached plate, in *mm*

c_x, c_y : Factor taking into account the stresses vertical to the stiffener's axis and distributed variable along the stiffener's length taken equal to:

$0.5(1+\psi)$ for $0 \le \psi \le 1$

$\dfrac{0.5}{1-\psi}$ for $\psi < 0$

A_x, A_y : Net sectional area, in *mm*^{2}, of the longitudinal or transverse stiffener respectively without attached plating

$$\tau_1 = \left[\tau - t\sqrt{R_{eH}E\left(\frac{m_1}{a^2}+\frac{m_2}{b^2}\right)}\right] \ge 0$$

m_1, m_2 : Coefficients taken equal to:

for longitudinal stiffeners:

$\dfrac{a}{b} \ge 2.0$: $m_1 = 1.47 \quad m_2 = 0.49$

$\dfrac{a}{b} < 2.0$: $m_1 = 1.96 \quad m_2 = 0.37$

for transverse stiffeners:

$\dfrac{a}{b} \ge 0.5$: $m_1 = 0.37 \quad m_2 = \dfrac{1.96}{n^2}$

$\dfrac{a}{b} < 0.5$: $m_1 = 0.49 \quad m_2 = \dfrac{1.47}{n^2}$

$w = w_0 + w_1$

w_0 : Assumed imperfection, in *mm*, taken equal to:

$$w_0 = \min\left(\frac{a}{250}, \frac{b}{250}, 10\right) \qquad \text{for longitudinal stiffeners}$$

$$w_0 = \min\left(\frac{a}{250}, \frac{n\cdot b}{250}, 10\right) \qquad \text{for transverse stiffeners}$$

For stiffeners sniped at both ends w_0 must not be taken less than the distance from the midpoint of attached plating to the neutral axis of the stiffener calculated with the effective width of its attached plating.

w_1 : Deformation of stiffener, in *mm*, at midpoint of stiffener span due to lateral load p. In case of uniformly distributed load the following values for w_1 may be used:

$$w_1 = \frac{pba^4}{384\cdot 10^7 EI_x} \qquad \text{for longitudinal stiffeners}$$

$$w_1 = \frac{5ap(nb)^4}{384\cdot 10^7 EI_y c_S^2} \qquad \text{for transverse stiffeners}$$

c_f : Elastic support provided by the stiffener, in *N/mm*^{2}, taken equal to:

- for longitudinal stiffeners

$$c_f = F_{Kix}\frac{\pi^2}{a^2}(1+c_{px})$$

$$c_{px} = \frac{1}{1+\frac{0.91\left(\frac{12\cdot 10^4 I_x}{t^3 b}-1\right)}{c_{xa}}}$$

c_{xa} : Coefficient taken equal to :

$$c_{xa} = \left[\frac{a}{2b}+\frac{2b}{a}\right]^2 \qquad \text{for } a \geq 2b$$

$$c_{xa} = \left[1+\left(\frac{a}{2b}\right)^2\right]^2 \qquad \text{for } a < 2b$$

- for transverse. stiffeners :

$$c_f = c_S F_{Kiy} \frac{\pi^2}{(n\cdot b)^2}\left(1+c_{py}\right)$$

$$c_{py} = \frac{1}{1+\frac{0.91\left(\frac{12\cdot 10^4 I_y}{t^3 a}-1\right)}{c_{ya}}}$$

c_{ya} : Coefficient taken equal to :

$$c_{ya} = \left[\frac{nb}{2a}+\frac{2a}{nb}\right]^2 \qquad \text{for } nb \geq 2a$$

$$c_{ya} = \left[1+\left(\frac{nb}{2a}\right)^2\right]^2 \qquad \text{for } nb < 2a$$

4.2.3 Equivalent criteria for longitudinal and transverse ordinary stiffeners not subjected to lateral pressure

Longitudinal and transverse ordinary stiffeners not subjected to lateral pressure are considered as complying with the requirement of **4.2.1** if their net moments of inertia I_x and I_y, in cm^4, are not less than the value obtained by the following formula:

- For longitudinal stiffener : $$I_x = \frac{p_{zx}a^2}{\pi^2 10^4}\left(\frac{w_{0x}h_w}{\frac{R_{eH}}{S}-\sigma_x}+\frac{a^2}{\pi^2 E}\right)$$

- For transverse stiffener : $$I_y = \frac{p_{zy}(nb)^2}{\pi^2 10^4}\left(\frac{w_{0y}h_w}{\frac{R_{eH}}{S}-\sigma_y}+\frac{(nb)^2}{\pi^2 E}\right)$$

4.3 Torsional buckling

4.3.1 Longitudinal stiffeners

The longitudinal ordinary stiffeners are to comply with the following criteria:

$$\frac{\sigma_x S}{\kappa_T R_{eH}} \leq 1.0$$

κ_T : Coefficient taken equal to:

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

$$\kappa_T = \frac{1}{\Phi+\sqrt{\Phi^2-\lambda_T^2}} \quad \text{for } \lambda_T > 0.2$$

$$\Phi = 0.5\left(1+0.21(\lambda_T-0.2)+\lambda_T^2\right)$$

λ_T : Reference degree of slenderness taken equal to:

$$\lambda_T = \sqrt{\frac{R_{eH}}{\sigma_{KiT}}}$$

$$\sigma_{KiT} = \frac{E}{I_P}\left(\frac{\pi^2 I_\omega 10^2}{a^2}\varepsilon + 0.385 I_T\right) \qquad \text{, in } N/mm^2$$

I_P : Net polar moment of inertia of the stiffener, in cm^4, defined in **Table 5**, and related to the point C as shown in **Fig. 2**

I_T : Net St. Venant's moment of inertia of the stiffener, in cm^4, defined in **Table 5**,

I_ω : Net sectorial moment of inertia of the stiffener, in cm^6, defined in **Table 5**, related to the point C as shown in **Fig. 2**

ε : Degree of fixation taken equal to:

$$\varepsilon = 1 + 10^{-3}\sqrt{\frac{a^4}{\frac{3}{4}\pi^4 I_w\left(b/t^3 + 4h_w/3t_w^{\ 3}\right)}}$$

A_w : Net web area equal to: $A_w = h_w t_w$

A_f : Net flange area equal to: $A_f = b_f t_f$

$$e_f = h_w + \frac{t_f}{2} \quad \text{, in } mm$$

Fig. 2 Dimensions of stiffeners

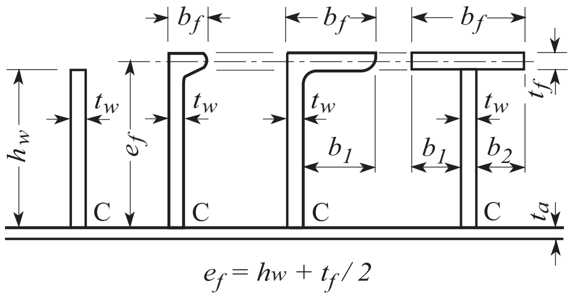


Table 4 Moments of inertia

Profile	I_P	I_T	I_w
Flat bar	$\frac{h_w^3 t_w}{3 \cdot 10^4}$	$\frac{h_w t_w^3}{3 \cdot 10^4}\left(1 - 0.63\frac{t_w}{h_w}\right)$	$\frac{h_w^3 t_w^3}{36 \cdot 10^6}$
Sections with bulb or flange	$\left(\frac{A_w h_w^2}{3} + A_f e_f^2\right)10^{-4}$	$\frac{h_w t_w^3}{3 \cdot 10^4}\left(1 - 0.63\frac{t_w}{h_w}\right)$ $+$ $\frac{b_f t_f^3}{3 \cdot 10^4}\left(1 - 0.63\frac{t_f}{b_f}\right)$	for bulb and angle sections: $\frac{A_f e_f^2 b_f^2}{12 \cdot 10^6}\left(\frac{A_f + 2.6A_w}{A_f + A_w}\right)$ for tee-sections $\frac{b_f^3 t_f e_f^2}{12 \cdot 10^6}$

4.3.2 Transverse stiffeners

Transverse stiffeners loaded by axial compressive stresses and which are not supported by longitudinal stiffeners are to comply with the requirements of **4.3.1** analogously.

5. Effective width of attached plating

5.1 Ordinary stiffeners

5.1.1

The effective width of attached plating of ordinary stiffeners is determined by the following formulae (see also **Fig. 1**):

- for longitudinal stiffeners: $b_m = \min(\kappa_x b, \kappa_s s)$

- for transverse stiffeners: $a_m = \min(\kappa_y a, \kappa_s s)$

  where:

  $$\kappa_s = 0.0035\left(\frac{\ell_{eff}}{s}\right)^3 - 0.0673\left(\frac{\ell_{eff}}{s}\right)^2 + 0.4422\left(\frac{\ell_{eff}}{s}\right) - 0.0056$$, to be taken not greater than 1.0

  s : Spacing of the stiffener, in *mm*

  ℓ_{eff} : Value taken as follows:

  - for longitudinal stiffeners:

    $\ell_{eff} = a$ if simply supported at both ends

    $\ell_{eff} = 0.6a$ if fixed at both ends

  - for transverse stiffeners:

    $\ell_{eff} = b$ if simply supported at both ends

    $\ell_{eff} = 0.6b$ if fixed at both ends

5.2 Primary supporting members

The effective width $e_m^{'}$ of stiffened flange plates of primary supporting members may be determined as described in **(a)** and **(b)**, with the notations:

e : Width of plating supported, in *mm*, measured from centre to centre of the adjacent unsupported fields

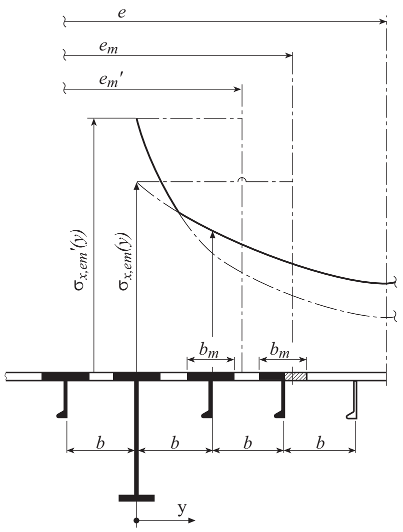
e_m : Effective width, in *mm*, of attached plating of primary supporting member according to **Table 6** considering the type of loading (special calculations may be required for determining the effective width of one-sided or non-symmetrical flanges).

e_{m1} is to be applied where primary supporting members are loaded by uniformly distributed loads or else by not less than 6 equally spaced single loads.

e_{m2} is to be applied where primary supporting members are loaded by 3 or less single loads.

a) Stiffening parallel to web of the primary supporting member (see **Fig. 3**)

Fig. 3 Stiffening parallel to web



$b < e_m$

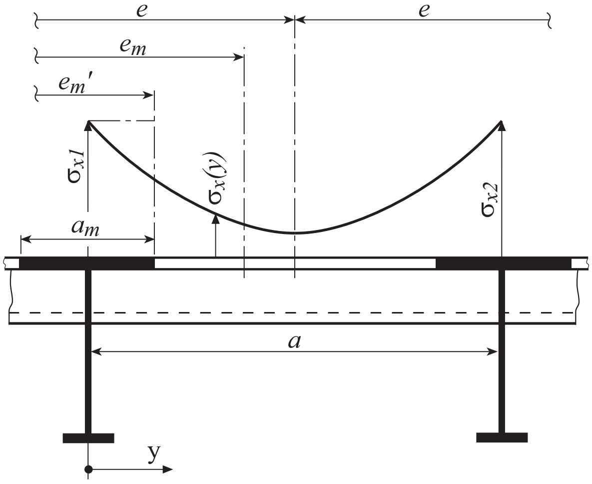
$e_m^{'} = n \cdot b_m$

n : Integral number of the stiffener spacing b inside the effective width e_m, taken equal to:

$$n = \text{int}\left(\frac{e_m}{b}\right)$$

b) Stiffening perpendicular to web of the primary supporting member (see **Fig. 4**)

Fig. 4 Stiffening perpendicular to web



$a \geq e_m$

$e_m^{'} = na_m < e_m$

$n = 2.7\dfrac{e_m}{a}$, to be taken not greater than 1.0

For $b \geq e_m$ or $a < e_m$ respectively, *b* and *a* must be exchanged.

Table 5 Effective Width of attached plating

ℓ/e	0	1	2	3	4	5	6	7	≥ 8
e_{m1}/e	0	0.36	0.64	0.82	0.91	0.96	0.98	1.00	1.00
e_{m2}/e	0	0.20	0.37	0.52	0.65	0.75	0.84	0.89	0.90

Intermediate values may be obtained by direct interpolation.

ℓ : Length between zero-points of bending moment curve, i.e. unsupported span in case of simply supported girders and 0.6 *times* the unsupported span in case of constraint of both ends of girder

6. Transverse vertically corrugated watertight bulkhead in flooded conditions for *BC-A* and *BC-B* ships

6.1 General

6.1.1 Shear buckling check of the bulkhead corrugation webs

The shear stress τ, calculated according to **Ch 6**, **Sec 2**, **3.2.6**, is to comply with the following formula:

$\tau \leq \tau_C$

where:

τ_C : Critical shear buckling stress to be obtained, in *N/mm*^{2}, from the following formulae:

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

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

τ_E : Euler shear buckling stress to be obtained, in *N/mm*^{2}, from the following formula:

$$\tau_E = 0.9k_t E\left(\frac{t_w}{10^3 c}\right)^2$$

k_t : Coefficient, to be taken equal to 6.34

t_W : Net thickness, in *mm*, of the corrugation webs

c : Width, in *m* of the corrugation webs (see **Ch 6**, **Sec 2**, **Fig 2**).

Section 4 PRIMARY SUPPORTING MEMBERS

Symbols

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

L_2 : Rule length L, but to be taken not greater than 300 *m*

I_Y : Net moment of inertia, in m^4, of the hull transverse section about its horizontal neutral axis, to be calculated according to **Ch 5**, **Sec 1**, **1.5**, on gross offered thickness reduced by $0.5t_C$ for all structural members

I_Z : Net moment of inertia, in m^4, of the hull transverse section about its vertical neutral axis, to be calculated according to **Ch 5**, **Sec 1**, **1.5**, on gross offered thickness reduced by $0.5t_C$ for all structural members

N : Z co-ordinate with respect to the reference co-ordinate system defined in **Ch 1, Sec 4, 4**, in *m*, of the centre of gravity of the hull net transverse section defined in **Ch 5, Sec 1, 1.2**, considering gross offered thickness reduced by $0.5t_C$ for all structural members

p_S, p_W : Still water and wave pressure, in kN/m^2, in intact conditions, defined in **2.1.2**

σ_X : Normal stress, in N/mm^2, defined in **2.1.5**

s : Spacing, in *m*, of primary supporting members

ℓ : Span, in *m*, of primary supporting members, measured between the supporting members, see **Ch 3**, **Sec 6**, **5.3**

h_w : Web height, in *mm*

t_w : Net web thickness, in *mm*

b_f : Face plate width, in *mm*

t_f : Net face plate thickness, in *mm*

b_p : Width, in *m*, of the plating attached to the member, for the yielding check, defined in **Ch 3**, **Sec 6**, **4.3**

w : Net section modulus, in cm^3, of the member, with an attached plating of width b_p, to be calculated as specified in **Ch 3**, **Sec 6**, **4.4**

A_{sh} : Net shear sectional area, in cm^2, of the member, to be calculated as specified in **Ch 3**, **Sec 6**, **5.5**

m : Coefficient taken equal to 10

τ_α : Allowable shear stress, in N/mm^2, taken equal to:

$\tau_\alpha = 0.4\ R_Y$

k : Material factor, as defined in **Ch 1**, **Sec 4**, **2.2.1**

x, y, z : X, Y and Z co-ordinates, in *m*, of the evaluation point with respect to the reference co-ordinate system defined in **Ch 1**, **Sec 4**

1. General

1.1 Application

1.1.1

The requirements of this Section apply to the strength check of pillars and primary supporting members, subjected to lateral pressure and hull girder normal stresses for such members contributing to the hull girder longitudinal strength.

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

1.2 Primary supporting members for ships less than 150 *m* in length (*L*)

1.2.1

For primary supporting members for ships having a length (L) less than 150 *m*, the strength check of such members is to be carried out according to the provisions specified in **2** and **4**.

1.2.2

Notwithstanding the above, the strength check of such members may be carried out by a direct strength assessment deemed as appropriate by the Society.

1.3 Primary supporting members for ships of 150 *m* or more in length (*L*)

1.3.1

For primary supporting members for ships having a length (*L*) of 150 *m* or more, the direct strength analysis is to be carried out according to the provisions specified in **Ch 7**. In addition, the primary supporting members for *BC-A* and *BC-B* ships are to comply with the requirements in **3** and **4**.

1.4 Net scantlings

1.4.1

As specified in **Ch 3**, **Sec 2**, all scantlings referred to in this Section are net, i.e. they do not include any corrosion addition.

The gross scantlings are obtained as specified in **Ch 3**, **Sec 2**, **3**.

1.5 Minimum net thicknesses of webs of primary supporting members

1.5.1

The net thickness of the web of primary supporting members, in *mm*, is to be not less than $0.6\sqrt{L_2}$.

2. Scantling of primary supporting members for ships of less than 150 *m* in length (*L*)

2.1 Load model

2.1.1 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 primary supporting members under consideration and the type of the compartments adjacent to it.

The wave lateral loads and hull girder loads are to be calculated, for the probability level of 10^{-8}, in the mutually exclusive load cases H1, H2, F1, F2, R1, R2, P1 and P2, as defined in **Ch 4**, **Sec 4**.

2.1.2 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 hydrostatic pressure, defined in **Ch 4**, **Sec 5**, **1**
- the still water internal pressure, defined in **Ch 4**, **Sec 6** for the various types of cargoes and for ballast.

Wave pressure (p_W) includes for each load case H1, H2, F1, F2, R1, R2, P1 and P2:

- the hydrodynamic pressure, defined in **Ch 4**, **Sec 5**, **1**
- the inertial pressure, defined in **Ch 4**, **Sec 6** for the various types of cargoes and for ballast.

2.1.3 Elements of the outer shell

The still water and wave lateral pressures are to be calculated considering separately:

- the still water and wave external sea pressures
- the still water and wave internal pressure, considering the compartment adjacent to the outer shell as being loaded

If the compartment adjacent to the outer shell is not intended to carry liquids, only the external sea pressures are to be considered.

2.1.4 Elements other than those of the outer shell

The still water and wave lateral pressures to be considered as acting on an element which separates two adjacent compartments are those obtained considering the two compartments individually loaded.

2.1.5 Normal stresses

The normal stress to be considered for the strength check of primary supporting members contributing to the hull girder longitudinal strength is the maximum value of σ_X between sagging and hogging conditions, when applicable, obtained, in N/mm^2, from the following formula:

$$\sigma_X = \left[C_{SW} \left| \frac{M_{SW}}{I_Y} \right| (z-N) + C_{WV} \left| \frac{M_{WV}}{I_Y} \right| (z-N) - C_{WH} \left| \frac{M_{WH}}{I_Z} \right| y \right] 10^{-3}$$

where:

M_{SW} : Permissible still water bending moments, in *kN-m*, in hogging or sagging as the case may be

M_{WV} : Vertical wave bending moment, in *kN-m*, in hogging or sagging as the case may be, as defined in **Ch 4**, **Sec 3**

M_{WH} : Horizontal wave bending moment, in *kN-m*, as defined in **Ch 4**, **Sec 3**

C_{SW} : Combination factor for each load case H1, H2, F1, F2, R1, R2, P1 and P2 and defined in the **Table 1**

C_{WV}, C_{WH} : Combination factors defined in **Ch 4**, **Sec 4**, **2.2** for each load case H1, H2, F1, F2, R1, R2, P1 and P2 and given in the **Table 1**

Table 1 Combination factors C_{SW}, C_{WV} and C_{WH}

LC	Hogging			Sagging		
	C_{SW}	C_{WV}	C_{WH}	C_{SW}	C_{WV}	C_{WH}
H1	Not Applicable			-1	-1	0
H2	1	1	0	Not Applicable		
F1	Not Applicable			-1	-1	0
F2	1	1	0	Not Applicable		
R1	1	0	$1.2-\frac{T_{LC}}{T_S}$	-1	0	$1.2-\frac{T_{LC}}{T_S}$
R2	1	0	$\frac{T_{LC}}{T_S}-1.2$	-1	0	$\frac{T_{LC}}{T_S}-1.2$
P1	1	$0.4-\frac{T_{LC}}{T_S}$	0	-1	$0.4-\frac{T_{LC}}{T_S}$	0
P2	1	$\frac{T_{LC}}{T_S}-0.4$	0	-1	$\frac{T_{LC}}{T_S}-0.4$	0

2.2 Center Girders and Side Girders

2.2.1 Net web thickness

The net thickness of girders in double bottom structure, in mm, is not to be less than the greatest of either of the value t_1 to t_3 specified in the followings according to each location:

$$t_1 = C_1 \frac{pS\left|x-x_c\right|}{\left(d_0-d_1\right)\tau_a}\left\{1-4\left(\frac{y}{B_{DB}}\right)^2\right\}$$ where $\left|x-x_c\right|$ is less than $0.25\ell_{DB}$, $\left|x-x_c\right|$ is to be taken as $0.25\ell_{DB}$

$$t_2 = 1.75\sqrt[3]{\frac{H^2a^2\tau_a}{C_1'}t_1}$$

$$t_3 = \frac{C_1''a}{\sqrt{k}}$$

where:

p : Differential pressure given by the following formula in *kN/m*^{2}:

$$p = \left|\left(p_{S,IB}+p_{W,IB}\right)-\left(p_{S,BM}+p_{W,BM}\right)\right|$$

$p_{S,IB}$: Cargo or ballast pressure of inner bottom plating in still water, in *kN/m*^{2}, as calculated at the centre of the double bottom structure under consideration, according to **Ch 4**, **Sec 6**

$p_{W,IB}$: Cargo or ballast pressure of inner bottom plating due to inertia, in *kN/m*^{2}, as calculated at the centre of the double bottom structure under consideration, according to **Ch 4**, **Sec 6**

$p_{S,BM}$: External sea and ballast pressure of bottom plating in still water, in *kN/m*^{2}, as calculated at the centre of the double bottom structure under consideration, according to **Ch 4**, **Sec 5** and **Ch 4**, **Sec 6**

$p_{W,BM}$: External sea and ballast pressure of bottom plating due to inertia, in *kN/m*^{2}, as calculated at the centre of the double bottom structure under consideration, according to **Ch 4**, **Sec 5** and **Ch 4**, **Sec 6**

S : Distance between the centre of the two spaces adjacent to the centre or side girder under consideration, in *m*

d_0 : Depth of the centre or side girder under consideration, in *m*

d_1 : Depth of the opening, if any, at the point under consideration, in *m*

ℓ_{DB} : Length of the double bottom, in *m*. Where stools are provided at transverse bulkheads, ℓ_{DB} may be taken as the distance between the toes.

x_c : *X* co-ordinate, in *m*, of the centre of double bottom structure under consideration with respect to the reference co-ordinate system defined in **Ch 1**, **Sec 4**

B_{DB} : Distance between the toes of hopper tanks at the midship part, in *m*, see **Fig 3**

C_1 : Coefficient obtained from **Table 2** depending on B_{DB} / ℓ_{DB}. For intermediate values of B_{DB} / ℓ_{DB}, C_1 is to be obtained by linear interpolation

a : Depth of girders at the point under consideration, in *m*. However, where horizontal stiffeners are fitted on the girder, *a* is the distance from the horizontal stiffener under consideration to the bottom shell plating or inner bottom plating, or the distance between the horizontal stiffeners under consideration

S_1 : Spacing, in *m*, of vertical ordinary stiffeners or floors

C_1' : Coefficient obtained from **Table 3** depending on S_1 / a. For intermediate values of S_1 / a, C_1' is to be determined by linear interpolation

H : Value obtained from the following formulae:

- where the girder is provided with an unreinforced opening : $H = 1 + 0.5\dfrac{\phi}{\alpha}$
- In other cases: $H = 1.0$

ϕ : Major diameter of the openings, in *m*

α : The greater of a or S_1, in *m*.

C_1'' : Coefficient obtained from **Table 4** depending on S_1 / a. For intermediate values of S_1 / a, C_1'' is to be obtained by linear interpolation.

Table 2 Coefficient C_1

B_{DB} / ℓ_{DB}	0.4 and under	0.6	0.8	1.0	1.2	1.4	1.6 and over
C_1	0.5	0.71	0.83	0.88	0.95	0.98	1.00

Table 3 Coefficient C_1'

$\dfrac{S_1}{a}$	0.3 and under	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4 and over
C_1'	64	38	25	19	15	12	10	9	8	7

Table 4 Coefficient C_1''

$\dfrac{S_1}{a}$		0.3 and under	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.6 and over
C_1''	Centre girder	4.4	5.4	6.3	7.1	7.7	8.2	8.6	8.9	9.3	9.6	9.7
	Side girder	3.6	4.4	5.1	5.8	6.3	6.7	7.0	7.3	7.6	7.9	8.0

2.3 Floors

2.3.1 Net web thickness

The net thickness of floors in double bottom structure, in *mm*, is not to be less than the greatest of either of the value t_1 to t_3 specified in the followings according to each location:

$$t_1 = C_2 \frac{pSB_{DB}}{(d_0 - d_1)\tau_a}\left(\frac{2|y|}{B'_{DB}}\right)\left\{1 - 2\left(\frac{x - x_c}{l_{DB}}\right)^2\right\}$$

where $|x - x_c|$ is less than $0.25\ell_{DB}$, $|x - x_c|$ is to be taken as $0.25\ell_{DB}$, and where $|y|$ is less than $B'_{DB}/4$, $|y|$ is to be taken as $b'/4$

$$t_2 = 1.75\sqrt[3]{\frac{H^2 a^2 \tau_a}{C'_2}t_1}$$

$$t_3 = \frac{8.5S_2}{\sqrt{k}}$$

where:

S : Spacing of solid floors, in *m*

d_0 : Depth of the solid floor at the point under consideration in *m*

d_1 : Depth of the opening, if any, at the point under consideration in *m*

B'_{DB} : Distance between toes of hopper tanks at the position of the solid floor under consideration, in *m*

C_2 : Coefficient obtained from **Table 5** depending on B_{DB}/ℓ_{DB}. For intermediate values of B_{DB}/ℓ_{DB}, C_2 is to be obtained by linear interpolation

p, B_{DB}, x_c, ℓ_{DB} : As defined in **2.2.1**

a : Depth of the solid floor at the point under consideration, in *m*. However, where horizontal stiffeners are fitted on the floor, a is the distance from the horizontal stiffener under consideration to the bottom shell plating or the inner bottom plating or the distance between the horizontal stiffeners under consideration

S_1 : Spacing, in *m*, of vertical ordinary stiffeners or girders

C'_2 : Coefficient given in **Table 6** depending on S_1/d_0. For intermediate values of S_1/d_0, C'_2 is to be determined by linear interpolation.

H : Value obtained from the following formulae:

(a) where openings with reinforcement or no opening are provided on solid floors:

  i) where slots without reinforcement are provided:

  $H = \sqrt{4.0\frac{d_2}{S_1} - 1.0}$, without being taken less than 1.0

  ii) where slots with reinforcement are provided: $H = 1.0$

(b) where openings without reinforcement are provided on solid floors:

  i) where slots without reinforcement are provided:

  $H = \left(1 + 0.5\frac{\phi}{d_0}\right)\sqrt{4.0\frac{d_2}{S_1} - 1.0}$, without being taken less than $1 + 0.5\frac{\phi}{d_0}$

  ii) where slots with reinforcement are provided:

  $H = 1 + 0.5\frac{\phi}{d_0}$

d_2 : Depth of slots without reinforcement provided at the upper and lower parts of solid floors, in *m*, whichever is greater

ϕ : Major diameter of the openings, in *m*

S_2 : The smaller of S_1 or a, in *m*.

Table 5 Coefficient C_2

$\frac{B_{DB}}{\ell_{DB}}$	0.4 and under	0.6	0.8	1.0	1.2	1.4	1.6 and over
C_2	0.48	0.47	0.45	0.43	0.40	0.37	0.34

Table 6 Coefficient C_2'

S_1 / d_0	0.3 and under	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4 and over
C_2'	64	38	25	19	15	12	10	9	8	7

2.4 Stringer of double side structure

2.4.1 Net web thickness

The net thickness of stringers in double side structure, in *mm*, is not to be less than the greatest of either of the value t_1 to t_3 specified in the followings according to each location:

$t_1 = C_3 \dfrac{pS|x - x_c|}{(d_0 - d_1)\tau_a}$, where $|x - x_c|$ is under $0.25\ell_{DS}$, $|x - x_c|$ is to be taken as $0.25\ell_{DS}$

$$t_2 = 1.75\sqrt[3]{\frac{H^2 a^2 \tau_a}{C_3'} t_1}$$

$$t_3 = \frac{8.5S_2}{\sqrt{k}}$$

where :

p : Differential pressure given by the following formula in *kN/m*^{2}:

$$p = \left| \left(p_{S,SS} + p_{W,SS}\right) - \left(p_{S,LB} + p_{W,LB}\right) \right|$$

$p_{S,SS}$: External sea and ballast pressure of side shell plating in still water, in *kN/m*^{2}, as measured vertically at the upper end of hopper tank, longitudinally at the centre of ℓ_{DS}, according to **Ch 4**, **Sec 5** and **Ch 4**, **Sec 6**

$p_{W,SS}$: External sea and ballast pressure of side shell plating due to inertia, in *kN/m*^{2}, as measured vertically at the upper end of hopper tank, longitudinally at the centre of ℓ_{DS}, according to **Ch 4**, **Sec 5** and **Ch 4**, **Sec 6**

$p_{S,LB}$: Ballast pressure of longitudinal bulkhead in still water, in *kN/m*^{2}, as measured vertically at the upper end of hopper tank, longitudinally at the centre of ℓ_{DS}, according to **Ch 4**, **Sec 6**

$p_{W,LB}$: Ballast pressure of longitudinal bulkhead due to inertia, in *kN/m*^{2}, as measured vertically at the upper end of hopper tank, longitudinally at the centre of ℓ_{DS}, according to **Ch 4**, **Sec 6**

S : Breadth of part supported by stringer, in *m*

d_0 : Depth of stringers, in *m*

d_1 : Depth of opening, if any, at the point under consideration, in *m*.

x_c : *X* co-ordinate, in *m*, of the center of double side structure under consideration with respect to the reference co-ordinate system defined in **Ch 1**, **Sec 4**

ℓ_{DS} : Length of the double side structure between the transverse bulkheads under consideration, in *m*

h_{DS} : Height of the double side structure between the upper end of hopper tank and the lower end of topside tank, in *m*

C_3 : Coefficient obtained from **Table 7** depending on h_{DS} / ℓ_{DS}. For intermediate values of h_{DS} / ℓ_{DS}, C_3 is to be obtained by linear interpolation.

a : Depth of stringers at the point under consideration, in *m*. However, where horizontal stiffeners are fitted on the stringer, *a* is the distance from the horizontal stiffener under consideration to the side shell plating or the longitudinal bulkhead of double side structure or the distance between the horizontal stiffeners under consideration

S_1 : Spacing, in *m*, of transverse ordinary stiffeners or web frames

C'_3 : Coefficient obtained from **Table 8** depending on S_1/a. For intermediate values of S_1/a, C'_3 is to be obtained by linear interpolation.

H : Value obtained from the following formulae:

- where the stringer is provided with an unreinforced opening: $H = 1 + 0.5\dfrac{\phi}{\alpha}$
- in other cases: $H = 1.0$

ϕ : Major diameter of the openings, in *m*

α : The greater of a or S_1, in *m*

S_2 : The smaller of a or S_1, in *m*

Table 7 Coefficient C_3

$\frac{h_{DS}}{\ell_{DS}}$	0.5 and under	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3 and over
C_3	0.16	0.23	0.30	0.36	0.41	0.44	0.47	0.50	0.54

Table 8 Coefficient C'_3

$\frac{S_1}{a}$	0.3 and under	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4 and over
C'_3	64	38	25	19	15	12	10	9	8	7

2.5 Transverse web in double side structure

2.5.1 Net web thickness

The net thickness of transverse webs in double side structure, in *mm*, is not to be less than the greatest of either of the value t_1 to t_3 specified in the followings according to each location:

$$t_1 = C_4 \frac{pSh_{DS}}{(d_0 - d_1)\tau_a}\left(1 - 1.75\frac{z - z_{BH}}{h_{DS}}\right)$$

where $z - z_{BH}$ is greater than $0.4h_{DS}$, $z - z_{BH}$ is to be taken as $0.4h_{DS}$

$$t_2 = 1.75\sqrt[3]{\frac{H^2 a^2 \tau_a}{C'_4}t_1}$$

$$t_3 = \frac{8.5S_2}{\sqrt{k}}$$

where :

S : Breadth of part supported by transverses, in *m*

d_0 : Depth of transverses, in *m*

d_1 : Depth of opening at the point under consideration, in *m*

C_4 : Coefficient obtained from **Table 9** depending on h_{DS}/ℓ_{DS}. For intermediate values of h_{DS}/ℓ_{DS}, C_4 is to be obtained by linear interpolation

z_{BH} : *Z* co-ordinates, in *m*, of the upper end of hopper tank with respect to the reference co-ordinate system defined in **Ch 1**, **Sec 4**

p, h_{DS} and ℓ_{DS} : as defined in the requirements of **2.4.1**

a : Depth of transverses at the point under consideration, in *m*. However, where vertical stiffeners are fitted on the transverse, *a* is the distance from the vertical stiffener under consideration to the side shell or the longitudinal bulkhead of double side hull or the distance between the vertical stiffeners under consideration.

S_1 : Spacing, in *m*, of horizontal ordinary stiffeners or stringers

C'_4 : Coefficient obtained from **Table 10** depending on S_1/a. For intermediate values of S_1/a, C'_4 is to be obtained by linear interpolation.

H : Value obtained from the following formulae :

- where the transverse is provided with an unreinforced opening: $H = 1 + 0.5\dfrac{\phi}{\alpha}$
- in other cases: $H = 1.0$

ϕ : Major diameter of the openings, in *m*

α : The greater of a or S_1, in *m*

S_2 : The smaller of a or S_1, in *m*

Table 9 Coefficient C_4

$\dfrac{h_{DS}}{\ell_{DS}}$	0.5 and under	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3 and over
C_4	0.62	0.61	0.59	0.55	0.52	0.49	0.46	0.43	0.41

Table 10 Coefficient C_4'

$\dfrac{S_1}{a}$	0.3 and under	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4 and over
C_4'	64	38	25	19	15	12	10	9	8	7

2.6 Primary supporting member in bilge hopper tanks and topside tanks and other structures

2.6.1 Load calculation point

For horizontal members, the lateral pressure and hull girder stress, if any, are to be calculated at mid-span of the primary supporting members considered, unless otherwise specified.

For vertical members, the lateral pressure p is to be calculated as the maximum between the values obtained at mid-span and the pressure obtained from the following formula:

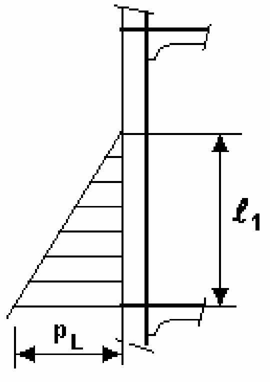
- $p = \dfrac{p_U + p_L}{2}$, when the upper end of the vertical member is below the lowest zero pressure level
- $p = \dfrac{\ell_1}{\ell}\dfrac{p_L}{2}$, when the upper end of the vertical member is at or above the lowest zero pressure level (see **Fig. 1**)

where:

ℓ_1 : Distance, in *m*, between the lower end of vertical member and the lowest zero pressure level

p_U , p_L : Lateral pressures at the upper and lower end of the vertical member span ℓ, respectively

Fig. 1 Definition of pressure for vertical members



2.6.2 Boundary conditions

The requirements of this sub-article apply to primary supporting members considered as clamped at both ends. For boundary conditions deviated from the above, the yielding check is to be considered on a case by case basis.

2.6.3 Net section modulus, net shear sectional area and web thickness under intact conditions

The net section modulus w, in *cm*^{3}, the net shear sectional area A_{sh}, in *cm*^{2}, and the net web thickness t_w, in *mm*, subjected to lateral pressure are to be not less than the values obtained from the following formulae:

$$w = \frac{(p_S + p_W)s\ell^2}{m\lambda_S R_Y}10^3$$

$$A_{sh} = \frac{5(p_S + p_W)s\ell}{\tau_a \sin\phi}$$

$$t_w = 1.75\sqrt[3]{\frac{h_w \tau_a}{10^4 C_5}A_{sh}}$$

where:

λ_S : Coefficient defined in **Table 11**

ϕ : Angle, in *deg*, between the primary supporting member web and the shell plate, measured at the middle of the member span; the correction is to be applied when ϕ is less than 75 *deg*.

C_5 : Coefficient defined in **Table 12** according to s_1 and d_0. For intermediate values of s_1/d_0, coefficient C_5 is to be obtained by linear interpolation.

s_1 : Spacing of stiffeners or tripping brackets on web plate, in *m*

d_0 : Spacing of stiffeners parallel to shell plate on web plate, in *m*

Table 11 Coefficient λ_S

Primary supporting members	Coefficient λ_S
Longitudinal members contributing to the hull girder longitudinal strength	$1.1\left(1.0 - 0.85\left\lvert\frac{\sigma_X}{R_Y}\right\rvert\right)$, without being taken greater than 0.8
Other members	0.8

Table 12 Coefficient C_5

s_1/d_0	0.3 and less	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0 and over
C_5	60.0	40.0	26.8	20.0	16.4	14.4	13.0	12.3	11.1	10.2

3. Additional requirements for primary supporting members of *BC-A* and *BC-B* ships

3.1 Evaluation of double bottom capacity and allowable hold loading in flooded conditions

3.1.1 Shear capacity of the double bottom

The shear capacity of the double bottom is to be calculated as the sum of the shear strength at each end of:

- all floors adjacent to both hopper tanks, less one half of the shear strength of the two floors adjacent to each stool, or transverse bulkhead if no stool is fitted (see **Fig. 2**); the floor shear strength is to be calculated according to **3.1.2**,
- all double bottom girders adjacent to both stools, or transverse bulkheads if no stool is fitted; the girder shear strength is to be calculated according to **3.1.3**.

Where in the end holds, girders or floors run out and are not directly attached to the boundary stool or hopper tank girder, their strength is to be evaluated for the one end only.

The floors and girders to be considered in calculating the shear capacity of the double bottom are those inside the hold boundaries formed by the hopper tanks and stools (or transverse bulkheads if no stool is fitted). The hopper tank side girders and the floors directly below the connection of the stools (or transverse bulkheads if no stool is fitted) to the inner bottom may not be included.

When the geometry and/or the structural arrangement of the double bottom is/are such as to make the above assumptions inadequate, the shear capacity of the double bottom is to be calculated by means of direct calculations to be carried out according to the requirements specified in **Ch 7**, as far as applicable.

3.1.2 Floor shear strength

The floor shear strength, in *kN*, is to be obtained from the following formulae:

- in way of the floor panel adjacent to the hopper tank:

$$S_{f1} = A_f \frac{\tau_A}{\eta_1} 10^{-3}$$

- in way of the openings in the outermost bay (i.e. that bay which is closer to the hopper tank):

$$S_{f2} = A_{f,h} \frac{\tau_A}{\eta_2} 10^{-3}$$

where:

A_f : Net sectional area, in mm^2, of the floor panel adjacent to the hopper tank

$A_{f,h}$: Net sectional area, in mm^2, of the floor panels in way of the openings in the outermost bay (i.e. that bay which is closer to the hopper tank)

τ_A : Allowable shear stress, in N/mm^2, equal to the lesser of:

$$\tau_A = 0.645 \frac{R_{eH}^{0.6}}{(s/t_N)^{0.8}} \quad \text{and} \quad \tau_A = \frac{R_{eH}}{\sqrt{3}}$$

t_N : Floor web net thickness, in *mm*

s : Spacing, in *m*, of stiffening members of the panel considered

η_1 : Coefficient to be taken equal to 1.1

η_2 : Coefficient to be taken equal to 1.2. It may be reduced to 1.1 where appropriate reinforcements are fitted in way of the openings in the outermost bay, to be examined by the Society on a case-by-case basis.

3.1.3 Girder shear strength

The girder shear strength, in *kN*, is to be obtained from the following formulae:

- in way of the girder panel adjacent to the stool (or transverse bulkhead, if no stool is fitted):

$$S_{g1} = A_g \frac{\tau_A}{\eta_1} 10^{-3}$$

- in way of the largest opening in the outermost bay (i.e. that bay which is closer to the stool, or transverse bulk-head, if no stool is fitted):

$$S_{g2} = A_{g,h} \frac{\tau_A}{\eta_2} 10^{-3}$$

A_g : Net sectional area, in mm^2, of the girder panel adjacent to the stool (or transverse bulkhead, if no stool is fitted)

$A_{g,h}$: Net sectional area, in mm^2, of the girder panel in way of the largest opening in the outermost bay (i.e. that bay which is closer to the stool, or transverse bulkhead, if no stool is fitted)

τ_A : Allowable shear stress, in N/mm^2, defined in **3.1.2**, where t_N is the girder web net thickness

η_1 : Coefficient to be taken equal to 1.1

η_2 : Coefficient to be taken equal to 1.15. It may be reduced to 1.1 where appropriate reinforcements are fitted in way of the largest opening in the outermost bay, to be examined by the Society on a case-by-case basis.

3.1.4 Allowable hold loading

The allowable hold loading is to be obtained, in *t*, from the following formula:

$$W = \rho_C V \frac{1}{F}$$

where:

F : Coefficient to be taken equal to:

$F = 1.1$ in general

$F = 1.05$ for steel mill products

V : Volume, in m^3, occupied by cargo at a level h_B

h_B : Level of cargo, in m^2, to be obtained from the following formula:

$$h_B = \frac{X}{\rho_C g}$$

X : Pressure, in kN/m^2, to be obtained from the following formulae:

- for dry bulk cargoes, the lesser of:

$$X = \frac{Z + \rho g (z_F - 0.1 D_1 - h_F)}{1 + \frac{\rho}{\rho_C}(perm - 1)}$$

$$X = Z + \rho g (z_F - 0.1 D_1 - h_F\, perm)$$

- for steel mill products:

$$X = \frac{Z + \rho g (z_F - 0.1 D_1 - h_F)}{1 - \frac{\rho}{\rho_C}}$$

D_1 : Distance, in *m*, from the base line to the freeboard deck at side amidships

h_F : Inner bottom flooding head is the distance, in *m*, measured vertically with the ship in the upright position, from the inner bottom to a level located at a distance z_F, in *m*, from the baseline.

z_F : Flooding level, in *m*, defined in **Ch 4**, **Sec 6**, **3.3.3**

$perm$: Permeability of cargo, which need not be taken greater than 0.3

Z : Pressure, in kN/m^2, to be taken as the lesser of:

$$Z = \frac{C_H}{A_{DB,H}}$$

$$Z = \frac{C_E}{A_{DB,E}}$$

C_H : Shear capacity of the double bottom, in *kN*, to be calculated according to **3.1.1**, considering, for each floor, the lesser of the shear strengths S_{f1} and S_{f2} (see **3.1.2**) and, for each girder, the lesser of the shear strengths S_{g1} and S_{g2} (see **3.1.3**)

C_E : Shear capacity of the double bottom, in *kN*, to be calculated according to **3.1.1**, considering, for each floor, the shear strength S_{f1} (see **3.1.2**) and, for each girder, the lesser of the shear strengths S_{g1} and S_{g2} (see **3.1.3**)

- $A_{DB,H} = \sum_{i=1}^{n} S_i B_{DB,i}$
- $A_{DB,E} = \sum_{i=1}^{n} S_i (B_{DB} - s)$

n : Number of floors between stools (or transverse bulkheads, if no stool is fitted)

S_i : Space of i-th floor, in m

$B_{DB,i}$: Length, in m, to be taken equal to :

$B_{DB,i} = B_{DB} - s$ for floors for which $S_{f1} < S_{f2}$ (see **3.1.2**)

$B_{DB,i} = B_{DB,h}$ for floors for which $S_{f1} \geq S_{f2}$ (see **3.1.2**)

B_{DB} : Breadth, in m, of double bottom between the hopper tanks (see **Fig. 3**)

$B_{DB,h}$: Distance, in m, between the two openings considered (see **Fig. 3**)

s : Spacing, in m, of inner bottom longitudinal ordinary stiffeners adjacent to the hopper tanks.

Fig. 2 Double bottom structure

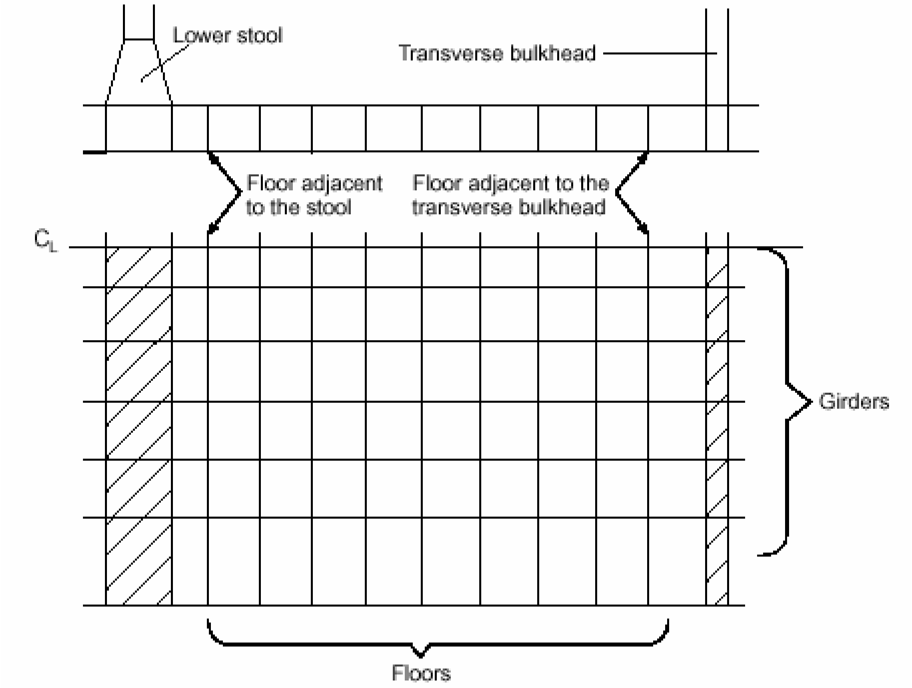
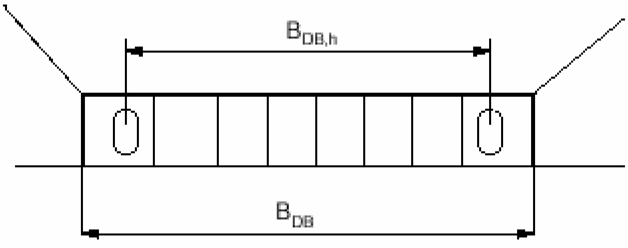


Fig. 3 Dimensions B_{DB} and $B_{DB,h}$



4. Pillars

4.1 Buckling of pillars subjected to compressive axial load

4.1.1 General

It is to be checked that the compressive stress of pillars does not exceed the critical column buckling stress calculated according to **4.1.2**.

4.1.2 Critical column buckling stress of pillars

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

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

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

where:

σ_{E1} : Euler column buckling stress, to be obtained, in N/mm^2, from the following formula:

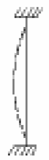
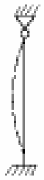
$$\sigma_{E1} = \pi^2 E \frac{I}{A(fl)^2} 10^{-4}$$

I : Minimum net moment of inertia, in cm^4, of the pillar

A : Net cross-sectional area, in cm^2, of the pillar

f : Coefficient to be obtained from **Table 13**.

Table 13 Coefficient f

Boundary conditions of the pillar	f
Both ends fixed 	0.5
One end fixed, one end pinned 	$\frac{\sqrt{2}}{2}$
Both ends pinned 	1.0

Appendix 1 BUCKLING & ULTIMATE STRENGTH

1. Application of Ch 6, Sec 3

1.1 General application

1.1.1 Mutable shear stress

If shear stresses are not uniform on the width b of the elementary plate panel, the greater of the two following values is to be used:

- mean value of τ
- $0.5\tau_{max}$

1.1.2 Change of thickness within an elementary plate panel

If the plate thickness of an elementary plate panel varies over the width b, the buckling check may be performed for an equivalent elementary plate panel $a \times b'$ having a thickness equal to the smaller plate thickness t_1.

The width of this equivalent elementary plate panel is defined by the following formula:

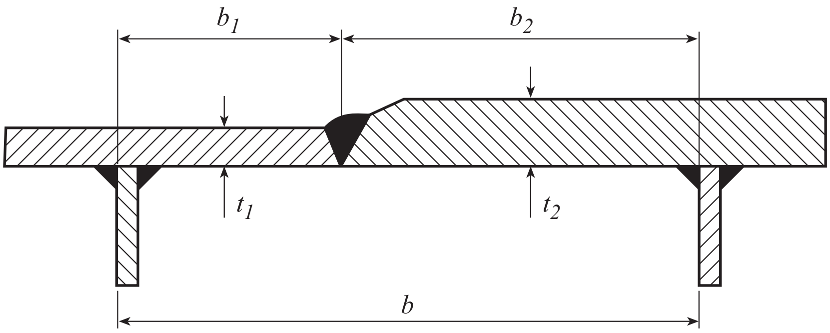
$$b' = b_1 + b_2 \left(\frac{t_1}{t_2} \right)^{1.5}$$

where:

b_1 : Width of the part of the elementary plate panel with the smaller plate thickness t_1

b_2 : Width of the part of the elementary plate panel with the greater plate thickness t_2

Fig. 1 Plate thickness change within the field breath



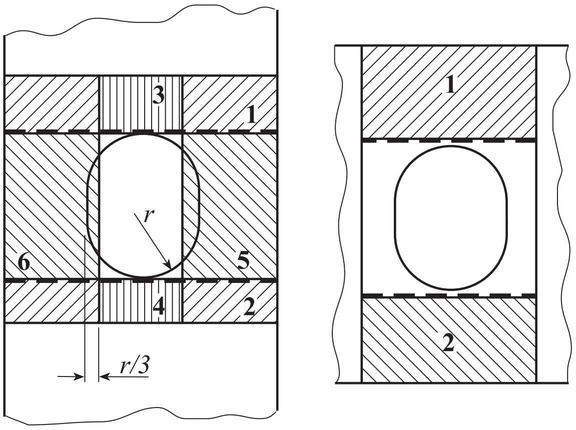
1.1.3 Evaluation of floors or other high girders with holes

The following procedure may be used to assess high girders with holes:

a) Divide the plate field in sub elementary plate panels according the **Fig. 2**

b) Assess the elementary plate panel and all sub elementary plate panels separately with the following boundary conditions:
   - for sub panels 1 to 4: all edges are simply supported (load cases 1 and 2 in **Ch 6**, **Sec 3**, **Table 2**)
   - for sub panels 5 and 6: simply supported, one side free (load case 3 in **Ch 6**, **Sec 3**, **Table 2**).

Fig. 2 Elementary plate panels of high girder with hole



1.2 Application to hull transverse section analysis

1.2.1 Idealization of elementary plate panels

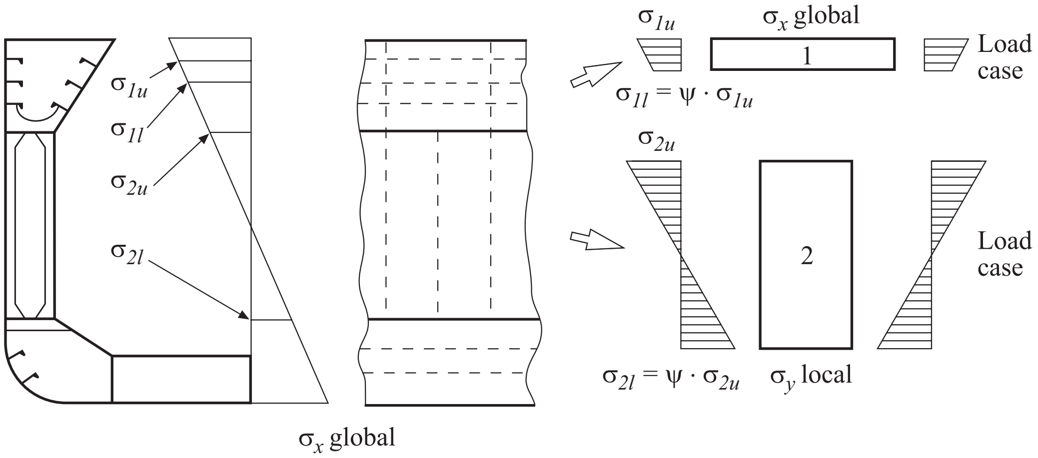
The buckling check of the elementary plate panel is to be performed under the loads defined in **Ch 6**, **Sec 3**, **2.1**, according to the requirements of **Ch 6**, **Sec 3**, **3**.

The determination of the buckling and reduction factors is made according to the **Ch 6**, **Sec 3**, **Table 2** for the plane plate panel and **Ch 6**, **Sec 3**, **Table 3** for the curved plate panel.

For the determination of the buckling and reduction factors in **Ch 6**, **Sec 3**, **Table 2**, the following cases are to be used according to the type of stresses and framing system of the plating:

- For the normal compressive stress:
- Buckling load case 1 for longitudinally framed plating, the membrane stress in *x*-direction σ_x being the normal stress σ_n defined in **Ch 6**, **Sec 3**, **2.1.2**
- Buckling load case 2 for transversely framed plating, the membrane stress in *y*-direction σ_y being the normal stress σ_n defined in **Ch 6**, **Sec3**, **2.1.2**, and the values *a* and *b* being exchanged to obtain α value greater than 1 as it is considered in load case 2.
- For the shear stress: Buckling case 5, τ being the shear stress τ_{SF} defined in **Ch 6**, **Sec 3**, **2.1.3**.

Fig. 3 Idealization of elementary plate panels



1.2.2 Ordinary stiffeners

The buckling check of the longitudinal and transverse ordinary stiffeners of partial and total plate panels (see **Ch 6, Sec 3, Fig. 1**) is to be performed under the loads defined in **Ch 6**, **Sec 3**, **2.1**, according to **Ch 6**, **Sec 3**, **4** with:

- σ_x = normal stress σ_n defined in **Ch 6**, **Sec 3**, **2.1.2**
- $\sigma_y = 0$

The effective width of the attached plating of the stiffeners is to be determined in accordance with **Ch 6**, **Sec 3**, **5**. A constant stress is to be assumed corresponding to the greater of the following values:

- stress at half length of the stiffener
- 0.5 of the maximum compressive stress of adjacent elementary plate panels

1.2.3 Primary supporting members with stiffeners in parallel

The effective width of the attached plating of the primary supporting members is to be determined in accordance with **Ch 6**, **Sec 3**, **5.2**.

In addition, when ordinary stiffeners are fitted on the attached plate and parallel to a primary supporting member, the buckling check is to consider a moment of inertia I_x taking account the moments of inertia of the parallel ordinary stiffeners connected to its attached plate (see **Ch 6**, **Sec 3**, **Fig. 3**).

1.2.4 Primary supporting members with stiffener perpendicular to girder

The effective width of the attached plating of the primary supporting members is to be determined in accordance with **Ch 6**, **Sec 3**, **5.2**.

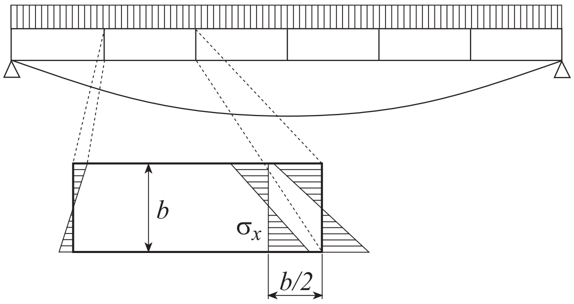
In addition, when ordinary stiffeners are fitted on the attached plate and perpendicular to a primary supporting member, the buckling check is to consider a moment of inertia I_x taking account the effective width according to (see **Ch 6**, **Sec 3**, **Fig. 4**).

1.3 Additional application to FEM analysis

1.3.1 Non uniform compressive stresses along the length of the buckling panel

If compressive stresses are not uniform over the length of the unloaded plate edge (e.g. in case of girders subjected to bending), the compressive stress value is to be taken at a distance of $b/2$ from the transverse plate edge having the largest compressive stress (see **Fig. 4**). This value is not to be less than the average value of the compressive stress along the longitudinal edge.

Fig. 4 Non uniform compressive stress along longitudinal edge *a*

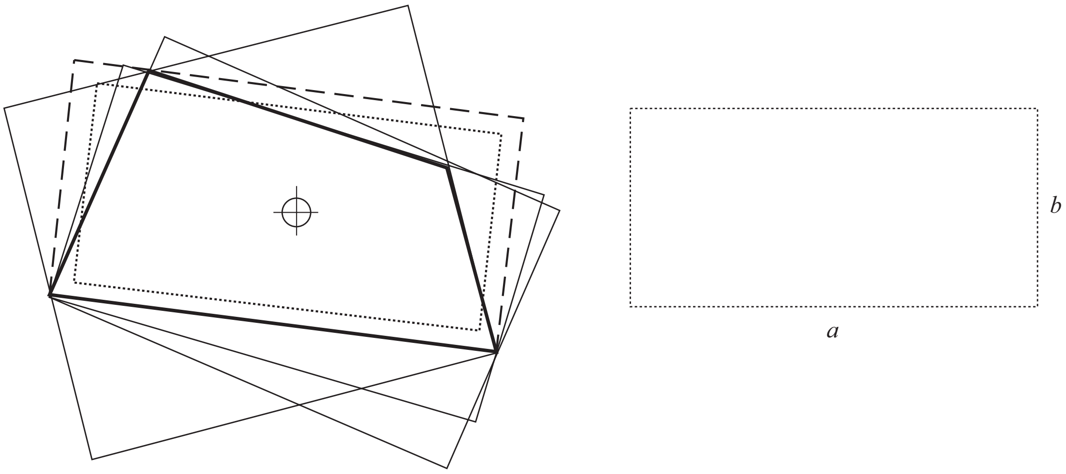


1.3.2 Buckling stress calculation of non rectangular elementary plate panels

a) Quadrilateral panels

According to **Fig. 5**, rectangles that completely surround the irregular buckling panel are searched. Among several possibilities the rectangle with the smallest area is taken. This rectangle is shrunk to the area of the original panel, where the aspect ratio and the centre are maintained. This leads to the final rectangular panel with the dimensions *a*, *b*.

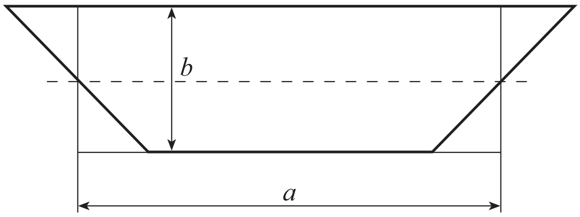
Fig. 5 Approximation of non rectangular elementary plate panels



Original irregular panel (▬▬)
Intermediate rectangles (───)
Rectangle with smallest area (— — —)
Final rectangle (┈┈┈)

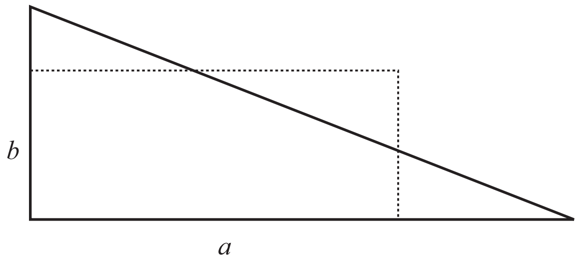
b) Trapezoidal elementary plate panel
A rectangle is derived with *a* being the mean value of the bases and *b* being the height of the original panel.

Fig. 6 Approximation of trapezoidal elementary plate panel



c) Right triangle
The legs of the right triangle are reduced by $\sqrt{0.5}$ to obtain a rectangle of same area and aspect ratio.

Fig. 7 Approximation of right triangle



d) General triangle
General triangle is treated according to **a)** above.

1.3.3 Buckling assessment of side shell plates

In order to assess the buckling criteria for vertically stiffened side shell plating, the following cases have to be considered:

In case vertical and shear stresses are approximately constant over the height of the elementary plate panel:

- Buckling load cases 1, 2 and 5, according to **Ch 6**, **Sec 3**, **Table 2** are to be considered
- $\psi = f(\sigma_1, \sigma_2)$ for horizontal stresses
- $\psi = 1.0$ for vertical stresses
- $t = t_{min}$ (Elementary plate panel)

In case of distributed horizontal, vertical and shear stresses over the height of the elementary plate panel, the following stress situations are to be considered separately:

a) Pure vertical stress
  - The size of buckling field to be considered is *b times b* ($\alpha = 1$)
  - $\psi = 1.0$
  - The maximum vertical stress in the elementary plate panel is to be considered in applying the criteria

b) Shear stress associated to vertical stress
  - The size of buckling field to be considered is 2*b times b* ($\alpha = 2$)
  - $\psi = 1.0$
  - The following two stress combinations are to be considered:
    - The maximum vertical stress in the elementary plate panel plus the shear stress and longitudinal stress at the location where maximum vertical stress occurs
    - The maximum shear stress in the elementary plate panel plus the vertical stress and longitudinal stress at the location where maximum shear stress occurs
  - The plate thickness *t* to be considered is the one at the location where the maximum vertical/shear stress occurs

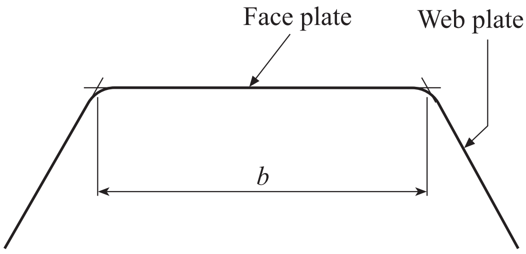
c) Distributed longitudinal stress associated with vertical and shear stress
  - The actual size of the elementary plate panel is to be used ($\alpha = f(a, b)$).
  - The actual edge factor ψ for longitudinal stress is to be used
  - The average values for vertical stress and shear stress are to be used.
  - $t = t_{min}$ (Elementary plate panel)

1.3.4 Buckling assessment of corrugated bulkheads

The transverse elementary plate panel (face plate) is to be assesed using the normal stress parallel to the corrugation. The slanted elementary plate panel (web plate) is to be assessed using the combination of normal and shear stresses.

The plate panel breadth *b* is to be measured according to **Fig. 8**.

Fig. 8 Measuring *b* of corrugated bulkheads



a) Face plate assessment
  - $F_1 = 1.1$ is to be used
  - The buckling load case 1, according to **Ch 6**, **Sec 3**, **Table 2**, is to be used
  - The size of the buckling field to be considered is *b times b* ($\alpha = 1$)
  - $\psi = 1.0$
  - The maximum vertical stress in the elementary plate panel is to be considered in applying the criteria
  - The plate thickness *t* to be considered is the one at the location where the maximum vertical stress occurs

b) Web plate assessment
  - $F_1 = 1.1$ is to be used

- The buckling load cases 1 and 5, according to **Ch 6**, **Sec 3**, **Table 2**, are to be used.
- The size of the buckling field to be considered is 2*b times b* ($\alpha = 2$)
- $\psi = 1.0$
- The following two stress combinations are to be considered:
  - The maximum vertical stress in the elementary plate panel plus the shear stress and longitudinal stress at the location where maximum vertical stress occurs
  - The maximum shear stress in the elementary plate panel plus the vertical stress and longitudinal stress at the location where maximum shear stress occurs
- The plate thickness *t* to be considered is the one at the location where the maximum vertical/shear stress occurs.