S11 Longitudinal strength standard

(1989)
(Rev. 1
1993)

S11.1 Application

This requirement applies only to steel ships of length 90 m and greater in unrestricted service. For ships having one or more of the following characteristics, special additional considerations will be given by each Classification Society.

(i)	Proportion	$L/B \leq 5$,	$B/D \geq 2{,}5$
(ii)	Length	$L \geq 500$ m	
(iii)	Block coefficient	$Cb < 0{,}6$	
(iv)	Large deck opening		
(v)	Ships with large flare		
(vi)	Carriage of heated cargoes		
(vii)	Unusual type or design		

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S11.2 Loads

S11.2.1 Still water bending moment and shear force

S11.2.1.1 General

Still water bending moments, Ms (kN-m), and still water shear forces, Fs (kN), are to be calculated at each section along the ship length for design load conditions and ballast conditions as specified in S11.2.1.2.
For these calculations, downward loads are assumed to be taken as positive values, and are to be integrated in the forward direction from the aft end of L. The sign conventions of Ms and Fs are as shown in Fig. 1.

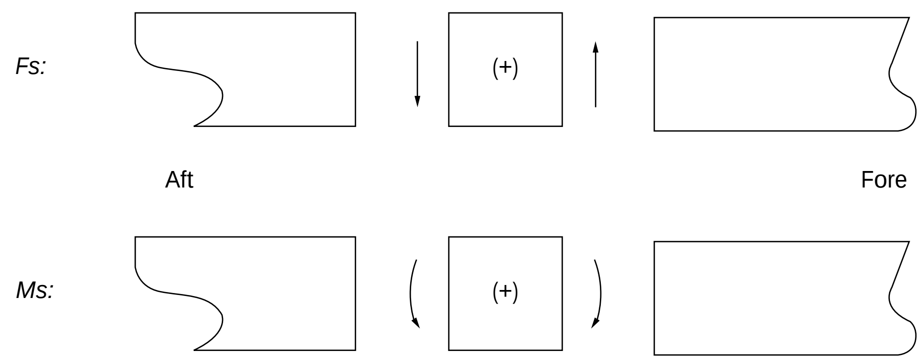

Fig. 1 Sign Conventions of *MS* and *Fs*

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S11.2.1.2 Load Conditions

In general, the following load conditions, based on amount of bunker, fresh water and stores at departure and arrival, are to be considered for the *Ms* and *Fs* calculations.

General cargo ships, container ships, roll-on/roll-off and refrigerated cargo carriers, bulk carriers, ore carriers:
- Homogeneous loading conditions at maximum draught
- Ballast conditions
- Special loading conditions e.g., container or light load conditions at less than the maximum draught, heavy cargo, empty holds or non-homogeneous cargo conditions, deck cargo conditions, etc., where applicable.

Oil tankers:
- Homogeneous loading conditions (excluding dry and clean ballast tanks) and ballast or part loaded conditions
- Any specified non-uniform distribution of loading
- Mid-voyage conditions relating to tank cleaning or other operations where these differ significantly from the ballast conditions.

Chemical tankers:
- Conditions as specified for oil tankers
- Conditions for high density or segregated cargo.

Liquefied gas carriers:
- Homogeneous loading conditions for all approved cargoes
- Ballast conditions
- Cargo conditions where one or more tanks are empty or partially filled or where more than one type of cargo having significantly different densities are carried.

Combination Carriers:
- Conditions as specified for oil tankers and cargo ships.

S11.2.2 Wave loads

S11.2.2.2 Wave bending moment

The wave bending moments, *Mw*, at each section along the ship length are given by the following formulae:

$Mw\ (+) = +\ 190\ M\ C\ L^2\ B\ Cb \times 10^{-3}$ (kN - m) ... For positive moment
$Mw\ (+) = -\ 110\ M\ C\ L^2\ B\ (Cb + 0{,}7) \times 10^{-3}$ (kN - m) ... For negative moment

where, M = Distribution factor given in Fig. 2

$$C = 10{,}75 - \left[\frac{300 - L}{100}\right]^{1{,}5} \quad \text{for } 90 \leqq L \leqq 300$$

$$\text{or } 10{,}75 \quad \text{for } 300 < L < 350$$

$$\text{or } 10{,}75 - \left[\frac{L - 350}{150}\right]^{1{,}5} \quad \text{for } 350 \leqq L \leqq 500$$

L = Length of the ships in metres, defined by S2
B = Greatest moulded breadth in metres
Cb = Block coefficient, defined by S2, but not to be taken less than 0,6

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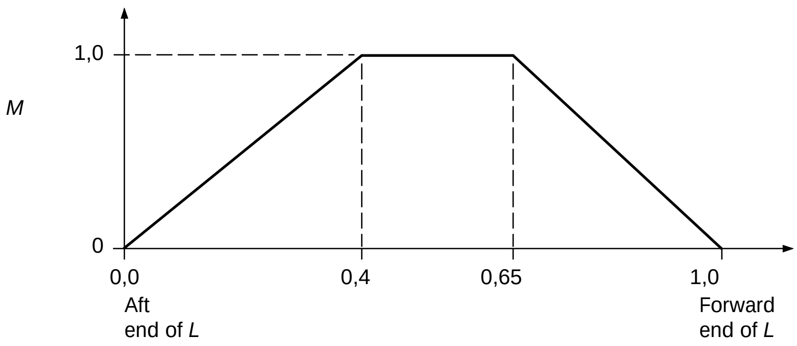

Fig. 2 Distribution factor *M*

S11 2.2.2 Wave shear force

The wave shear forces, *Fw*, at each section along the length of the ship are given by the following formulae:

$Fw\ (+) = +\ 30\ F1\ C\ L\ B\ (Cb + 0{,}7) \times 10^{-2}$ (kN) ... For positive shear force
$Fw\ (-) = -\ 30\ F2\ C\ L\ B\ (Cb + 0{,}7) \times 10^{-2}$ (kN) ... For negative shear force

Where, *F1*, *F2* = Distribution factors given in Figs. 3 and 4
C, *L*, *B*, *Cb* = As specified in S11.2.2.1

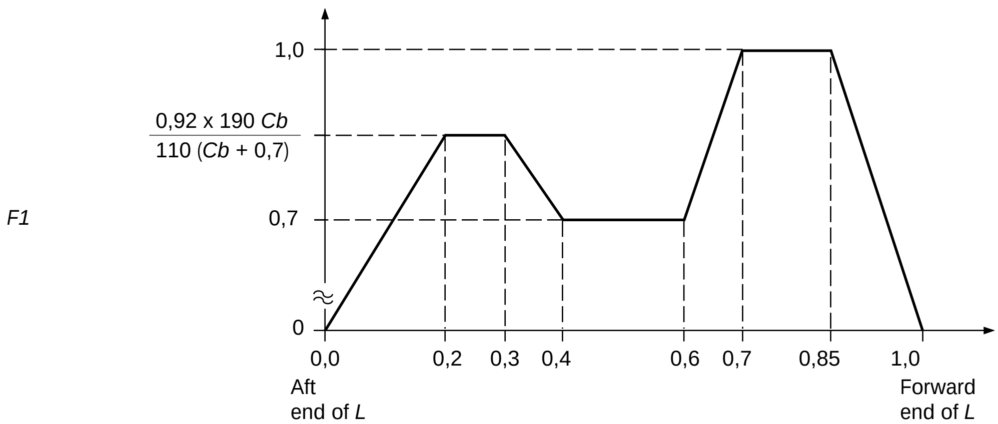

Fig. 3 Distribution factor *F1*

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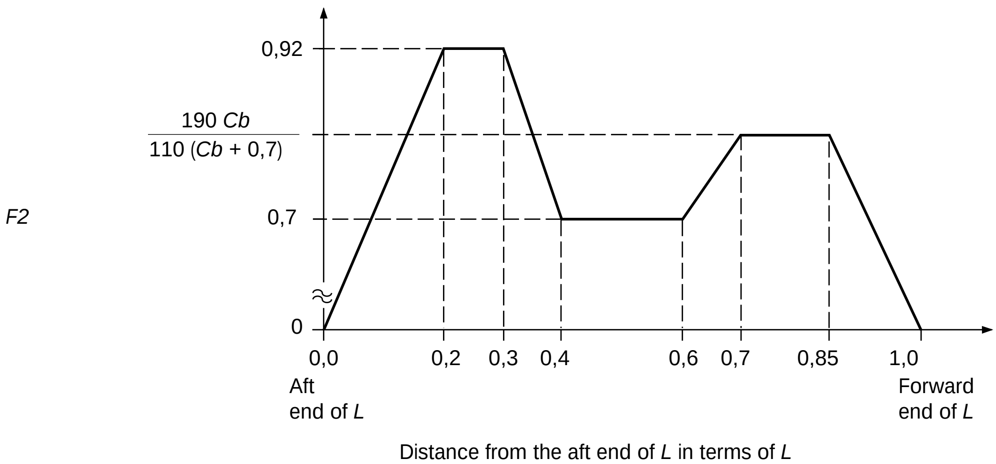

Fig. 4 Distribution factor *F2*

S11.3 Bending strength

S11.3.1 Bending strength amidships

S11 3.1.1 Section modulus

(i) Hull section modulus, Z, calculated in accordance with S5, is not to be less than the values given by the following formula in way of 0,4 *L* midships for the still water bending moments *Ms* given in S11.2.1.1 and the wave bending moments *Mw* given in S11.2.2.1, respectively:

$$\frac{Ms + Mw}{\sigma s} \times 10 \ (cm^3)$$

where, σ = 175 /k (N/mm^2)
k = 1,0 for ordinary hull structural steel
k < 1,0 for higher tensile steel according to S4.

(ii) In any case, the longitudinal strength of the ship is to be in compliance with S7.

S11 3.1.2 Moment of inertia

Moment of inertia of hull section at the midship point is not to be less than

$$I_{min} = 3CL^3B\,(Cb + 0{,}7) \qquad (cm^4)$$

Where *C, L, B, Cb* = As specified in S11.2.2.1.

S11.3.2 Bending strength outside amidships.

The required bending strength outside 0,4 *L* amidships is to be determined at the discretion of each Classification Society.

S11.4 Shearing strength

S11.4.1 General

The thickness requirements given in S11.4.2 or S11.4.3 apply unless smaller values are proved satisfactory by a method of direct stress calculation approved by each Classification Society, where the

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calculated shear stress is not to exceed 110/*k* (N/mm^2).

S11.4.2 Shearing strength for ships without effective longitudinal bulkheads

(i) The thickness of side shell is not to be less than the values given by the following formula for the still water shear forces *Fs* given in S11.2.1.1 and the wave shear forces *Fw* given in S11.2.2.2, respectively:

$$t = \frac{0{,}5 \quad Fs + Fw}{\tau} \quad \frac{S}{I} \quad \times 10^2 \qquad \text{(mm)}$$

where, I = Moment of inertia in cm^4 about the horizontal neutral axis at the section under consideration

S = First moment in cm^3, about the neutral axis, of the area of the effective longitudinal members between the vertical level at which the shear stress is being determined and the vertical extremity of effective longitudinal members, taken at the section under consideration

τ = 110/k (N/mm^2)

k = As specified in S11.3.1.1 (i)

(ii) The value of *Fs* may be corrected for the direct transmission of forces to the transverse bulkheads at the discretion of each Classification Society.

S11.4.3 Shearing strength for ships with two effective longitudinal bulkheads

The thickness of side shell and longitudinal bulkheads are not to be less than the values given by the following formulae:

For side shell:

$$t = \frac{(0.5 - \phi)\,(Fs + Fw) + \Delta Fsh}{\tau} \quad \frac{S}{I} \quad \times 10^2 \qquad \text{(mm)}$$

For longitudinal bulkheads:

$$t = \frac{\left| \phi\,(Fs + Fw) + \Delta Fbl \right|}{\tau} \quad \frac{S}{I} \quad \times 10^2 \qquad \text{(mm)}$$

where, ϕ = ratio of shear force shared by the longitudinal bulkhead to the total shear force, and given by each Classification Society.

ΔFsh, ΔFbl = shear force acting upon the side shell plating and longitudinal bulkhead plating, respectively, due to local loads, and given by each Classification Society, subject to the sign convention specified in S11.2.1.1

S, I, τ = As specified in S11.4.2 (i)

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S 11.5 Buckling strength

S 11.5.1 Application

These requirements apply to plate panels and longitudinals subject to hull girder bending and shear stresses.

S 11.5.2 Elastic buckling stresses

S 11.5.2.1 Elastic buckling of plates

1. Compression

The ideal elastic buckling stress is given by:

$$\sigma_E = 0.9m\,E\left(\frac{t_b}{1000s}\right)^2 \quad (N/mm^2)$$

For plating with longitudinal stiffeners (parallel to compressive stress):

$$m = \frac{8.4}{\Psi + 1.1} \qquad \text{for } (0 \le \Psi \le 1)$$

For plating with transverse stiffeners (perpendicular to compressive stress):

$$m = c\left[1 + \left(\frac{s}{\ell}\right)^2\right]^2 \frac{2.1}{\Psi + 1.1} \qquad \text{for } (0 \le \Psi \le 1)$$

where

E = modulus of elasticity of material

= 2.06×10^5 N/mm^2 for steel

t_b = net thickness, in mm, of plating, considering standard deductions equal to the values given in the table here after:

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Structure	Standard deduction (mm)	Limit values min-max (mm)
- Compartments carrying dry bulk cargoes - One side exposure to ballast and/or liquid cargo Vertical surfaces and surfaces sloped at an angle greater than 25° to the horizontal line	0.05 t	0.5 - 1
- One side exposure to ballast and/or liquid cargo Horizontal surfaces and surfaces sloped at an angle less than 25° to the horizontal line - Two side exposure to ballast and/or liquid cargo Vertical surfaces and surfaces sloped at an angle greater than 25° to the horizontal line	0.10 t	2 - 3
- Two side exposure to ballast and/or liquid cargo Horizontal surfaces and surfaces sloped at an angle less than 25° to the horizontal line	0.15 t	2 - 4

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s = shorter side of plate panel, in m,

ℓ = longer side of plate panel, in m,

c = 1.3 when plating stiffened by floors or deep girders,

= 1.21 when stiffeners are angles or T-sections,

= 1.10 when stiffeners are bulb flats,

= 1.05 when stiffeners are flat bars,

ψ = ratio between smallest and largest compressive σa stress when linear variation across panel.

2. Shear

The ideal elastic buckling stress is given by:

$$\tau_E = 0.9 k_t E \left(\frac{t_b}{1000s} \right)^2 \qquad (\text{N/mm}^2)$$

$$K_t = 5.34 + 4\left(\frac{s}{\ell}\right)^2$$

E, t_b, s and ℓ are given in 1.

S 11.5.2.2 Elastic buckling of longitudinals

1. Column buckling without rotation of the cross section

For the column buckling mode (perpendicular to plane of plating) the ideal elastic buckling stress is given by:

$$\sigma_E = 0.001 E \frac{I_a}{A\ell^2} \qquad (\text{N/mm}^2)$$

I_a = moment of inertia, in cm^4, of longitudinal, including plate flange and calculated with thickness as specified in S 11.5.2.1.1,

A = cross-sectional area, in cm^2, of longitudinal, including plate flange and calculated with thickness as specified in S 11.5.2.1.1,

ℓ = span, in m, of longitudinal,

A plate flange equal to the frame spacing may be included.

2. Torsional buckling mode

The ideal elastic buckling stress for the torsional mode is given by:

$$\sigma_E = \frac{\pi^2 E L_w}{10^4 I_p \ell^2}\left(m^2 + \frac{K}{m^2}\right) + 0.385 E \frac{I_t}{I_p} \quad (\text{N/mm}^2)$$

$$K = \frac{C\ell^4}{\pi^4 E I_w} 10^6$$

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m = number of half waves, given by the following table:

	0< K < 4	4 < K < 36	36 < K < 144	$(m-1)^2 m^2 < K \le m^2 (m+1)^2$
m	1	2	3	m

I_t = St Venant's moment of inertia, in cm^4, of profile (without plate flange)

$$= \frac{h_w t_w^{\;3}}{3} 10^{-4} \quad \text{for flat bars (slabs)}$$

$$= \frac{1}{3}\left[h_w t_w^{\;3} + b_f t_f^{\;3}\left(1 - 0.63\frac{t_f}{b_f}\right)\right]10^{-4} \quad \text{for flanged profiles}$$

I_p = polar moment of inertia, in cm^4, of profile about connection of stiffener to plate

$$= \frac{h_w^{\;3} t_w}{3} 10^{-4} \quad \text{for flat bars (slabs)}$$

$$= \left(\frac{h_w^{\;3} t_w}{3} + h_w^{\;2} b_f t_f\right)10^{-4} \quad \text{for flanged profiles}$$

I_w = sectional moment of inertia, in cm^6, of profile about connection of stiffener to plate

$$= \frac{h_w^{\;3} t_w^{\;3}}{36} 10^{-6} \quad \text{for flat bars (slabs)}$$

$$= \frac{t_f b_f^{\;3} h_w^{\;2}}{12} 10^{-6} \quad \text{for "Tee" profiles}$$

$$= \frac{b_f^{\;3} h_w^{\;2}}{12(b_f + h_w)^2}\left[t_f\left(b_f^{\;2} + 2b_f h_w + 4h_w^{\;2}\right) + 3t_w b_f h_w\right]10^{-6} \quad \text{for angles and bulb profiles}$$

h_w = web height, in mm,

t_w = web thickness, in mm, considering standard deductions as specified in S 11.5.2.1.1,

b_f = flange width, in mm,

t_f = flange thickness, in mm, considering standard deductions as specified in S 11.5.2.1.1. For bulb profiles the mean thickness of the bulb may be used.

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ℓ = span of profile, in m,

s = spacing of profiles, in m,

C = spring stiffeness exerted by suporting plate p

$$= \frac{k_p E t_p^{\,3}}{3s\left(1 + \dfrac{1.33 k_p h_w t_p^{\,3}}{1000 s t_w^{\,3}}\right)} 10^{-3}$$

k_p = 1 - ηp not to be taken less than zero

t_p = plate thickness, in mm, considering standard deductions as specified in S 11.5.2.1.1.

$$\eta_p = \frac{\sigma_a}{\sigma_{Ep}}$$

σ_a = calculated compressive stress. For longitudinals, see S 11.5.4.1,

σ_{Ep} = elastic buckling stress of supporting plate as calculated in S 11.5.2.1,

For flanged profiles, k_p need not be taken less than 0.1.

3. Web and flange buckling

For web plate of longitudinals the ideal elastic buckling stress is given by:

$$\sigma_E = 3.8E\left(\frac{t_w}{h_w}\right)^2 \qquad (\text{N/mm}^2)$$

For flanges on angles and T-sections of longitudinals, buckling is taken care of by the following requirement:

$$\frac{b_f}{t_f} \le 15$$

b_f = flange width, in mm, for angles, half the flange width for T-sections.
t_f = as built flange thickness.

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S 11.5.3 Critical buckling stresses

S 11.5.3.1 Compression

The critical buckling stress in compression σ_c is determined as follows:

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S 11.5.4.2 Shear stresses

1. Ships without effective longitudinal bulkheads

For side shell

$$\tau_a = \frac{0.5 \,|\, F_s + F_w \,|}{t} \cdot \frac{S}{I} \cdot 10^2 \ \text{N/mm}^2$$

F_S, F_W, t, s, I as specified in S 11.4.2

2. Ships with two effective longitudinal bulkheads

For side shell

$$\tau_a = \frac{|\,(0.5 - \phi)(F_s + F_w) + \Delta F_{sh}\,|}{t} \cdot \frac{S}{I} \cdot 10^2 \ \text{N/mm}^2$$

For longitudinal bulkheads

$$\tau_a = \frac{|\,\phi \ (F_s + F_w) + \Delta F_{b\ell}\,|}{t} \cdot \frac{S}{I} \cdot 10^2 \ \text{N/mm}^2$$

F_S, F_W, ΔF_{sh}, $\Delta F_{b\ell}$, t, S, I as specified in S 11.4.3.

S 11.5.5 Scantling criteria

S 11.5.5.1 Buckling Stress

The design buckling stress σ_c of plate panels and longitudinals (as calculated in S 11.5.3.1) is not to be less than:

$$\sigma_c \geq \beta \sigma_a$$

where

$\beta = 1$ for plating and for web plating of stiffeners (local buckling)

$\beta = 1.1$ for stiffeners

The critical buckling stress τ_c of plate panels (as calculated in S 11.5.3.2) is not to be less than:

$$\tau_c \geq \tau_a$$

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$$\sigma_C = \sigma_E \quad \text{when} \quad \sigma_E \le \frac{\sigma_F}{2}$$

$$= \sigma_F\left(1 - \frac{\sigma_F}{4\sigma_E}\right) \quad \text{when} \quad \sigma_E > \frac{\sigma_F}{2}$$

σ_F = yield stress of material, in N/mm^2 σ_F may be taken as 235 N/mm^2 for mild steel,

σ_E = ideal elastic buckling stress calculated according to S 11.5.2.

S 11.5.3.2 Shear

The critical buckling stress in shear τ_c is determined as follows:

$$\tau_C = \tau_E \quad \text{when} \quad \tau_E \le \frac{\tau_F}{2}$$

$$= \tau_F\left(1 - \frac{\tau_F}{4\tau_E}\right) \quad \text{when} \quad \tau_E > \frac{\tau_F}{2}$$

$$\tau_F = \frac{\sigma_F}{\sqrt{3}}$$

σ_F = as given in S 11.5.3.1,

τ_E = ideal elastic buckling stress in shear calculated according to S11.5.2.1.2.

S 11.5.4 Working stress

S 11.5.4.1 Longitudinal compressive stresses

The compressive stresses are given in the following formula:

$$\sigma_a = \frac{M_s + M_w}{I_n} y \cdot 10^5 \text{ N/mm}^2$$

$$= \text{minimum} \frac{30}{k}$$

M_s = still water bending moment (kN.m), as given in S 11.2.1,

M_w = wave bending moment (kN.m) as given in S 11.2.2.1,

I_n = moment of inertia, in cm4, of the hull girder,

y = vertical distance, in m, from neutral axis to considered point.

k = as specified in S 11.3.1.1 (i).

M_s and M_w are to be taken as sagging or hogging bending moments, respectively, for members above or below the neutral axis.

Where the ship is always in hogging condition in still water, the sagging bending moment (M_s + M_w) is to be specially considered.

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