RULES FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

GUIDANCE FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

Part C Hull Construction and Equipment

Rules for the Survey and Construction of Steel Ships
Part C 2015 AMENDMENT NO.3
Guidance for the Survey and Construction of Steel Ships
Part C 2015 AMENDMENT NO.3

Rule No.63 / Notice No.82 25th December 2015
Resolved by Technical Committee on 28th July 2015 / 19th November 2015
Approved by Board of Directors on 14th September 2015 / 14th December 2015

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NIPPON KAIJI KYOKAI

RULES FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

Part C Hull Construction and Equipment

RULES

2015 AMENDMENT NO.3

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Rule No.63 25th December 2015
AMENDMENT TO THE RULES FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

"Rules for the survey and construction of steel ships" has been partly amended as follows:

Part C HULL CONSTRUCTION AND EQUIPMENT

Chapter 1 GENERAL

1.1 General

1.1.3 Ships of Unusual Form or Proportion, or Intended for Carriage of Special Cargoes

Sub-paragraph -4 has been amended as follows.

4 Reinforcement of the ship for loading containers is to be done in accordance with the provisions of **32.~~3~~4.1**. Cell guide constructions, where provided, are to be in accordance with the provisions of **32.~~7~~11**.

1.1.7 Materials

Sub-paragraph -2 has been amended as follows.

2 Where high tensile steel specified in **Chapter 3, Part K of the Rules** is used, the construction and scantlings of the ship are to comply with the following requirements in **(1)** to **(3)**:
(1) The section modulus of the transverse section of the hull is not to be less than the value obtained by multiplying the following coefficient with the value specified in ~~**Chapter 15**~~**32.2.4** for ships subject to the requirements in **Chapter 32** and **15.2** for other ships. However, where special consideration is given to the type of high tensile steel used, this value may be different, subject to the approval of the Society, from the following coefficients. Moreover, the extent of high tensile steel use is to be at the discretion of the Society.
  0.78: where high tensile steels *KA*32, *KD*32, *KE*32 or *KF*32 are used
  0.72: where high tensile steels *KA*36, *KD*36, *KE*36 or *KF*36 are used
  0.68: where high tensile steels *KA*40, *KD*40, *KE*40 or *KF*40 are used.
  0.62: where high tensile steel *KE*47 is used (However, only applies to ships subject to **Chapter 32**).
((2) and (3) are omitted.)

Paragraph 1.1.22 has been amended as follows.

1.1.22 Direct Calculations

1 Where approved by the Society, direct calculations may be used to determine the scantlings of primary members. ~~Where direct calculations are used, the data necessary for the calculations are to be submitted to the Society.~~ Where the scantlings determined based upon direct calculation exceed the scantlings required in this Chapter, the former is to be adopted.

2 Where deemed necessary by the Society based on factors such as the type and size of the ship, the scantlings of primary members are to be determined by the direct strength analysis.

3 Where direct calculations specified in **-1** above are used, the data necessary for the calculations are to be submitted to the Society.

Chapter 15 LONGITUDINAL STRENGTH

15.1 General

Paragraph 15.1.1 has been amended as follows.

15.1.1 Special Cases in Application

1 Notwithstanding the requirements in this Chapter, the longitudinal strength for ships subject to **Chapter 32** is to comply with the requirements in **Chapter 32**.

2 Where there are items for which direct application of the requirements in this Chapter is deemed unreasonable for the following ships given in **(1)** through **(5)**, these items are to be in accordance with the discretion of the Society.

(1) Ships of unusual proportion
(2) Ships with especially large hatches
(3) Ships with especially small C_b
(4) Ships with large flares and high speed
(5) Other ships (ships of special form or construction, ships with special loading requirements, etc.)

Chapter 16 PLATE KEELS AND SHELL PLATING

16.1 General

Paragraph 16.1.2 has been amended as follows.

16.1.2 Consideration for Buckling

With regard to the prevention of buckling of the shell, adequate consideration is to be given to the prevention of buckling due to compression in addition to complying with the requirements in **32.2.7** for ships subject to the requirements in **Chapter 32** and **15.4** for other ships.

Chapter 17 DECKS

17.2 Effective Sectional Area of Strength Deck

Paragraph 17.2.1 has been amended as follows.

17.2.1 ~~Definition~~General

<u>**1**</u> The effective sectional area of the strength deck is the sectional area, on each side of the ship, of steel plating, longitudinal beams, longitudinal girders, etc. extending for 0.5*L* amidships.
<u>**2** The requirements in **32.2** are to apply to ships subject to **Chapter 32** in place of the requirements in this Chapter.</u>

17.2.2 Effective Sectional Area of Strength Deck

1 The effective sectional area for the midship part for which the modulus of athwartship section of the hull is specified in **Chapter 15** is to be so determined as to comply with the requirements in **Chapter 15**.
2 Beyond the midship part, the effective sectional area of strength deck may be gradually reduced less than the value at the end of the midship part. However, the values at the position 0.15*L* from the after and fore end of *L*, respectively, are not to be less than 0.4 times the value at the middle point of *L* for ships with machinery amidships, or 0.5 times for ships with machinery aft.
3 Where the section modulus of the athwartship section other than the midship part is greater than the value approved by the Society, the requirements specified in the provisory clause in **-2** may not be necessarily applied.

17.2.3 Strength Deck Beyond 0.15*L* from Each End

Beyond 0.15*L* from each end, the effective sectional area and the thickness of the strength deck may be gradually reduced avoiding abrupt changes.

17.2.4 Effective Sectional Area of Strength Deck within Long Poop

Notwithstanding the requirements in **17.2.2**, the effective sectional area of the strength deck within long poop may be properly modified.

17.2.5 Deck Within Superstructure Where Superstructure Deck is Designed as Strength Deck

Where the superstructure deck is designed as the strength deck, the strength deck plating clear of the superstructure is to extend into the superstructure for about 0.05*L* without reducing the effective sectional area, and may be gradually reduced within.

Chapter 32 has been amended as follows.

Chapter 32 CONTAINER CARRIERS

32.1 General

32.1.1 Application

1 The construction and equipment of ships intended to be registered as "container carriers" are to be in accordance with the requirements in this Chapter.

2 Except where especially required in this Chapter, the general requirements for the construction and equipment of steel ships are to be applied.

3 The requirements in this Chapter are for ships which are intended solely for the carriage of containers and which have ~~a single deck~~ large openings in the deck, double bottoms in cargo holds, and decks and bottoms framed longitudinally.

4 Container carriers with a different construction from that specified in **-3** above, to which the requirements in this Chapter are not applicable, are to be at the discretion of the Society.

~~32.1.2 Direct Calculation~~

~~Where approved by the Society, scantlings of structural members may be determined based upon direct calculation. Where the scantlings determined based upon direct calculation exceed the scantlings required in this Chapter, the former is to be adopted.~~

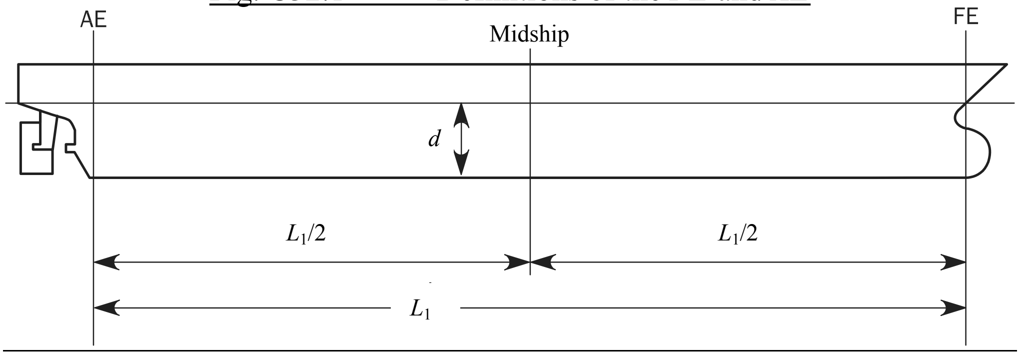
32.1.2 Definitions

1 The definitions of L_1, *FE* (fore end of L_1) and *AE* (aft end of L_1) are given in **Table C32.1** and **Fig. C32.1**.

Table C32.1 Definitions of L_1, *FE* and *AE*

	Definition
L_1	Length (*m*) of ship specified in **2.1.2, Part A** or 0.97 *times* the length of ship on the designed maximum load line, whichever is smaller.
FE	The fore end of L_1, defined as the perpendicular to the designed maximum load draught at the forward side of the stem.
AE	The aft end of L_1, defined as the perpendicular to the designed maximum load draught at a distance L_1 aft of the fore end (*FE*).

Fig. C32.1 Definitions of the *FE* and *AE*

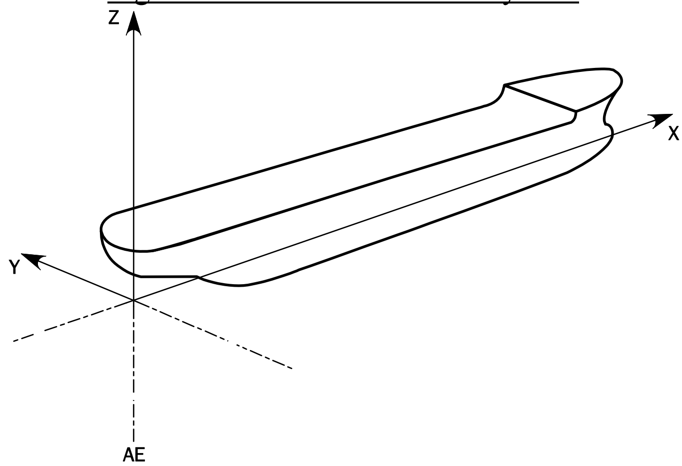


2 The definitions of the coordinate systems for ship geometry, motions, accelerations and loads are given in **Table C32.2** and **Fig. C32.2**.

Table C32.2 Definition of Coordinate System

	Definition
Origin	At the intersection of the longitudinal plane of symmetry of ship, *AE* (the aft end of L_1) and the baseline
X-axis	Longitudinal axis, positive forwards
Y-axis	Transverse axis, positive towards portside
Z-axis	Vertical axis, positive upwards

Fig. C32.2 Coordinate System

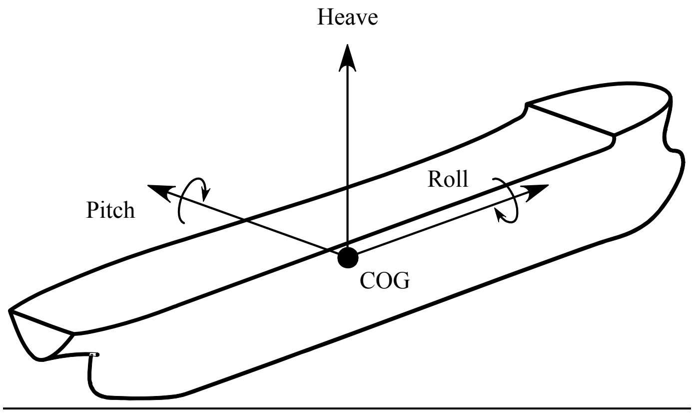


3 The definitions of positive and negative ship motions are given in **Table C32.3** and **Fig. C32.3**.

Table C32.3 Sign Convention for Ship Motions

	Definition of positive ship motions
Heave	Positive heave is translation in the Z-axis direction (positive upwards).
Roll	Positive roll motion is positive rotation about a longitudinal axis through the COG (starboard down and port up).
Pitch	Positive pitch motion is positive rotation about a transverse axis through the COG (bow downward stem up).

Fig.C32.3 Definition of Positive Motions

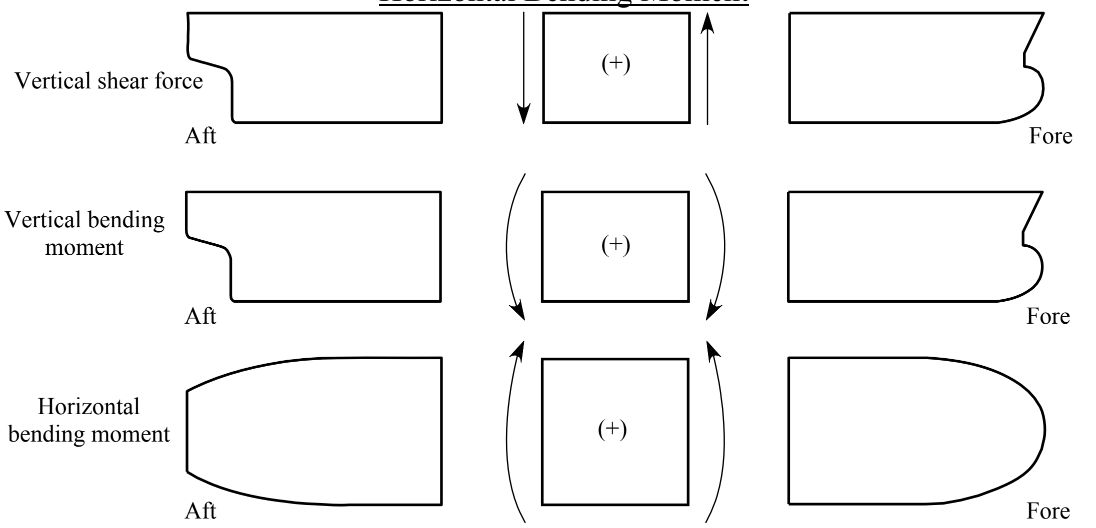


4 The definitions of positive and negative vertical shear forces, vertical bending moments and horizontal bending moments at any ship transverse section are as shown in **Table C32.4** and **Fig. C32.4**.

Table C32.4 Sign Convention for Vertical Shear Force, Vertical Bending Moment and Horizontal Bending Moment

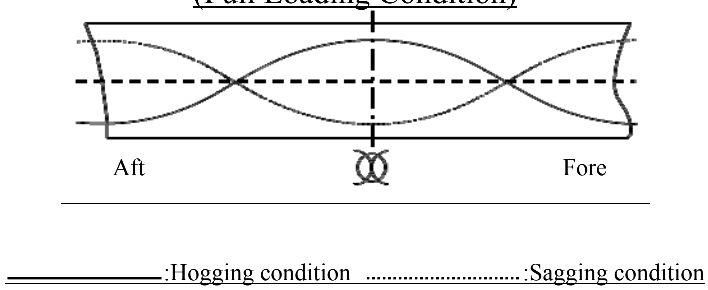
	Definition of positive force and moments
Vertical shear force (*kN*)	Positive in the case of downward resulting forces acting aft of the transverse section and upward resulting forces acting forward of the transverse section under consideration.
Vertical bending moment (*kN*)	Positive when inducing tensile stresses in strength deck (hogging bending moment) and negative when inducing tensile stresses in the bottom (sagging bending moment).
Horizontal bending moment (*kN-m*)	Positive when inducing tensile stresses in the starboard side and negative when inducing tensile stresses in the port side.

Fig. C32.4 Definition of Positive Vertical Shear Force, Vertical Bending Moment and Horizontal Bending Moment



5 The definition of waves in hogging and sagging conditions is according to **Fig. C32.5**.

Fig. C32.5 Definition of Waves in Hogging and Sagging Conditions (Full Loading Condition)



32.1.3 Net Scantling Approach

1 In **32.2** and **32.9**, the strength is to be assessed using the net scantling approach on all scantlings if not otherwise specified. In **32.3** to **32.8**, the strength is assessed using the gross scantling approach where the gross scantling means the built scantling.

2 The net thickness of plating, t_{net} (mm), for the plates, webs, and flanges is obtained by the following formula.

$$t_{net} = t_{as\_built} - t_{vol\_add} - \alpha t_c$$

t_{as_built} : Built thickness (mm)

t_{vol_add} : Voluntary addition (mm)

α : Corrosion addition factor whose values are defined in **Table C32.5**

t_c : Total corrosion addition (mm) whose value is defined in **-4**

3 The voluntary addition, if being used, is to be clearly indicated on the drawings.

4 The corrosion addition of the structural members considered is to be in accordance with the following **(1)** to **(3)**:

(1) The total corrosion addition, t_c (mm), for both sides of the structural member is obtained by the following formula.

$$t_c = (t_{c1} + t_{c2}) + 0.5$$

t_{c1}, t_{c2}: Corrosion addition for each of the two sides of a structural member, specified in **Table C32.6**

(2) For an internal member within a given compartment, the total corrosion addition, t_c, is obtained from the following formula.

$t_c = 2t_{c1} + 0.5$ t_{c1}: As specified in **(1)**

(3) The corrosion addition of a stiffener is to be determined according to the location of its connection to the attached plating.

Table C32.5 Values of Corrosion Addition Factor

Requirement		α
Stiffness assessment and yield strength assessment (**32.2.5** and **32.2.6**)		0.5
Buckling strength (**32.2.7**)	Sectional properties (stress determination)	0.5
	Buckling capacity	1.0
Hull girder ultimate strength (**32.2.8**)		0.5
Strength assessment by direct strength calculation (**32.9.8** and **32.9.9**)	Stress determination	0.5
	Buckling capacity	1.0

Table C32.6 Corrosion Addition for One Side of a Structural Member

Compartment type	One side corrosion addition t_{c1}, t_{c2} (mm)
Exposed to sea water	1.0
Exposed to atmosphere	1.0
Ballast water tank	1.0
Void and dry spaces	0.5
Fresh water, fuel oil and lube oil tanks	0.5
Accommodation spaces	0.0
Container holds	1.0
Compartment types not mentioned above	0.5

32.1.4 Minimum Thickness

1 The gross minimum thickness of girders, struts and their end brackets and bulkhead plates in double side spaces, the interior of which are used as deep tanks, and double bottom spaces (including bilge parts) are to be in accordance with **Table C32.7**.

2 The gross minimum thickness of watertight bulkhead and partial bulkhead constructions in cargo holds as well as girders, struts and their end brackets and bulkhead plates in double side spaces interior of which are not used as deep tanks, may be reduced by 1.0 *mm* from the thickness prescribed in **Table C32.7**.

3 The gross thickness of structural members in cargo holds, double bottom constructions and double side hull constructions is not to be less than 6 *mm*.

Table C32.7 Minimum Gross Thickness

Length of ship L (m)	More than or equal to	90	105	120	135	150	165	180	195	225	275
	Less than	105	120	135	150	165	180	195	225	275	
Thickness (mm)		7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5

32.2 Longitudinal Bending Strength

~~32.2.1 Bending Strength~~

~~The section modulus of the athwartship section of the hull is to be as given in **15.2**. However, in case the athwartship section changes greatly in shape, adequate care is to be taken against deflection of the hull.~~

~~32.2.2 Torsional Strength~~

~~Where the width of the hatchway at the midship exceeds 0.7*B*, special considerations are to be made to additional stresses and deformation of hatchway openings due to torsion. However, where the ship has two or more rows of hatchways, the distance between the outermost lines of hatchway openings is to be taken as the width of the hatchway.~~

~~32.2.3 Fatigue Strength~~

~~For bottom longitudinals, side longitudinals, hatch corners, hatch side coamings, and areas of stress concentrations such as bench corners in forward holds, sufficient consideration is to be given for fatigue strength.~~

32.2.1 General

1 The wave induced load requirements specified in this Chapter apply to ships meeting the criteria in the following **(1)** to **(3)**:

(1) Length of ship L_1: $90m \le L_1 \le 500m$

(2) Proportion: $5 \le L_1 / B \le 9$, $2 \le B / d \le 6$

(3) Block coefficient at the designed maximum load line: $0.55 \le C'_b \le 0.9$

C'_b is the volume of displacement corresponding to the designed maximum load line divided by $L_1 Bd$

2 For ships that do not meet all of the criteria specified in **-1(1)** to **(3)**, applied wave induced loads is specially to be obtained from the direct loading analysis method, etc.

3 Continuity of structure is to be maintained throughout the length of the ship.

4 Where significant changes in structural arrangement occur, adequate transitional structure is to be provided.

32.2.2 Longitudinal Extent of Strength Assessment

1 The stiffness, yield strength, buckling strength and hull girder ultimate strength assessment

specified in this Chapter are to be carried out in way of $0.2L_1$ to $0.75L_1$ if not otherwise specified, with due consideration given to locations where there are significant changes in hull cross section.
2 Strength assessments are to be carried out outside $0.2L_1$ to $0.75L_1$ by the method deemed appropriate by the Society. As a minimum, assessments are to be carried out at forward end of the foremost cargo hold, the aft end of the aft most cargo hold and locations where there are significant changes in hull section.

32.2.3 Loads

1 Vertical still water bending moments, M_S (*kN-m*), and vertical still water shear forces, F_S (*kN*), are to be calculated at each section along the ship length for ,in general, the design cargo and ballast loading conditions, based on amount of bunker, fresh water and stores at departure and arrival.
2 Where the amount and disposition of consumables at any intermediate stage of the voyage are considered more severe, calculations for such intermediate conditions are to be submitted in addition to those for departure and arrival conditions.
3 Where any ballasting and/or de-ballasting is intended during voyage, calculations of the intermediate condition just before and just after ballasting and/or de-ballasting any ballast tank are to be submitted to the Society and where approved included in the loading manual for guidance.
4 The permissible maximum and minimum vertical still water bending moments, $M_{S\,max}$ (*kN-m*) and $M_{S\,min}$ (*kN-m*), and the permissible maximum and minimum vertical still water shear forces, $F_{S\,max}$ (*kN*) and $F_{S\,min}$ (*kN*), in seagoing conditions at any longitudinal position are to envelop the following **(1)** and **(2)**:

(1) The maximum and minimum vertical still water bending moments and shear forces for the seagoing loading conditions defined in the loading manual.
(2) The maximum and minimum vertical still water bending moments and shear forces specified by the designer

5 The loading manual is to include the relevant loading conditions, which envelop the still water hull girder loads for seagoing conditions, including the loading conditions which are separately specified by the Society.
6 The distribution of the vertical wave induced bending moments, M_W (*kN-m*), along the ship length is given in **Fig. C32.6**. $M_{W-Hog-Mid}$ and $M_{W-Sag-Mid}$ are to be obtained using the following formulae.

$$M_{W-Hog-Mid} = +1.5 f_R L_1^3 C C_W \left(\frac{B}{L_1}\right)^{0.8} f_{NL-Hog}$$

$$M_{W-Sag-Mid} = -1.5 f_R L_1^3 C C_W \left(\frac{B}{L_1}\right)^{0.8} f_{NL-Sag}$$

f_R: Factor, to be taken as 0.85

C: Wave parameter, to be taken as:

$$C = 1 - 1.50\left(1 - \sqrt{\frac{L_1}{L_{ref}}}\right)^{2.2} \quad \text{for } L_1 \le L_{ref}$$

$$C = 1 - 0.45\left(\sqrt{\frac{L_1}{L_{ref}}} - 1\right)^{1.7} \quad \text{for } L_1 > L_{ref}$$

L_{ref} : Reference length (m), to be taken as:

$$L_{ref} = 315 C_W^{-1.3}$$

C_W : Waterplane coefficient at the designed maximum load draught, to be taken as:

$$C_W = \frac{A_W}{L_1 B}$$

A_W : Waterplane area at the designed maximum load draught (m^2)

f_{NL-Hog} : Non-linear correction factor for hogging, to be taken as:

$$f_{NL-Hog} = 0.3 \frac{C_b'}{C_W} \sqrt{d}$$, not to be taken greater than 1.1

f_{NL-Sag} : Non-linear correction factor for sagging, to be taken as:

$$f_{NL-Sag} = 4.5 \frac{1 + 0.2 f_{Bow}}{C_W \sqrt{C_b'} L_1^{0.3}}$$, not to be taken less than 1.0

f_{Bow} : Bow flare shape coefficient, to be taken as:

$$f_{Bow} = \frac{A_{DK} - A_{WL}}{0.2 L_1 Z_f}$$

A_{DK} : Projected area in horizontal plane of uppermost deck (m^2) including the forecastle deck, if any, extending from $0.8L_1$ (see **Fig. C32.7**). Any other structures, e.g. plated bulwark, are to be excluded.

A_{WL} : Waterplane area (m^2) at the designed maximum load draught, extending from $0.8L_1$ forward

Z_f : Vertical distance (m) from the waterline at the designed maximum load draught to the uppermost deck (or forecastle deck), measured at FE (see **Fig. C32.7**). Any other structures, e.g. plated bulwark, are to be excluded.

C_b' : Volume of displacement corresponding to the designed maximum load line divided by $L_1 B d$

Fig. C32.6 Distribution of Vertical Wave Induced Bending Moment (M_W) along the Ship Length

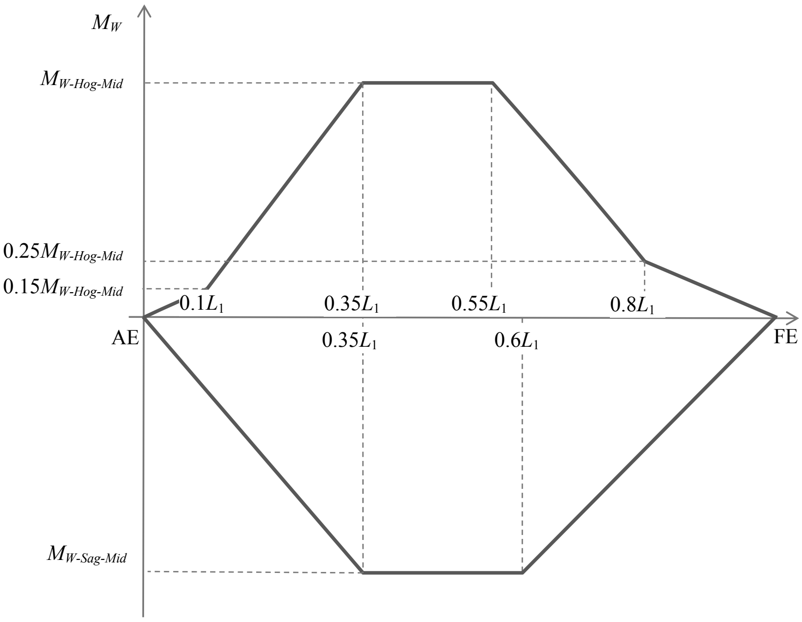
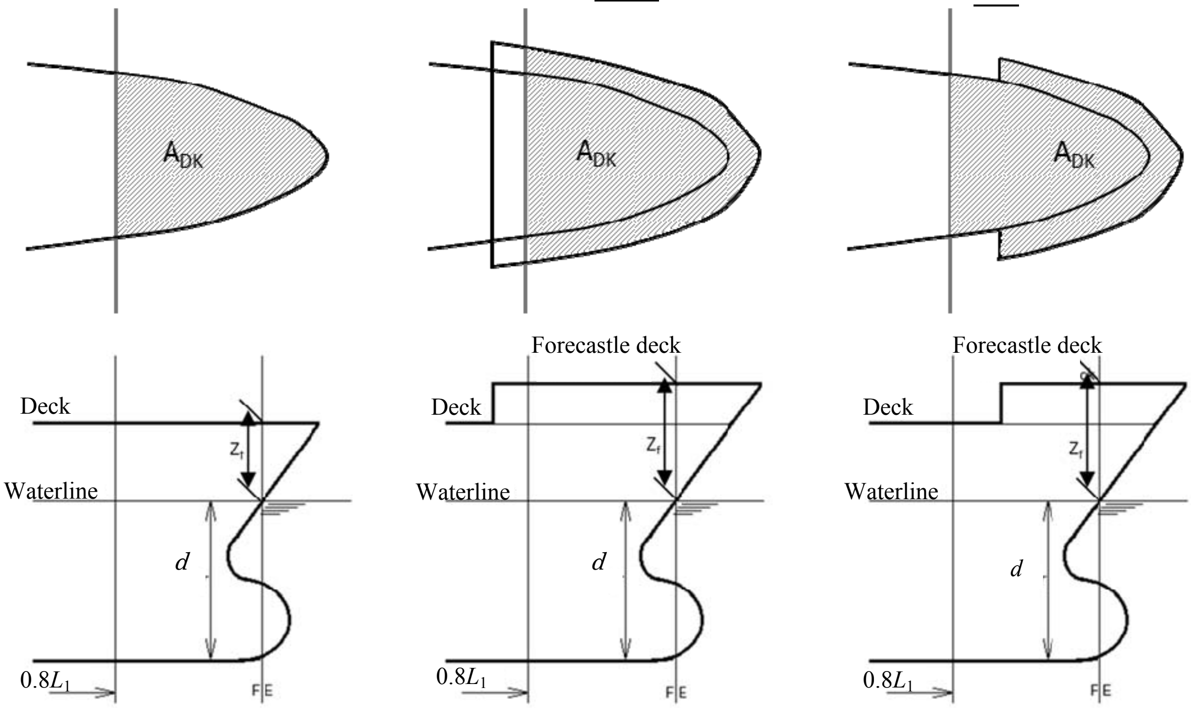


Fig. C32.7 Project Area (A_{DK}) and Vertical Distance (Z_f)



7 The distribution of the vertical wave induced shear forces, F_W (*kN*), along the ship length is given in **Fig. C32.8**. $F_{W-Hog-Aft}$, $F_{W-Hog-Fore}$, $F_{W-Sag-Aft}$, $F_{W-Sag-Fore}$, and F_{W-Mid} are to be obtained using the following formulae.

$$F_{W-Hog-Aft} = +5.2 f_R L_1^2 C C_w \left(\frac{B}{L_1} \right)^{0.8} (0.3 + 0.7 f_{NL-Hog})$$

$$F_{W-Hog-Fore} = -5.7 f_R L_1^2 C C_w \left(\frac{B}{L_1} \right)^{0.8} f_{NL-Hog}$$

$$F_{W-Sag-Aft} = -5.2 f_R L_1^2 C C_w \left(\frac{B}{L_1} \right)^{0.8} (0.3 + 0.7 f_{NL-Sag})$$

$$F_{W-Sag-Fore} = +5.7 f_R L_1^2 C C_w \left(\frac{B}{L_1} \right)^{0.8} (0.25 + 0.75 f_{NL-Sag})$$

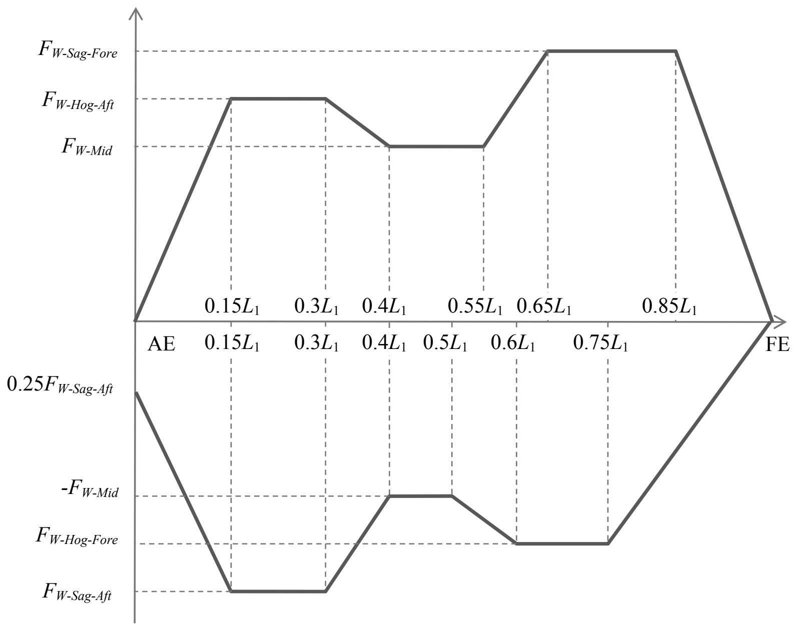
$$F_{W-Mid} = +4.0 f_R L_1^2 C C_w \left(\frac{B}{L_1} \right)^{0.8}$$

f_R, C_W, f_{NL-Hog} and f_{NL-Sag} : As specified in **-6** above

C : As specified in **-6** above. However, L_{ref} is to be obtained from the following formula:

$$L_{ref} = 330 C_W^{-1.3}$$

Fig. C32.8 Distribution of Vertical Wave Induced Shear Force (F_W) along the Ship Length



8 For the strength assessments, the maximum hogging and sagging load cases given in **Table C32.8** are to be checked. For each load case, the still water condition at each section, as defined in **-1** to **-5** above, is to be combined with the wave condition, as defined in **-6** and **-7** above. (See **Fig. C32.9** for reference)

Table C32.8 Combination of Still Water and Wave Induced Bending Moments and Shear Forces

Load case	Bending moment		Shear force	
	M_S	M_W	F_S	F_W
Hogging	M_{Smax}	M_{W-Hog}	F_{Smax} for $x \le 0.5L_1$	F_{Wmax} for $x \le 0.5L_1$
			F_{Smin} for $x > 0.5L_1$	F_{Wmin} for $x > 0.5L_1$
Sagging	M_{Smin}	M_{W-Sag}	F_{Smin} for $x \le 0.5L_1$	F_{Wmin} for $x \le 0.5L_1$
			F_{Smax} for $x > 0.5L_1$	F_{Wmax} for $x > 0.5L_1$

Notes:

M_{Smax} : Permissible maximum vertical still water bending moment in seagoing condition (*kN-m*) at the cross section under consideration

M_{Smin} : Permissible minimum vertical still water bending moment in seagoing condition (*kN-m*) at the cross section under consideration

M_{W-Hog} : Vertical wave induced bending moment in hogging at the cross section under consideration, to be taken as the positive value of M_W as defined in **Fig. C32.6**.

M_{W-Sag} : Vertical wave induced bending moment in sagging at the cross section under consideration, to be taken as the negative value of M_W as defined in **Fig. C32.6**.

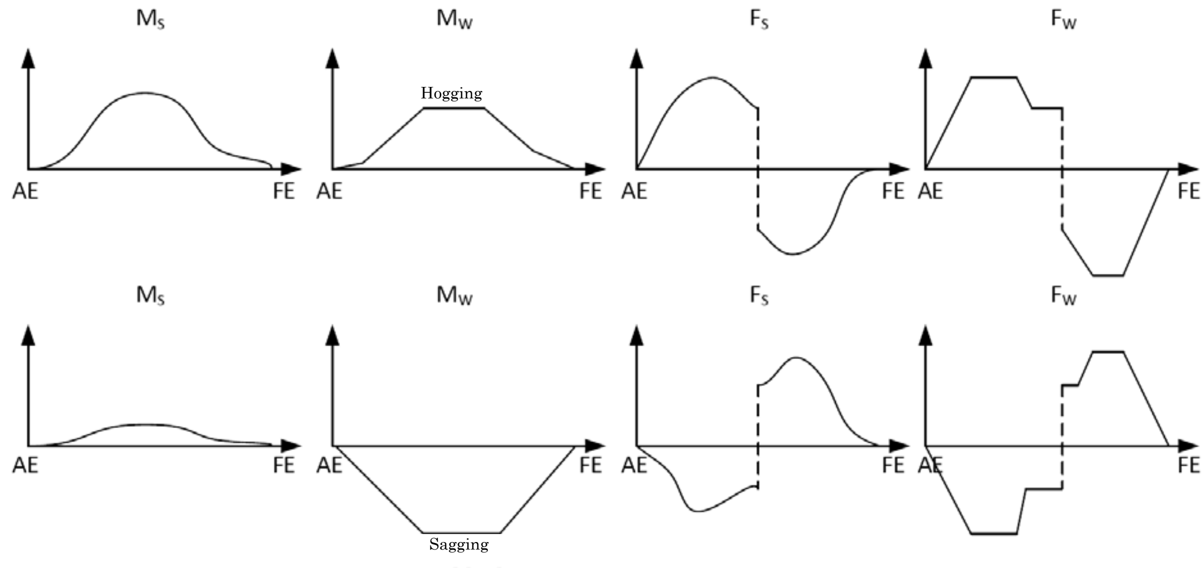
F_{Smax} : Permissible maximum vertical still water shear force in seagoing condition (*kN*) at the cross section under consideration

F_{Smin} : Permissible minimum vertical still water shear force in seagoing condition (*kN*) at the cross section under consideration

F_{Wmax} : Maximum value of the wave induced shear force at the cross section under consideration, to be taken as the positive value of F_W as defined **Fig. C32.8**.

F_{Wmin} : Minimum value of the wave induced shear force at the cross section under consideration, to be taken as the negative value of F_W as defined **Fig. C32.8**.

Fig. C32.9 Load Combination to Determine the Maximum Hogging and Sagging Load Cases as given in **Table C32.8**



9 The hull girder bending stress (N/mm^2) and hull girder shear stress (N/mm^2) are to be obtained from the formulae in the following **(1)** and **(2)**.

(1) Hull girder bending stress σ_{HG}

$$\sigma_{HG} = \frac{\gamma_S M_S + \gamma_W M_W}{1000I}(z - z_n)$$

γ_S, γ_W : Partial safety factors, to be taken as 1.0

M_S, M_W : Vertical still water bending moment and vertical wave induced bending moment for the load cases "hogging" and "sagging" as specified in **32.2.3-8**

I : Moment of inertia (m^4) for the cross section under consideration

z : Vertical co-ordinate of the location under consideration (m)

z_n : Distance from the baseline to the horizontal neutral axis (m)

(2) Hull girder shear stress τ_{HG}

$$\tau_{HG} = \frac{1000(\gamma_S F_S + \gamma_W F_W)q_v}{t}$$

γ_S, γ_W : As specified in **(1)** above

F_S, F_W : Vertical still water shear force and vertical wave induced shear force for the load cases "hogging" and "sagging" as specified in **32.2.3-8**

q_v : Shear flow at any location when shear force acts along the cross section under consideration, to be determined according to the calculation method which are separately specified by the Society

t : Thickness of plate considered (mm)

32.2.4 Minimum Section Modulus

1 The gross section modulus of the transverse section of the hull at the mid-point of L is not to be less than the value of W_{gr_min} (cm^4) obtained from the following formula:

$$W_{gr\_min} = C_1 L_1^2 B(C_b' + 0.7)$$

C_1 : As given by the following formulae:

$$10.75 - \left(\frac{300 - L_1}{100}\right)^{1.5} \quad \text{for } L_1 \leq 300m$$

$$10.75 \quad \text{for } 300m < L_1 \leq 350m$$

$$10.75 - \left(\frac{L_1 - 350}{150}\right)^{1.5} \quad \text{for } 350m < L_1$$

C_b' : Volume of displacement corresponding to the designed maximum load line divided by $L_1 Bd$

However, the value is to be taken as 0.6, where it is less than 0.6.

2 The scantlings of longitudinal members in way of the midship part are not to be less than the scantlings of longitudinal members at the mid-point of L which are determined by the requirement in **-1** above, excluding changes in the scantlings due to variations in the sectional form of the transverse section of the hull.

32.2.5 Stiffness Assessment

The moment of inertia (m^4) is to be in accordance with the following formula:

$$I \geq 1.55 L_1 |M_S + M_W| 10^{-7}$$

M_S, M_W: Vertical still water bending moment and vertical wave induced bending moment for the load cases "hogging" and "sagging" as specified in **32.2.3-8**

32.2.6 Yield Strength Assessment

1 For each of the load cases "hogging" and "sagging" as defined in **32.2.3-8**, the equivalent hull girder stress σ_{eq} (N/mm^2) is to be in accordance with the following formula:

$$\sigma_{eq} < \sigma_{perm}$$

$$\sigma_{eq} = \sqrt{\sigma_x{}^2 + 3\tau^2}$$

where σ_x and τ are combination of hull girder stresses, to be taken as the following formulae according to the bending strength assessment and shear strength assessment, and where σ_{HG} and τ_{HG} are to be in accordance with **32.2.3-9**.

$\sigma_x = \sigma_{HG}$, $\tau = 0$, for bending strength assessment

$\sigma_x = 0$, $\tau = \tau_{HG}$, for shear strength assessment

σ_{perm}: Permissible stress(N/mm^2), to be taken as

$$\sigma_{perm} = \frac{\sigma_Y}{\gamma_1 \gamma_2}$$

σ_Y: Specified minimum yield stress of the material (N/mm^2)

γ_1: Partial safety factor for material, to be taken as

$$\gamma_1 = K \frac{\sigma_Y}{235}$$

γ_2: Partial safety factor for load combinations and permissible stress, to be taken as follows:

$\gamma_2 = 1.24$, for bending strength assessment

$\gamma_2 = 1.13$, for shear stress assessment

K: Coefficient corresponding to the kind of steel

e.g. 1.0 for mild steel, the values specified in **1.1.7-2.(1)** for high tensile steel

2 The assessment locations of the bending stress and shear stress are to be in accordance with the following **(1)** and **(2)**:

(1) The assessment locations of the bending stress are shown in the following location of cross section:

(a) at bottom

(b) at deck

(c) at top of hatch coaming

(d) at any point where there is a change of steel yield strength

(2) The assessment locations of the shear stress are all structural elements that contribute to the shear strength capability.

32.2.7 Buckling Strength Assessment

1 For the plate panels and longitudinal stiffeners subject to hull girder bending and shear stresses, the following formula is to be applied.

$$\eta_{act} \le 1$$

η_{act} : Maximum utilisation factor which are separately specified by the Society

2 During the buckling strength assessment, the following two stress combinations are to be considered for each of load cases "hogging" and "sagging" as specified in **32.2.3-8**.

Where, σ_{HG} and τ_{HG} are to be in accordance with **32.2.3-9**.

(1) σ_{HG}, $0.7\tau_{HG}$

(2) $0.7\sigma_{HG}$, τ_{HG}

32.2.8 Hull Girder Ultimate Strength Assessment

1 For ships not less than 150 *m* in length L_1, the hull girder ultimate bending moment capacity M_U is to be satisfy the following formula.

$$\gamma_S M_S + \gamma_W M_W \le \frac{M_U}{\gamma_M \gamma_{DB}}$$

γ_S : Partial safety factor for the vertical still water bending moment, to be taken as follows.

$$\gamma_S = 1.0$$

γ_W : Partial safety factor for the vertical wave induced bending moment, to be taken as follows.

$$\gamma_w = 1.2$$

M_S, M_W : Vertical still water bending moment and vertical wave induced bending moment for the load cases "hogging" and "sagging" as specified in **32.2.3-8**

M_U: Hull girder ultimate bending moment capacity (*kN-m*), calculated by the method which is separately specified by the Society.

γ_M : Partial safety factor for the hull girder ultimate strength, to be taken as follows.

$$\gamma_M = 1.05$$

γ_{DB} : Partial safety factor for the hull girder ultimate bending moment capacity, considering the effect of double bottom bending given by the following formula. However, for cross sections where the double bottom of the inner bottom is less than that at amidships or where the double bottom structure differs from at amidships (e.g., engine rooms), the factor γ_{DB} for hogging condition may be reduced subject to approval by the Society.

・For hogging condition, $\gamma_{DB} = 1.15$

・For sagging condition, $\gamma_{DB} = 1.0$

2 For ships not less than 300 *m* in length *L* or which exceed 32.26 *m* in breadth *B*, in addition to the requirements specified in **-1** above, the hull girder ultimate bending moment capacity M_{U_DB} is to be satisfy the following formula for the hogging condition. Notwithstanding the provisions under this paragraph, the effect of whipping and the hull girder ultimate strength considering the effect of lateral loads can be calculated more directly where deemed appropriate by the Society. This requirement applies to the transverse section located in the vicinity of the centre of the cargo hold at midship.

$$\gamma_S M_{S\max} + \gamma_{Wh} M_{W-Hog-Mid} \le M_{U\_DB}$$

γ_S : Partial safety factor for the vertical still water bending moment, to be taken as follows:

$\gamma_S = 1.0$

γ_{Wh} : Partial safety factor for the vertical wave induced bending moment, considering the effect of whipping, to be taken as follows:

$\gamma_{Wh} = 1.5$

$M_{S\,max}$: Permissible maximum vertical still water bending moment at the cross section under consideration

$M_{W-Hog-Mid}$: As specified in **32.2.3-6**

M_{U_DB}: Hull girder ultimate bending moment capacity (*kN-m*), considering the effect of lateral loads, calculated by the method which is separately specified by the Society.

32.2.9 Calculation of Section Modulus and Moment of Inertia of Transverse Section of Hull

The calculation of the section modulus and the moment of inertia of the transverse section of the hull specified in this Chapter is to be based on the following requirements, as given in **(1)** through **(6)**.

(1) All longitudinal members which are considered effective to the longitudinal strength are to be included in the calculation.

(2) Deck openings on the strength deck are to be deducted from the sectional area used in the calculation of the section modulus. However, small openings not exceeding 2.5 *m* in length and 1.2 *m* in breadth need not be deducted, provided that the sum of their breadths in any single transverse section is not more than $0.06(B - \Sigma b)$. Σb is the sum of the openings exceeding 1.2 *m* in breadth or 2.5 *m* in length.

(3) Notwithstanding the requirement in **(2)**, small openings on the strength deck need not be deducted, provided that the sum of their breadths in one single transverse section does not reduce the section modulus at the strength deck or the ship bottom by more than 3%

(4) Deck openings specified in **(2)** and **(3)** include shadow areas obtained by drawing two tangential lines with an opening angle of 30 degrees having their apex on the line drawn through the centre of the small openings along the length of the ship.

(5) The section modulus at the strength deck is to be calculated by dividing the moment of inertia of the athwartship section about its horizontal neutral axis by the following distance **(a)** or **(b)**, whichever is greater.

(a) Vertical distance (*m*) from the neutral axis to the top of the strength deck beam and the side of the ship

(b) Distance (*m*) obtained from the following formula:

$$Y\left(0.9 + 0.2\frac{X}{B}\right)$$

X : Horizontal distance (*m*) from the top of continuous strength member to the centre line of the ship

Y : Vertical distance (*m*) from the neutral axis to the top of the continuous strength member

In this case, X and Y are to be measured at the point which gives the largest value for the above formula.

(6) The section modulus at the ship bottom is to be calculated by dividing the moment of inertia of the athwartship section about its horizontal neutral axis by the vertical distance from the neutral axis to the top of the keel.

32.3 Torsional Strength

32.3.1 General

Where the width of the hatchway at the midship exceeds 0.7B, special considerations are to be made to additional stresses and deformation of hatchway openings due to torsion. However, where the ship has two or more rows of hatchways, the distance between the outermost lines of hatchway openings is to be taken as the width of the hatchway.

32.34 Double Bottom Construction

32.34.1 General

1 The construction of the double bottom in holds which are exclusively loaded with containers is to be in accordance with the requirements in **32.34**. Unless otherwise specified in **32.34**, such construction is also to be in accordance with the requirements in **Chapter 6**.

2 Side girders or solid floors are to be provided in the double bottoms under corner fittings, or double bottoms are to be constructed so as to effectively support the loads of the containers.

3 The thickness of girders, struts and their end brackets and bulkhead plates in double bottom spaces, the interior of which are used as deep tanks, are to be in accordance with the requirement of **14.1.4** according to the kind and size of the tank. However, in the application of the requirement in **14.1.4**, the thickness may be reduced by 1.0 *mm* from the thickness prescribed in **Table C14.1**.

43 In application of the requirements in **-1** above, The the thickness of bottom shell plating and inner bottom plating in the double bottom spaces for void spaces, fuel oil tanks, etc. which do not contain sea water in service conditions may be reduced by 0.5 *mm* from the thickness prescribed in 32.3 each respective applicable requirement.

32.34.2 Longitudinals

1 The section modulus of bottom longitudinals Z is not to be less than that obtained from the following formula:

$$Z = \frac{90CK}{24 - 15.5 f_B K}\left\{d + 0.013L'\left(\frac{2}{B}y + 1\right) + h_1\right\}Sl^2 \quad (cm^3)$$

Where:

C : Coefficient given below:
Where no strut specified in **32.34.3** is provided midway between floors C = 1.0
Where a strut specified in **32.34.3** is provided midway between floors C = 0.625
However, where the widths of the vertical stiffeners provided on floors and those of struts are especially large, the coefficient may be appropriately reduced.

h_1 : As given in **(I)** or **(II)**

(I) For 0.3L from the fore end:

$h_1 = \frac{3}{2}(17 - 20C'_b)(1 - x)$

C'_b : Block coefficient C_b

Where C_b exceeds 0.85, C'_b is to be taken as 0.85.

(II) For elsewhere:

0

x : As given by the following formula

$\frac{X}{0.3L}$

X : Distance (m) from the fore end for side shell plating. However, where X is less than that 0.1L, X is to be taken as 0.1L and where X exceeds 0.3L, X is to be taken as 0.3 L.

f_B : Ratio of the section modulus Z'_σ of the transverse section of the hull on the basis of mild steel required in ~~Chapter 15~~ the following formula to the actual net section modulus of the transverse section of the hull at the bottom

$Z'_\sigma = 5.27|M_S + M_W|$ (cm^3)

M_S, M_W : Vertical still water bending moment and vertical wave induced bending moment for the load cases "hogging" and "sagging" as specified in **32.2.3-8**

K : Coefficient corresponding to the kind of steel

e.g. 1.0 for mild steel, the values specified in **1.1.7-2(1)** for high tensile steel

L' : Length of ship L (m)

Where L exceeds 230 m, L' is to be taken as 230 m.

y : Horizontal distance (m) from the centre line of the ship to the longitudinals under consideration

l : Spacing of solid floors (m)

S : Spacing of longitudinals (m)

2 The section modulus Z of inner bottom longitudinals is not to be less than that obtained from the following formula. However, the section modulus is not to be less than 75% of that specified for the bottom longitudinals at the same place.

$Z = 100C_1C_2Shl^2 \quad (cm^3)$

Where:

C_1 : Coefficient given in the following formula, however, for h_2 and h_3, C_1 is to be taken as $\frac{K}{18}$

$C_1 = \frac{K}{24 - \alpha K}$, however, the value of C_1 is not to be less than $\frac{K}{18}$

α : As obtained from the following formula:

$$\alpha = 15.5 f_B \left(1 - \frac{z}{z_B}\right)$$

K and f_B : As specified in **-1** above

z : Vertical distance (m) from the top of the keel to the bottom of inner bottom plating

z_B : Vertical distance (m) from the top of the keel amidships to the horizontal neutral axis of the transverse section

C_2: As determined from **Table C32.~~1~~9**

S: Spacing of stiffeners (m)

h : The following h_1, h_2 and h_3, however, where the double bottom space is void, h is to be taken as h_1

h_1 : Vertical distance (m) from the mid point between the bottom of inner bottom plating and the upper end of the overflow pipe

h_2 : As obtained from the following formula:

$$h_2 = 0.85(h_1 + \Delta h) \quad (m)$$

Δh : As obtained from the following formula:

$$\Delta h = \frac{16}{L}(l_t - 10) + 0.25(b_t - 10) \quad (m)$$

l_t : Tank length (m)

It is not to be less than 10m.

b_t : Tank breadth (m)

It is not to be less than 10m.

h_3 : Value obtained by multiplying 0.7 by the vertical distance from the tank top plating to the point 2.0 m above the top of overflow pipe

l : Spacing of girders (m)

Table C32.~~1~~9 Value of C_2

Other end	One end		
	Rigid connection by bracket	Soft connection by bracket	Supported by girders or lug-connection
Rigid connection by bracket	0.70	1.15	0.85
Soft connection by bracket	1.15	0.85	1.30
Supported by girders or lug-connection	0.85	1.30	1.00

Notes:

1. "Rigid connection by bracket" is a connection by bracket of the stiffener to the double bottom or to a stiffener of equivalent strength attached to the face plates of adjacent members, or a connection of equivalent strength. (*see* **Fig.C13.1(a) of the Rules**)
2. "Soft connection by bracket" is a connection by bracket of the stiffener to transverse members such as beams, frames, or the equivalent thereto. (*see* **Fig.C13.1 (b) of the Rules**)

32.~~3~~4.3 Vertical Struts

Where vertical struts are provided, the sectional area A is not to be less than that obtained from the following formula:

$$A = 0.9CKSb(d + 0.026L') \quad (cm^2)$$

Where:

C : Coefficient obtained from the following formula, but C is not to be less than 1.43

$$C = \frac{1}{1 - 0.5\dfrac{l_s}{k\sqrt{K}}}$$

K : As specified in **32.~~3~~4.2-1**

l_s : Length of struts (m)

k : Minimum radius (cm) of gyration of struts obtained from the following formula:

$$k = \sqrt{\frac{I}{A}}$$

I : The least moment of inertia of struts (cm^4)

A : Sectional area of struts (cm^2)

S : Spacing of longitudinals (m)

b : Width (m) of the area supported by struts

32.~~3~~4.4 Thickness of Inner Bottom Plating

~~**1** The thickness of inner bottom plating is to be in accordance with the requirement in **6.5.1-1.** However, in the application of the second formula in the requirement, h is to be obtained from the following formula:~~

~~$h = 1.13(d - d_0)$~~

~~Where:~~

~~d_0 : Height of centre girder (m)~~

~~**2** Notwithstanding the requirement in **-1**, the thickness t of inner bottom plating is to be not less than obtained from the following formula.~~

~~$t = 3.6CS\sqrt{Kh} + 3.0$ (mm)~~

1 The thickness of inner bottom plating is not to be less than the greater of the values obtained from the following formulae.

$$t_1 = \frac{C_1}{1000} \cdot \frac{B^2 d}{d_0} + 2.5 \quad (mm)$$

$$t_2 = C_2 S\sqrt{1.13(d - d_0)} + 2.5 \quad (mm)$$

$$t_3 = 3.6 C_3 S\sqrt{Kh} + 3.0 \quad (mm)$$

C_1: b_0 or $\alpha' b_1$ given below according to the value of $\frac{B}{l_H}$:

b_0 for $\frac{B}{l_H} < 0.8$

b_0 or $\alpha' b_1$, whichever is greater for $0.8 \le \frac{B}{l_H} < 1.2$

$\alpha' b_1$ for $1.2 \le \frac{B}{l_H}$

l_H : Length (m) of the hold

b_0 and b_1 : As given in **Table C32.10** according to the value of $\frac{B}{l_H}$

However, for transverse framing, b_1 is to be 1.1 times the value given in this Table.

α' : As given by the following formula.

$$\frac{13.8}{24 - 11 f_B}$$

f_B : As specified in **32.4.2-1**

d_0 : Height (m) of centre girders

C_2: Coefficient given by the following formula, according to the value of $\frac{l}{S}$.

$$0.43\frac{l}{S}+2.5 \text{ for } 1\le\frac{l}{S}<3.5$$

$$4.0 \text{ for } 3.5\le\frac{l}{S}$$

l: Distance (m) between floors for longitudinal framing or distance (m) between girders for transverse framing

S: Spacing of stiffeners (m)

h: As specified in **32.~~3~~4.2-2**

K: As specified in **32.~~3~~4.2-1**

~~C~~C_3: Coefficient given in the following formulae according to the stiffening system of inner bottom plating used, however, for h_2 and h_3, ~~C~~C_3 is to be taken as 1.

(a) For transverse system

$$\sout{C=\frac{27.7}{\sqrt{767-\alpha^2K^2}}}\quad C_3=\frac{27.7}{\sqrt{767-\alpha^2K^2}}$$

α: As specified in **32.~~3~~4.2-2**

(b) For longitudinal system

$$\sout{C=\frac{3.72}{\sqrt{27.7-\alpha K}}}\quad C_3=\frac{3.72}{\sqrt{27.7-\alpha K}},$$ However, ~~C~~C_3 is not to be less than 1.0.

α: As specified in **32.~~3~~4.2-2**

Table C32.10 Coefficients b_0 and b_1

B/l_H and over		0.4	0.6	0.8	1.0	1.2	1.4	1.6
B/l_H less than	0.4	0.6	0.8	1.0	1.2	1.4	1.6	
b_0	4.4	3.9	3.3	2.2	1.6	-	-	-
b_1	-	-	-	2.2	2.1	1.9	1.7	1.4

~~3~~**2** The inner bottom plating with which the lower ends of corner fittings of containers are in contact is to be strengthened by means of doubling or by other appropriate means.

32.~~3~~4.5 Bottom Shell Plating

1 The thickness t of bottom shell plating is not to be less than ~~that~~ the greater of the values obtained from the following formulae ~~**(1) and (2)** or from the requirements in **6.5.5**, whichever is greater. However, in the application of the requirements in **6.5.5**, the thickness need not apply to the formulae in requirement of **16.3.4**.~~:

$$t_1=\frac{C_1}{1000}\cdot\frac{B^2d}{d_0}+2.5\ (mm)$$

$$t_2=C_2C_3S\sqrt{d+0.0175L'\left(\frac{2}{B}y+1\right)+h_1}+2.5\ (mm)$$

d_0: Height (m) of centre girders

C_1: As specified in **32.4.4-1**. However α' is to be obtained from the following formula.

$$\alpha'=\frac{13.8}{24-15.5f_B}$$

~~(1) In ships with transverse framing, the thickness is not to be less than that obtained from the following formula:~~

~~$$t = C_1 C_2 S \sqrt{d + 0.0175L'\left(\frac{2}{B}y + 1\right) + h_1} + 2.5 \quad (mm)$$~~

Where:

S : Spacing (m) of ~~transverse frames~~stiffeners

L', y, h_1: As specified in **32.~~3~~4.2-1**

~~C_1~~C_2: Coefficient given below:

Where L is 230 *metres* and under: 1.0

Where L is 400 *metres* and over: 1.07

For intermediate values of L, ~~C_1~~C_2 is to be obtained by linear interpolation.

~~C_2~~C_3: Coefficient given ~~below~~ in the following formulae according to the stiffening system of inner bottom plating used:

~~$$C_2 = \frac{91}{\sqrt{576 - (15.5 f_B x)^2}}$$~~

(a) In case of a transverse system

$$C_3 = \frac{91}{\sqrt{576 - (15.5 f_B)^2}}$$

f_B: As specified in **32.4.2-1**

(b) In case of a longitudinal system

$$C_3 = 13\sqrt{\frac{K}{24 - 15.5 f_B K}}$$, however, the value of C_3 is not to be less than $3.78\sqrt{K}$

f_B and K: As specified in **32.4.2-1**

~~x : As given by the following formula~~

~~$$\frac{X}{0.3L}$$~~

~~X : Distance (m) from the fore end for side shell plating afore the midship, or from the after end for side shell plating after the midship. However, where X is less than that 0.1L, X is to be taken as 0.1L and where X exceeds 0.3L, X is to be taken as 0.3 L.~~

~~(2) In ships with longitudinal framing, the thickness of side shell plating is not to be less than that obtained from the following formula:~~

~~$$t = C_1 C_2 S \sqrt{d + 0.0175L'\left(\frac{2}{B}y + 1\right) + h_1} + 2.5 \quad (mm)$$~~

~~Where:~~

~~S: Spacing (m) of longitudinal frames~~

~~L', C_1 and h_1: As given in **(1)**~~

~~C_2 : Coefficient given by the following formula, but it is not to be less than $3.78\sqrt{K}$~~

~~$$C_2 = 13\sqrt{\frac{K}{24 - 15.5 f_B K x}}$$~~

~~x: As given in **(1)**~~

2 Notwithstanding the requirement in **-1**, the thickness t of bottom shell plating is to be not less than obtained from the following formula.

$$t = \sqrt{KL'} \quad (mm)$$

L': Length ~~(m)~~ of ship L (m)

However, where L exceeds 330 m, L' is to be taken as 330 m.

K: As specified in **32.~~3~~4.2-1**

~~**3** The breadth and thickness of plate keels are to be in accordance with the requirement of **16.2.1**. However, in the application of the requirement of **16.2.1-2**, "**16.3.4**" is to be read as "**32.3.5**".~~

3 The breadth of the plate keel over the whole length of the ship is not to be less than that obtained from the following formula.

$2L+1000$ (mm)

4 The thickness of the plate keel over the whole length of the ship is not to be less than the thickness of the bottom shell for the midship part obtained from the requirements in **32.4.5** plus 2.0 mm. However, this thickness is not to be less than that of adjacent bottom shell plating.

32.~~4~~5 Double Side Construction

32.~~4~~5.1 General

1 The side construction of holds is to be of double hull construction as far as practicable and is to be thoroughly stiffened by providing side transverse girders and side stringers within the double hull.

2 The construction of the double side construction in holds which are exclusively loaded with containers is to be in accordance with the requirements in **32.~~4~~5**. Unless otherwise specified in **32.~~4~~5**, such construction is also to be in accordance with the requirements in **Chapter 13**.

3 Double side shell structures, the interiors of which are used as deep tanks, are to be in accordance with the requirements in **Chapter 14** unless otherwise specified in **32.~~4~~5**.

~~**4** The thickness of girders, struts and their end brackets and bulkhead plates in the double side spaces, the interior of which are used as deep tanks, are to be in accordance with the requirement of **14.1.4** according to the kind and size of the tank. However, in the application of the requirement in **14.1.4**, the thickness may be reduced by 1.0mm from the thickness prescribed in **Table C14.1**.~~

~~5~~4 In the application of the requirements in **-2** ~~to **-4**~~ and **-3,** the thickness of side shell plating and inner hull plating in double side spaces for void spaces, fuel oil tanks, etc. which do not contain sea water in service conditions may be reduced by 0.5 mm from the thickness prescribed in each respective applicable requirement.

~~6~~5 Side stringers are to be spaced appropriately according to the depths of holds. Side transverse girders are to be provided at solid floors in double bottoms.

~~7~~6 Where the width of the double side shell changes in the bilge part, the scantlings are to be at the discretion of the Society.

~~8~~7 Where structures effectively support deck structures and side shell structures in the midway of holds, the requirements in **32.~~4~~5** may be appropriately modified.

~~9~~8 Where the height from the designed maximum load line to the strength deck is especially large, the scantlings are to be at the discretion of the Society.

~~10~~9 Where the inner hull plating and the inner bottom plating are combined, considerations are to be made to their structural arrangement so as not to cause stress concentration.

~~11~~10 At the fore and aft ends of the double side structure, sufficient considerations are to be made to the continuity of construction and strength.

32.~~4~~5.2 Side Transverse Girders and Side Stringers

1 The thickness of side transverse girders is not to be less than that obtained from the following formulae, whichever is the greatest:

$$t_1 = 0.083\frac{CKSl_H}{d_1 - a}(d + 0.038L') + 2.5 \quad (mm)$$

$$t_2 = 8.6\sqrt[3]{\frac{d_1^2(t_1 - 2.5)}{kK}} + 2.5 \quad (mm)$$

$$t_3 = \frac{8.5}{\sqrt{K}} S_2 + 2.5 \quad (mm)$$

C : As obtained from the following formula:

$$C = (C_1 + \beta_T C_2) C_3$$

C_1 and C_2 : As obtained from **Table C 32.~~2~~11** in accordance with the value of h / l_H

For intermediate values of h / l_H, the values of C_1 and C_2 are to be determined by linear interpolation.

h : Vertical distance (m) from the top of inner bottom to the strength deck at side

l_H : Length of hold (m)

β_T : As obtained from the following formula:

$$\beta_T = 1 + \frac{0.42\left(\frac{B}{D_s}\right)^2 - 0.5}{0.59\frac{D_s - \frac{d_0}{2}}{B - d_1}\left(\frac{d_0}{d_1}\right)^2 + 1.0}$$

d_0 : Height of centre girder (m)

d_1 : Depth of side transverse girder (m)

Where the depth of the web is divided by stiffeners attached in the direction of the length of the girder, d_1 in the formulae for t_2 and t_3 may be taken as the divided depth.

C_3 : As obtained from the following formula, but not to be less than 0.2:

$$C_3 = 1 - 1.8\frac{y}{h}$$

y : Distance (m) from the lower end of h to the location under consideration

K: As specified in **32.~~3~~4.2-1**

S : Width (m) of the area supported by the side transverse girders

a : Depth (m) of the openings at the location under consideration

L' : Length of ship L (m).

However, where L exceeds 230 m, L' is to be taken as 230 m.

k : Coefficient obtained from **Table C 32.~~3~~12** in accordance with the ratio of the spacing S_1 (m) of the stiffeners provided on the web of side transverse girders in the direction of the depth of the girders and d_1

For intermediate values of S_1/d_1, the value of k is to be determined by linear interpolation.

S_2 : S_1 or d_1, whichever is smaller

However, t_3 can be determined by other analytical measures against compressive buckling strength of the girder

Table C32.~~2~~11 Coefficients, C_1 and C_2

h/l_H	0.50 and under	0.75	1.00	1.25	1.50	1.75 and above
C_1	0.18	0.21	0.24	0.25	0.26	0.27
C_2	0.05	0.08	0.09	0.10	0.11	0.12

Table C32.~~3~~12 Coefficient k

S_1/d_1	0.3 and under	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0 and above
k	60.0	40.0	26.8	20.0	16.4	14.4	13.0	12.3	11.1	10.2

2 The thickness of side stringers is not to be less than that obtained from the following formulae, whichever is the greatest:

$$t_1 = 0.083\frac{CKSl_H}{d_1 - a}(d + 0.038L') + 2.5 \quad (mm)$$

$$t_2 = 8.6\sqrt[3]{\frac{d_1^2(t_1 - 2.5)}{kK}} + 2.5 \quad (mm)$$

$$t_3 = \frac{8.5}{\sqrt{K}}S_2 + 2.5 \quad (mm)$$

Where:

C : As obtained from the following formula:

$$C = (C_1 - \beta_L C_2)C_3$$

C_1 and C_2 : As obtained from **Table C 32.~~4~~13**, in accordance with the value of h/l_H

For intermediate values of h/l_H, the values of C_1 and C_2 are to be determined by linear interpolation.

β_L : As obtained from the following formula:

$$\beta_L = 1 + \frac{0.18\left(\frac{B}{Ds}\right)^2 - 0.5}{0.59\frac{Ds - \frac{d_0}{2}}{B - d_1}\left(\frac{d_0}{d_1}\right)^2 + 1.0}$$

h, l_H, d_0 and L' : As specified in **-1** above

d_1 : Depth of side stringers (m)

However, where the depth of the web is divided by stiffeners attached in the direction of the length of the stringer, d_1 in the formulae for t_2 and t_3 may be taken as the divided depth.

C_3 : As obtained from the following formula:

$$C_3 = \left|1 - \frac{2x}{l_H}\right|$$

x : Distance (m) from the end of l_H to the location under consideration

K: As specified in **32.~~3~~4.2-1**

S : Width (m) of the area supported by the side stringers

a : Depth (m) of the openings at the location under consideration

k : Coefficient obtained from **Table C32.~~3~~12** in accordance with the ratio of the spacing $S_1(m)$ of the stiffeners provided on the web of the side stringer in the direction of the depth of the stringer and d_1

For intermediate values of S_1/d_1, the value of k is to be determined by linear interpolation.

S_2 : S_1 or d_1, whichever is smaller

However, t_3 can be determined by other analytical measures against compressive buckling strength of the girder

Table C32.~~4~~13 Coefficients C_1 and C_2

h/l_H	0.50 and under	0.75	1.00	1.25	1.50 and above
C_1	0.20	0.24	0.26	0.26	0.26
C_2	0.07	0.05	0.03	0.01	0.00

32.~~4~~5.3 Inner Hull Construction

The thickness t of inner hull plating where the interior of the double side structure is used as deep water tanks, and the section modulus Z of longitudinal stiffeners are not to be less than those obtained from the following formulae, respectively:

(1) Thickness of inner hull plating

$$t = 3.6CS\sqrt{Kh} + 2.0 \quad (mm)$$

Where:

S : Spacing of stiffeners (m)

K: As specified in **32.3~~3~~4.2-1**

h : The following h_1, h_2 and h_3, however, where the double bottom space is void, h is to be taken as h_1

h_1 : Vertical distance (m) from the lower edge of the bulkhead plating under consideration to the mid-point between the point on the tank top and the upper end of the overflow pipe

h_2 : As obtained from the following formula:

$$h_2 = 0.85(h_1 + \Delta h) \quad (m)$$

Δh :As obtained from the following formula:

$$\Delta h = \frac{16}{L}(l_t - 10) + 0.25(b_t - 10) \quad (m)$$

l_t : Tank length (m)

It is not to be less than 10m.

b_t : Tank breadth (m)

It is not to be less than 10m.

h_3 : Value obtained by multiplying 0.7 by the vertical distance from the lower edge of the bulkhead plating under consideration to the point 2.0 m above the top of overflow pipe

C : Coefficient given in the following formulae according to the stiffening system of inner hull plating used, however, for h_2 and h_3, C is to be taken as 1:

(a) For transverse system

$$C = \frac{27.7}{\sqrt{767 - \alpha^2 K^2}}$$

Where:

α : As obtained from the following formulae, whichever is greater:

$$\alpha = 15.5 f_B \left(1 - \frac{z}{z_B}\right) \quad \text{where} \quad z \le z_B$$

$$\alpha = 15.5 f_D \frac{z - z_B}{Z'} \quad \text{where} \quad z_B < z$$

$$\alpha = \frac{1}{9.81} \frac{M_H}{I_H} y_H \times 10^5$$

f_B: As specified in **32.~~3~~4.2-1**

z: Vertical distance (m) from the top of the keel to the lower edge of inner hull plating

z_B: As specified in **32.~~3~~4.2-2**

f_D: Ratio of the section modulus of the transverse section of hull on the basis of mild steel required in **32.4.2-1** to the net actual section modulus of the hull at the strength deck

Z': The greater of the values specified in ~~**15.2.3(5)(a) or (b)**~~ **32.2.9(5)(a)** and **(b)**

M_H: As given by the following formula

$$M_H = 0.45 C_1 L^2 d (C_b + 0.05) C_H \quad (kN\text{-}m)$$

C_1: As given by the following formula

$10.75 - \left(\frac{300 - L_1}{100}\right)^{1.5}$ for $L_1 \le 300m$

10.75 for $300m < L_1 \le 350m$

$10.75 - \left(\frac{L_1 - 350}{150}\right)^{1.5}$ for $350m < L_1$

~~L_1: Length (m) of ship specified in **2.1.2, Part A** or 0.97 *times* the length of~~ ship ~~on the designed maximum load line, whichever is smaller~~

C_H: Coefficient, as given in **Table C32.~~5~~14**, based on the ratio of L to x, where x is the distance (m) from the aft end of L to the section under consideration
Intermediate values are to be determined by interpolation.

I_H: Moment of inertia (cm^4) of the cross section about the vertical neutral axis of the transverse section under consideration

y_H: Horizontal distance (m) from the vertical neutral axis to the evaluation position

(b) For longitudinal system

$C = \frac{3.72}{\sqrt{27.7 - \alpha K}}$, however, C is not to be less than 1.0.

Where:

α: As specified in **(a)**

(2) Section modulus Z of longitudinal stiffeners on inner hull plating

$$Z = 100 C_1 C_2 S h l^2 \quad (cm^3)$$

Where:

C_1: Coefficient given in the following formula, however, for h_2 and h_3, C_1 is to be taken as $\frac{K}{18}$

$C_1 = \frac{K}{24 - \alpha K}$, however, the value of C_1 is not to be less than $\frac{K}{18}$

α: As specified in **(1)(a)**

C_2 : As specified in **32.~~3~~4.2-2**

S : Spacing of stiffeners (m)

h : As specified in ~~**(a)**~~**(1)**

Where "the lower edge of the bulkhead plating under consideration" is to be construed as "the stiffener under consideration"

l : Spacing of girders (m)

Table C32.~~5~~14 Coefficient C_H

x/L	0.0	0.4	0.7	1.0
C_H	0.0	1.0	1.0	0.0

~~32.4.4 Brackets~~

~~Brackets are to be provided on the upper and lower corners inside the double side structure, at every frame where transversely stiffened and at an appropriate spacing between side transverse girders where longitudinally stiffened.~~

~~32.4.5~~32.5.4 Side Shell plating

1 The side shell plating below the strength deck is to be in accordance with the requirements in ~~**32.4.5**~~**32.5.4**. Unless otherwise specified in ~~**32.4.5**~~**32.5.4**, such plating is also to be in accordance with the requirements in **Chapter 16**.

2 The thickness t of side shell plating other than the sheer strake specified in **16.3.3** is ~~to be as required in the following **(1)** and **(2)** in addition to the requirements in **15.3.1** and **15.3.2**.~~not to be less than that obtained from the following formula:

~~(1) In ships with transverse framing, the thickness of side shell plating is not to be less than that obtained from the following formula:~~

$$t = C_1 C_2 S \sqrt{d - z' + 0.05L' + h_1} + 2.0 \quad (mm)$$

Where:

~~S: Spacing (m) of transverse frames~~

~~L', C_1 and h_1: As specified in **32.3.5-1(1)**~~

~~z': Vertical distance (m) from the top of the keel to the upper turn of the bilge at midship. The upper turn of the bilge is a point of the end of curvature at upper turn of the bilge on the side shell.~~

~~C_2~~C_1: Coefficient given ~~below:~~in the following formulae according to the stiffening system of inner bottom plating used.

~~$C_2 = 91\sqrt{\frac{K}{576 - \alpha^2 K^2 x^2}}$~~

(a) For transverse system

$$C_1 = 91\sqrt{\frac{K}{576 - \alpha^2 K^2 x^2}}$$

K: As specified in **32.~~3~~4.2-1**

α : As given in following formulae, whichever is greater

$\alpha = 15.5 f_B \left(1 - \frac{z}{z_B}\right)$

$\alpha = \frac{1}{9.81} \frac{M_H}{I_H} y_H \times 10^5$

z_B: As specified in **32.34.2-2**

z: Vertical distance (m) from the top of keel to the lower edge of the side shell plating under consideration

f_B: As specified in **32.34.2-1**

M_H, I_H and y_H:As specified in **32.45.3(1)(a)**

x : As specified in **32.3.5-1(1)**

(b) For longitudinal system

$C_1 = 13\sqrt{\frac{K}{24 - \alpha K x}}$,however, C_1 is not to be less than $3.78\sqrt{K}$

K, α : As specified in **(a)** above

S: Spacing of stiffeners (m)

C_2, L' and h_1: As specified in **32.4.5-1.**

z': Vertical distance (m) from the top of the keel to the upper turn of the bilge at midship. The upper turn of the bilge is a point of the end of curvature at upper turn of the bilge on the side shell.

(2) In ships with longitudinal framing, the thickness of side shell plating is not to be less than that obtained from the following formula:

$t = C_1 C_2 S\sqrt{d - z' + 0.05L' + h_1} + 2.0 \quad (mm)$

Where:

S : Spacing (m) of longitudinal frames

z', L', C_1 and h_1: As specified in **(1)**

C_2: Coefficient given by the following formula, but it is not to be less than $3.78\sqrt{K}$

$C_2 = 13\sqrt{\frac{K}{24 - \alpha K x}}$

K, α and x : As specified in **(1)**

3 Notwithstanding the requirement in **-2**, the thickness t of side shell plating below the strength deck is to be not less than obtained from the following formula. in **32.3.5-2.**

$t = \sqrt{KL'} \quad (mm)$

L': Length of ship L (m)

However, where L exceeds 330 m, L' is to be taken as 330 m.

K: As specified in **32.4.2-1**

32.4.632.5.5 Side Longitudinals

1 The section modulus Z of side longitudinals below the freeboard deck is not to be less than that obtained from the following formulae **(1)** and **(2)**, whichever is greater:

(1) $Z = 90CShl^2 \quad (cm^3)$

Where:

S: Spacing (m) of longitudinals

l: Spacing of girders (m)

h: Vertical distance (m) from the side longitudinal concerned to a point $d + 0.038L' + h_1$ above the top of keel

h_1, K and ~~L~~ L': As specified in **32.~~3~~4.2-1**

C: Coefficient given by the following formula:

$C = \frac{K}{24 - \alpha K}$, however, the value of C is not to be less than $\frac{K}{18}$

α : As obtained from the following formulae, whichever is greater:

$$\alpha = 15.5 f_B \left(1 - \frac{z}{z_B}\right) \quad \text{where} \quad z \le z_B$$

$$\alpha = 15.5 f_D \frac{z - z_B}{Z'} \quad \text{where} \quad z_B < z$$

$$\alpha = \frac{1}{9.81} \frac{M_H}{I_H} y_H \times 10^5$$

z: Vertical distance (m) from the top of keel to the longitudinal under consideration

z_B: As specified in **32.~~3~~4.2-2**

f_B, f_D and Z': As specified in **32.~~4~~5.3(1)(a)**

M_H, I_H and y_H: As specified in **32.~~4~~5.3(1)(a)**

(2) $Z = 2.9K\sqrt{L'}Sl^2 \quad (cm^3)$

K, L', S and l: As specified in **~~(2)~~(1)**

2 The section modulus Z of side longitudinals where the interior of the double side structure is used as deep water tanks are to be in accordance with the requirement in **32.~~4~~5.3(2)**.

32.~~5~~6 Transverse Bulkheads

32.~~5~~6.1 Construction

Transverse bulkheads are to be constructed so as to be sufficiently supported at the deck. Where the width of the bulkhead is especially large, the upper parts of transverse bulkheads are to be appropriately strengthened by providing box-shaped structures or by other means.

32.~~5~~6.2 Partial Bulkheads

Where non-watertight partial bulkheads are provided in cargo holds, the construction and scantlings are to be of sufficient strength and rigidity based on factors such as the size of the cargo hold and the depth of the bulkheads.

32.~~6~~7 Deck Construction

32.~~6~~7.1 Decks Inside the Line of Deck Openings

The scantlings of decks inside the line of deck openings in relation to bending in the deck plane are not to be less than those obtained from the following formulae. When calculating the section modulus and moment of inertia, the deck inside the line of deck openings is to be regarded as a web and the hatch end coaming as a flange. Where the construction is box-shaped or of similar construction, the second term of the formula for the thickness of deck plating is to be taken as 5.0.

(1) Thickness t of deck plating (including the bottom plate in case of box-shaped construction)

$$t = 0.00417 C_1 K \left(\frac{l_v^2 l_c}{w_c}\right) + 2.5 \quad (mm)$$

Where:

K: As specified in **32.~~3~~4.2-1**

l_v: Distance (m) from the top of inner bottom plating to the bulkhead deck at the centre line of the ship

l_c: Width of hatchway (m)

Where two or more rows of hatchways are provided, the width of the widest hatchway is to be taken.

w_c: Width (m) of deck inside the line of deck openings

C_1: As obtained from **Table C 32.~~6~~15** in accordance with the value of α

For intermediate values of α, the values of C_1 are to be determined by linear interpolation.

α: As obtained from the following formula:

$$\alpha = 0.5 l_c \sqrt[4]{\frac{3}{4 S l_v^3} \frac{I_v}{I_c}}$$

S: Spacing (m) of vertical webs provided on transverse bulkheads

I_v: Moment of inertia (cm^4) of vertical webs provided on transverse bulkheads

I_c: Moment of inertia (cm^4) of decks inside the line of deck openings

(2) Section modulus Z

$$Z = 1.43 C_2 K l_v^2 l_c^2 \quad (cm^3)$$

Where:

C_2: As obtained from **Table C 32.~~6~~15** in accordance with the value of α

For intermediate values of α, the values of C_2 are to be determined by linear interpolation.

α, l_v and l_c: As specified in **(1)**

(3) Moment of inertia

$$I = 0.38 \frac{l_c^4}{S l_v^3} I_v \quad (cm^4)$$

Where:

S, l_c, l_v and I_v: As specified in **(1)**

Table C32.~~6~~15 Coefficients, C_1 and C_2

α	0.50 and under	1.50 and above
C_1	1.00	0.37
C_2	0.50	0.10

32.~~6~~7.2 Crossties

1 Where the length of the hatchway is large in comparison with the width, crossties are to be provided in the hatchway opening at an appropriate spacing.

2 Where structures effectively supporting the loads from the side and deck of the ship are not provided at the location of crossties in holds, special considerations are to be made regarding the scantlings of crossties.

32.~~6~~7.3 Continuity of Thickness of Deck Plating

Consideration is to be made to the continuity in the thickness of deck plating, and to the avoidance of remarkable differences between the thicknesses inside and outside the line of deck openings.

32.6.4 Structural Details

1 Free edges including hatch corners of hatch side coamings are not to have any defects such as notches that may adversely affect fatigue strength. Appropriate edge treatment, including the treatment of corner edges, is to be carried out so that edges have sufficient fatigue strength. Details of the edge treatment used are generally to be clearly mentioned in relevant drawings.

2 In cases where equipment such as hatch cover pads and container pads is fitted, the ends of such equipment are to be tapered so that extreme differences in rigidity do not occur between the equipment and the hull structure. Measures such as increasing the thickness of plating at the attachment location are also to be adopted appropriately. Equipment materials and welding procedures are to be considered. If deemed necessary by the Society, a fatigue strength assessment of the relevant part is to be carried out.

3 Hatch side coaming ends, including fillet-welded parts to strength decks, are to be designed so as to have sufficient fatigue strength. For this reason, fatigue strength assessment, including detailed finite element analysis, are generally to be carried out. Fillet welds for hatch side coaming ends and strength decks are generally to be full penetration welds within a certain range. In addition, boxing welds at the ends are to be smoothened out using a grinder or other means.

4 For members in way of drain holes and other holes installed in hatch side coamings, special consideration is to be given to fatigue strength.

32.7 Container Supporting Arrangements

32.7.1 General

1 Container supporting arrangements are to be constructed so as to effectively transmit the loads to the double bottom structure, side construction and transverse bulkheads.

2 The strength of container supporting arrangements is to be sufficient for the loads from the bottom and side of the ship and the loads due to the containers.

32.8 Strength at Large Flare Locations

32.8.1 Shell Plating

For side shell plating where the flare is especially large, sufficient consideration is to be made regarding reinforcement against forces acting on the bow such as wave impact pressure.

32.8.2 Frames

The frames that are fitted where the bow flare is considered to endure large wave impact pressure are to be properly strengthened and particular attention is to be paid to the effectiveness of their end connections.

32.8.3 Girders

The girders that are fitted where the bow flare is considered to endure large wave impact pressure are to be properly strengthened and particular attention is to be paid to the effectiveness of their end connections.

32.9 Direct Strength Calculations for Primary Structural Members

32.9.1 Application

1 For ships of not less than 150 *m* in length L_1, the structural arrangements and scantlings of primary structural members are to be determined based upon the direct strength calculations prescribed in this section. Primary structural members are members of girder or stringer type which provide overall structural integrity for the hull envelope and cargo hold boundaries, such as the following **(1)** to **(4)**:

(1) Double bottom structure (bottom plate, inner bottom plate, girders, floors);
(2) Double side structure (shell plating, inner hull, stringers and web frames);
(3) Bulkhead structure; and
(4) Deck and cross deck structure

2 For ships of less than 150 *m* in length L_1, the structural arrangements and scantlings of primary structural members, as specified in **-1** above, may be determined based upon direct strength calculations deemed appropriate by the Society.

3 Where the structural arrangements and scantlings of primary structural members are determined in accordance with **-1** and **-2**, formulae in this chapter which can be substituted for by direct strength calculations need not be applied.

32.9.2 Verification of Calculation Method and Accuracy

1 Where the structural arrangements and scantlings of primary structural members are determined by direct strength calculation, necessary documents and data related to the calculation method are to be submitted beforehand to the Society for approval.

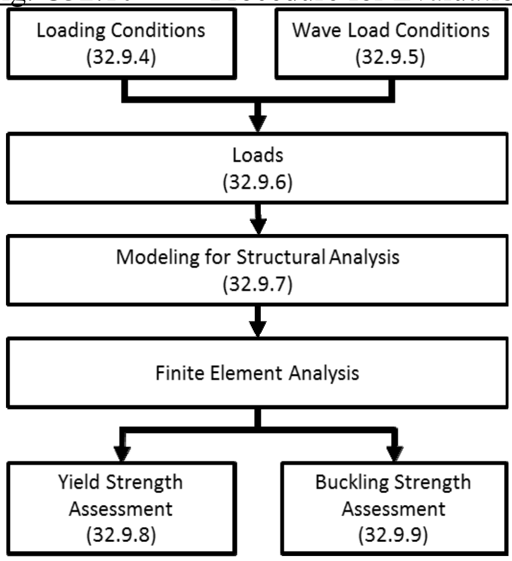
2 Analysis programs are to have sufficient accuracy. If deemed necessary, the Society may require the submission of details regarding the analysis method, verification of accuracy, etc.

32.9.3 Procedure for Evaluation

The procedure for evaluation of primary structural members is given in the following **(1)** to **(4)** (See **Fig. C32.10**):

(1) Corrosion additions are deducted from the members being modelled. In principal, the longitudinal extent of the cargo hold structural model is to cover three cargo hold lengths;
(2) Each load case represents a considered combination of loading conditions and wave load conditions;
(3) Loads and boundary conditions for a load case are applied to the structural model, and stresses are determined by performing structural analysis using Finite Element Method (FEM); and
(4) Yielding strength and buckling strength are evaluated using the stresses calculated by structural analysis. The evaluation area is to be the middle hold of the three cargo hold length FE model and is to include any watertight bulkheads and their supporting members located forward and aft of the considered cargo hold.

Fig. C32.10 Procedure for Evaluation

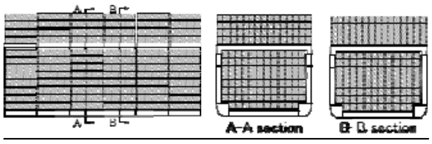
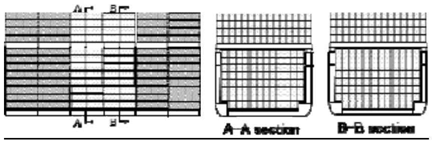
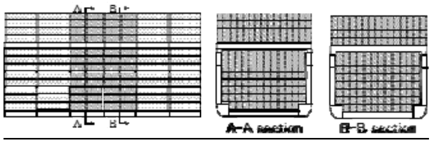
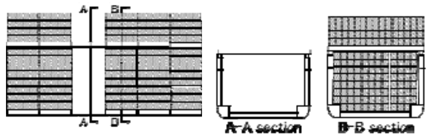


Note: Numbers in parentheses indicate section number

32.9.4 Loading Conditions

The minimum set of loading conditions for yielding strength assessment and buckling strength assessment is specified in **Table C32.16**. In addition, loading conditions specified in the loading manual are to be considered where deemed necessary.

Table C32.16 Loading Conditions

Loading condition	Loading patterns	Draught	Container weight of cargo hold to be evaluated	Ballast and fuel oil tanks	Vertical still water bending moment M_S
40' containers loading condition *FH4*		d	40' containers weight(1)	Empty	$M_{S\max}$
Light 40' containers loading condition *FL4*(4)		d	Light 40' containers weight (2), (3)	Empty	$M_{S\max}$
20' containers loading condition *RH2*(5)		$0.9d$	20' containers weight(1)	Empty	$M_{S\min}$
One bay empty condition *OH4*(6)		d	40' containers weight(1)	Empty	$M_{S\max}$

Notes:

$M_{S\max}$: Permissible maximum vertical still water bending moment in seagoing condition (*kN-m*) at the cross section under consideration.

$M_{S\min}$: Permissible minimum vertical still water bending moment in seagoing condition (*kN-m*) at the cross section under consideration.

(1): Container unit weight is to be calculated as the permissible stacking weight divided by the maximum number of tiers planned.

(2): Light container unit weight in hold is to be taken as 50% of its related container unit weight.

(3): Light container unit weight on deck is to be taken as 50% of its related container unit weight or 17 metric tons, whichever is the lesser.

(4): For loading condition *FL4*, 40' containers are assumed to be loaded in the cargo holds not being evaluated.

(5): For loading condition *RH2*, light 40' containers are assumed to be loaded in the cargo holds not being evaluated.

(6): For one bay empty condition, if the cargo hold consists of two or more bays, then each bay is to be considered entirely empty in hold and on deck (other bays full) in turn as separate load cases.

32.9.5 Wave Load Conditions

1 The wave load conditions considered in this section are given in **Table C32.17**. The definitions of weather side down and weather side up are according to **Fig. C32.11**.

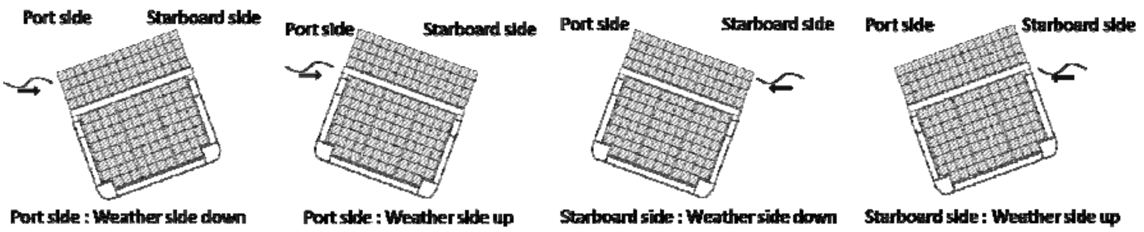
2 The wave loads may be set based upon the sea conditions in a restricted area, such as a calm water area or a coastal area, if the ship is planned for service in calm water area or coastal area and is registered under the condition of the restricted area.

3 Notwithstanding **-1** above, wave loads may be changed accordingly when the loading conditions are limited to sea areas where the effects of waves are small, such as in enclosed seas or harbours.

Table C32.17 Wave Load Conditions

Wave load condition		Heading	Conditions	
L-180	*L-180-1*	Head sea	Hogging	Vertical wave induced bending moment amidships reaches its maximum in head sea
	L-180-2	Head sea	Sagging	Vertical wave induced bending moment amidships reaches its maximum in head sea
L-0	*L-0-1*	Following sea	Hogging	Vertical wave induced bending moment amidships reaches its maximum in following sea
	L-0-2	Following sea	Sagging	Vertical wave induced bending moment amidships reaches its maximum in following sea
R	*R-P1*	Beam sea	Port side: weather side down	Roll of vessel reaches its maximum
	R-P2	Beam sea	Port side: weather side up	Roll of vessel reaches its maximum
	R-S1	Beam sea	Starboard side: weather side down	Roll of vessel reaches its maximum
	R-S2	Beam sea	Starboard side: weather side up	Roll of vessel reaches its maximum
P	*P-P1*	Beam sea	Port side: weather side down	Hydrodynamic pressure at the waterline amidships reaches its maximum
	P-P2	Beam sea	Port side: weather side up	Hydrodynamic pressure at the waterline amidships reaches its maximum
	P-S1	Beam sea	Starboard side: weather side down	Hydrodynamic pressure at the waterline amidships reaches its maximum
	P-S2	Beam sea	Starboard side: weather side up	Hydrodynamic pressure at the waterline amidships reaches its maximum

Fig. C32.11 Definitions of Weather Side Down and Weather Side Up



32.9.6 Loads

1 Ship motion and acceleration are to be in accordance with the following **(1)** to **(3)**:

(1) The pitch angle, θ, and roll angle, ϕ, are to be as given in **Table C32.18**.

Table C32.18 Ship Motion

Pitch angle	$\theta = \frac{5.4}{L_1^{1.2}\sqrt{C_b'}} H_{L-180}$ (rad.)
Roll angle	$\phi = \frac{4}{T_R\sqrt{B}} H_R$ (rad.)

Notes:

C_b' : As specified in **32.2.4-1**.

H_{L-180} : As given by the following formula:

$$H_{L-180} = 1.1C_1C_2\sqrt{\frac{L_1+\lambda_{L-180}-25}{L_1}}$$

H_R : As given by the following formula:

$$H_R = 0.64C_1C_2\sqrt{\frac{L_1+\lambda_R-25}{L_1}}$$

C_1: Coefficient to be taken as follows:

$C_1 = 10.75-\left(\frac{300-L_1}{100}\right)^{1.5}$ for $L_1 \leq 300\ m$

$C_1 = 10.75$ for $300\ m < L_1 \leq 350\ m$

$C_1 = 10.75-\left(\frac{L_1-350}{150}\right)^{1.5}$ for $350\ m < L_1$

C_2: Coefficient to be taken as follows:

$C_2 = 0.85$

λ_{L-180} : As given by the following formula:

$$\lambda_{L-180} = 0.5\left(1+\frac{d_i}{d}\right)L_1\ (m)$$

λ_R : As given by the following formula:

$$\lambda_R = \frac{g}{2\pi}T_R^2\ (m)$$

d_i: Draught amidships for the relevant loading condition (*m*).

g: Gravity acceleration, taken as 9.81 (m/s^2).

T_R : As given by the following formula:

$$T_R = C\frac{2K_{xx}}{\sqrt{GM}}\ (s)$$

C: Coefficient, taken as 1.1

K_{xx}: Roll radius of gyration (*m*). If K_{xx} is not available, K_{xx} may be calculated as $K_{xx} = 0.35B$

GM: Metacentric height (*m*); If GM is not available, GM may be calculated from the following formulae, but is not to be taken as $0.06B$ or below.

$GM = 0.52B-0.55D_S-5.26$ for loading condition *FH4*, *FL4*, *OH4*

$GM = 0.52B-0.53D_S-4.84$ for loading condition *RH2*

(2) The acceleration at the centre of gravity of the ship due to pitch motion a_{pitch}, roll motion a_{roll}, and heave motion a_{heave} are to be as given in **Table C32.19**.

Table C32.19 Acceleration of the Centre of Gravity of the Ship

Acceleration at the centre of gravity of the ship due to pitch motion	$a_{pitch} = \theta \cdot \frac{2\pi \cdot g}{\lambda_{L-180}}$ $(rad./s^2)$
Acceleration at the centre of gravity of the ship due to roll motion	$a_{roll} = \phi \cdot GM \left(\frac{\pi}{C \cdot K_{xx}} \right)^2$ $(rad./s^2)$
Acceleration at the centre of gravity of the ship due to heave motion	$a_{heave} = \frac{5.4g}{(B \cdot L_1)^{0.6} \sqrt{C_b^{'}}} H_P$ (m/s^2)

Notes:

$C_b^{'}$, θ, ϕ, λ_{L-180}, GM, K_{xx}: As specified in **Table C32.18**.

g: Acceleration due to gravity, taken as 9.81 (m/s^2).

C: Coefficient, taken as 1.1

H_P: As given by the following formula:

$$H_P = 0.93 C_1 C_2 \sqrt{\frac{L_1 + \lambda_P - 25}{L_1}}$$

C_1 and C_2: As specified in **Table C32.18**.

λ_P: As given by the following formula:

$$\lambda_P = \left(0.2 + 0.15 \frac{d_i}{d} \right) L_1 \ (m)$$

d_i: Draught amidships for the relevant loading condition (m).

(3) The vertical acceleration a_v, transverse acceleration a_t, and longitudinal acceleration a_ℓ at the centre of gravity of a container are to be as given in **Table C32.20**.

Table C32.20 Acceleration at Centre of Gravity of a Container

Wave load condition		Acceleration at the centre of gravity of the container (m/s^2) (vertical acceleration)	Acceleration at the centre of gravity of the container (m/s^2) (transverse acceleration)	Acceleration at the centre of gravity of the container (m/s^2) (longitudinal acceleration)
L-180	*L-180-1*	$a_v = -0.3a_{heave}$	0	$a_\ell = g\theta + (z_i - z_g)a_{pitch}$
	L-180-2	$a_v = 0.3a_{heave}$	0	$a_\ell = -g\theta - (z_i - z_g)a_{pitch}$
L-0	*L-0-1*	0	0	0
	L-0-2	0	0	0
R	*R-P1*	$a_v = 0.1a_{heave} + y_i a_{roll}$	$a_t = -g\phi - (z_i - z_g)a_{roll}$	0
	R-P2	$a_v = -0.1a_{heave} - y_i a_{roll}$	$a_t = g\phi + (z_i - z_g)a_{roll}$	0
	R-S1	$a_v = 0.1a_{heave} - y_i a_{roll}$	$a_t = g\phi + (z_i - z_g)a_{roll}$	0
	R-S2	$a_v = -0.1a_{heave} + y_i a_{roll}$	$a_t = -g\phi - (z_i - z_g)a_{roll}$	0
P	*P-P1*	$a_v = a_{heave} + 0.5y_i a_{roll}$	$a_t = -0.5g\phi$	0
	P-P2	$a_v = -a_{heave} - 0.5y_i a_{roll}$	$a_t = 0.5g\phi$	0
	P-S1	$a_v = a_{heave} - 0.5y_i a_{roll}$	$a_t = 0.5g\phi$	0
	P-S2	$a_v = -a_{heave} + 0.5y_i a_{roll}$	$a_t = -0.5g\phi$	0

Notes:

g: Acceleration due to gravity, taken as 9.81 (m/s^2).

θ and ϕ : As specified in **Table C32.18**.

a_{pitch} , a_{roll} and a_{heave} : As specified in **Table C32.19**.

y_i: *Y* coordinate, in *metres*, of the centre of gravity of the container. The centre of gravity may be considered as the midpoint of the container.

z_g: *Z* coordinate, in *metres*, of the centre gravity of the ship.

z_i: *Z* coordinate, in *metres*, of the centre of gravity of the container. The centre of gravity may be considered as the midpoint of the container.

2 Sea pressures are to be considered as external pressures acting on the hull structures. The sea pressures are the sum of hydrostatic pressures and hydrodynamic pressures, and are not to be taken as less than 0. Hydrostatic pressure and hydrodynamic pressures are to be in accordance with the following **(1)** and **(2)**.

(1) The pressure corresponding to the draught in still water is to be considered the hydrostatic pressure for each loading condition. The hydrostatic pressure is to be as given in **Table C32.21**.

(2) Hydrodynamic pressure is to be in accordance with the following requirements **(a)** to **(c)**:

(a) The hydrodynamic pressures *P* corresponding to the wave load conditions *L-180* and *L-0* are to be as given in **Table C32.22**, **Fig. C32.12** and **Fig. C32.13**;

(b) The hydrodynamic pressure *P* corresponding to the wave load condition *R* is to be as given in **Table C32.23** and **Fig. C32.14**; and

(c) The hydrodynamic pressure *P* corresponding to the wave load condition *P* is to be as given in **Table C32.24** and **Fig. C32.15**.

Table C32.21 Hydrostatic Pressure

Location	Hydrostatic Pressure (kN/m^2)
$z \le d_i$	$\rho g(d_i - z)$
$z > d_i$	0

Notes:

ρ: Density of sea water, taken as 1.025 (m/s^2).

g: Acceleration due to gravity, taken as 9.81 (m/s^2).

d_i: Draught amidships for the relevant loading condition (m).

z: Z coordinate, in *metres*, at the position considered.

Table C32.22 Hydrodynamic Pressure Corresponding to Wave Load Conditions *L-180* and *L-0*

Wave load condition		Hydrodynamic pressure (kN/m^2)		
		$z \le d_i$	$d_i < z \le d_i + h_w$	$z > d_i + h_w$
L-180	*L-180-1*	$P = \max(P_{D,L-180}, \rho g(z - d_i))$	$P = P_{WL} - \rho g(z - d_i)$	$P = 0$
	L-180-2	$P = \max(-P_{D,L-180}, \rho g(z - d_i))$		
L-0	*L-0-1*	$P = \max(P_{D,L-0}, \rho g(z - d_i))$		
	L-0-2	$P = \max(-P_{D,L-0}, \rho g(z - d_i))$		

Notes:

$P_{D,L-180}$: As given by the following formula:

$$P_{D,L-180} = 2.3C_3\left(\frac{z}{d_i} + \frac{|2y|}{B} + 1\right)H_{L-180}$$

$P_{D,L-0}$: As given by the following formula:

$$P_{D,L-0} = 2.3C_3C_{L-0}\left(\frac{z}{d_i} + \frac{|2y|}{B} + 1\right)H_{L-0}$$

C_3: Coefficient to be taken as :

$C_3 = 0.5$ for wave load condition *L-180*

$C_3 = 1$ for wave load condition *L-0*

C_{L-0}: Coefficient to be taken as :

$C_{L-0} = 0.8$

d_i: Draught amidships for the relevant loading condition (m).

y: Y coordinate, in m, at the position considered.

z: Z coordinate, in m, at the position considered.

H_{L-180}: As specified in **Table C32.18**.

H_{L-0}: As given by the following formula:

$$H_{L-0} = 1.1C_1C_2\sqrt{\frac{L_1 + \lambda_{L-0} - 25}{L_1}}$$

C_1 and C_2: As specified in **Table C32.18**.

λ_{L-0}: As given by the following formula:

$$\lambda_{L-0} = 0.5\left(1 + \frac{2}{3}\frac{d_i}{d}\right)L_1 \ (m)$$

Table C32.22 Hydrodynamic Pressure Corresponding to Wave Load Conditions *L-180* and *L-0* (continued)

Notes:

P_{WL} : Wave pressure at the waterline (kN/m^2) for the considered wave load condition, to be taken as P for $z = d_i$

h_W: Water head equivalent to the pressure at waterline, in *metres*, to be taken as follows:

$$h_W = \frac{P_{WL}}{\rho g}$$

ρ : Density of sea water, taken as 1.025 (m/s^2) .

g: Acceleration due to gravity, taken as 9.81 (m/s^2) .

Fig. C32.12 Distribution of Hydrodynamic Pressure at Midship Section (Wave Load Condition *L-180-1*)

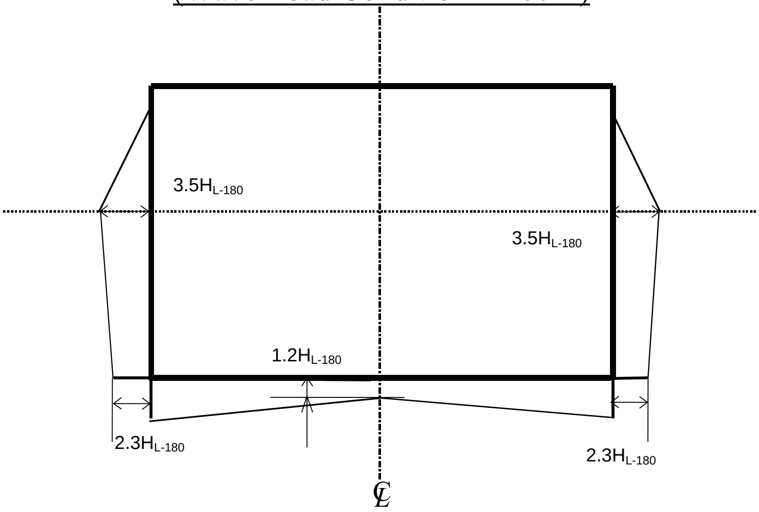


Table C32.13 Distribution of Hydrodynamic Pressure at Midship Section (Wave Load Condition *L-0-1*)

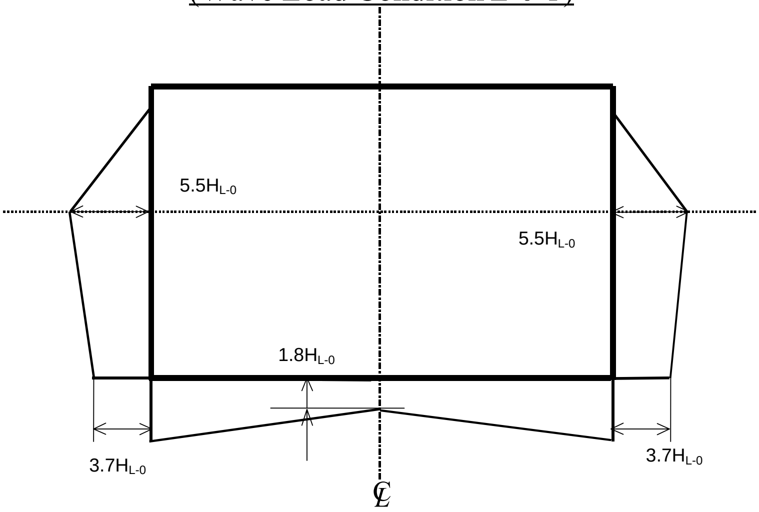


Table C32.23 Hydrodynamic Pressure Corresponding to Wave Load Condition *R*

Wave load condition		Hydrodynamic pressure (kN/m^2)		
		$z \le d_i$	$d_i < z \le d_i + h_w$	$z > d_i + h_w$
R	*R-P1*	$P = \max(P_{D,R-P}, \rho g(z-d_i))$	$P = P_{WL} - \rho g(z-d_i)$	$P = 0$
	R-P2	$P = \max(-P_{D,R-P}, \rho g(z-d_i))$		
	R-S1	$P = \max(P_{D,R-S}, \rho g(z-d_i))$		
	R-S2	$P = \max(-P_{D,R-S}, \rho g(z-d_i))$		

Notes:

$P_{D,R-P}$: As given by the following formula:

$$P_{D,R-P} = 10y\sin\phi + \left(\frac{|2y|}{B}+1\right)H_R$$

$P_{D,R-S}$: As given by the following formula:

$$P_{D,R-S} = -10y\sin\phi + \left(\frac{|2y|}{B}+1\right)H_R$$

y: *Y* coordinate, in *metres*, at the position considered.

z: *Z* coordinate, in *metres*, at the position considered.

ϕ and H_R : As specified in **Table C32.18**.

P_{WL} : Wave pressure at the waterline (kN/m^2) for the considered wave load condition, to be taken as P for $z = d_i$

h_W: Water head equivalent to the pressure at waterline, in *metres*, to be taken as follows:

$$h_W = \frac{P_{WL}}{\rho g}$$

ρ : Density of sea water, taken as 1.025 (m/s^2) .

g: Acceleration due to gravity, taken as 9.81 (m/s^2) .

Fig. C32.14 Distribution of Hydrodynamic Pressure at Midship Section (Wave Load Condition *R-P1*)

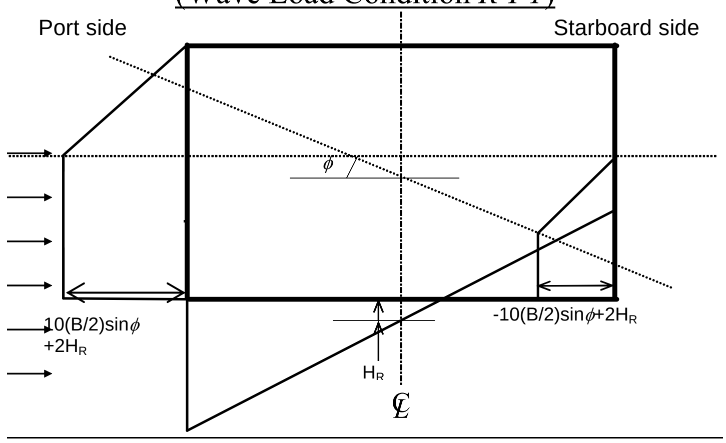


Table C32.24 Hydrodynamic Pressure Corresponding to Wave Load Condition *P*

Wave load condition		Transverse position	Hydrodynamic pressure (kN/m^2)		
			$z \le d_i$	$d_i < z \le d_i + h_w$	$z > d_i + h_w$
P	*P-P1*	$y \ge 0$	$P = \max\left(P_{D,P}, \rho g(z - d_i)\right)$	$P = P_{WL} - \rho g(z - d_i)$	$P = 0$
		$y < 0$	$P = \max\left(\frac{1}{3} P_{D,P}, \rho g(z - d_i)\right)$		
	P-P2	$y \ge 0$	$P = \max\left(-P_{D,P}, \rho g(z - d_i)\right)$		
		$y < 0$	$P = \max\left(-\frac{1}{3} P_{D,P}, \rho g(z - d_i)\right)$		
	P-S1	$y \ge 0$	$P = \max\left(\frac{1}{3} P_{D,P}, \rho g(z - d_i)\right)$		
		$y < 0$	$P = \max\left(P_{D,P}, \rho g(z - d_i)\right)$		
	P-S2	$y \ge 0$	$P = \max\left(-\frac{1}{3} P_{D,P}, \rho g(z - d_i)\right)$		
		$y < 0$	$P = \max\left(-P_{D,P}, \rho g(z - d_i)\right)$		

Notes:

$P_{D,P}$: As given by the following formula:

$$P_{D,P} = 2.4\left(2\frac{z}{d_i} + 3\frac{|2y|}{B}\right)H_P$$

y: *Y* coordinate, in *metres*, at the position considered.

z: *Z* coordinate, in *metres*, at the position considered, *max.*$(z) = d_i$

d_i: Draught amidships for the relevant loading condition (m).

H_P : As specified in **Table C32.19**.

P_{WL} : Wave pressure at the waterline (kN/m^2) for the considered wave load condition, to be taken as P for $z = d_i$

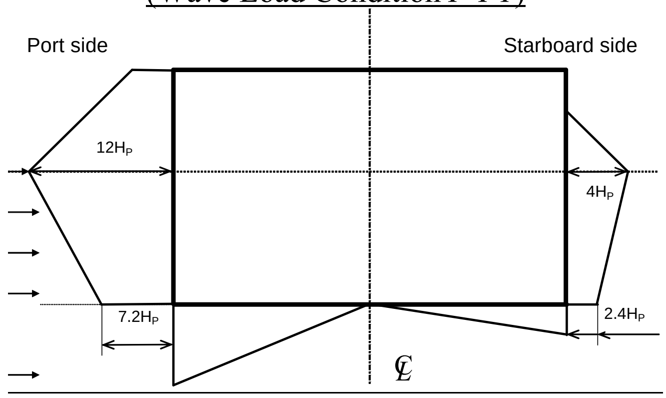
h_W: Water head equivalent to the pressure at waterline, in *metres*, to be taken as follows:

$$h_W = \frac{P_{WL}}{\rho g}$$

ρ : Density of sea water, taken as 1.025 (m/s^2) .

g: Acceleration due to gravity, taken as 9.81 (m/s^2) .

Fig. C32.15 Distribution of Hydrodynamic Pressure at Midship Section (Wave Load Condition *P-P1*)



3 For internal loads, the loads due to containers are to be considered. The loads due to containers are the sum of static and dynamic loads. The static and dynamic loads of containers are to be in accordance with the following **(1)** and **(2)**:

(1) The static loads of containers are considered to be the container weight, W_S (*kN*);

(2) The dynamic loads of containers, W_C (*kN*), are to be as given in **Table C32.25**.

Table C32.25 Dynamic Loads of Containers

Vertical load W_{CV} (*kN*)	Transverse load W_{CT} (*kN*)	Longitudinal load W_{CL} (*kN*)
$-W_S \dfrac{a_v}{g}$	$-W_S \dfrac{a_t}{g}$	$-W_S \dfrac{a_\ell}{g}$
Notes: g: Acceleration due to gravity, taken as 9.81 (m/s^2) . W_S: Container weight W_S (*kN*) . a_v , a_t and a_ℓ : As specified in **Table C32.19**.		

4 The effect of the weight of the hull structure is to be included in static loads, but is not to be included in dynamic loads.

5 Vertical bending moments and horizontal bending moments for direct strength calculations are to be obtained from the following equations:

Vertical bending moment: $M_{V-HG} = M_S + C_4 M_W$ (*kN-m*)

Horizontal bending moment: $M_{H-HG} = C_5 M_H$ (*kN-m*)

C_4: As specified in **Table C32.26**

C_5: As specified in **Table C32.26**

M_S: Vertical still water bending moment (*kN-m*) at the cross section under consideration, corresponding to each loading condition. (See **Fig. C32.16**)

M_W: Vertical wave induced bending moment (*kN-m*) at the cross section under consideration, as specified in **Table C32.26**. (See **32.2.3-6.**)

M_H: Horizontal wave induced bending moment (*kN-m*) at the cross section under consideration, as specified in **Table C32.26**. $M_H(+)$ or $M_H(-)$ is to be taken according to wave load conditions.

$$M_H(+) = 0.32 C_1 L_1^2 d_i \sqrt{\frac{L_1 - 35}{L_1}} \quad (kN\text{-}m)$$

$$M_H(-) = -0.32 C_1 L_1^2 d_i \sqrt{\frac{L_1 - 35}{L_1}} \quad (kN\text{-}m)$$

C_1: As specified in **Table C32.18**

d_i: Draught amidships for the relevant loading condition (*m*)

$C_b^{'}$: As specified in **Table C32.18**

Table C32.26 Superimposition Ratio of Vertical Wave Induced Bending Moment and Horizontal Wave Induced Bending Moment

Wave load condition		C_4	M_W	C_5	M_H
L-180	*L-180-1*	1.0	Hogging M_{W-Hog}	–	–
	L-180-2		Sagging M_{W-Sag}		
L-0	*L-0-1*	0.8	Hogging M_{W-Hog}	–	–
	L-0-2		Sagging M_{W-Sag}		
R	*R-P1*	$0.75\frac{d_i}{d}-0.55$	Sagging M_{W-Sag}	$1.2-\frac{d_i}{d}$	Port side (Compression) $M_H(+)$
	R-P2		Hogging M_{W-Hog}		Port side (Tension) $M_H(-)$
	R-S1		Sagging M_{W-Sag}		Starboard side (Compression) $M_H(-)$
	R-S2		Hogging M_{W-Hog}		Starboard side (Tension) $M_H(+)$
P	*P-P1*	$\frac{d_i}{d}-0.55$	Sagging M_{W-Sag}	$0.7-0.6\frac{d_i}{d}$	Port side (Compression) $M_H(+)$
	P-P2		Hogging M_{W-Hog}		Port side (Tension) $M_H(-)$
	P-S1		Sagging M_{W-Sag}		Starboard side (Compression) $M_H(-)$
	P-S2		Hogging M_{W-Hog}		Starboard side (Tension) $M_H(+)$

Notes:
d_i: Draught amidships for the relevant loading condition (m) .
M_{W-Hog} : Vertical wave induced bending moment in hogging at the cross section under consideration. (See **Fig. C32.6**).
M_{W-Sag} : Vertical wave induced bending moment in sagging at the cross section under consideration. (See **Fig. C32.6**).

32.9.7 Modelling for Structural Analysis

1 Both the port and starboard sides of the ship are to be modelled.

2 The members to be modelled are the longitudinal members and primary supporting members within the extent of the whole analysed area. Load transmitting members such as longitudinal stiffeners, watertight bulkhead stiffeners and web stiffeners are also to be included in the model.

3 For modelling, the thickness of the model and dimensions of the stiffeners are to be based upon the net scantling approach specified in **32.1.3**.

4 Finite element types are to be in accordance with the following **(1)** to **(3)**:

(1) Shell elements are to be used to represent plates;

(2) Beam elements are to be used to represent stiffeners; and

(3) Face plates of primary supporting members and brackets are to be modelled using rod or beam elements.

5 The meshing of elements is to be performed so as to accurately reproduce structural responses within the evaluation area.

6 Openings are to be modelled when deemed necessary by the Society.

7 The manner of applying loads to structural models is to be in accordance with the following **(1)**

to **(3)**:

(1) Constant pressure, calculated at the element's centroid, is to be applied to the shell element of the loaded surfaces (e.g., outer shells and decks for external pressure and cargo hold boundaries for internal pressure).

(2) Loads due to containers are to be applied to the nearest nodal point from the location where the container comes into contact as the nodal load.

(3) Adjustment moments are to be applied at the fore and aft ends of the model so that the values of the vertical bending moment and horizontal bending moment at the centre of the evaluation area are not less than those of vertical bending moment and horizontal bending moment specified in **32.9.6-5**.

8 Boundary conditions are to be set accordingly to correctly reflect the stress distributions caused by the adjustment moments in **-7(3)** above with the applicable condition being that model is simply supported at its fore and aft ends.

32.9.8 Yield Strength Assessment

1 Each element within the evaluation area is to be verified according to the criteria given in the following equation.

$$\sigma_{ref} \le \frac{235}{K}$$

σ_{ref} : As specified below:

For rod elements, axial stress σ_a (N/mm^2)

For shell elements, equivalent stress at the mid plane of the element σ_{eq} (N/mm^2)

$$\sigma_{eq} = \sqrt{\sigma_1{}^2 - \sigma_1 \cdot \sigma_2 + \sigma_2{}^2 + 3\tau_{12}{}^2}$$

σ_1, σ_2: In-plane normal stresses at the mid plane of the element (N/mm^2)

τ_{12}: Shear stress corresponding to σ_1, σ_2 at the mid plane of the element (N/mm^2)

K: Coefficient corresponding to the kind of steel (e.g., 1.0 for mild steel, the values specified in **1.1.7-2(1)** for high tensile steel)

2 When the opening is not modelled, the stresses of any elements around opening are to be modified by a method deemed appropriate by the Society.

32.9.9 Buckling Strength Assessment

1 The buckling strength of panels and stiffeners within the evaluation area are to be verified as being adequate.

2 A structural member is considered to have an acceptable buckling strength if it satisfies the following criterion:

$$\eta_{act} \le 1$$

η_{act}: Buckling utilisation factor based upon the applied stress obtained from structural analysis, which is separately specified by the Society.

3 Buckling strength assessments of the web plates of primary supporting members with openings are to be carried out by a method deemed appropriate by the Society.

32.10 Fatigue Strength

32.10.1 Fatigue Strength Assessment

For bottom longitudinals, side longitudinals, hatch corners, hatch side coamings, and areas of stress concentrations, such as bench corners in forward holds, sufficient consideration is to be given to fatigue strength. The Society may request detailed fatigue strength assessments if deemed necessary.

32.10.2 Structural Details

1 Free edges, including hatch corners of hatch side coamings, are not to have any defects such as notches that may adversely affect fatigue strength. Appropriate edge treatment, including the treatment of corner edges, is to be carried out so that edges have sufficient fatigue strength. Details of the edge treatment used are, in principle, to be clearly mentioned in relevant drawings.

2 In cases where equipment such as hatch cover pads and container pads is fitted, the ends of such equipment are to be tapered so that extreme differences in rigidity do not occur between the equipment and the hull structure. Measures such as increasing the thickness of the plating at the attachment location appropriately, etc. are also to be adopted. Consideration is to be given to equipment materials and welding procedures. In addition, a fatigue strength assessment of the relevant part is to be carried out when deemed necessary by the Society.

3 Hatch side coaming ends, including fillet-welded parts to strength decks, are to be designed so as to have sufficient fatigue strength. For this reason, fatigue strength assessments, including detailed finite element analysis, are to be carried out in principle. In addition, fillet welds for hatch side coaming ends and strength decks are, in principle, to be full penetration welds within a certain range, and boxing welds at the ends are to be smoothened out using a grinder or other means.

4 Special consideration is to be given to fatigue strength in way of drain holes and other holes installed in hatch side coamings.

32.11 Container Supporting Arrangements

32.11.1 General

1 Container supporting arrangements are to be constructed so as to effectively transmit the loads to the double bottom structure, side construction and transverse bulkheads.

2 The strength of container supporting arrangements is to be sufficient for the loads from the bottom and sides of the ship and the loads due to the containers.

32.~~9~~12 Welding

32.~~9~~12.1 Application

1 Fillet welding is to be applied to longitudinals with a web plate thickness above 40*mm* and up to 80*mm*, which are used for the strength deck or for side shell plating and longitudinal bulkheads that extend upwards from a position 0.25*D* below the strength deck.

2 Where longitudinals with a web plate thickness above 80*mm* are used, the kind and size of the weldings are to be at the discretion of the Society.

32.~~9~~12.2 Fillet Welding

1 Fillet welding is to be continuous.

2 The size of fillet is to be not less than 8*mm*.

32.~~10~~13 Special Requirements for Container Carriers applying Extremely Thick Steel Plates

32.~~10~~13.1 General

This section gives measures for identification and prevention of brittle fractures in container carriers to which extremely thick steel plates are applied for longitudinal structural members. These include measures to prevent brittle crack initiation and to arrest brittle crack propagation in case brittle crack initiates.

32.~~10~~13.2 Application

1 This section applied to which any of *KA*36, *KD*36 ,*KE*36, *KA*40, *KD*40, *KE*40 and *KE*47 steel plates having thickness of over 50*mm* and not greater than 100*mm*.

2 Notwithstanding the requirement given in **-1** above, when as-built thickness of the hatch side coaming (includes top plates and longitudinal stiffeners) is not greater than 50*mm*, this section may not be necessarily applied regardless of the thickness and grade of steel of the strength deck.

3 The structural members of container carriers applying extremely thick steel plates are to comply with the requirements in **32.1** to **32.~~9~~12** in addition to the requirements in **32.~~10~~13**.

32.~~10~~13.3 Measures for prevention of brittle fracture

Measures for prevention of brittle fracture applying to extremely thick steel plates are to be utilized the combination shown in **Table C32.~~7~~27** according to the thickness and grade of steel of the hatch side coaming.

Table C32.~~7~~27 Application of measures for prevention of brittle fractures

Hatch side coaming		Non-destructive inspection during ship construction specified in **1.4.2-1(3), Part M of the Rules**	Brittle crack arrest design specified in **32.~~10~~13.4**
Grade of steel	Thickness(*mm*)		
*KA*36 *KD*36 *KE*36	$50 < t \leq 100$	X	N.A.
*KA*40 *KD*40 *KE*40	$50 < t \leq 85$		
	$85 < t \leq 100$	X	X(1)
*KE*47 (where electro-gas welding is applied at block-to-block butt joints)	$50 < t \leq 100$	X	X
*KE*47 (where welding procedures other than electro-gas welding are applied at block-to-block butt joints)	$50 < t \leq 100$	X	X(1)

(SYMBOL)
X : To be applied
N.A. : Need not to be applied
(1) : Other measures deemed by the Society to be equivalent in effectiveness to brittle crack arrest designs may be accepted.

32.~~10~~13.4 Brittle crack arrest design

1 Brittle crack arrest design is to be utilized to prevent large scale fractures of the hull girder by arresting propagation of the brittle crack at a proper position, even in case where brittle crack initiation occurs within the cargo hold region.

2 Following **(1)** and **(2)** are to be considered as the points of brittle crack initiation.

(1) Block-to-block butt joints both of hatch side coaming and strength deck; and

(2) Any welds other than **(1)** above.

3 Following **(1)** to **(3)** are to be considered as the cases of brittle crack propagation.

(1) Cases where the brittle crack initiates from block-to-block butt joint and runs straight along the butt joint;

(2) Cases where the brittle crack initiates from block-to-block butt joint and deviate away from butt joint and runs into base metal; and

(3) Cases where the brittle crack initiates from any welds other than **(1)** and **(2)** above and runs into base metal.

4 With the consideration of the requirements in **-3** above, measures specified in the following **(1)** to **(3)** are to be applied as brittle crack arrest design;

(1) Brittle crack arrest steel is to be provided for strength deck.

(2) Brittle crack arrest steel is to be provided for hatch side coaming; however, such steel is not necessary to be provided in the attached top plate and longitudinal stiffeners.

(3) Appropriate measures is to be provided at a point of block-to-block butt joint between hatch side coaming and strength deck in order to arrest brittle crack propagation running straight along the butt joint.

5 Notwithstanding the provisions in **-4** above, where the equivalency is verified through technical data and/or brittle fracture tests, etc., brittle crack arrest design other than those specified in **-4** above may be accepted by the Society.

6 Brittle crack arrest steel specified in **-4(1)** and **(2)** above is to be a steel which have brittle crack arrest properties for $A600$ or equivalent as specified in **3.12, Part K of the Rules**. Where the steel plate having thickness of over 80*mm* is provided as brittle crack arrest steel, brittle crack arrest properties of such steel are to be at the discretion of the Society.

EFFECTIVE DATE AND APPLICATION

1. The effective date of the amendments is 1 April 2016.

2. Notwithstanding the amendments to the Rules, the current requirements may apply to ships for which the date of contract for construction is before the effective date.

GUIDANCE FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

Part C Hull Construction and Equipment

GUIDANCE

2015 AMENDMENT NO.3

Notice No.82 25th December 2015

Resolved by Technical Committee on 28th July 2015 / 19th November 2015

Notice No.82 25th December 2015
AMENDMENT TO THE GUIDANCE FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

"Guidance for the survey and construction of steel ships" has been partly amended as follows:

Part C HULL CONSTRUCTION AND EQUIPMENT

Amendment 3-1

C29 TANKERS

C29.6 Girders

C29.6.2 Direct Strength Calculations for Girders

Sub-paragraph -3 has been amended as follows.

3 Load

Load to be applied to structural models are to be a combination of internal loads and external loads specified below. Where, however, another combination of loads is clearly severer than that specified, the latter may be omitted.

(1) Internal loads

(a) Hydrostatic test condition

The water head is to be the vertical distance (*m*) from each point to 2.4~~5~~ *m* above the ~~deck at side~~ top of the tank. Examples are shown in **Table C29.6.2-1** to **Table C29.6.2-3**.

(b) Navigating condition

(Omitted.)

((2) is omitted.)

C29.12 Special Requirements for Hatchways and Freeing Arrangements

C29.12.2 Hatchways to Cargo Oil Tanks

Sub-paragraph -3 has been amended as follows.

3 The tightening devices of covers of tank-cleaning hatches are to be capable of keeping ample tightness under pressure corresponding to a water head of 2.4~~5~~ *m* above the tank top. If the devices are constructed as mentioned below or equivalent, the height of hatch coamings required by the provisions of **20.2.2-1, Part C** of the Rules may be reduced in accordance with the provisions of **20.2.2-2** and **20.2.5-4(2), Part C** of the Rules.

((1) and (2) are omitted.)

C30 ORE CARRIERS

C30.1 General

C30.1.2 Direct Calculations

The direct calculations for determination of structural scantlings of ore carriers are to comply with the following conditions **(1)** to **(4)**:

((1) is omitted.)

(2) Loads, boundary conditions, and supporting condition and modelling of structure

Assumed loads, structural models, boundary conditions and supporting condition for the calculation are to be as follows:

(a) Loads

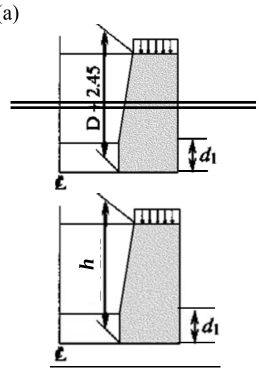
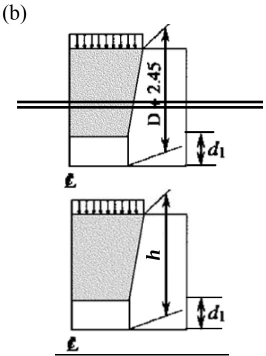
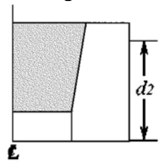
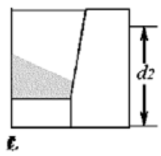
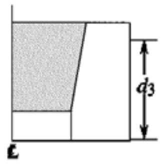
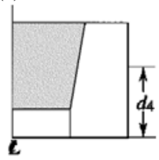
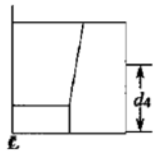
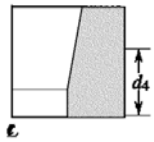
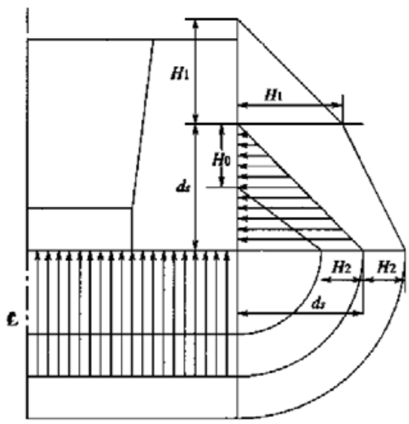
The loads are to be as shown in the Load column in **Table C30.1.2-1**. Among these, the hydraulic test condition **(b)**, the oil loading condition and the ballasted condition **(a)** apply to ore/oil carriers only.

((b) and (c) are omitted.)

((3) and (4) are omitted.)

Table C30.1.2-1 has been amended as follows.

Table C30.1.2-1

		Hydraulic test	Ore loading	Oil loading	Ballasted
Load	In still water	(a)  (b)  d_1 = 1/3×Designed maximum load draught h = vertical distance from the top of the keel to the top of the tank + 2.4 (m)	(a) In case the density of ore is light  (b) In case the density of ore is heavy  d_2 = Designed maximum load draught	(a)  d_3 = Designed maximum load draught	(a)  (c)  (b)  d_4 = Ballasted draught
	In waves		 d_s ; Draught in still water H_w ; $0.61L^{\frac{1}{2}}$ ・・・ $L \leq 150m$ $1.41L^{\frac{1}{3}}$ ・・・ $150m < L \leq 250m$ $2.23L^{\frac{1}{4}}$ ・・・ $250m < L \leq 300m$ $9.28m$ ・・・ $300m < L$ $H_0 = H_w/2$ $H_1 = h_1 \times H_0$ $H_2 = h_2 \times H_0$ $h_1 = 1.8$ $h_2 = 0.5$ H_0, H_1 and H_2 are to be added to or subtracted from d_s as shown in the above figure.		
Range of strength calcul.		All transverses	In the range where load (a) to (c) are present		

Notes:

1. The density, loading height and angle of repose under ore loading, oil loading and ballasted conditions are to be selected in

reference to the loading manual. The angle of repose is to be taken at 35° unless specified otherwise.
2. The ballasted draught is to be the mean of the draughts at A.P. and F.P.
3. When the density of cargoes is not specified (e.g. in the loading manual), it is to be taken as 3.0 t/m^3 and the apparent density of cargoes as W/V.
   W : Maximum mass of cargoes for the hold (t)
   V : Volume of the hold excluding its hatchway (m^3)

C31 BULK CARRIERS

C31.1 General

C31.1.5 Direct Calculations

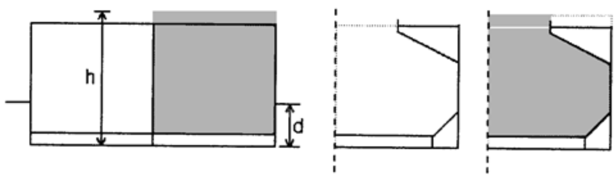
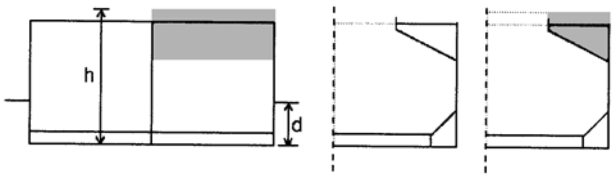
When determining the scantlings of structural members of cargo holds of a bulk carrier by direct calculations, the necessary documents and data on the calculation procedure are to be submitted beforehand to the Society for approval. The procedure is to comply with the following **(1)** to **(4)**.

(2) Loads

(a) The loading conditions to be taken into consideration are, as a rule, to be the conditions specified in the following. When there are special loading conditions or cargoes of especially high density are to be loaded, such conditions are to be included in the calculations. **Table C31.1.5-1** gives an example.

Table C31.1.5-1 has been amended as follows.

Table C31.1.5-1 Loading Conditions (Example)

	Loading Condition	Illustration for reference	Application
1	Hydrostatic Test Condition (a) (Centre Tank Test)	 Hydrostatic test with a head of water to the level of 2.4~~5~~ m above the ~~deck at ship's side~~ top of the tank. h = ~~D~~ vertical distance from the top of the keel to the top of the tank+2.4~~5~~(m) d = 1/3 × design maximum load draught	Transverse bulkhead, Sloping plate of stool, Double bottom structure, Topside tank, Bilge hopper tank, Hold frame
2	Hydrostatic Test Condition (b) (Side Tank Test)	 Hydrostatic test with a head of water to the level of 2.4~~5~~ m above the ~~deck at ship's side~~ top of the tank. h = ~~D~~ vertical distance from the top of the keel to the top of the tank+2.4~~5~~(m) d = 1/3 × design maximum load draught	Topside tank
(Omitted)			

Annex C1.1.22-1 GUIDANCE FOR DIRECT CALCULATIONS

1.2 Design Loads

1.2.3 Hydrostatic Pressure

1 Hydrostatic Pressure at Draught in Still Water

The water head at the draught in still water (d_s), corresponding to respective loading conditions is to be considered as hydrostatic pressure at the ships bottom and sides.

Sub-paragraph -2(1) has been amended as follows.

2 Load for Hydraulic Pressure Test

(1) The upper end of the water head of a tank being subjected to a hydraulic pressure test is to be a point at a height of 2.4~~5~~ m above the top of the tank.

(2) The water pressure at the bottom and sides under the hydraulic pressure test is to be the hydrostatic pressure corresponding to a draught equal to 1/3 of the design load draught.

EFFECTIVE DATE AND APPLICATION (Amendment 3-1)

1. The effective date of the amendments is 1 January 2016.

2. Notwithstanding the amendments to the Guidance, the current requirements may apply to ships for which the date of contract for construction* is before the effective date.

* "contract for construction" is defined in the latest version of IACS Procedural Requirement (PR) No.29.

IACS PR No.29 (Rev.0, July 2009)

1. The date of "contract for construction" of a vessel is the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. This date and the construction numbers (i.e. hull numbers) of all the vessels included in the contract are to be declared to the classification society by the party applying for the assignment of class to a newbuilding.

2. The date of "contract for construction" of a series of vessels, including specified optional vessels for which the option is ultimately exercised, is the date on which the contract to build the series is signed between the prospective owner and the shipbuilder.

For the purpose of this Procedural Requirement, vessels built under a single contract for construction are considered a "series of vessels" if they are built to the same approved plans for classification purposes. However, vessels within a series may have design alterations from the original design provided:

(1) such alterations do not affect matters related to classification, or

(2) If the alterations are subject to classification requirements, these alterations are to comply with the classification requirements in effect on the date on which the alterations are contracted between the prospective owner and the shipbuilder or, in the absence of the alteration contract, comply with the classification requirements in effect on the date on which the alterations are submitted to the Society for approval.

The optional vessels will be considered part of the same series of vessels if the option is exercised not later than 1 year after the contract to build the series was signed.

3. If a contract for construction is later amended to include additional vessels or additional options, the date of "contract for construction" for such vessels is the date on which the amendment to the contract, is signed between the prospective owner and the shipbuilder. The amendment to the contract is to be considered as a "new contract" to which **1.** and **2.** above apply.

4. If a contract for construction is amended to change the ship type, the date of "contract for construction" of this modified vessel, or vessels, is the date on which revised contract or new contract is signed between the Owner, or Owners, and the shipbuilder.

Note:
This Procedural Requirement applies from 1 July 2009.

Amendment 3-2

C15 LONGITUDINAL STRENGTH

C15.1 General

Paragraph C15.1.1 has been amended as follows.

C15.1.1 Special Cases in Application

The ships stated in **15.1.1-2, Part C** of the Rules are to be treated as follows.

((1) is omitted.)

(2) Ships with especially large hatches

Ships that have hatches with a breadth exceeding 0.7B in the midship part are to have their torsional strength examined in accordance with the requirements in **C32.~~2~~3**.

((3) to (5) are omitted.)

C15.2 Bending Strength

Paragraph C15.2.2 has been amended as follows.

C15.2.2 Bending Strength at Sections Other Than the Midship Part

"Where the Society considers that the application of requirements of **-1** above is inappropriate" stated in **15.2.2-2**, **Part C** of the Rules refers to cases in which the bending strength for the locations categorised in the following **(1)** to **(3)** is examined. In these cases, the bending strength is to be in accordance with the requirement specified in **15.2.1-1**, **Part C** of the Rules by using the coefficient C_2 obtained from the dotted line in **Fig. C15.2**.

(1) Locations categorized in the following **(a)** to **(d)** for all ships:
- (a) In way of the forward end of the engine room
- (b) In way of the forward end of the foremost cargo hold
- (c) At any locations where there are significant changes in the hull cross-section
- (d) At any locations where there are changes in the framing system

(2) In addition to the locations specified in **-1** above, locations categorized in the following **(a)** to **(c)** for ships with large deck openings ~~such as container ships~~. However, locations categorized in **(b)** and **(c)** are for only those ships with cargo holds aft of the superstructure, deckhouse or engine room.
- (a) At or near to the aft and forward quarter length positions
- (b) In way of the aft end of the aft-most holds
- (c) Aft end of the deckhouse or engine room

(3) In addition to the locations specified in **-1** and **-2** above, locations where deemed necessary by the Society for those ships categorised in the following **(a)** and **(b)**:
- (a) Ships with a C_b of less than 0.7
- (b) Ships whose longitudinal bending moments in still water at parts other than the midship part are equal to or greater than that at the midship part

C32 has been amended as follows.

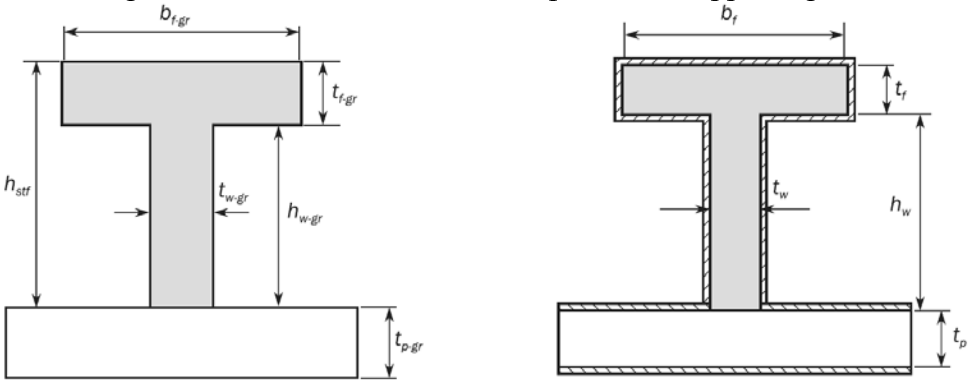
C32 CONTAINER CARRIERS

C32.1 General

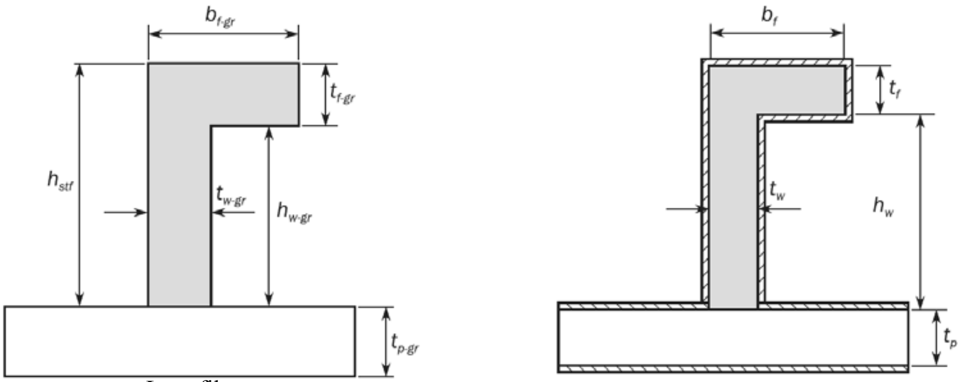
C32.1.3 Net Scantling Approach

The net section modulus, moment of inertia and shear area properties of a supporting member are to be calculated using the net dimensions of the attached plate, web and flange, as defined in **Fig. C32.1.3-1**. The net cross-sectional area, the moment of inertia about the axis parallel to the attached plate and the associated neutral axis position are to be determined through applying a corrosion magnitude of $0.5\alpha t_c$ deducted from the surface of the profile cross section.

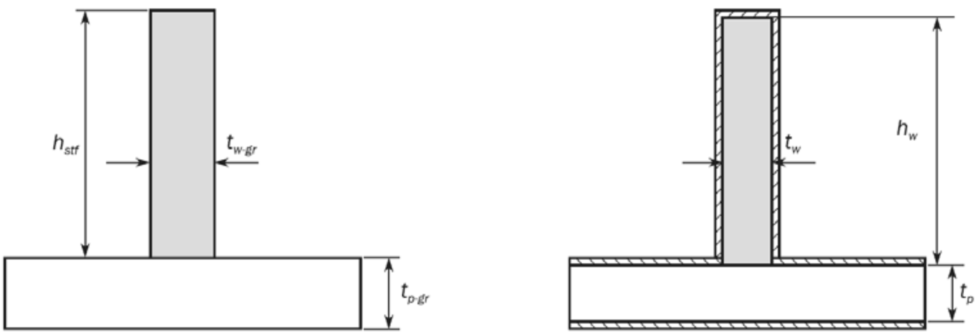
Fig. C32.1.3-1 Net Sectional Properties of Supporting Members



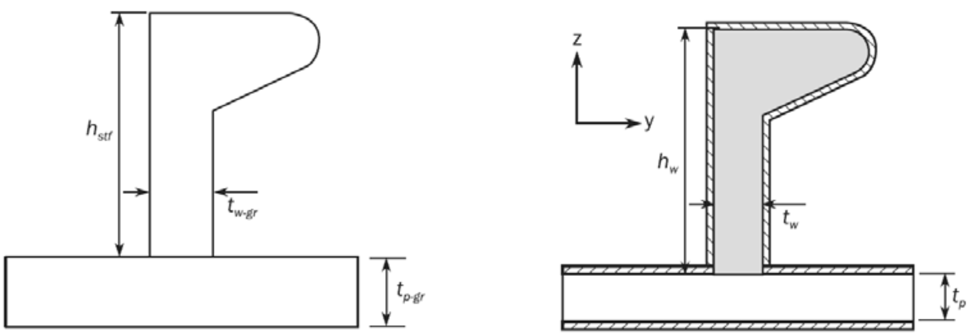
T profile



L profile



FB Profile



Bulb and similar profiles

C32.2 Longitudinal Bending Strength

C32.2.1 Bending Strength

1 The moment of inertia of the transverse section of the hull at the midpoint of L is to be greater than the following value.

$$3.2W_{min}L_1 \quad (cm^4)$$

Where:

W_{min} : As specified in the requirements in **15.2.1, Part C** of the Rules

L_1 : As specified in the requirements in **15.2.1-1, Part C** of the Rules

2 The scantlings of longitudinal members amidships are not to be less than the scantlings of longitudinal members at the midpoint of L as determined in accordance with **-1** above and **15.2.1-2, Part C** of the Rules, except for the scantlings of members which differ with the change in sectional form of the hull.

C32.2.2 Torsional Strength

1 The torsional strength of hull is to comply with the following **(1)** or **(2)**:

(1) The torsional strength of the hull at each sectional position from the collision bulkhead to the watertight bulkhead at the fore end of the machinery space is to be such that the following relationship is satisfied.

$$\sqrt{(0.75\sigma_V)^2 + \sigma_H^2 + \sigma_\omega^2} + \sigma_S \leq \frac{1000}{5.72K}$$

Where:

σ_S, σ_V and σ_H : As obtained from the following formula

However warping stress is to be added to σ_S when torsional moment is generated in the ship by unbalanced loading of cargoes.

$$\sigma_S = 1000\frac{|M_S|}{Z_V}$$

$$\sigma_V = 1000\frac{M_W}{Z_V}$$

$$\sigma_H = 1000\frac{M_H}{Z_H}$$

M_S :As specified in **15.2.1-1, Part C** of the Rules

M_W : M_W (+) or M_W (-) as specified in **15.2.1-1, Part C** of the Rules whichever is of the same sign as M_S

M_H : As obtained from the following formula:

$$0.45C_1L^2d(C_b + 0.05)C_H \quad (kN\text{-}m)$$

C_H : Coefficient, as given in **Table C32.2.2-1**, based on the ratio of L to x, where x is the distance (m) from the aft end of L to the section under consideration Intermediate values are to be determined by interpolation.

Z_V : Section modulus (cm^3) of strength deck with respect to longitudinal bending of the hull at the position of the section under consideration

Z_H : Section modulus (cm^3) of hatch side with respect to horizontal bending of the hull at the position of the section under consideration

C_1: As specified in **15.2.1-1, Part C** of the Rules

Table C32.2.2-1 Coefficient C_H

x/L	0.0	0.4	0.7	1.0
C_H	0.0	1.0	1.0	0.0

σ_ω: Warping stress (N/mm^2) due to torsion of the hull calculated according to the following formula for ships of ordinary construction using the dimensions and scantlings at the midship section

Values for other types are to be in accordance with the discretion of the Society.

$$\sigma_\omega = 0.000318\frac{\omega l_C M_T}{I_\omega + 0.04 l_C^2 J}$$

M_T: As given by the following formula:

$$M_T = 7.0 K_2 C_w^2 B^3 \left(1.75 + 1.5\frac{e}{D_S}\right) \quad (kN\text{-}m)$$

C_w: Water plane area coefficient

e: As given by the following formula:

$$e = e_1 - \frac{d_0}{2}$$

e_1: As given by the following formula:

$$e_1 = \frac{(3D_1 - d_1)d_1 t_d + (D_1 - d_1)^2 t_S}{3d_1 t_d + 2(D_1 - d_1)t_S + B_1 t_b / 3}$$

d_0: Height of double bottom (m)

d_1: Breadth of double hull side (m)

D_1: As given by the following formula:

$$D_1 = D_S - \frac{d_0}{2}$$

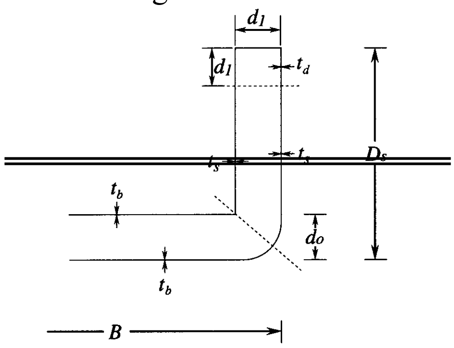
B_1: As given by the following formula:

$$B_1 = B - d_1$$

t_d, t_s, t_b: Mean thickness (m) of deck, ship's side, and bottom specified in **Fig. C32.2.2-1**

Mean thickness may be determined including all the longitudinal strength members within this range.

~~Fig. C32.2.2-1~~



~~K_2: As given by the following formulae:~~

$$K_2 = \sqrt{1-\left(\frac{300-L_1}{300}\right)^2} \quad \text{for ships with } L_1 < 300\ m$$

$$1.0 \quad \text{for ships with } L_1 \geq 300\ m$$

~~ω: As given by the following formula:~~

$$\omega = \frac{B_1}{2}(D_1 - e_1) + \frac{d_1}{2}(D_1 + e_1)$$

~~l_C: Distance (m) from the collision bulkhead to watertight bulkhead of the fore end of machinery room~~

~~I_ω: As given by the following formula:~~

$$I_\omega = B_1^{\,2}\{d_1 t_d I_d + (D_1 - d_1) t_S I_S + B_1 t_b I_b\}$$

~~I_d: As given by the following formula:~~

$$I_d = (D_1 - e_1)\left\{\frac{3}{2}(D_1 - e_1) - d_1\right\} + \frac{d_1^2}{3}$$

~~I_S: As given by the following formula:~~

$$I_S = (D_1 - d_1)\left\{\frac{1}{3}(D_1 - d_1) - e_1\right\} + e_1^2$$

~~I_b: As given by the following formula:~~

$$I_b = \frac{e_1^2}{6}$$

~~J: As given by the following formula~~

~~However, the mean thicknesses of t'_d, t'_S, t'_b are to be calculated only using the strength deck, side shell, bottom shell, inner bottom and longitudinal bulkhead plating. Other longitudinal strength members are not to be included.~~

$$J = \frac{2\{Bd_0 + 2(D_S - d_0)d_1\}^2}{3d_1 / t'_d + 2(D_1 - d_1)/t'_S + B_1 / t'_b}$$

~~K: Coefficient corresponding to the kind of steel~~

~~*e.g.* 1.0 for mild steel, the values specified in **1.1.7-2(1) of the Rules** for high tensile steel~~

~~(2) Torsional strength assessments are to be carried out in accordance with the **"Guidelines for Hull Girder Torsional Strength Assessment"** in the **"Guidelines for Container Carrier**~~

~~**Structures"**~~

~~**2** Notwithstanding the requirements of **-1** above, torsional strength assessments specified in **-1(2)** above may be required when deemed necessary by the Society.~~

~~**C32.2.3 Fatigue Strength**~~

~~**1** Fatigue strength assessments for bottom longitudinals and side longitudinals are to be in accordance with the requirements in **1.1.23-4** and **-5, Part C of the Rules**.~~

~~**2** Fatigue strength assessments for the longitudinal structural members of upper decks, including hatch side coamings and bench corner in foreword hold, are to be as follows:~~

~~(1) Hatch side coaming top plate at hatch corner~~

~~(a) Hatch side coaming top plates at hatch corners are to have sufficient fatigue strength. The Society may require fatigue strength assessments according to the **"Guidelines for Fatigue Strength Assessment"** in the **"Guidelines for Container Carrier Structures"** in consideration of the kind of steel used, the size of the ship, and the structural arrangement, etc. Hot-spot stresses at hatch corners (hot-spot mean stress and hot-spot stress fluctuation range) are to be determined using detailed Finite Element Analysis (FEA) using fine mesh elements. Element sizes, details of analysis and so on are to be at the Society's discretion.~~

~~(b) Butt welds for hatch side coamings, and fillet welded joints for attaching equipment is to be set at an sufficient distance from hatch corners so that effects of stress concentration are avoided. The Society may require the submission of drawings and data related to arrangement of welded joints.~~

~~(2) Welded joints of hatch side coamings~~

~~For butt welded joints and fillet welded joints of hatch side coamings (including welds for attaching equipment, etc.), special consideration is to be given to fatigue strength. The Society may require the submission of relevant fatigue strength assessments.~~

~~(3) Fatigue strength of locations other than hatch side coamings~~

~~(a) The fatigue strength at locations other than hatch side coamings (strength decks, sheer strakes, uppermost strakes of longitudinal bulkheads) are to sufficiently consider in conjunction with increase of hull girder stress (longitudinal bending stress and torsional stress).~~

~~(b) The Society may require fatigue assessments according to the **"Guidelines for Fatigue Strength Assessment"** in the **"Guidelines for Container Carrier Structures"** in consideration of the kind of steel used, the size of the ship, and the structural arrangement, etc. If deemed necessary, the Society may require detailed Finite Element Analysis (FEA) be used to calculate hatch corner hot-spot stresses.~~

~~(c) The fatigue strength of hatch corner in way of forward holds is to be carefully considered. If deemed necessary by the Society, a fatigue strength assessment of the relevant part may be required.~~

~~**3** When deemed necessary by the Society, fatigue strength assessments may be required for structural members other than those specified in **-2(1)** to **(3)**.~~

C32.2.2 Longitudinal Extent of Strength Assessment

1 "Locations where there are significant changes in hull cross section" specified in **32.2.2, Part C of the Rules** refers to the locations such as changing of framing system, the fore and aft ends of the engine room, and the fore and aft ends of the forward bridge block in case of two-island designs, etc.

2 "The method deemed appropriate by the Society" specified in **32.2.2-2, Part C of the Rules** refers to yield strength assessments and buckling strength assessments according to **32.2.6 and 32.2.7, Part C of the Rules** with necessary modifications.

C32.2.3 Loads

1 With respect to the provisions of **32.2.3, Part C of the Rules**, calculation of the vertical still water bending moment is to be as follows:

(1) To perform the calculation of the vertical still water bending moment, the method of calculation used is to be submitted for prior approval by the Society.

(2) For ships undergoing Classification Survey During Construction, calculation sheets for longitudinal strength in the still water corresponding to the actual loading plans and the data necessary for the calculations are to be submitted to the Society.

(3) In Classification Surveys, longitudinal strength calculations in still water are to be performed at the time of completion of the ship for each type of operating condition, and the necessary data and results of these calculations are to be included in the loading manual specified in **34.1.1, Part C of the Rules**.

2 For application of the provision of **32.2.3-3, Part C of the Rules**, reference is to be made to **Annex C15.2.1 "GUIDANCE FOR THE ASSESSMENT OF HULL GIRDER STRENGTH RELATED TO BALLASTING/DEBALLASTING"**.

3 "The loading conditions which are separately specified by the Society" specified in **32.2.3-5, Part C of the Rules** refers to the loading conditions specified in **1.3.1-1(1), Annex C34.1.2 "GUIDANCE FOR PREPARATION OF LOADING MANUAL"**.

4 "The calculation method which is separately specified by the Society" specified in **32.2.3-9(2), Part C of the Rules** refers to the calculation method specified in **Annex C32.2.3-4 "GUIDANCE FOR CALCULATION OF SHEAR FLOW"**.

C32.2.7 Buckling Strength Assessment

1 Maximum utilisation factor specified in **32.2.7-1, Part C of the Rules** is to be calculated in accordance with **Annex C32.2.7 "GUIDANCE FOR BUCKLING STRENGTH ASSESSMENT"**.

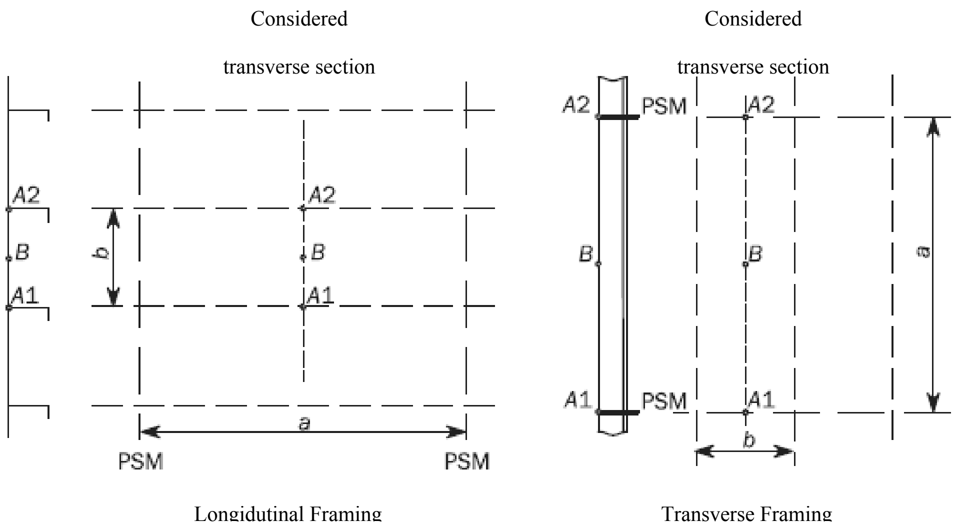
2 The hull girder bending stress and shear stress for elementary plate panels (EPP) are to be calculated at the load calculation points defined in **Table C32.2.7-1**. Here, "elementary plate plane" refers to the unstiffened part of the plating as well as all edges which are forced to remain straight due to the surrounding structure/ neighbouring plates.

3 The hull girder bending stress and shear stress for longitudinal stiffeners are to be calculated at the following calculation point, which is at the mid-length of the considered stiffener, and at the intersection point between the stiffener and its attached plate

Table C32.2.7-1 Load Calculation Point (*LCP*) Coordinates for Plate Buckling Assessment

LCP coordinate	Hull girder bending stress		Hull girder shear stress
	Non horizontal plating	Horizontal plating	
X coordinate	Mid-length of the EPP		
Y coordinate	Corresponding to *X* and *Z*	Outboard and inboard ends of the EPP (points A1 and A2 in **Fig.C32.2.7-1**)	Mid-point of EPP (point B in **Fig. C32.2.7-1**)
Z coordinate	Upper and lower ends of EPP (points A1 and A2 in **Fig.C32.2.7-1**)	Corresponding to *X* and *Y* values	

Fig.C32.2.7-1 *LCP* for Plate Buckling Assessment
(PSM stands for primary supporting members)



C32.2.8 Hull Girder Ultimate Strength Assessment

1 "The method which is separately specified by the Society" to calculate M_U (*kN-m*) specified in **32.2.8-1, Part C of the Rules** refers to the method specified in **Annex C32.2.8-1 "GUIDANCE FOR THE HULL GIRDER ULTIMATE STRENGTH ASSESSMENT"**.

2 "The method which is separately specified by the Society" to calculate M_{U_DB} (*kN-m*) specified in **32.2.8-2, Part C of the Rules** refers to the method specified in **Annex C32.2.8-2 "GUIDANCE FOR THE HULL GIRDER ULTIMATE STRENGTH ASSESSMENT CONSIDERING THE EFFECT OF LATERAL LOADS"**.

C32.2.9 Calculation of Section Modulus and Moment of Inertia of Transverse Section of Hull

1 The section modulus and moment of inertia of transverse section of hull is to have five significant figures.

2 The ratio of inclusion of members effective for longitudinal strength is to be as follows.

(1) All intercostal plates may be included if the fillet welding complies with **Note 1** of **Table C1.5, Part C**.

(2) All doubling plates may be included if fitted during ship construction or 90% if fitted during conversion or addition.

(3) For side stringers, slots for frames are to be deducted.

(4) Scallops complying with the following conditions need not be deducted from the sectional area. (*See* **Fig. C32.2.9-1**)

(a) d_s not exceeding $d/4$ nor exceeding $7t$, maximum 75 *mm*

(b) S more than $5b$ and more than $10d_s$

(5) As for the longitudinal continuous decks between hatchways of ships having 2 or 3 rows of cargo hatches, the ratio of sectional area to be included in the calculation of the section modulus is to be obtained from **Table C32.2.9-1**. For intermediate values of ξ and l/L, linear interpolation is to be applied.

(6) Where the sectional area of longitudinals, which are unable to be continued due to factors such

as the arrangement of small hatch openings are compensated by adjacent ones, they may be included in the calculation of the section modulus of the transverse section.

3 Openings in strength decks are to be treated as mentioned below.

(1) Where the shape and dimensions do not meet the conditions in **Table C32.2.9-2**, reinforcement by means of rings, thicker plates, etc. is required (*See* **Fig. C32.2.9-3** and **Fig. C32.2.9-4**).

(2) Where the intervals between centres of holes e do not meet the conditions in **Fig. C32.2.9-5**, reinforcement as per **(1)** above is needed.

Fig. C32.2.9-1 S, b and d_s of Scallops

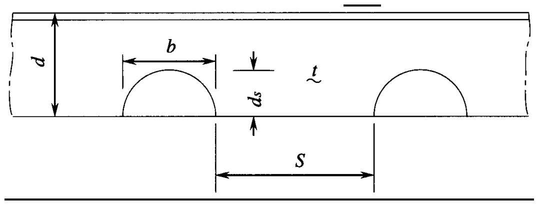


Table C32.2.9-1 Ratio of Inclusion of Sectional Area

ξ	Hatches in 2 rows			Hatches in 3 or more rows		
	l/L					
	0.10	0.20	0.30	0.10	0.15	0.20
0	0.96	0.85	0.70	0.96	0.91	0.85
0.5	0.65	0.57	0.48	0.89	0.80	0.69
1.0	0.48	0.43	0.36	0.83	0.73	0.62
2.0	0.32	0.29	0.25	0.73	0.63	0.53
3.0	0.24	0.22	0.18	0.65	0.57	0.47

Notes:

ξ = Values obtained from the following formula:

$$\frac{ab^3}{lI_c}\left\{\frac{1+2\mu}{6(2+\mu)}\times 10^4 + 2.6\frac{I_c}{a_c b^2}\right\}$$

where

I_c : Moment of inertia (cm^4) of deck between hatches, including hatch coamings

a_c : Effective shear area (cm^2) of deck between hatches

a : Sectional area (cm^2) of continuous deck between hatches (port or starboard side half)

l : Length (m) of hatch

μ , b : As per **Fig. C32.2.9-2** (m)

Table C32.2.9-2

	Elliptic holes	Circular holes
Oil tankers	$\frac{a}{b}\le\frac{1}{2}, a\le 0.06B$ ($a_{max}=900$ mm)	$a\le 0.03B$ ($a_{max}=450$ mm)
Cargo ships	$\frac{a}{b}\le\frac{1}{2}, a\le 0.03(B-b_H)$ ($a_{max}=450$ mm)	$a\le 0.015(B-b_H)$ ($a_{max}=200$ mm)

Fig. C32.2.9-2 l, b and μ

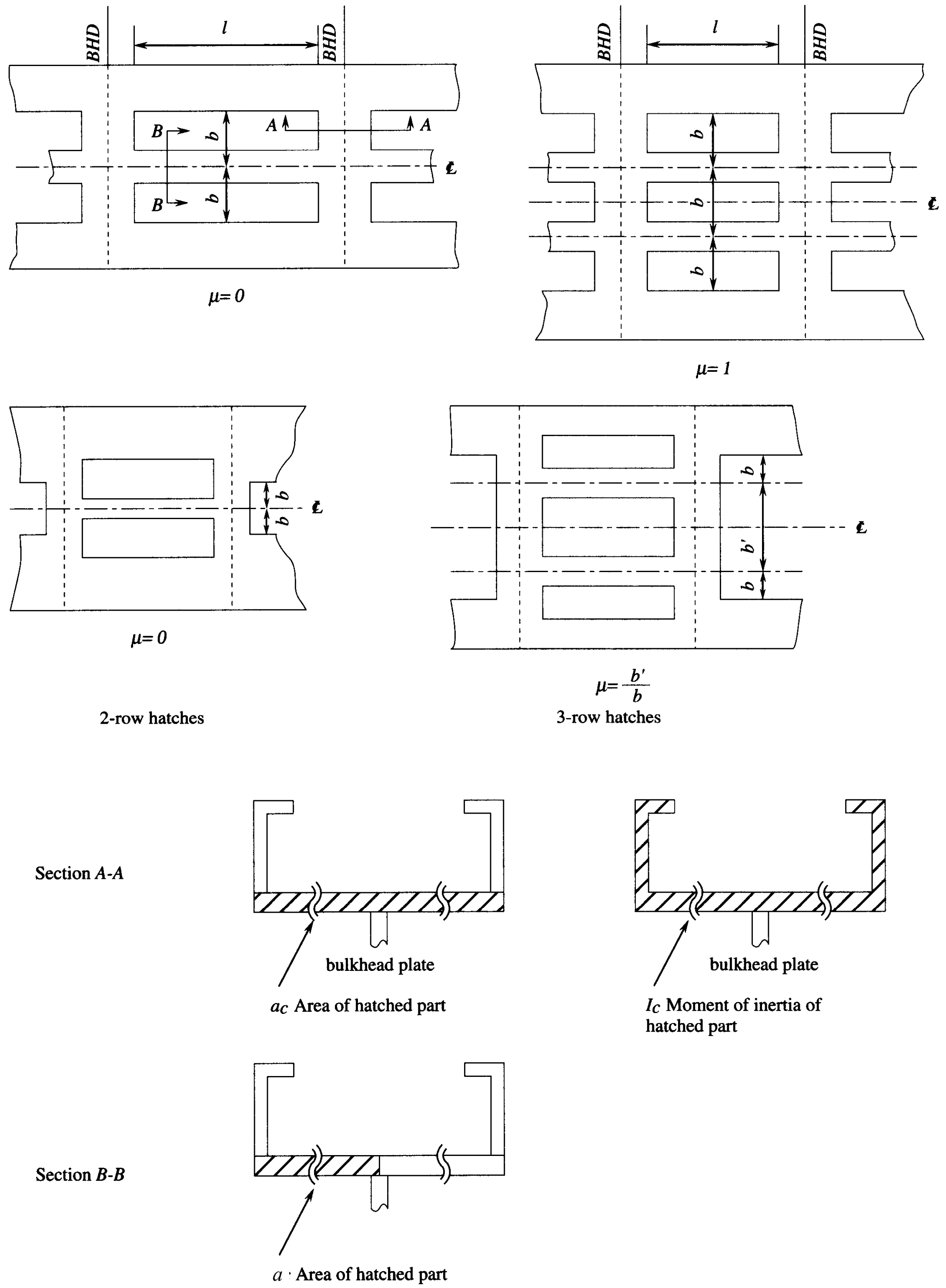


Fig. C32.2.9-3 Where Elliptic Hole and Circular Hole are in Same Cross-section

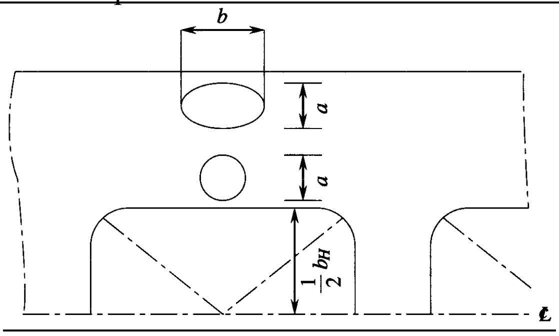


Fig. C32.2.9-4 Reinforcement by Means of Ring

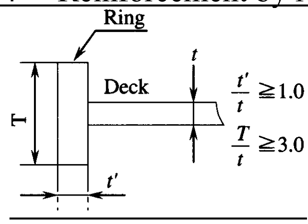
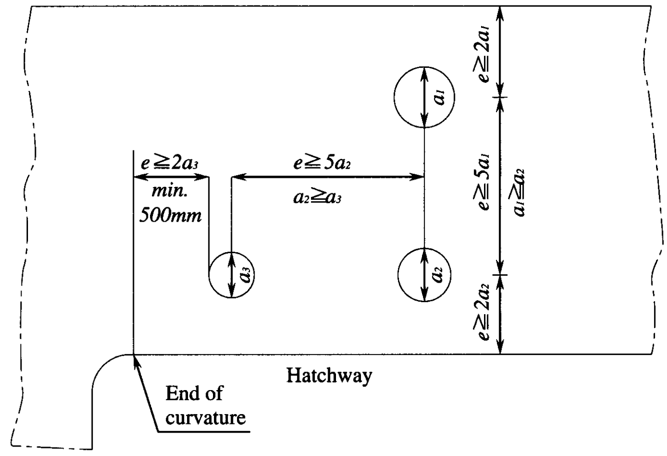


Fig. C32.2.9-5 Intervals Between Centres of Holes



C32.3 Torsional Strength

C32.3.1 General

1 The torsional strength of the hull is to comply with the following **(1)** or **(2)**:

(1) The torsional strength of the hull at each sectional position from the collision bulkhead to the watertight bulkhead at the fore end of the machinery space is to be such that the following relationship is satisfied.

$$\sqrt{(0.75\sigma_V)^2 + \sigma_H^2 + \sigma_\omega^2} + \sigma_S \leq \frac{1000}{5.72K}$$

where

σ_S, σ_V and σ_H : As obtained from the following formula

However, warping stress is to be added to σ_S when torsional moment is generated in the ship by unbalanced loading of cargoes.

$$\sigma_S = 1000\frac{|M_S|}{Z_V}$$

$$\sigma_V = 1000\frac{M_W}{Z_V}$$

$$\sigma_H = 1000\frac{M_H}{Z_H}$$

M_S : As specified in **15.2.1-1, Part C of the Rules**

M_W : M_W (+) or M_W (-) as specified in **15.2.1-1, Part C of the Rules** whichever is of the same sign as M_S

M_H : As obtained from the following formula:

$$0.45C_1L^2d(C_b + 0.05)C_H \quad (kN\text{-}m)$$

C_H : Coefficient, as given in **Table C32.3.1-1**, based on the ratio of *L* to *x*, where *x* is the distance (*m*) from the aft end of *L* to the section under consideration. Intermediate values are to be determined by interpolation.

Z_V : Section modulus (cm^3) of strength deck with respect to longitudinal bending of the hull at the position of the section under consideration

Z_H : Section modulus (cm^3) of hatch side with respect to horizontal bending of the hull at the position of the section under consideration

C_1 : As specified in **15.2.1-1, Part C of the Rules**

Table C32.3.1-1 Coefficient C_H

x/L	0.0	0.4	0.7	1.0
C_H	0.0	1.0	1.0	0.0

σ_ω : Warping stress (*N/mm*^{2}) due to torsion of the hull calculated according to the following formula for ships of ordinary construction using the dimensions and scantlings at the midship section.
Values for other types are to be in accordance with the discretion of the Society.

$$\sigma_\omega = 0.000318\frac{\omega l_C M_T}{I_\omega + 0.04 l_C^2 J}$$

M_T : As given by the following formula:

$$M_T = 7.0K_2C_w^2B^3\left(1.75 + 1.5\frac{e}{D_S}\right) \quad (kN\text{-}m)$$

C_w : Water plane area coefficient

e : As given by the following formula:

$$e = e_1 - \frac{d_0}{2}$$

e_1 : As given by the following formula:

$$e_1 = \frac{(3D_1 - d_1)d_1 t_d + (D_1 - d_1)^2 t_S}{3d_1 t_d + 2(D_1 - d_1)t_S + B_1 t_b / 3}$$

d_0 : Height of double bottom (m)

d_1 : Breadth of double hull side (m)

D_1 : As given by the following formula:

$$D_1 = D_S - \frac{d_0}{2}$$

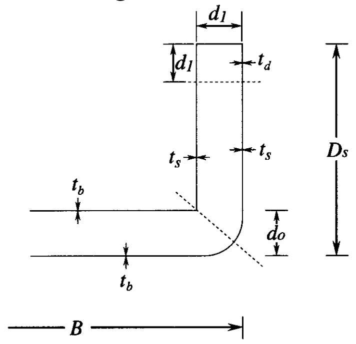
B_1 : As given by the following formula:

$$B_1 = B - d_1$$

t_d, t_s, t_b : Mean thickness (m) of deck, ship side, and bottom specified in **Fig. C32.3.1-1**

Mean thickness may be determined by including all the longitudinal strength members located within this range.

Fig. C32.3.1-1



K_2 : As given by the following formulae:

$$K_2 = \sqrt{1 - \left(\frac{300 - L_1}{300}\right)^2} \quad \text{for ships with } L_1 < 300\ m$$

1.0 for ships with $L_1 \geq 300\ m$

ω : As given by the following formula:

$$\omega = \frac{B_1}{2}(D_1 - e_1) + \frac{d_1}{2}(D_1 + e_1)$$

l_C : Distance (m) from the collision bulkhead to watertight bulkhead of the fore end of the machinery room

I_ω : As given by the following formula:

$$I_\omega = B_1^2 \{d_1 t_d I_d + (D_1 - d_1) t_S I_S + B_1 t_b I_b\}$$

I_d : As given by the following formula:

$$I_d = (D_1 - e_1)\left\{\frac{3}{2}(D_1 - e_1) - d_1\right\} + \frac{d_1^2}{3}$$

I_S: As given by the following formula:

$$I_S = (D_1 - d_1)\left\{\frac{1}{3}(D_1 - d_1) - e_1\right\} + e_1^2$$

I_b: As given by the following formula:

$$I_b = \frac{e_1^2}{6}$$

J: As given by the following formula

However, the mean thicknesses of t'_d, t'_S, t'_b are to be calculated using only the strength deck, side shell, bottom shell, inner bottom and longitudinal bulkhead plating. Other longitudinal strength members are not to be included.

$$J = \frac{2\{Bd_0 + 2(D_S - d_0)d_1\}^2}{3d_1 / t'_d + 2(D_1 - d_1)/t'_S + B_1 / t'_b}$$

K: Coefficient corresponding to the kind of steel

e.g.,1.0 for mild steel, the values specified in **1.1.7-2(1) of the Rules** for high tensile steel

(2) Torsional strength assessments are to be carried out in accordance with the **"Guidelines for Hull Girder Torsional Strength Assessment"** in the **"Guidelines for Container Carrier Structures"**

2 Notwithstanding the requirements of **-1** above, torsional strength assessments specified in **-1(2)** above may be required when deemed necessary by the Society.

~~**C32.3 Double Bottom Construction**~~

~~**C32.3.1 General**~~

~~Where the thickness of inner bottom plating is determined by the requirements of **6.5.1, Part C** of the Rules, the requirements of **6.5.1-3, Part C** of the Rules need not be applied.~~

C32.~~4~~5 Double Side Construction

C32.~~4~~5.1 General

1 Where the breadth of double side construction varies in the bilge part, t_1 in **32.~~4~~5.2-1** and **-2, Part C** of the Rules is to be determined as follows:

(1) β_T and β_L are to be obtained from the following formulae:

$$\beta_T = 1 + \frac{0.42\left(\frac{B}{D_S}\right)^2 - 0.5}{0.59\frac{D_S - \frac{d_0}{2} - l_{0R}}{B - d_1 - 2l_{1R}}\left(\frac{d_0}{d_1}\right)^2 + 1.0}$$

$$\beta_L = 1 + \frac{0.18\left(\frac{B}{D_S}\right)^2 - 0.5}{0.59\frac{D_S - \frac{d_0}{2} - l_{0R}}{B - d_1 - 2l_{1R}}\left(\frac{d_0}{d_1}\right)^2 + 1.0}$$

l_{0R} and l_{1R} are to be obtained as follows:

(a) Bilge hopper type (*See* **Fig. C32.~~4~~5.1-1**)

(b) Stepped type (*See* **Fig. C32.~~4~~5.1-2**)

(2) The lower end of *h* is to be a point at a height of l_{0R} above the inner bottom.

(3) ($d - l_{0R} + 0.038L'$) is to be substituted for ($d + 0.038L'$).

Fig. C32.~~4~~5.1-1

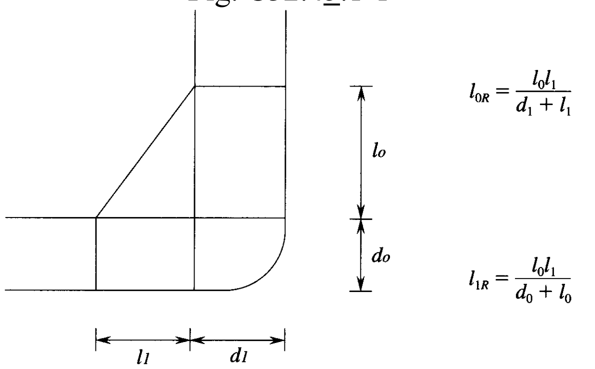
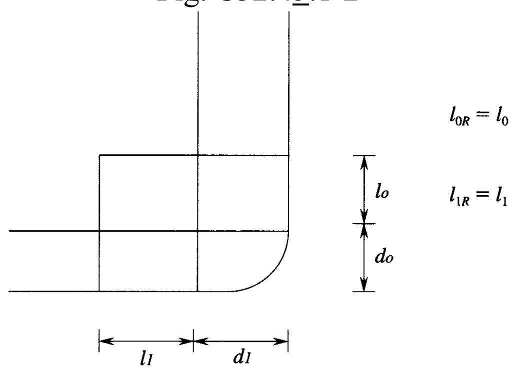


Fig. C32.~~4~~5.1-2



2 Where there is a combination of a cross-tie with ample sectional area and a non-watertight partial bulkhead or any other similar construction in the midway of the hold, l_H in the provisions of **32.~~4~~5, Part C** of the Rules may be measured from a watertight bulkhead to this construction.

3 Where the height from the designed maximum load line to the strength deck is unusually large, t_1 as per **32.~~4~~5.2-1** and **-2, Part C** of the Rules is to be calculated as follows.

(1) β_T and β_L are to be obtained from the following formulae:

$$\beta_T = 1 + \frac{0.42\frac{B^2}{D_S D'} - 0.5}{0.59\frac{D_S - \frac{d_0}{2}}{B - d_1}\left(\frac{d_0}{d_1}\right)^2 + 1.0}$$

$$\beta_L = 1 + \frac{0.18\frac{B^2}{D_S D'} - 0.5}{0.59\frac{D_S - \frac{d_0}{2}}{B - d_1}\left(\frac{d_0}{d_1}\right)^2 + 1.0}$$

Where:

D' : Depth of the ship (*m*)

Where the imaginary freeboard deck is provided according to **C1.1.3-2(1)**, D' may be the height (*m*) from the top of keel to this assumed deck.

(2) The value obtained from the following formula is to be substituted for ($d + 0.038L'$).

$$\left(d + 0.038L'\right) \times \sqrt{\frac{D'}{D_S}}$$

Where:

D' : As per **(1)**

4 Where the breadth of angles or flat bars supporting stiffeners in the double hull of side construction is unusually large, the scantlings of stiffeners may be determined in accordance with the provision of **C1.1.13-1**.

C32.8 Strength at Large Flare Locations

C32.8.1 Shell Plating

The thickness of shell plating above the load line for 0.2L forward is to be in accordance with **C16.4.1.**

C32.8.2 Frames

The thickness t_w of web plates and the plastic section modulus Z_p of frames above the load line for 0.2L forward are to be in accordance with **C7.1.8-1.**

C32.8.3 Girders

1 The thickness t_{wG} of web plating and the section modulus Z_G of girders above the load line for 0.2L forward are to be in accordance with **C8.1.4-1.**

2 Buckling strength of girder webs specified in **-1** is to be examined by the requirements in **C8.1.4-2** and **-3**.

C32.9 Direct Strength Calculations for Primary Structural Members

C32.9.1 Application

The "formulae in this chapter which can be substituted for by direct strength calculations" specified in **32.9.1-3, Part C** of the Rules means the formulae shown in **Table C32.9.1-1**.

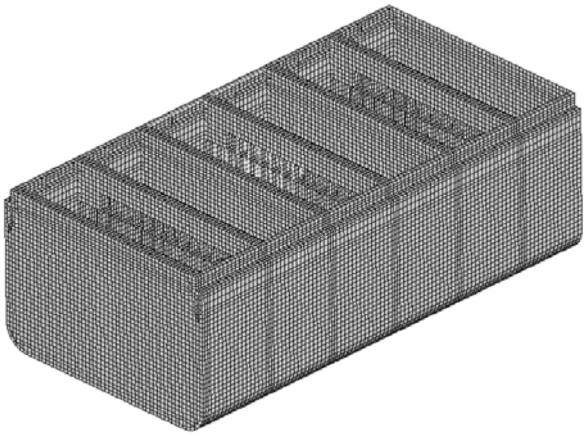
Table C32.9.1-1 Formulae Which Can Be Substituted for by Direct Strength Calculations

Part C of the Rules	formulae
32.4.4-1	the first formula of the formulae for the thickness of inner bottom plating
32.4.5-1	the first formula of the formulae for the thickness of bottom shell plating
32.5.2-1	the formulae for the thickness of side transverse girders
32.5.2-2	the formulae for the thickness of side stringers
32.7.1(1)	the formula for the thickness of decks inside the line of deck openings
32.7.1(2)	the formula for the section modulus of decks inside the line of deck openings
32.7.1(3)	the formula for the moments of inertia of decks inside the line of deck openings
6.2.3(1) and **(2)**	the formulae for the thicknesses of centre girder plates and side girder plates
6.3.2(1) and **(2)**	the formulae for the thickness of solid floors

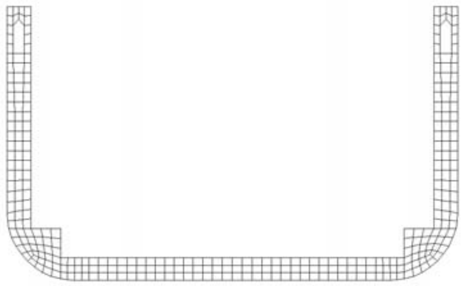
C32.9.7 Modelling for Structural Analysis

1 Examples of structural models are shown in **Fig. C32.9.7-1**.

Fig. C32.9.7-1 Example of Structural Model



(a) Overall View



(b) Transverse Section

2 Stiffeners are to be modelled so as to take the eccentricity of the neutral axis into account.

3 As for the meshing of elements required in **32.9.7-5, Part C of the Rules**, the shell element mesh is to follow the stiffening system as far as practicable, hence representing the actual plate panels between stiffeners. In principle, the shell element mesh is to satisfy the following **(1)** to **(4)**:

(1) One element between every longitudinal stiffener. Longitudinally, element length is not to be greater than 2 longitudinal spaces with a minimum of three elements between primary supporting members;

(2) One element between every stiffener on transverse bulkheads;

(3) One element between every web stiffener on transverse and vertical web frames, and stringers; and

(4) At least 3 elements over the depth of transverse web frames, vertical web frames and horizontal stringers on transverse bulkheads.

4 The "deemed necessary by the Society" specified in **32.9.7-6, Part C of the Rules** means openings in the transverse girder in the bilge part, and openings in the vertical webs of the partial bulkheads, etc. Openings are modelled by recreating the opening's shape with fine mesh, or removing the appropriate elements in consideration of size and position of the opening.

5 Where loads due to containers are to be determined in accordance with **32.9.7-7, Part C of the Rules**, the dynamic load due to a container is to be taken according to the direction of gravity and inertial force of the container, and is to be accordance with the following **(1)** and **(2)**:

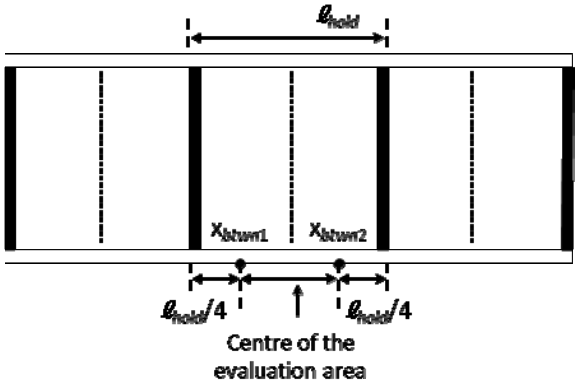
(1) As for containers stowed in holds, vertical loads are applied to the structural members coming

in contact with the bottom of container stack, and longitudinal and transverse loads are applied to the structural members attached to the container supporting arrangements. The longitudinal and the transverse dynamic loads of containers in holds which are applied to the structural members attached to the container supporting arrangements are considered to be the half of their respective longitudinal and transverse dynamic loads of containers in holds.

(2) As for containers stowed on decks, vertical loads are applied to the position of the top of the hatch coaming, and longitudinal loads are applied to the position of the locking devices of the hatch covers. All containers loaded on a hatch cover may be considered as a single load for said hatch cover.

6 The "centre of the evaluation area" specified in **32.9.7-7(3), Part C of the Rules** means the area of centre $\ell_{hold}/2$ in **Fig. C32.9.7-2**.

Fig. C32.9.7-2 Extent of Modelling



7 Where the adjustment moments are applied at the fore and aft ends of the model in accordance with **32.9.7-7(3), Part C** of the Rules, the procedure is to be accordance with the following **(1)** to **(3)**:

(1) The maximum and minimum bending moment M_{V_Max}, M_{H_Max}, M_{V_Min} and M_{H_Min}, which are taken as the maximum and minimum values between the vertical bending moment and horizontal bending moment due to local loads at location x_{btwn1} of a cargo hold in the evaluation area and those at location x_{btwn2} of a cargo hold in the evaluation area, are to be obtained by the following formulae. The weight of the hull structure, container weight, dynamic load of the container, hydrostatic pressure and hydrodynamic pressure are to be considered as local loads.

$M_{V\_Max} = \max(M_{V\_FEM}(x_{btwn1}), M_{V\_FEM}(x_{btwn2}))$ (*kN-m*)

$M_{V\_Min} = \min(M_{V\_FEM}(x_{btwn1}), M_{V\_FEM}(x_{btwn2}))$ (*kN-m*)

$M_{H\_Max} = \max(M_{H\_FEM}(x_{btwn1}), M_{H\_FEM}(x_{btwn2}))$ (*kN-m*)

$M_{H\_Min} = \min(M_{H\_FEM}(x_{btwn1}), M_{H\_FEM}(x_{btwn2}))$ (*kN-m*)

$M_{V\_FEM}(x)$: Vertical bending moment due to local loads at any position *x*, to be taken as follows:

$$M_{V\_FEM}(x) = -(x - x_{aft})R_{V\_aft} - (x - x_i)\sum_i^{x_i<x} f_{vi} \quad (kN\text{-}m)$$

$M_{H\_FEM}(x)$: Horizontal bending moment due to local loads at any position *x*, to be taken as follows:

$$M_{H\_FEM}(x) = (x - x_{aft})R_{H\_aft} + (x - x_i)\sum_i^{x_i<x} f_{hi} \quad (kN\text{-}m)$$

x_{aft}, x_{fore}: *X*–coordinate, in *m*, of the support points at the fore and aft ends of the model.

R_{V_fore}, R_{V_aft}, R_{H_fore}, R_{H_aft}: Vertical and horizontal reaction forces at the support points at the fore and aft ends of the model, to be taken as follows:

$$R_{V\_fore} = -\frac{\sum_i (x_i - x_{aft}) f_{vi}}{x_{fore} - x_{aft}} \quad (kN)$$

$$R_{V\_aft} = -\sum_i f_{vi} - R_{V\_fore} \quad (kN)$$

$$R_{H\_fore} = -\frac{\sum_i (x_i - x_{aft}) f_{hi}}{x_{fore} - x_{aft}} \quad (kN)$$

$$R_{H\_aft} = -\sum_i f_{hi} - R_{H\_fore} \quad (kN)$$

x_i: *X*–coordinate, in *metres*, of the considered longitudinal station *i*.

f_{vi} and f_{hi}: Vertical and horizontal local loads at x_i (*kN*).

x_{btwn1}: *X*–coordinate, in *metres*, at the 1/4 length of the evaluation area forward from the aft end of the cargo hold in the evaluation area. (See **Fig. C32.9.7-2**) .

x_{btwn2}: *X*–coordinate, in *metres*, at the 3/4 length of the evaluation area forward from the aft end of the cargo hold in the evaluation area. (See **Fig. C32.9.7-2**) .

(2) The adjustment vertical bending moment, M_{V-end}, and adjustment horizontal bending moment, M_{H-end}, are obtained by the following formulae.

$M_{V-end} = M_{V-HG} - M_{V\_Min}$ (*kN-m*) for $M_{V-t\arg} \geq 0$

$M_{V-end} = M_{V-HG} - M_{V\_Max}$ (*kN-m*) for $M_{V-t\arg} < 0$

$M_{H-end} = M_{H-HG} - M_{H\_Min}$ (*kN-m*) for $M_{H-t\arg} \geq 0$

$M_{H-end} = M_{H-HG} - M_{H\_Max}$ (*kN-m*) for $M_{H-t\arg} < 0$

M_{V-HG}, M_{H-HG}: Vertical bending moment and horizontal bending moment in **32.9.6-5, Part C of the Rules**.

(3) The adjustment moments M_{V-end} and M_{H-end} derived from **(2)** above are to be applied to the support points at the fore and aft ends of the model.

8 In the application of **32.9.7-8, Part C of the Rules**, the boundary conditions applied at the fore and aft end of the model are to be according to **Table C32.9.7-1**. Rigid links are to connect the nodes on the longitudinal members at the model ends to an independent point at the neutral axis in the centreline.

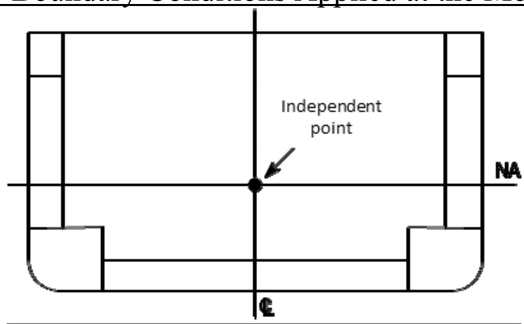
Table C32.9.7-1 Boundary Constraints at Model Ends

Location	Translation			Rotation		
	δ_x	δ_y	δ_z	θ_x	θ_y	θ_z
Aft End						
Independent point	-	Fix	Fix	Fix	$-M_{V\text{-}end}$	$-M_{H\text{-}end}$
Cross section	Rigid link	Rigid link	Rigid link	Rigid link	Rigid link	Rigid link
Fore End						
Independent point	Fix	Fix	Fix	Fix	$+M_{V\text{-}end}$	$+M_{H\text{-}end}$
Cross section	Rigid link	Rigid link	Rigid link	Rigid link	Rigid link	Rigid link

Notes:
$M_{V\text{-}end}$, $M_{H\text{-}end}$: Adjustment vertical bending moment, M_{V-end}, and adjustment horizontal bending moment, M_{H-end}, to be taken as given in **C32.9.7-7(2)**.

(1): [-] means no constraint applied (free)
(2): See **Fig.C32.9.7-3**.

Fig. C32.9.7-3 Boundary Conditions Applied at the Model End Sections



C32.9.8 Yield Strength Assessment

1 In the application of **32.9.8, Part C of the Rules**, when fine mesh is used rather than the standard mesh given in **C32.9.7-3**, the mean stress corresponding to the standard mesh may be used.

2 The "deemed appropriate by the Society" specified in **32.9.8-2, Part C of the Rules** means calculating the shear stress and the stress in the spanwise direction of girder in consideration of the effective shear area of the web. The effective shear area of the web is to be taken as the web area deducting the area lost due to openings in accordance with the following **(1)** and **(2)**:

(1) When both sides of the web are plate members, the equivalent stress σ_{eq_cor} is to be calculated with the shear stress modified in accordance with following formula:

$$\sigma_{eq\_cor} = \sqrt{\sigma_{elem\_s}{}^2 - \sigma_{elem\_s} \cdot \sigma_{elem\_d} + \sigma_{elem\_d}{}^2 + 3\tau_{cor}{}^2}$$

τ_{cor}: Corrected element shear stress, in N/mm^2, to be taken as follows:

$$\tau_{cor} = \frac{ht_{mod-n50}}{A_{shr-n50}} \tau_{elem}$$

τ_{elem}: Element shear stress (N/mm^2) before correction.

$t_{mod-n50}$: Modelled web thickness (*mm*) in way of the opening.

h: Height of web of girder (*mm*) in way of the opening.

$A_{shr-n50}$: Effective net shear area of web (mm^2) taken as the web area deducting the area lost due to openings calculated with an effective web height h_{eff} (*mms*), which is to be taken as the lesser of the following:

$h_{eff} = h_w$

$h_{eff} = h_{w3} + h_{w4}$

$h_{eff} = h_{w1} + h_{w2} + h_{w4}$

h_w: Web height of primary supporting member (*mm*).

h_{w1}, h_{w2}, h_{w3}, h_{w4}: Dimensions shown in **Fig. C32.9.8-1**.

σ_{elem_s}: Stress in the spanwise direction of the girder (N/mm^2) before correction.

σ_{elem_d}: Stress in the depth direction of the girder (N/mm^2) before correction.

(2) When both sides of the web are any case other than those in **(1)** above, the equivalent stress σ_{eq_cor} is to be calculated with the shear stress modified in accordance with following formula:

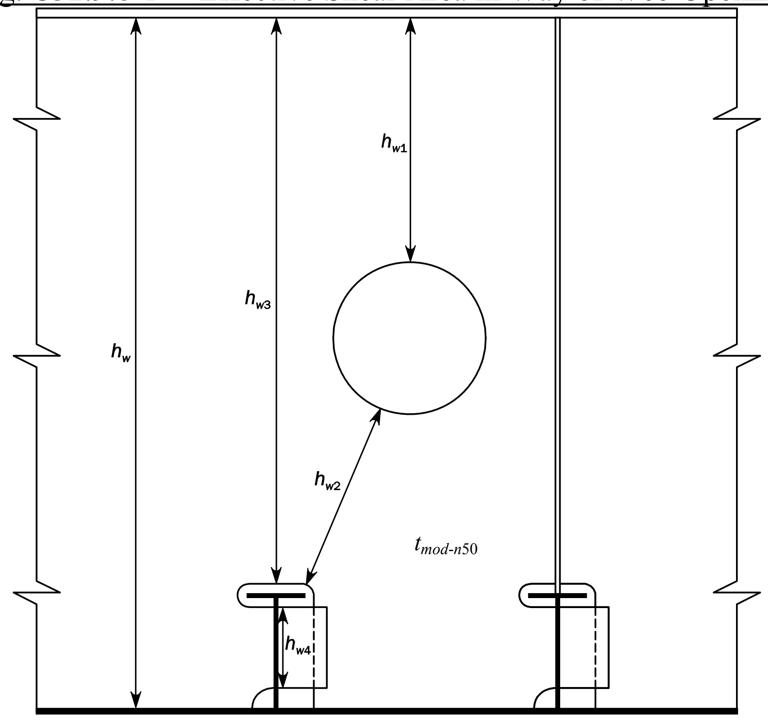
$$\sigma_{eq\_cor} = \sqrt{\sigma_{cor\_s}{}^2 - \sigma_{cor\_s} \cdot \sigma_{elem\_d} + \sigma_{elem\_d}{}^2 + 3\tau_{cor}{}^2}$$

σ_{cor_s}: Corrected stress in the spanwise direction of girder(N/mm^2) to be taken as follows:

$$\sigma_{cor\_s} = \frac{ht_{mod-n50}}{A_{shr-n50}} \sigma_{elem\_s}$$

τ_{cor}, σ_{elem_s}, σ_{elem_d}, $t_{mod-n50}$, *h*, $A_{shr-n50}$: As specified in **(1)** above.

Fig. C32.9.8-1 Effective Shear Area in Way of Web Openings



C32.9.9 Buckling Strength Assessment

1 Where the plate thickness along a plate panel is not constant, the plate thickness used for the buckling assessment is to be modified with a weighted average thickness taken as follows:

$$t_{avr} = \frac{\sum_{1}^{n} A_i t_i}{\sum_{1}^{n} A_i}$$

A_i: Area of the i-th plate element.

t_i: Net thickness of the i-th plate element.

n: Number of finite elements defining the buckling plate panel.

2 The panel yield stress σ_{YP} is to be taken as the minimum value of the specified yield stresses of the elements within the plate panel.

3 The buckling assessment is to be carried out according to one of the following two methods, taking into account the continuity of the panel and the boundary condition types:

Method A: Critical buckling stresses are calculated by assuming that all the boundary edges of the panel are forced to remain straight due to the surrounding structure /neighbouring plates.

Method B: Critical buckling stresses are calculated by assuming that the boundary edges of the panel are not forced to remain straight due to low in-plane stiffness at the edges and/or no surrounding structure/ neighbouring plates.

4 The buckling strength assessment for each member is to be accordance with the following requirements:

(1) All plate and girder members of the hull are to be modelled as plane panels, which are separated by stiffeners or girder members, and the buckling utilization factor of each panel is to be calculated by the method given in **Annex C32.2.7 "GUIDANCE FOR BUCKLING**

STRENGTH ASSESSMENT" in consideration of the following **(a)** and **(b)**.

(a) Method A is used for the rectangular shape panels of plate members, which are regularly stiffened, and the panels of girder members which are regularly stiffened in the depth direction of the girder.

(b) Method B is used for panels of plate members, which are stiffened using irregular spacing or irregular angles, and the panels of girder members which are stiffened in the spanwise direction of the girder. Non-rectangular shaped panels are to be calculated by an appropriate method so that they can be replaced by an equivalent rectangular shape panel.

(2) The buckling utilization factors of stiffeners specified in the following **(a)** and **(b)** are to be calculated by the method given in **Annex C32.2.7 "GUIDANCE FOR BUCKLING STRENGTH ASSESSMENT"**.

(a) Stiffeners fitted on longitudinal structural members.

(b) Stiffeners other than **(a)** above, under large compression loads.

(3) For members not subject to **(1)** and **(2)** above for special reasons, the buckling utilization factor may be obtained by non-linear analysis, etc.

5 The "deemed appropriate by the Society" specified in **32.9.9-3, Part C** of the Rules means the method given in **2.5** of **Annex C32.2.7 "GUIDANCE FOR BUCKLING STRENGTH ASSESS"**.

C32.10 Fatigue Strength

C32.10.1 Fatigue Strength Assessment

1 Fatigue strength assessments for bottom longitudinals and side longitudinals are to be in accordance with the requirements in **1.1.23-4** and **-5, Part C of the Rules**.

2 Fatigue strength assessments for the longitudinal structural members of upper decks, including hatch side coamings and bench corners in forword holds, are to be as follows:

(1) Hatch side coaming top plate at hatch corner is to be in accordance with the followings:

(a) Hatch side coaming top plates at hatch corners are to have sufficient fatigue strength. The Society may require fatigue strength assessments according to the **"Guidelines for Fatigue Strength Assessment"** in the **"Guidelines for Container Carrier Structures"** in consideration of the kind of steel used, the size of the ship, and the structural arrangement, etc. Hot-spot stresses at hatch corners (hot-spot mean stress and hot-spot stress fluctuation range) are to be determined using detailed Finite Element Analysis (FEA) using fine mesh elements. Element sizes, details of analysis and so on are to be at the Society's discretion.

(b) Butt welds for hatch side coamings and fillet welded joints for attaching equipment are to be set at a sufficient distance from hatch corners so that the effects of stress concentration are avoided. The Society may require the submission of drawings and data related to arrangement of welded joints.

(2) For butt welded joints and fillet welded joints of hatch side coamings (including welds for attaching equipment, etc.), special consideration is to be given to fatigue strength. The Society may require the submission of relevant fatigue strength assessments.

(3) Fatigue strength of locations other than hatch side coamings is to be in accordance with the following:

(a) The fatigue strength at locations other than hatch side coamings (strength decks, sheer strakes, uppermost strakes of longitudinal bulkheads) are to be sufficiently considered in conjunction with increases of hull girder stress (longitudinal bending stress and torsional stress).

(b) The Society may require fatigue assessments according to the **"Guidelines for Fatigue Strength Assessment"** in the **"Guidelines for Container Carrier Structures"** in consideration of the kind of steel used, the size of the ship, and the structural arrangement, etc. If deemed necessary, the Society may require that detailed Finite Element Analysis (FEA) be used to calculate hatch corner hot-spot stresses.

(c) The fatigue strength of hatch corner in way of forward holds is to be carefully considered. If deemed necessary by the Society, a fatigue strength assessment of the relevant part may be required.

3 When deemed necessary by the Society, fatigue strength assessments may be required for structural members other than those specified in **-1** and **-2** above.

C32.~~10~~13 Special Requirements for Container Carriers applying Extremely Thick Steel Plates

C32.~~10~~13.3 Measures for prevention of brittle fracture

1 "Other measures deemed by the Society to be equivalent in effectiveness to brittle crack arrest designs" in Note~~s~~ (1) of **Table C32.~~7~~27, Part C of the Rules** means the non-destructive testing of particularly Time-of-flight diffraction (*TOFD*) technique specified in **1.1.2-3** of **Annex ~~M1.4.2-2 "GUIDANCE FOR NON-DESTRUCTIVE INSPECTIONS ON SURFACE IMPERFECTIONS OF THE WELDED JOINTS OF HULL CONSTRUCTIONS"~~ M1.4.2-3(1) "GUIDANCE FOR NON-DESTRUCTIVE INSPECTION ON INTERNAL IMPERFECTIONS OF THE WELDED JOINTS OF HULL CONSTRUCTIONS"** is carried out at location specified in **1.2.4** of **Annex ~~M1.4.2-2~~M1.4.2-3(1)**.

2 Where the measures specified in **-1** above is applied, it may be considered as equivalent in effectiveness as measures specified **32.~~10~~13.4-4(2)** and **(3), Part C of the Rules**.

C32.~~10~~13.4 Brittle crack arrest design

1 "Appropriate measure" in **32.~~10~~13.4-4(3), Part C of the Rules** means that the block-to-block butt welds of the hatch side coaming are to be shifted from those of the strength deck, this shift is to be greater than or equal to 300*mm* in principle and welded joints between hatch side coaming and strength deck are to be fillet weld at each side without groove for an appropriate region.

2 If detailed documentation (including information such as construction procedure, application and procedure of non-destructive inspections at joints, etc.) which demonstrates the applicability as an alternative measure to **-1** above is submitted to and approved by the Society, the following **(1)** and **(2)** may be applied instead. In such cases, where deemed necessary by the Society, brittle fracture tests may be required to confirm the effectiveness of the alternative measure.

(1) Where crack arrest holes are provided in way of the block-to-block butt welds at the region where hatch side coaming weld meets the deck weld, the fatigue strength of the lower end of the butt weld is to be assessed.

(2) Where arrest insert plates of brittle crack arrest steel or weld metal inserts with high crack arrest toughness properties are provided in way of the block-to-block butt welds at the region where hatch side coaming weld meets the deck weld.

3 In **32.~~10~~13.4-6, Part C of the Rules**, where steel plate being evaluated using the manner of assessment other than specified in **3.12, Part K of the Rules** is for use as crack arresting steel, documents related to the manner of assessment and the applicability which the measure has equivalent with brittle crack arrest properties for *A*600 are submitted to the Society for approval. In this case, where deemed necessary by the Society, additional test may be required.

C34 LOADING MANUAL AND LOADING COMPUTER

C34.1 General

C34.1.3 Loading Computer

Sub-paragraph -2 has been amended as follows.

2 The accuracy of the loading computer is to be verified by either procedure **(1)** or **(2)** below, by selecting not less than four loading conditions stated in the loading manual. The computing accuracy may be reasonably altered at the points where the absolute values of still water shearing force and longitudinal still water bending moment become particularly insignificant.

((1) is omitted.)

(2) The values of still water shearing force and longitudinal still water bending moment computed by a computing procedure as deemed appropriate by the Society in accordance with the requirements of **15.2.1-1** and **15.3.1-1, Part C** of the Rules or the vertical still water shear force and vertical still water bending moment computed in accordance with the requirement of **32.2.3, Part C of the Rules** for ships to which the requirements in **Chapter 32, Part C of the Rules** apply, are to be compared with those values computed by the loading computer under consideration, and it is to be confirmed that respective errors are to be less than ±3%. The calculation data is to be submitted to the Society.

Annex C15.2.1 GUIDELINE FOR THE ASSESSMENT OF HULL GIRDER STRENGTH RELATING TO BALLSTING/DEBALLASTING

1.1 General

Paragraph 1.1.1 has been amended as follows.

1.1.1 Application

This Annex provides general guidelines for the determination of loading conditions to be considered in the application of **32.2, Part C of the Rules** for ships subject to the requirements in **Chapter 32, Part C of the Rules** and **Chapter 15, Part C of the Rules**, for ships intended to be operated with partially filled ballast tanks and ships in which any ballasting and/or deballasting of ballast tanks is intended during voyages.

1.2 Guidelines for the Assessment of Hull Girder Strength

Paragraph 1.2.1 has been amended as follows.

1.2.1 Loading Conditions to be Considered

1 Ships intending to operate with partially filled ballast tanks are required to be designed so as to comply with the requirements of hull girder strength specified in **32.2, Part C of the Rules** for ships subject to the requirements in **Chapter 32, Part C of the Rules** and **Chapter 15, Part C of the Rules**, when the ballast tanks are full and when they are empty. For this purpose, compliance with the hull girder strength requirements of **32.2, Part C of the Rules** for ships subject to the requirements in **Chapter 32, Part C of the Rules** and **Chapter 15, Part C of the Rules** is to be assessed for conditions just before and just after such ballasting/deballasting operation is conducted, for partially filled conditions, as well as when such ballast tanks are assumed empty or full. (Refer to **C15.2.1(4)**.)

(-2 is omitted.)

3 For ships intending to ballast/deballast during the voyage, loading conditions corresponding to all steps of the ballasting/deballasting operation are to be included in the ships' loading manuals as intermediate conditions which are part of the standard loading conditions. For this purpose, "step" is a condition just before and just after a ballasting/deballasting operation for each tank. Such intermediate conditions are to be assessed in compliance with the requirements of **32.2, Part C of the Rules** for ships subject to the requirements in **Chapter 32, Part C of the Rules** and **Chapter 15, Part C of the Rules**. (Refer to **1.3.1-2 of Annex C34.1.2** and **C15.2.1(4)**)

(-4 to -6 are omitted.)

Annex C32.2.3-4 has been added as follows.

Annex C32.2.3-4 GUIDANCE FOR CALCULATION OF SHEAR FLOW

1.1 General

1.1.1 General

This Guidance describes the procedures of direct calculation of shear flow which is working along a ship cross section due to hull girder vertical shear force. Shear flow q_v, at each location in the cross section, is calculated where considering the cross section is subjected to a unit vertical shear force, 1*N*, in the direction of *z* coordinate. The unit shear flow per millimetre, q_v in *N/mm*, can be considered equal to:

$q_v = q_D + q_I$

q_D : Determinate shear flow, as defined in **1.2**.

q_I : Indeterminate shear flow which circulates around the closed cells, as defined in **1.3**.

In the calculation of the unit shear flow, q_v, the longitudinal stiffeners are to be taken into account.

1.2 Determinate Shear Flow

1.2.1 Determinate Shear Flow

The determinate shear flow, q_D in *N/mm*, at each location in the cross section can be obtained from the following line integration:

$$q_D(s) = -\frac{1}{10^6 I_y}\int_0^s (z - z_n)t\,ds$$

s : Coordinate value of running coordinate along the cross section, in *m*.

I_y : Moment inertia of the cross section, in m^4.

t : Thickness of plating.

z_n : *Z* coordinate of horizontal neutral axis from baseline, in *m*.

It is assumed that the cross section is composed of line segments as shown in **Fig. 1**: where each line segment has a constant plate net thickness. The determinate shear flow is obtained by the following equation.

$$q_{Dk} = -\frac{t\ell}{2\times 10^6 I_y}(z_k + z_i - 2z_n) + q_{Di}$$

q_{Dk}, q_{Di} : Determinate shear flow at node *k* and node *i* respectively , in *N/mm*.

ℓ : Length of line segments, in *m*.

y_k, y_i : *Y* coordinate of the end points *k* and *i* of line segment, in *m*, as defined in **Fig. 1**.

z_k, z_i: *Z* coordinate of the end points *k* and *i* of line segment, in *m*, as defined in **Fig. 1**.

Where the cross section includes closed cells, the closed cells are to be cut with virtual slits, as shown in **Fig. 2** in order to obtain the determinate shear flow. However, the virtual slits are not to be located at the walls by which the other closed cell is also bounded. Calculations of the determinate shear flow at bifurcation points can be calculated such as water flow calculations as shown in **Fig. 2**.

Fig.1 Definition of Line Segment

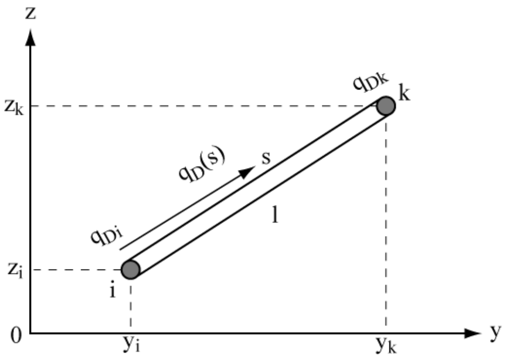
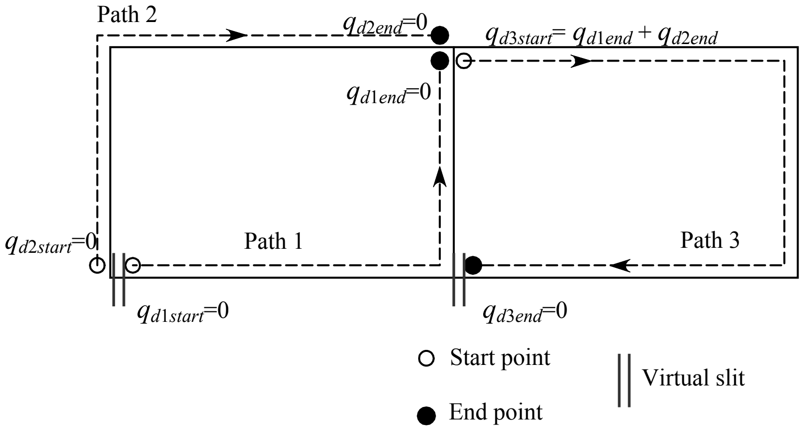


Fig.2 Calculation of Determinate Shear Flow at Bifurcation



1.3 Indeterminate Shear Flow

1.3.1 Indeterminate Shear Flow

The indeterminate shear flow is working around the closed cells and can be considered as a constant value within the same closed cell. The following system of equation for determination of indeterminate shear flows can be developed. In the equations, contour integrations of several parameters around all closed cells are performed.

$$q_{Ic}\oint_{c}\frac{1}{t}ds-\sum_{m=i}^{Nw}q_{Im}\oint_{c\&m}\frac{1}{t}ds=-\oint_{c}\frac{q_D}{t}ds$$

Nw : Number of common walls shared by cell *c* and all other cells.

c&m : Common wall shared by cells *c* and *m*

q_{Ic}, q_{Im} : Indeterminate shear flow around the closed cell *c* and *m* respectively, in *N/mm*.

Under the assumption of the assembly of line segments shown in **Fig. 1** and constant plate thickness of each line segment, the above equation can be expressed as follows:

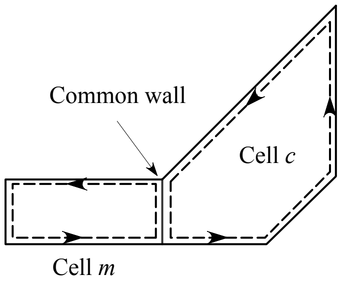
$$q_{Ic}\sum_{j=1}^{Nc}\left(\frac{\ell}{t}\right)_j-\sum_{m=1}^{Nw}\left\{q_{\mathrm{Im}}\left[\sum_{j=1}^{Nm}\left(\frac{\ell}{t}\right)_j\right]_m\right\}=-\sum_{j=1}^{Nc}\phi_j$$

$$\phi_j=\left[-\frac{\ell^2}{6\times10^3 I_y}(z_k+2z_i-3z_n)+\frac{\ell}{t}q_{Di}\right]_j$$

N_c : Number of line segments in cell *c*.
N_m : Number of line segments on the common wall shared by cells *c* and *m*.
q_{Di} : Determinate shear flow, in *N*/*mm*, calculated according to **1.2**.

The difference in the directions of running coordinates specified in **1.2** and in this section has to be considered.

Fig. 3 Closed Cells and Common Wall



1.4 Computation of Sectional Properties

1.4.1 Computation of Sectional Properties

Properties of the cross section are to be obtained by the following formulae where the cross section is assumed as the assembly of line segments:

$$\ell = \sqrt{(y_k - y_i)^2 + (z_k - z_i)^2}$$

$$a = 10^{-3}\ell t \qquad A = \sum a$$

$$s_y = \frac{a}{2}(z_k + z_i) \qquad S_y = \sum s_y$$

$$i_{y0} = \frac{a}{3}(z_k^2 + z_k z_i + z_i^2) \qquad I_{y0} = \sum i_{y0}$$

a, *A* : Area of the line segment and the cross section respectively, in m^2.
s_y, S_y : First moment of the line segment and the cross section about the baseline, in m^3.
i_{y0}, I_{y0} : Moment of inertia of the line segment and the cross section about the baseline, in m^4.

The height of horizontal neutral axis, z_n, in *m*, is to be obtained as follows:

$$z_n = \frac{S_y}{A}$$

Inertia moment about the horizontal neutral axis, in m^4, is to be obtained as follows:

$$I_y = I_{y0} - z_n^2 A$$

Annex C32.2.7 has been added as follows.

Annex C32.2.7 GUIDANCE FOR BUCKLING STRENGTH ASSESSMENT

1.1 General

1.1.1 Definitions

1 Unless specified otherwise, the definitions of the symbols used in this Guidance are as specified in **Table 1**.

2 In this Guidance, compressive stresses are taken as positive stresses while tensile stresses are taken as negative stresses.

Table 1 Symbols

Symbol	Unit	Definition
x axis		Local axis of a rectangular buckling panel parallel to its long edge.
y axis		Local axis of a rectangular buckling panel perpendicular to its long edge.
σ_x	N/mm^2	Stress applied on the edge along *x* axis of the buckling panel.
σ_y	N/mm^2	Stress applied on the edge along *y* axis of the buckling panel.
τ	N/mm^2	Applied shear stress.
σ_a	N/mm^2	Axial stress in the stiffener, defined in **2.4.4-2**.
σ_b	N/mm^2	Bending stress in the stiffener, defined in **2.4.4-3**.
σ_w	N/mm^2	Warping stress in the stiffener, defined in **2.4.4-4**.
σ_{cx}, σ_{cy}, τ_c	N/mm^2	Critical stress, defined in **2.2.1-1** for plates.
σ_{YS}	N/mm^2	Specified minimum yield stress of the stiffener, defined in **2.4.4-1**.
σ_{YP}	N/mm^2	Specified minimum yield stress of the plate.
a	*mm*	Length of the longer side of the plate panel. (See **Table 4**)
b	*mm*	Length of the shorter side of the plate panel. (See **Table 4**)
d	*mm*	Length of the side parallel to the axis of the cylinder corresponding to the curved plate panel as shown in **Table 5**.
σ_E	N/mm^2	Elastic buckling reference stress, to be taken as: For the application of plate limit state according to **2.2.1-2**: $\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_p}{b}\right)^2$ For the application of curved plate panels according to **2.2.2**: $\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_p}{d}\right)^2$
υ		Poisson's ratio, taken as 0.3.
t_p	*mm*	Thickness of plate panel.
t_w	*mm*	Stiffener web thickness.
t_f	*mm*	Flange thickness.

Table 1 Symbols (continued)

Symbol	Unit	Definition
b_f	*mm*	Breadth of the stiffener flange.
h_w	*mm*	Depth of stiffener web.
e_f	*mm*	Distance from attached plating to centre of flange, to be taken as follows: $e_f = h_w$ for flat bar profile. $e_f = h_w - 0.5\ t_f$ for bulb profile. $e_f = h_w + 0.5\ t_f$ for angle and Tee profiles.
α		Aspect ratio of the plate panel, to be taken as follows: $\alpha = \frac{a}{b}$
β		Coefficient taken as follows: $\beta = \frac{1-\psi}{\alpha}$
ψ		Edge stress ratio to be taken as follows: $\psi = \frac{\sigma_2}{\sigma_1}$
γ		Stress multiplier factor acting on loads. When the factor is such that the loads reach the interaction formulae, $\gamma = \gamma_c$.
γ_c		Stress multiplier factor at failure.
σ_1	N/mm^2	Maximum stress.
σ_2	N/mm^2	Minimum stress.
R	*mm*	Radius of curved plate panel.
E	N/mm^2	Young's modulus, to be taken as 2.06×10^5 (N/mm^2).
ℓ	*mm*	Span of stiffener equal to spacing between primary supporting members.
s	*mm*	Spacing of stiffener to be taken as the mean spacing between the stiffeners of the considered stiffened panel.

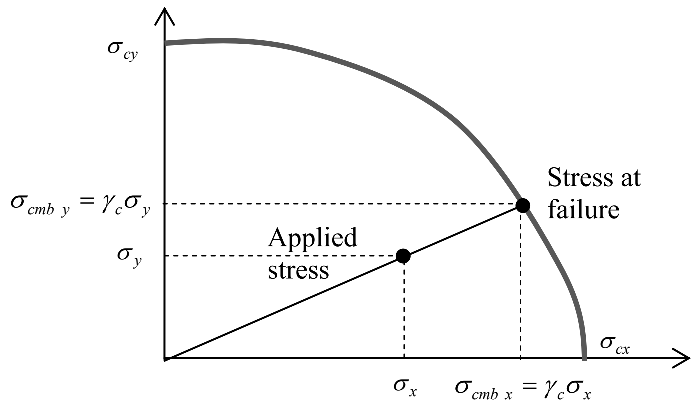
1.1.2 Buckling Utilisation Factor

The buckling utilization factor is to be taken as follows:

$$\eta_{act} = \frac{1}{\gamma_c}$$

γ_c : Stress multiplier factor at failure. Buckling strength assessment for plate is to be in accordance with **2.2.1** or **2.2.2**, and buckling strength assessment for stiffener is to be in accordance with **2.3.1** and **2.4.4**. The concept to calculate the stress multiplier factor at failure for applied stress combination is to be as given in **Fig. 1**.

Fig.1 Failure Limit State Curve



Notes:

σ_x, σ_y : Applied stress combination for buckling.

$\sigma_{cmb\ x}$, $\sigma_{cmb\ y}$: Critical buckling stresses for the stress combination for buckling.

2.1 Elementary Plate Panel (*EPP*)

2.1.1 Definition

An Elementary Plate Panel (*EPP*) is the part of the plating between stiffeners and/or primary supporting members. All the edges of the elementary plate panel are forced to remain straight (but free to move in the in-plane directions) due to the surrounding structure/neighbouring plates (usually longitudinal stiffened panels in deck, bottom, and inner-bottom plating, shell and longitudinal bulkheads).

2.1.2 *EPP* with Different Thickness

1 Longitudinally Stiffened *EPP* with Different Thicknesses

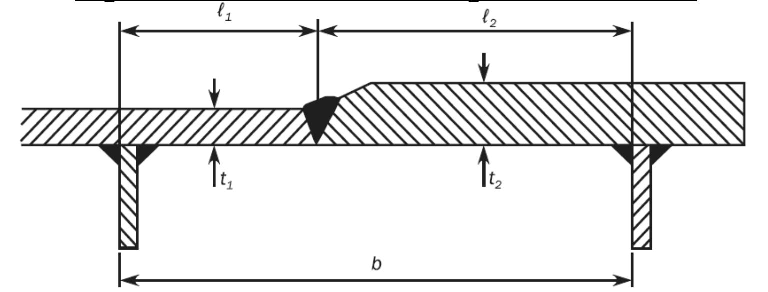
In longitudinal stiffening arrangement, when the plate thickness varies over the width, *b*, in *mm*, of a plate panel, the buckling capacity is calculated on an equivalent plate panel width, having a thickness equal to the smaller plate thickness, t_1. The width of this equivalent plate panel, b_{eq}, in *mm*, is defined by the following formula:

$$b_{eq} = \ell_1 + \ell_2 \left(\frac{t_1}{t_2} \right)^{1.5}$$

ℓ_1 : Width of the part of the plate panel with the smaller plate thickness, t_1, in *mm*, as defined in **Fig. 2**.

ℓ_2 : Width of the part of the plate panel with the greater plate thickness, t_2, in *mm*, as defined in **Fig. 2**.

Fig. 2 Plate Thickness Change over the Width



2 Transversally Stiffened *EPP* with Different Thicknesses

In transverse stiffening arrangement, when an *EPP* is made of different thicknesses, the buckling check of the plate and stiffeners is to be made for each thickness considered constant on the *EPP*.

2.2 Buckling Capacity of Plates

2.2.1 Plate Panel

1 Plate Limit State

The plate limit state is based on the following interaction formulae:

$$\left(\frac{\gamma_{c1}\sigma_x}{\sigma_{cx}}\right)^{e_0} - B\left(\frac{\gamma_{c1}\sigma_x}{\sigma_{cx}}\right)^{e_0/2}\left(\frac{\gamma_{c1}\sigma_y}{\sigma_{cy}}\right)^{e_0/2} + \left(\frac{\gamma_{c1}\sigma_y}{\sigma_{cy}}\right)^{e_0} + \left(\frac{\gamma_{c1}|\tau|}{\tau_c}\right)^{e_0} = 1$$

$$\left(\frac{\gamma_{c2}\sigma_x}{\sigma_{cx}}\right)^{2/\beta_p^{0.25}} + \left(\frac{\gamma_{c2}|\tau|}{\tau_c}\right)^{2/\beta_p^{0.25}} = 1 \text{ for } \sigma_x \geq 0$$

$$\left(\frac{\gamma_{c3}\sigma_y}{\sigma_{cy}}\right)^{2/\beta_p^{0.25}} + \left(\frac{\gamma_{c3}|\tau|}{\tau_c}\right)^{2/\beta_p^{0.25}} = 1 \text{ for } \sigma_y \geq 0$$

$$\frac{\gamma_{c4}|\tau|}{\tau_c} = 1$$

$$\gamma_c = \min(\gamma_{c1}, \gamma_{c2}, \gamma_{c3}, \gamma_{c4})$$

σ_{cx} : Ultimate buckling stress in N/mm^2 in direction parallel to the longer edge of the buckling panel as defined in **-3**.

σ_{cy} : Ultimate buckling stress in N/mm^2 in direction parallel to the shorter edge of the buckling panel as defined in **-3**.

τ_c : Ultimate buckling shear stress, in N/mm^2 as defined in **-3**.

$\gamma_{c1}, \gamma_{c2}, \gamma_{c3}, \gamma_{c4}$: Stress multiplier factors at failure for each of the above different limit states. γ_{c2} and γ_{c3} are only to be considered when $\sigma_x \geq 0$ and $\sigma_y \geq 0$ respectively.

B : Coefficient given in **Table 2**.

e_0: Coefficient given in **Table 2**.

β_p : Plate slenderness parameter taken as:

$$\beta_p = \frac{b}{t_p}\sqrt{\frac{\sigma_{YP}}{E}}$$

Table 2 Definition of Coefficients B and e_0

Applied Stress	B	e_0
$\sigma_x \geq 0$ and $\sigma_y \geq 0$	$0.7 - 0.3\beta_p/\alpha^2$	$2/\beta_p^{0.25}$
$\sigma_x < 0$ or $\sigma_y < 0$	1.0	2.0

2 Reference Degree of Slenderness

The reference degree of slenderness λ is to be taken as:

$$\lambda = \sqrt{\frac{\sigma_{YP}}{K\sigma_E}}$$

K: Buckling factor, as defined in **Table 4** and **Table 5**.

3 Ultimate Buckling Stresses

The ultimate buckling stress of plate panel σ_{cx} and σ_{cy}, in N/mm^2, is to be taken as:

$$\sigma_{cx} = C_x\sigma_{YP}$$

$$\sigma_{cy} = C_y\sigma_{YP}$$

The ultimate buckling stress of plate panels subject to shear τ_c, in N/mm^2, is to be taken as:

$$\tau_c = C_\tau \frac{\sigma_{YP}}{\sqrt{3}}$$

C_x, C_y, C_τ : Reduction factors, as defined in **Table 4**.

For the first equation of **-1** above, when $\sigma_x < 0$ or $\sigma_y < 0$, the reduction factors are to taken as:

$C_x = C_y = C_\tau = 1$

For the other cases: For Method A (See **C32.9.9-3**), C_y is calculated according to **Table 4** by using

$$c_1 = \left(1 - \frac{1}{\alpha}\right) \geq 0$$

For the other cases: For Method B (See **C32.9.9-3**), C_y is calculated according to **Table 4** by using

$$c_1 = 1$$

The boundary conditions for plates are to be considered as simply supported (see cases 1, 2 and 15 of **Table 4**). If the boundary conditions differ significantly from simple support, a more appropriate boundary condition can be applied according to the different cases of **Table 4** subject to the approval the Society.

4 Correction Factor F_{long}

The correction factor F_{long} depending on the edge stiffener types on the longer side of the buckling panel is defined in **Table 3**. An average value of F_{long} is to be used for plate panels having different edge stiffeners. For stiffener types other than those mentioned in **Table 3**, the value of c is to be agreed by the Society. In such a case, value of c higher than those mentioned in **Table 3** can be used, provided it is verified by buckling strength check of panel using non-linear FE analysis and deemed appropriate by Society.

Table 3 Correction Factor F_{long}

<table>
<tr><td colspan="3">Structural element types</td><td>F_{long}</td><td>c</td></tr>
<tr><td colspan="3">Unstiffened panel</td><td>1.0</td><td>N/A</td></tr>
<tr><td rowspan="6">Stiffened panel</td><td colspan="2">Stiffener not fixed at both ends</td><td>1.0</td><td>N/A</td></tr>
<tr><td rowspan="5">Stiffener fixed at both ends</td><td>Flat bar [1]</td><td rowspan="2">$F_{long} = c + 1$ for $\frac{t_w}{t_p} > 1$</td><td>0.10</td></tr>
<tr><td>Bulb profile</td><td>0.30</td></tr>
<tr><td>Angle profile</td><td rowspan="2">$F_{long} = c\left(\frac{t_w}{t_p}\right)^3 + 1$ for $\frac{t_w}{t_p} \leq 1$</td><td>0.40</td></tr>
<tr><td>T profile</td><td>0.30</td></tr>
<tr><td>Girder of high rigidity (e.g., bottom transverse)</td><td>1.4</td><td>N/A</td></tr>
<tr><td colspan="5">(1) : t_w is the web thickness, in mm, without the correction defined in **2.4.3-5**.</td></tr>
</table>

Table 4 Buckling Factor and Reduction Factor for Plane Plate Panels

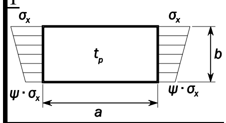
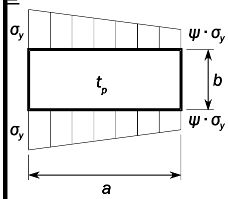
Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
1  	$1 \geq \psi \geq 0$		$K_x = F_{long} \dfrac{8.4}{\psi + 1.1}$	When $\sigma_x \leq 0$: $C_x = 1$ When $\sigma_x > 0$: $C_x = 1$ for $\lambda \leq \lambda_c$ $C_x = c\left(\dfrac{1}{\lambda} - \dfrac{0.22}{\lambda^2}\right)$ for $\lambda > \lambda_c$ Where: $c = (1.25 - 0.12\psi) \leq 1.25$ $\lambda_c = \dfrac{c}{2}\left(1 + \sqrt{1 - \dfrac{0.88}{c}}\right)$
	$0 \geq \psi > -1$		$K_x = F_{long}\left[7.63 - \psi(6.26 - 10\psi)\right]$	
	$\psi \leq -1$		$K_x = F_{long}\left[5.975(1-\psi)^2\right]$	
2  	$1 \geq \psi \geq 0$		$K_y = \dfrac{2\left(1 + \dfrac{1}{\alpha^2}\right)^2}{1 + \psi + \dfrac{(1-\psi)}{100}\left(\dfrac{2.4}{\alpha^2} + 6.9 f_1\right)}$	When $\sigma_y \leq 0$: $C_y = 1$ When $\sigma_y > 0$: $C_y = c\left(\dfrac{1}{\lambda} - \dfrac{R + F^2(H-R)}{\lambda^2}\right)$ Where: $c = (1.25 - 0.12\psi) \leq 1.25$ $R = \lambda(1 - \lambda / c)$ for $\lambda < \lambda_c$ $R = 0.22$ for $\lambda \geq \lambda_c$ $\lambda_c = 0.5c\left(1 + \sqrt{1 - 0.88/c}\right)$ $F = \left[1 - \left(\dfrac{K}{0.91} - 1\right)/\lambda_p^2\right] c_1 \geq 0$ $\lambda_p^2 = \lambda^2 - 0.5$ for $1 \leq \lambda_p^2 \leq 3$ c_1 as defined **2.2.1-3**. $H = \lambda - \dfrac{2\lambda}{c(T + \sqrt{T^2 - 4})} \geq R$ $T = \lambda + \dfrac{14}{15\lambda} + \dfrac{1}{3}$
		$\alpha \leq 6$	$f_1 = (1-\psi)(\alpha - 1)$	
		$\alpha > 6$	$f_1 = 0.6\left(1 - \dfrac{6\psi}{\alpha}\right)\left(\alpha + \dfrac{14}{\alpha}\right)$ but not greater than $14.5 - \dfrac{0.35}{\alpha^2}$	
	$0 > \psi \geq 1 - \dfrac{4\alpha}{3}$		$K_y = \dfrac{200\left(1 + \beta^2\right)^2}{(1 - f_3)\left(100 + 2.4\beta^2 + 6.9 f_1 + 23 f_2\right)}$	
		$\alpha > 6(1-\psi)$	$f_1 = 0.6\left(\dfrac{1}{\beta} + 14\beta\right)$ but not greater than $14.5 - 0.35\beta^2$ $f_2 = f_3 = 0$	
		$3(1-\psi) \leq \alpha \leq 6(1-\psi)$	$f_1 = \dfrac{1}{\beta} - 1$ $f_2 = f_3 = 0$	

Table 4 Buckling Factor and Reduction Factor for Plane Plate Panels (continued)

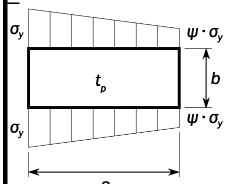
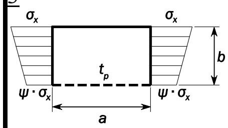
2 	$0 > \Psi \ge 1 - \frac{4\alpha}{3}$	$1.5(1-\Psi) \le \alpha < 3(1-\Psi)$	$f_1 = \frac{1}{\beta} - (2-\omega\beta)^4 - 9(\omega\beta - 1)\left(\frac{2}{3} - \beta\right)$ $f_2 = f_3 = 0$	When $\sigma_y \le 0$: $C_y = 1$ When $\sigma_y > 0$: $C_y = c\left(\frac{1}{\lambda} - \frac{R + F^2(H-R)}{\lambda^2}\right)$ $c = (1.25 - 0.12\psi) \le 1.25$ $R = \lambda(1 - \lambda / c)$ for $\lambda < \lambda_c$ $R = 0.22$ for $\lambda \ge \lambda_c$ $\lambda_c = 0.5c\left(1 + \sqrt{1 - 0.88/c}\right)$ $F = \left[1 - \left(\frac{K}{0.91} - 1\right)/\lambda_p^2\right]c_1 \ge 0$ $\lambda_p^2 = \lambda^2 - 0.5$ for $1 \le \lambda_p^2 \le 3$ c_1 as defined in **2.2.1-3**. $H = \lambda - \frac{2\lambda}{c(T + \sqrt{T^2 - 4})} \ge R$ $T = \lambda + \frac{14}{15\lambda} + \frac{1}{3}$
		$1 - \Psi \le \alpha < 1.5(1-\Psi)$	For $\alpha > 1.5$: $f_1 = 2\left(\frac{1}{\beta} - 16\left(1 - \frac{\omega}{3}\right)^4\right)\left(\frac{1}{\beta} - 1\right)$ $f_2 = 3\beta - 2$ $f_3 = 0$ For $\alpha \le 1.5$: $f_1 = 2\left(\frac{1.5}{1-\psi} - 1\right)\left(\frac{1}{\beta} - 1\right)$ $f_2 = \frac{\psi\left(1 - 16 f_4^{\,2}\right)}{1-\alpha}$ $f_3 = 0$ $f_4 = \left(1.5 - Min(1.5;\alpha)\right)^2$	
		$0.75(1-\Psi) \le \alpha < 1 - \Psi$	$f_1 = 0$ $f_2 = 1 + 2.31(\beta - 1) - 48\left(\frac{4}{3} - \beta\right) f_4^{\,2}$ $f_3 = 3 f_4 (\beta - 1)\left(\frac{f_4}{1.81} - \frac{\alpha - 1}{1.31}\right)$ $f_4 = \left(1.5 - Min(1.5;\alpha)\right)^2$	
	$\Psi < 1 - \frac{4\alpha}{3}$	$K_y = 5.972 \frac{\beta^2}{1 - f_3}$ $f_3 = f_5\left(\frac{f_5}{1.81} + \frac{1 + 3\psi}{5.24}\right)$ $f_5 = \frac{9}{16}\left(1 + Max(-1;\psi)\right)^2$		
3 	$1 \ge \Psi \ge 0$	$K_x = \frac{4\left(0.425 + 1/\alpha^2\right)}{3\psi + 1}$		$C_x = 1$ for $\lambda \le 0.7$ $C_x = \frac{1}{\lambda^2 + 0.51}$ for $\lambda > 0.7$
	$0 > \Psi \ge -1$	$K_x = 4\left(0.425 + 1/\alpha^2\right)(1 + \psi) - 5\psi(1 - 3.42\psi)$		

Table 4 Buckling Factor and Reduction Factor for Plane Plate Panels (continued)

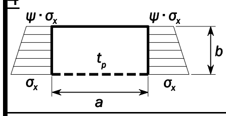
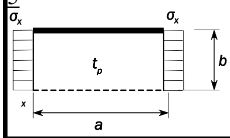
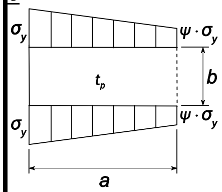
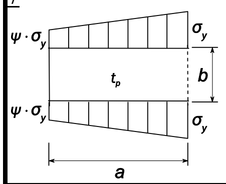
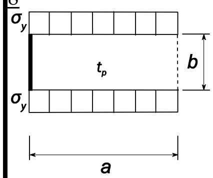
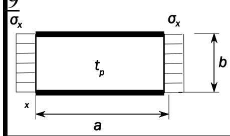
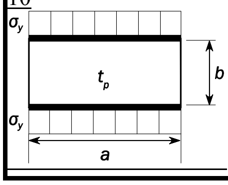
4 	$1 \geq \psi \geq -1$	$K_x = \left(0.425 + \frac{1}{\alpha^2}\right)\frac{3-\psi}{2}$	
5 	1	$\alpha \geq 1.64$: $K_x = 1.28$ $\alpha < 1.64$: $K_x = \frac{1}{\alpha^2} + 0.56 + 0.13\alpha^2$	$C_x = 1$ for $\lambda \leq 0.7$ $C_x = \frac{1}{\lambda^2 + 0.51}$ for $\lambda > 0.7$
6 	$1 \geq \psi \geq 0$	$K_y = \frac{4(0.425 + \alpha^2)}{(3\psi + 1)\alpha^2}$	
	$0 > \psi \geq -1$	$K_y = 4(0.425 + \alpha^2)(1+\psi)\frac{1}{\alpha^2} - 5\psi(1 - 3.42\psi)\frac{1}{\alpha^2}$	
7 	$1 \geq \psi \geq -1$	$K_y = 4(0.425 + \alpha^2)\frac{(3-\psi)}{2\alpha^2}$	$C_y = 1$ for $\lambda \leq 0.7$ $C_y = (\frac{1}{\lambda^2 + 0.51})$ for $\lambda > 0.7$
8 	1	$K_y = 1 + \frac{0.56}{\alpha^2} + \frac{0.13}{\alpha^4}$	
9 	1	$K_x = 6.97$	$C_x = 1$ for $\lambda \leq 0.83$ $C_x = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
10 	1	$K_y = 4 + \frac{2.07}{\alpha^2} + \frac{0.67}{\alpha^4}$	$C_y = 1$ for $\lambda \leq 0.83$ $C_y = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$

Table 4 Buckling Factor and Reduction Factor for Plane Plate Panels (continued)

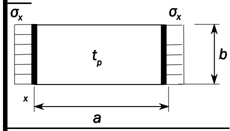
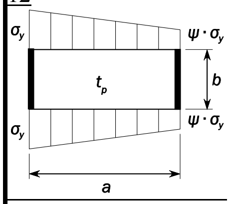
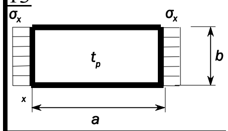
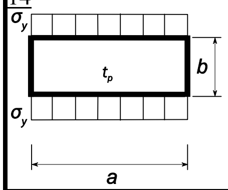
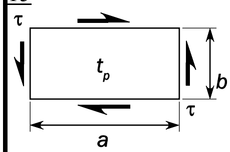
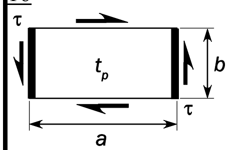
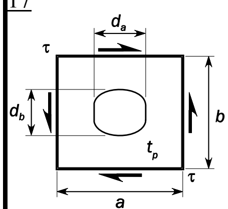
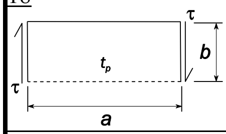
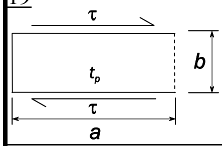
11 	-	$\alpha \geq 4$	$K_x = 4$	$C_x = 1$ for $\lambda \leq 0.83$
		$\alpha < 4$	$K_x = 4 + 2.74\left[\frac{4-\alpha}{3}\right]^4$	$C_x = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
12 	-	$K_y = K_y$ determined as per case 2		For $\alpha < 2$: $C_y = C_{y2}$ For $\alpha \geq 2$: $C_y = \left(1.06 + \frac{1}{10\alpha}\right)C_{y2}$ where: C_{y2} : C_y determined as per case 2
13 	-	$\alpha \geq 4$	$K_x = 6.97$	$C_x = 1$ for $\lambda \leq 0.83$
		$\alpha < 4$	$K_x = 6.97 + 3.1\left[\frac{4-\alpha}{3}\right]^4$	$C_x = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
14 	-	$K_y = \frac{6.97}{\alpha^2} + \frac{3.1}{\alpha^2}\left[\frac{4-1/\alpha}{3}\right]^4$		$C_y = 1$ for $\lambda \leq 0.83$ $C_y = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
15 	-	$K_\tau = \sqrt{3}\left[5.34 + \frac{4}{\alpha^2}\right]$		
16 	-	$K_\tau = \sqrt{3}\left\{5.34 + Max\left[\frac{4}{\alpha^2}; \frac{7.15}{\alpha^{2.5}}\right]\right\}$		$C_\tau = 1$ for $\lambda \leq 0.84$ $C_\tau = \frac{0.84}{\lambda}$ for $\lambda > 0.84$
17 	-	$K_\tau = K_{\tau case15} r$ $K_{\tau case15}$: K_τ according to case 11 r: opening reduction factor taken as: $r = \left(1 - \frac{d_a}{a}\right)\left(1 - \frac{d_b}{b}\right)$ with $\frac{d_a}{a} \leq 0.7$ and $\frac{d_b}{b} \leq 0.7$		

Table 4 Buckling Factor and Reduction Factor for Plane Plate Panels (continued)

18 	-	$K_\tau = \sqrt{3}(0.6 + 4/\alpha^2)$	$C_\tau = 1$ for $\lambda \le 0.84$ $C_\tau = \frac{0.84}{\lambda}$ for $\lambda > 0.84$
19 	-	$K_\tau = 8$	
Edge boundary conditions: - - - - - - - - - - Plate edge free. ———— Plate edge simply supported. ▬▬▬▬ Plate edge clamped.			
Notes: F_{long} : Coefficient, as defined in **2.2.1-4**. ω : Coefficient to be taken as : $\omega = \min(3;\alpha)$			
(1): Cases listed are general cases. Each stress component (σ_x , σ_y) is to be understood in local coordinates.			

2.2.2 Curved Plate Panels

This requirement for curved plate limit state is applicable when $R/t_p \le 2500$. Otherwise, the requirement for plate limit state given in **2.2.1-1** is applicable. The curved plate limit state is based on the following interaction formula:

$$\left(\frac{\gamma_c \sigma_{ax}}{C_{ax}\sigma_{YP}}\right)^{1.25} + \left(\frac{\gamma_c \tau\sqrt{3}}{C_\tau \sigma_{YP}}\right)^2 = 1.0$$

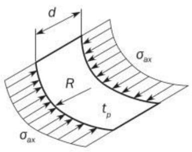
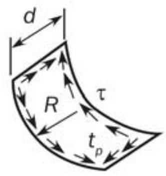
σ_{ax}: Applied axial stress to the cylinder corresponding to the curved plate panel, in N/mm^2.

In case of tensile axial stresses, $\sigma_{ax} = 0$.

C_{ax}, C_τ : Buckling reduction factor of the curved plate panel, as defined in **Table 5**.

The stress multiplier factor, γ_c, of the curved plate panel need not be taken less than the stress multiplier factor, γ_c, for the expanded plane panel according to **2.2.1-1**.

Table 5 Buckling Factor and Reduction Factor for Curved Plate Panels

Case	Aspect ratio	Buckling factor K	Reduction factor C
1 	$\frac{d}{R} \le 0.5\sqrt{\frac{R}{t_p}}$	$K = 1 + \frac{2}{3}\frac{d^2}{Rt_p}$	For general application: $C_{ax} = 1$ for $\lambda \le 0.25$ $C_{ax} = 1.233 - 0.933\lambda$ for $0.25 < \lambda \le 1$ $C_{ax} = 0.3/\lambda^3$ for $1 < \lambda \le 1.5$ $C_{ax} = 0.2/\lambda^2$ for $\lambda > 1.5$ For curved single fields, e.g. bilge strake, which are bounded by plane panels: $C_{ax} = \frac{0.65}{\lambda^2} \le 1.0$
	$\frac{d}{R} > 0.5\sqrt{\frac{R}{t_p}}$	$K = 0.267\frac{d^2}{Rt_p}\left[3 - \frac{d}{R}\sqrt{\frac{t_p}{R}}\right]$ $\ge 0.4\frac{d^2}{Rt_p}$	
2 	$\frac{d}{R} \le 8.7\sqrt{\frac{R}{t_p}}$	$K = \sqrt{3}\sqrt{28.3 + \frac{0.67d^3}{R^{1.5}t_p^{1.5}}}$	$C_\tau = 1$ for $\lambda \le 0.4$ $C_\tau = 1.274 - 0.686\lambda$ for $0.4 < \lambda \le 1.2$ $C_\tau = \frac{0.65}{\lambda^2}$ for $\lambda > 1.2$
	$\frac{d}{R} > 8.7\sqrt{\frac{R}{t_p}}$	$K = \sqrt{3}\frac{0.28d^2}{R\sqrt{Rt_p}}$	
Explanations for boundary conditions: Plate edge free			

2.3 Buckling Capacity of Overall Stiffened Panel

2.3.1

The elastic stiffened panel limit state is based on the following interaction formula:

$$\frac{P_z}{c_f} = 1$$

where c_f, and P_z are defined in **2.4.4-3**.

2.4 Buckling Capacity of Longitudinal Stiffeners

2.4.1 Stiffener Limit States

The buckling capacity of longitudinal stiffeners is to be checked for the following limit states:

(1) Stiffener induced failure (*SI*)

(2) Associated plate induced failure (*PI*)

2.4.2 Lateral Pressure

The lateral pressure is to be considered as constant in the buckling strength assessment of longitudinal stiffeners.

2.4.3 Stiffener Idealization

1 Effective Length of the Stiffener ℓ_{eff}

The effective length of the stiffener ℓ_{eff}, in *mm*, is to be taken equal to:

$\ell_{eff} = \dfrac{\ell}{\sqrt{3}}$ for stiffener fixed at both ends.

$\ell_{eff} = 0.75\ell$ for stiffener simply supported at one end and fixed at the other.

$\ell_{eff} = \ell$ for stiffener simply supported at both ends.

2 Effective Width of the Attached Plating b_{eff1}

The effective width of the attached plating of a stiffener b_{eff1}, in *mm*, without the shear lag effect is to be taken equal to:

For $\sigma_x > 0$: For FE analysis: $b_{eff1} = C_x b$

For prescriptive assessment: $b_{eff1} = \dfrac{C_{x1} b_1 + C_{x2} b_2}{2}$

For $\sigma_x \le 0$: $b_{eff1} = b$

C_x: Reduction factor defined in **Table 4**.

C_{x1}, C_{x2}: Reduction factor defined in **Table 4** calculated for the *EPP*1 and *EPP*2 on each side of the considered stiffener according to case 1.

b_1, b_2: Width of plate panel on each side of the considered stiffener, in *mm*.

3 Effective Width of Attached Plating of Stiffeners b_{eff}

The effective width of attached plating of stiffeners, b_{eff}, in *mm*, is to be taken as:

For $\sigma_x > 0$: For FE analysis: $b_{eff} = \min\left(C_x b, \chi_s s\right)$

For prescriptive assessment: $b_{eff} = \min\left(\dfrac{C_{x1} b_1 + C_{x2} b_2}{2}, \chi_s s\right)$

For $\sigma_x \le 0$: $b_{eff} = \chi_s s$

C_x: Reduction factor defined in **Table 4**.

C_{x1}, C_{x2}: Reduction factor defined in **Table 4** calculated for the *EPP*1 and *EPP*2 on each side of the considered stiffener according to case 1.

b_1, b_2: Width of plate panel on each side of the considered stiffener,in *mm*.

χ_s: Effective width coefficient to be taken as:

$$\chi_s = \min\left[\frac{1.12}{1+\dfrac{1.75}{\left(\dfrac{\ell_{eff}}{s}\right)^{1.6}}};1.0\right] \quad \text{for } \frac{\ell_{eff}}{s} \ge 1$$

$$\chi_s = 0.407\frac{\ell_{eff}}{s} \quad \text{for } \frac{\ell_{eff}}{s} < 1$$

ℓ_{eff}: Effective length of the stiffener, in *mm*, as specified in **-1**.

4 Thickness of Attached Plating

Thickness of attached plating t_p, in *mm*,to be taken as:

(1) For prescriptive assessment:

The mean of the two attached plating panels

(2) For FE analysis:

The thickness of the considered *EPP* on one side of the stiffener.

5 Effective Web Thickness of Flat Bar

For accounting the decrease of stiffness due to local lateral deformation, the effective web thickness of flat bar stiffener, in *mm*, is to be used for the calculation of the sectional area, A_s, the section modulus, Z, and the moment of inertia, I, of the stiffener and is taken as:

$$t_{w\_red} = t_w \left(1 - \frac{2\pi^2}{3} \left(\frac{h_w}{s} \right)^2 \left(1 - \frac{b_{eff1}}{s} \right) \right)$$

6 Net Section Modulus of a Stiffener

The section modulus Z of a stiffener, in cm^3, including effective width of plating is to be taken equal to:

(1) For stiffener induced failure (*SI*)

The section modulus Z is to be calculated at the top of stiffener flange.

(2) For plate induced failure (*PI*)

The section modulus Z is to be calculated at the attached plating.

7 Moment of Inertia of a Stiffener

The moment of inertia I, in cm^4, of a stiffener including effective width of attached plating is to comply with the following requirement:

$$I \geq \frac{s t_p^3}{12 \times 10^4}$$

8 Idealisation of Bulb Profile

Bulb profiles may be considered as equivalent angle profiles. The dimensions of the equivalent built-up section are to be obtained from the following formulae.

$$h_w = h'_w - \frac{h'_w}{9.2} + 2 \ (mm)$$

$$b_f = \alpha \left(t'_w + \frac{h'_w}{6.7} - 2 \right) (mm)$$

$$t_f = \frac{h'_w}{9.2} - 2 \ (mm)$$

$$t_w = t'_w \ (mm)$$

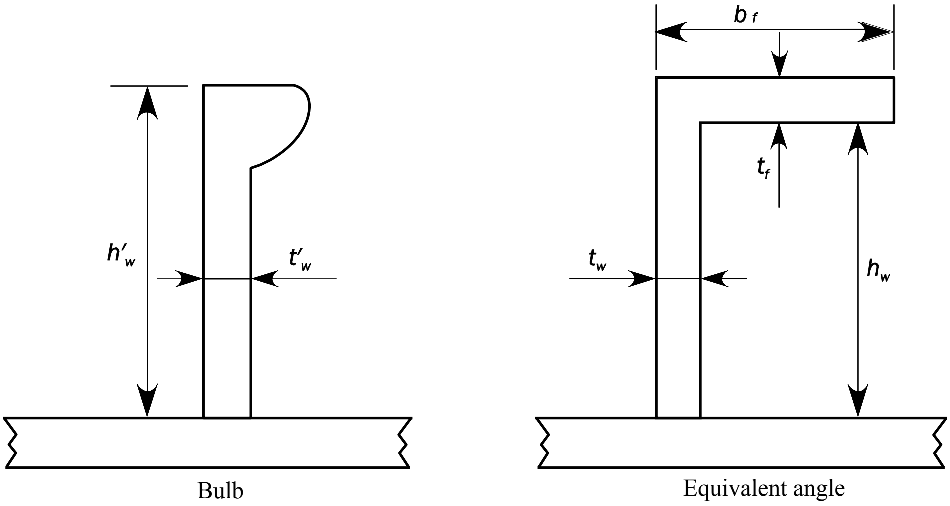
h'_w, t'_w: Height and thickness of a bulb section, in *mm*, as shown in **Fig. 3**.

α : Coefficient equal to:

$$\alpha = 1.1 + \frac{(120 - h'_w)^2}{3000} \quad \text{for } h'_w \leq 120$$

$$\alpha = 1.0 \quad \text{for } h'_w > 120$$

Fig. 3 Idealisation of Bulb Stiffener



2.4.4 Ultimate Buckling Capacity

1 Longitudinal Stiffener Limit State

When $\sigma_a + \sigma_b + \sigma_w > 0$, the ultimate buckling capacity for stiffener is to be checked according to the following interaction formula:

$$\frac{\gamma_c \sigma_a + \sigma_b + \sigma_w}{\sigma_Y} = 1$$

σ_a : Effective axial stress, in N/mm^2, at mid-span of the stiffener, defined in **-2**.

σ_b : Bending stress in the stiffener, in N/mm^2, defined in **-3**.

σ_w : Stress due to torsional deformation, in N/mm^2, defined in **-4**.

σ_Y : Specified minimum yield stress of the material, in N/mm^2.

$\sigma_Y = \sigma_{YS}$ for stiffener induced failure (*SI*)

$\sigma_Y = \sigma_{YP}$ for plate induced failure (*PI*)

2 Effective Axial Stress σ_a

The effective axial stress σ_a, in N/mm^2, at mid - span of the stiffener, acting on the stiffener with its attached plating is to be taken equal to:

$$\sigma_a = \sigma_x \frac{s t_p + A_s}{b_{eff1} t_p + A_s}$$

σ_x : Nominal axial stress, in N/mm^2, acting on the stiffener with its attached plating.

For FE analysis: σ_x is the FE corrected stress as defined in **-5** in the attahed plating in the direction of the stiffener axis.

For prescriptive assessment: σ_x is the axial stress calculated at load calculation point of the stiffener.

b_{eff1}: The effective width of the attached plating of a stiffener without the shear lag effect, according to **2.4.3-2**.

A_s: Sectional area, in mm^2, of the considered stiffener.

3 Bending Stress σ_b

The bending stress in the stiffener σ_b, in N/mm^2, is to be taken equal to:

$$\sigma_b = \frac{M_0 + M_1}{Z} 10^{-3}$$

Z: Section modulus of stiffener, in cm^3, including effective width of plating, according to **2.4.3-6**.

M_1: Bending moment, in *N-mm*, due to the lateral load P:

$$M_1 = C_i \frac{|P| s \ell^2}{24} 10^{-3} \quad \text{for continuous stiffener}$$

$$M_1 = C_i \frac{|P| s \ell^2}{8} 10^{-3} \quad \text{for sniped stiffener}$$

P: Lateral load, in kN/m^2.
For FE analysis: P is the average pressure in the attached plating.
For prescriptive assessment: P is the pressure calculated at load calculation point of the stiffener.

C_i: Pressure coefficient:
$C_i = C_{SI}$ for stiffener induced failure (*SI*)
$C_i = C_{PI}$ for plate induced failure (*PI*)

C_{PI}: Plate induced failure pressure coefficient:
$C_{PI} = 1$ if the lateral pressure is applied on the side opposite to the stiffener.
$C_{PI} = -1$ if the lateral pressure is applied on the same side as the stiffener.

C_{SI}: Stiffener induced failure pressure coefficient
$C_{SI} = -1$ if the lateral pressure is applied on the side opposite to the stiffener.
$C_{SI} = 1$ if the lateral pressure is applied on the same side as the stiffener.

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

$$M_0 = F_E \left(\frac{P_z w}{c_f - P_z} \right) \quad \text{with } c_f - P_z > 0$$

F_E: Ideal elastic buckling force of the stiffener, in *N*.

$$F_E = \left(\frac{\pi}{\ell} \right)^2 EI 10^4$$

P_z: Nominal lateral load, in N/mm^2, acting on the stiffener due to stress, σ_x, σ_y and τ, in the attached plating in way of the stiffener mid span:

$$P_z = \frac{t_p}{s} \left(\sigma_{xl} \left(\frac{\pi s}{\ell} \right)^2 + 2 c \gamma \sigma_y + \sqrt{2} \tau_1 \right)$$

$$\sigma_{xl} = \gamma \sigma_x \left(1 + \frac{A_s}{s t_p} \right) \quad \text{but not less than 0}$$

$$\tau_1 = \gamma |\tau| - t_p \sqrt{\sigma_{YP} E \left(\frac{m_1}{a^2} + \frac{m_2}{s^2} \right)} \quad \text{but not less than 0}$$

σ_y: Stress applied on the edge along y axis of the buckling panel, in N/mm^2, but not less than 0.

For FE analysis: σ_y is the FE corrected stress as defined in **-5** in the attached plating in the direction perpendicular to the stiffener axis.

For prescriptive assessment: $\sigma_y = 0$

τ: Applied shear stress, in N/mm^2

For FE analysis: τ is the reference shear stress in the attached plating

For prescriptive assessment: τ is the shear stress calculated at load calculation point of the stiffener attached plating.

m_1, m_2: Coefficients taken equal to:

$m_1 = 1.47$, $m_2 = 0.49$ for $\alpha \geq 2$

$m_1 = 1.96$, $m_2 = 0.37$ for $\alpha < 2$

w: Deformation of stiffener, in mm:

$$w = w_0 + w_1$$

w_0: Assumed imperfection, in mm, to be taken as:

$w_0 = \ell 10^{-3}$ in general

$w_0 = -w_{na}$ for stiffeners sniped at both ends considering stiffener induced failure (*SI*)

$w_0 = w_{na}$ for stiffeners sniped at both ends considering plate induced failure (*PI*)

w_{na}: Distance from the mid-point of attached plating to the neutral axis of the stiffener calculated with the effective width of the attached plating.

w_1: Deformation of stiffener, in mm, at mid-point of stiffener span due to lateral load P. In case of uniformly distributed load, w_1 is taken as:

$w_1 = C_i \dfrac{|P| s \ell^4}{384 EI} 10^{-7}$ in general

$w_1 = C_i \dfrac{5 |P| s \ell^4}{384 EI} 10^{-7}$ for stiffeners sniped at both ends

c_f: Elastic support provided by the stiffener, in N/mm^2.

$$c_f = F_E \left(\frac{\pi}{\ell} \right)^2 (1 + c_p)$$

c_p: Coefficient to be taken as :

$$c_p = \frac{1}{1 + \dfrac{0.91}{c_{xa}} \left(\dfrac{12 I}{s t_p^3} 10^4 - 1 \right)}$$

c_{xa}: Coefficient to be taken as :

$$c_{xa} = \left(\frac{\ell}{2s} + \frac{2s}{\ell} \right)^2 \quad \text{for } \ell \geq 2s$$

$$c_{xa} = \left(1 + \left(\frac{\ell}{2s} \right)^2 \right)^2 \quad \text{for } \ell < 2s$$

4 Stress Due to Torsional Deformation σ_w

The stress due to torsional deformation σ_w, in *N/mm*², is to be taken equal to:

$$\sigma_w = E y_w \left(\frac{t_f}{2} + h_w \right) \Phi_0 \left(\frac{\pi}{\ell} \right)^2 \left(\frac{1}{1 - \dfrac{0.4\sigma_{YS}}{\sigma_{ET}}} - 1 \right) \quad \text{for stiffener induced failure } (SI)$$

$\sigma_w = 0$ for plate induced failure (*PI*)

y_w: Distance, in *mm,* from centroid of stiffener cross section to the free edge of stiffener flange, to be taken as:

$$y_w = \frac{t_w}{2} \quad \text{for flat bar.}$$

$$y_w = b_f - \frac{h_w t_w^2 + t_f b_f^2}{2A_s} \quad \text{for angle and bulb profiles.}$$

$$y_w = \frac{b_f}{2} \quad \text{for T profile.}$$

Φ_0: Coefficient to be taken as :

$$\Phi_0 = \frac{\ell}{h_w} 10^{-3}$$

σ_{ET}: Reference stress for torsional buckling, in *N/mm*².

$$\sigma_{ET} = \frac{E}{I_p} \left(\frac{\varepsilon \pi^2 I_\omega}{\ell^2} 10^2 + 0.385 I_T \right)$$

I_P: Polar moment of inertia of the stiffener about point *C* as shown in **Fig. 4**, as defined in **Table 6**, in *cm*⁴.

I_T: St. Venant's moment of inertia of the stiffener, as defined in **Table 6**, in *cm*⁴.

I_ω: Sectional moment of inertia of the stiffener about point *C* as shown in **Fig. 4**, as defined in **Table 6**, in *cm*⁶.

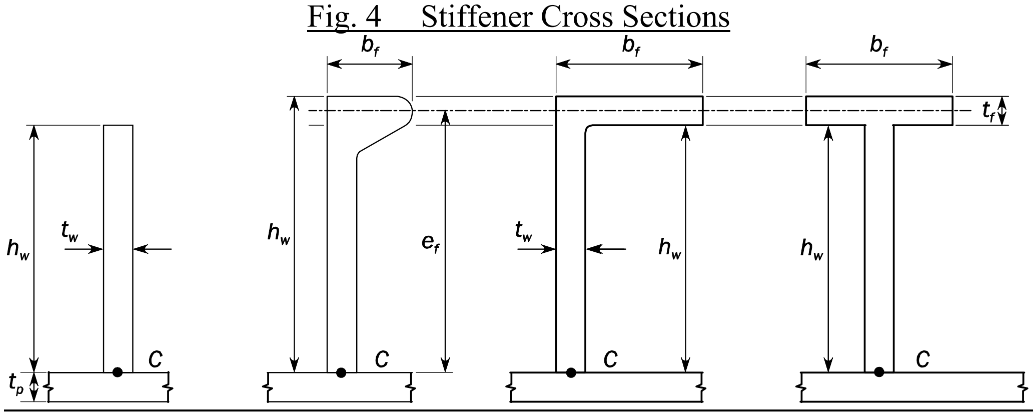
ε: Degree of fixation.

$$\varepsilon = 1 + \frac{\left(\dfrac{\ell}{\pi} \right)^2 10^{-3}}{\sqrt{I_\omega \left(\dfrac{0.75s}{t_p^3} + \dfrac{e_f - 0.5t_f}{t_w^3} \right)}}$$

Table 6 Moments of Inertia

	Flat bars	Bulb, angle and Tee profiles
I_P	$\dfrac{h_w^3 t_w}{3\times10^4}$	$\left(\dfrac{A_w(e_f-0.5t_f)^2}{3}+A_f e_f^2\right)10^{-4}$
I_T	$\dfrac{h_w t_w^3}{3\times10^4}\left(1-0.63\dfrac{t_w}{h_w}\right)$	$\dfrac{(e_f-0.5t_f)t_w^3}{3\times10^4}\left(1-0.63\dfrac{t_w}{e_f-0.5t_f}\right)+\dfrac{b_f t_f^3}{3\times10^4}\left(1-0.63\dfrac{t_f}{b_f}\right)$
I_ω	$\dfrac{h_w^3 t_w^3}{36\times10^6}$	$\dfrac{A_f e_f^2 b_f^2}{12\times10^6}\left(\dfrac{A_f+2.6A_w}{A_f+A_w}\right)$ for bulb and angle profiles $\dfrac{b_f^3 t_f e_f^2}{12\times10^6}$ for Tee profiles
A_w: Web area, in mm^2.		
A_f: Flange area, in mm^2.		

Fig. 4   Stiffener Cross Sections



5   FE Corrected Stress for Stiffener Capacity

When the reference stress σ_x and σ_y obtained by FE analysis are both compressive, they are to be corrected according to the following formulae:

(1) If $\sigma_x < 0.3\sigma_y$:

$$\sigma_{xcor}=0$$

$$\sigma_{ycor}=\sigma_y$$

(2) If $\sigma_y < 0.3\sigma_x$:

$$\sigma_{xcor}=\sigma_x$$

$$\sigma_{ycor}=0$$

(3) If the other cases:

$$\sigma_{xcor}=\sigma_x-0.3\sigma_y$$

$$\sigma_{ycor}=\sigma_y-0.3\sigma_x$$

2.5 Primary Supporting Members

2.5.1 Web Plate In Way of Openings

1 Web Plate In Way of Openings

The web plate of primary supporting members with openings is to be assessed for buckling based on the combined axial compressive and shear stresses.

The web plate adjacent to the opening on both sides is to be considered as individual unstiffened plate panels as shown in **Table 7**. The interaction formula of **2.2.1-1** is to be used with:

(1) $\sigma_x = \sigma_{av}$

(2) $\sigma_y = 0$

(3) $\tau = \tau_{av}$

σ_{av}: Weight average compressive stress, in *N*/*mm*^{2}, in the area of web plate being considered, i.e., *P*1, *P*2, or *P*3 as shown in **Table 7**.

τ_{av}: Weight average shear stress, in *N*/*mm*^{2}, in the area of web plate being considered,.

For the application of the **Table 7**, the weighted average shear stress is to be taken as:

(1) Opening modelled in primary supporting members:

τ_{av}: Weight average shear stress, in *N*/*mm*^{2}, in the area of web plate being considered, i.e., *P*1, *P*2, or *P*3 as shown in **Table 7**.

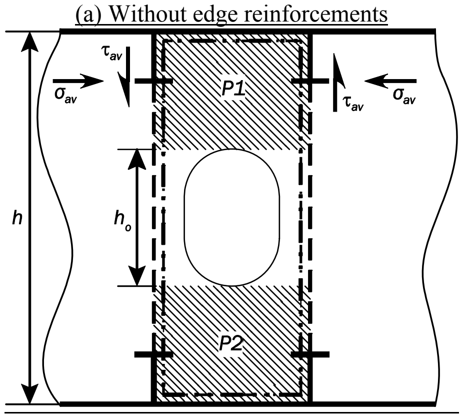
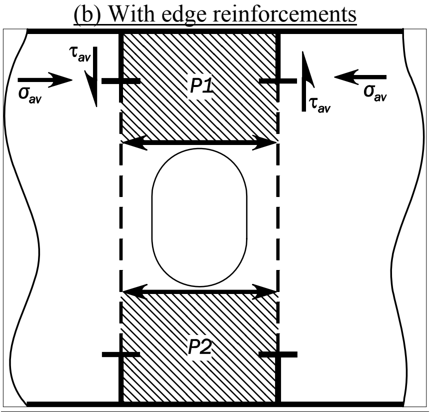
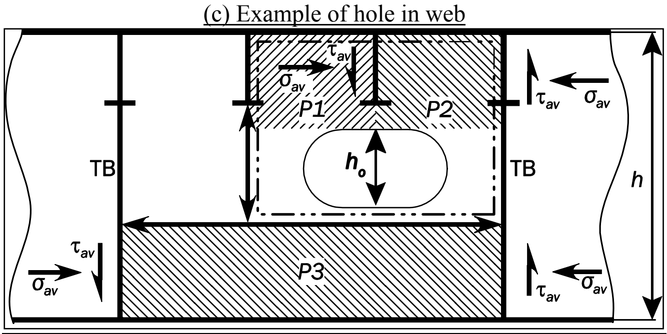
(2) Opening not modelled in primary supporting members:

τ_{av}: Weighted average shear stress, in *N*/*mm*^{2}, given in **Table 7**.

2 Reduction Factor of Web Plate In Way of Openings

The reduction factors, C_x or C_y in combination with, C_τ of the plate panel(s) of the web adjacent to the opening is to be taken as shown in **Table 7**.

Table 7 Reduction Factor

Configuration	C_x, C_y	C_τ Opening modelled in PSM	C_τ Opening not modelled in PSM
(a) Without edge reinforcements 	Separate reduction factors are to be applied to areas $P1$ and $P2$ using case 3 or case 6 in **Table 4**, with edge stress ratio: $\psi = 1.0$	Separate reduction factors are to be applied to areas $P1$ and $P2$ using case 18 or case 19 in **Table 4**.	When case 17 of **Table 4** is applicable: A common reduction factor is to be applied to areas $P1$ and $P2$ using case 17 in **Table 4** with: $\tau_{av} = \tau_{av}(web)$ When case 17 of **Table 4** is not applicable: Separate reduction factors are to be applied to areas $P1$ and $P2$ using case 18 or case 19 in **Table 4** with: $\tau_{av} = \tau_{av}(web)h/(h-h_0)$
(b) With edge reinforcements 	Separate reduction factors are to be applied to areas $P1$ and $P2$ using C_x for case 1 or C_y for case 2 in **Table 4**, with stress ratio: $\psi = 1.0$	Separate reduction factors are to be applied for areas $P1$ and $P2$ using case 15 in **Table 4**.	Separate reduction factors are to be applied to areas $P1$ and $P2$ using case 15 in **Table 4** with: $\tau_{av} = \tau_{av}(web)h/(h-h_0)$
(c) Example of hole in web 		Panels $P1$ and $P2$ are to be evaluated in accordance with **(a)**. Panel $P3$ is to be evaluated in accordance with **(b)**.	

Notes:

h: Height, in m, of the web of the primary supporting member in way of the opening.

h_0: Height, in m, of the opening measured in the depth of the web.

$\tau_{av}(web)$: Weighted average shear stress, in N/mm^2, over the web height h of the primary supporting member.

(1): Web panels to be considered for buckling in way of openings are shown shaded and numbered $P1$, $P2$, etc.

Annex C32.2.8-1 has been added as follows.

Annex C32.2.8-1 "GUIDANCE FOR THE HULL GIRDER ULTIMATE STRENGTH ASSESSMENT".

1.1 General

1.1.1 Definitions

Unless specified otherwise, the definitions of the symbols used in this Guidance are as specified in **Table 1**.

Table 1 Definition of the Symbols

Symbol	Unit	Definition
I_y	m^4	Moment of inertia of the hull transverse section around its horizontal neutral axis
Z_B, Z_D	m^3	Section moduli at bottom and deck, respectively
σ_{YS}	N/mm^2	Minimum yield stress of the material of the considered stiffener
σ_{YP}	N/mm^2	Minimum yield stress of the material of the considered plate
A_s	cm^2	Sectional area of stiffener, without attached plating
A_p	cm^2	Sectional area of attached plating

2.1 General Assumptions

2.1.1

The method for calculating the ultimate hull girder capacity is to identify the critical failure modes of all main longitudinal structural elements.

2.1.2

Structures compressed beyond their buckling limit have reduced load carrying capacity. All relevant failure modes for individual structural elements, such as plate buckling, torsional stiffener buckling, stiffener web buckling, lateral or global stiffener buckling and their interactions, are to be considered in order to identify the weakest inter-frame failure mode.

2.2 Incremental-iterative method

2.2.1 Assumptions

In applying the incremental-iterative method, the following assumptions are generally to be made:

(1) The ultimate strength is calculated at transverse sections between two adjacent transverse webs;

(2) The hull girder transverse section remains plane during each curvature increment;

(3) The hull material has an elasto-plastic behaviour; and

(4) The hull girder transverse section is divided into a set of elements which are considered to act independently. (*See* **2.2.2-2**)

According to the iterative procedure, the bending moment M_i acting on the transverse section at each curvature value χ_i is obtained by summing the contribution given by the stress σ acting on each element. The stress σ corresponding to the element strain ε is to be obtained for each curvature increment from the non-linear load-end shortening curves $\sigma - \varepsilon$ of the element.

These curves are to be calculated, for the failure mechanisms of the element, from the formulae specified in **2.2.3**. The stress σ is selected as the lowest among the values obtained from each of the considered load-end shortening curves $\sigma - \varepsilon$.

The procedure is to be repeated until the value of the imposed curvature reaches the value χ_F (m^{-1}) in hogging and sagging condition, obtained from the following formula:

$$\chi_F = \pm 0.003 \frac{M_Y}{EI_y}$$

M_Y: Lesser of the values M_{Y1} and M_{Y2}, in *kN-m*.

$M_{Y1} = 10^3 \sigma_Y Z_B$

$M_{Y2} = 10^3 \sigma_Y Z_D$

If the value χ_F is not sufficient to evaluate the peaks of the curve M-χ, the procedure is to be repeated until the value of the imposed curvature permits the calculation of the maximum bending moments of the curve.

2.2.2 Procedure

1 General

The curve $M - \chi$ is to be taken as follows:

(1) The curve $M - \chi$ is to be obtained by means of an incremental-iterative approach, summarised in the flow chart in **Fig. 1**.

(2) In this procedure, the ultimate hull girder bending moment capacity M_U is defined as the peak value of the curve with vertical bending moment M versus the curvature χ of the ship cross section as shown in **Fig. 1**. The curve is to be obtained through an incremental-iterative approach.

(3) Each step of the incremental procedure is represented by the calculation of the bending moment M_i which acts on the hull transverse section as the effect of an imposed curvature χ_i.

(4) For each step, the value χ_i is to be obtained by summing an increment of curvature $\Delta\chi$ to the value relevant to the previous step χ_{i-1}. This increment of curvature corresponds to an increment of the rotation angle of the transverse section around its horizontal neutral axis.

(5) This rotation increment induces axial strains ε in each hull structural element whose value depends on the position of the element. In hogging condition, the structural elements above the neutral axis are lengthened, while the elements below the neutral axis are shortened, and vice-versa in sagging condition.

(6) The stress σ induced in each structural element by the strain ε is to be obtained from the load-end shortening curve $\sigma - \varepsilon$ of the element, which takes into account the behaviour of the element in the non-linear elasto-plastic domain.

(7) The distribution of the stresses induced in all the elements composing the hull transverse section determines, for each step, a variation of the neutral axis position since the relationship $\sigma - \varepsilon$ is non-linear. The new position of the neutral axis relevant to the step considered is to

be obtained by means of an iterative process, imposing the equilibrium among the stresses acting in all the hull elements on the transverse section.

(8) Once the position of the neutral axis is known and the relevant element stress distribution in the section is obtained, the bending moment of the section M_i around the new position of the neutral axis, which corresponds to the curvature χ_i imposed in the step considered, is to be obtained by summing the contribution given by each element stress.

(9) The main steps of the incremental-iterative approach described above are summarised as follows: (See **Fig. 1**)

(a) Step 1: Divide the transverse section of hull into stiffened plate elements.

(b) Step 2: Define stress-strain relationships for all elements as shown in **Table 2**.

(c) Step 3: Initialise curvature χ_i and neutral axis for the first incremental step with the value of incremental curvature (i.e. curvature that induces a stress equal to 1% of yield strength in strength deck) as follows:

$$\chi_1 = \Delta\chi = 0.01\frac{\sigma_Y}{E}\frac{1}{z_D - z_n}$$

z_D : Z-coordinate (m) of strength deck at side.

z_n : Z-coordinate (m) of horizontal neutral axis of the hull transverse section

(d) Step 4: Calculate for each element the corresponding strain $\varepsilon_i = \chi(z_i - z_n)$ and the corresponding stress σ_i

(e) Step 5: Determine the neutral axis z_{NA_cur} at each incremental step by establishing force equilibrium over the whole transverse section as:

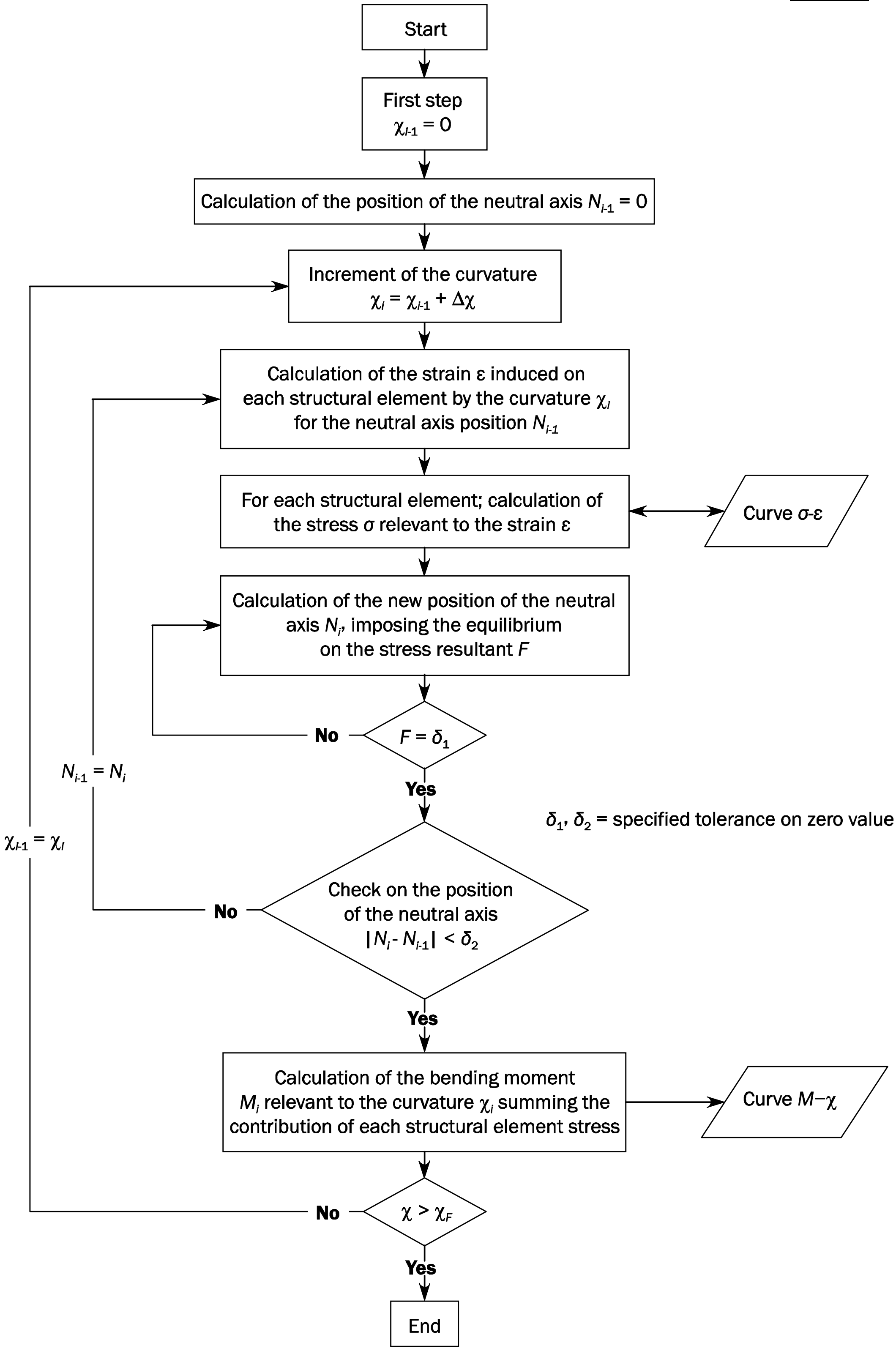
$\sum A_i\sigma_i = \sum A_j\sigma_j$ (i-th element is under compression, j-th element under tension)

(f) Step 6: Calculate the corresponding moment by summing the contributions of all elements as follows:

$$M_U = \sum \sigma_{Ui} A_i \left|(z_i - z_{NA\_cur})\right|$$

(g) Step 7: Compare the moment in the current incremental step with the moment in the previous incremental step. If the slope in $M - \chi$ relationship is less than a negative fixed value, terminate the process and define the peak value of M_U. Otherwise, increase the curvature by the amount of $\Delta\chi$ and go to Step 4.

Fig.1 Flow Chart of the Procedure for the Evaluation of the Curve $M-\chi$



2 Classification of the structural members

Hull girder transverse sections are to be considered as being constituted by the members contributing to the hull girder ultimate strength.

Sniped stiffeners are also to be modelled, taking account that they do not contribute to the hull girder strength.

The structural members are categorised into a stiffener element, a stiffened plate element or a hard corner element.

The plate panel including web plate of girder or side stringer is idealised into either a stiffened plate element, an attached plate of a stiffener element or a hard corner element.

The plate panel is categorised into the following two kinds:

- Longitudinally stiffened panel of which the longer side is in the longitudinal direction; or
- Transversely stiffened panel of which the longer side is in the perpendicular direction to the longitudinal direction.

(1) Hard corner element:

Hard corner elements are sturdier elements composing the transverse section, which collapse mainly according to an elasto-plastic mode of failure (material yielding); they are generally constituted by two plates not lying in the same plane.

The extent of a hard corner element from the point of intersection of the plates is taken equal to $20t$ on a transversely stiffened panel and to $0.5s$ on a longitudinally stiffened panel. (See **Fig. 2**)

t: Thickness of the plate (mm)

s: Spacing of the adjacent longitudinal stiffener (m)

Bilge, sheer strake-deck stringer elements, girder-deck connections and face plate-web connections on large girders are typical hard corners.

(2) Stiffener element:

The stiffener constitutes a stiffener element together with the attached plate.

The attached plate width is in principle:

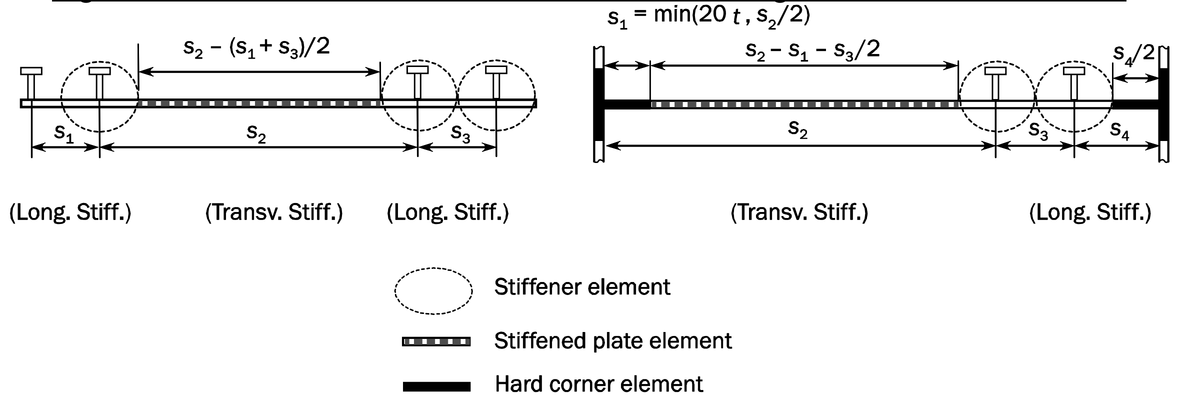
(a) Equal to the mean spacing of the stiffener when the panels on both sides of the stiffener are longitudinally stiffened, or

(b) Equal to the width of the longitudinally stiffened panel when the panel on one side of the stiffener is longitudinally stiffened and the other panel is of the transversely stiffened. (See **Fig. 2**)

(3) Stiffened plate element

The plate between stiffener elements, between a stiffener element and a hard corner element or between hard corner elements is to be treated as a stiffened plate element (See **Fig. 2**)

Fig. 2 Extension of the Breadth of the Attached Plating and Hard Corner Element



3 Modelling of the hull girder cross section

The typical examples of modelling of hull girder section are illustrated in **Fig. 3**. Notwithstanding the principle of **-2** above, these figures are to be applied to **Fig. 3** in the modelling in the vicinity of upper deck, sheer strake and hatch side girder.

(1) In case of the knuckle point as shown in **Fig. 4**, the plating area adjacent to knuckles in the plating with an angle greater than 30 degrees is defined as a hard corner. The extent of one side of the corner is taken equal to 20*t* on transversely framed panels and to 0.5*s* on longitudinally framed panels from the knuckle point.

(2) Where the plate members are stiffened by non-continuous longitudinal stiffeners, the non-continuous stiffeners are considered only as dividing a plate into various elementary plate panels.

(3) Where attached plating is made of steels having different thicknesses and/or yield stresses, an average thickness or average yield stress obtained from the following formula is to be used for the calculation.

$$t = \frac{t_1 s_1 + t_2 s_2}{s}$$

$$\sigma_{YP} = \frac{\sigma_{YP1} t_1 s_1 + \sigma_{YP2} t_2 s_2}{ts}$$

σ_{YP1}, σ_{YP2}, t_1, t_2, s_1, s_2 and s: As defined in **Fig. 5**.

Fig. 3 Examples of the Configuration of Stiffened Plate Elements, Stiffener Elements and Hard Corner Elements on a Hull Section

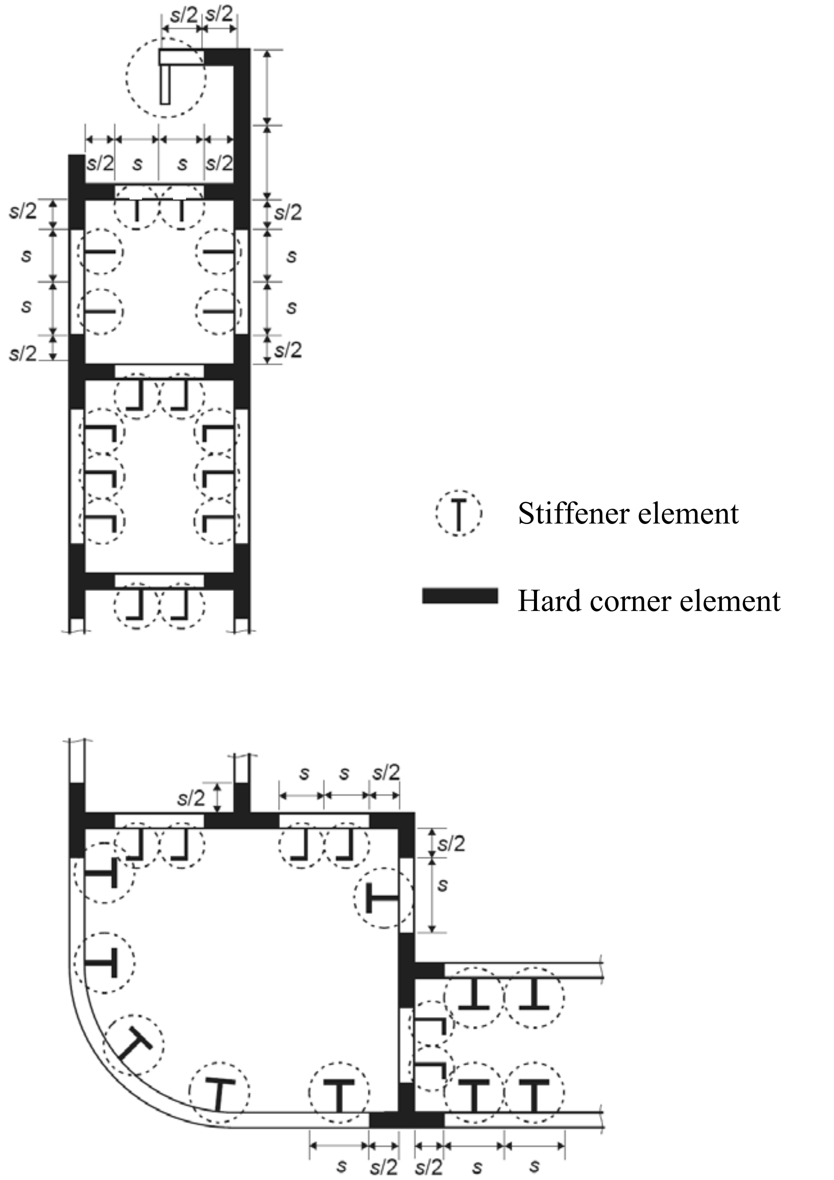


Fig. 4 Plating with Knuckle Point

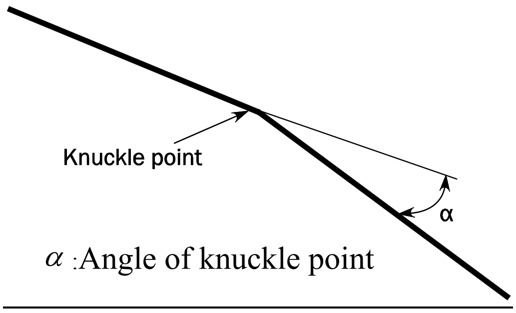
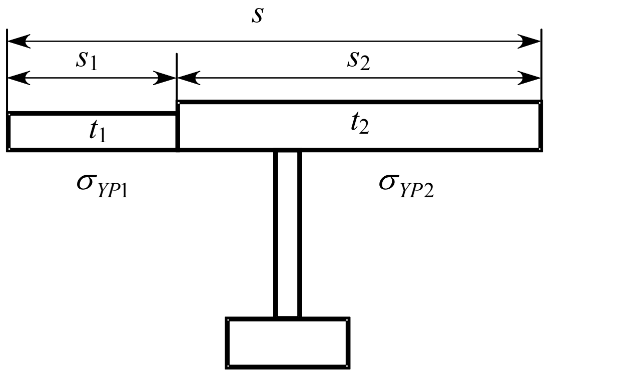


Fig. 5 Element with Different Thickness and Yield Strength



2.2.3 Load-end Shortening Curves

1 Stiffened plate element and stiffener element

Stiffened plate element and stiffener element composing the hull girder transverse sections may collapse following one of the modes of failure specified in **Table 2**.

(1) Where the plate members are stiffened by non-continuous longitudinal stiffeners, the stress of the element is to be obtained in accordance with **-2** to **-7**, taking into account the non-continuous longitudinal stiffener. In calculating the total forces for checking the hull girder ultimate strength, the area of non-continuous longitudinal stiffener is to be assumed as 0.

(2) Where the opening is provided in the stiffened plate element, the considered area of the stiffened plate element is to be obtained by deducting the opening area from the plating in calculating the total forces for checking the hull girder ultimate strength.

(3) For stiffened plate element, the effective width of plate for the load shortening portion of the stress-strain curve is to be taken as full plate width, i.e. to the intersection of other plate or longitudinal stiffener – neither from the end of the hard corner element nor from the attached plating of stiffener element, if any. In calculating the total forces for checking the hull girder ultimate strength, the area of the stiffened plate element is to be taken between the hard corner element and the stiffener element or between the hard corner elements, as applicable.

Table 2 Modes of Failure of Stiffened Plate Element and Stiffener Element

Element	Mode of failure	Curve $\sigma - \varepsilon$ defined in
Lengthened stiffened plate element or stiffener element	Elasto-plastic collapse	**2.2.3-2**
Shortened stiffener element	Beam column buckling Torsional buckling Web local buckling of flanged profiles Web local buckling of flat bars	**2.2.3-3** **2.2.3-4** **2.2.3-5** **2.2.3-6**
Shortened stiffened plate element	Plate buckling	**2.2.3-7**

2 Elasto-plastic collapse of structural elements (hard corner element)

The equation describing the load-end shortening curve $\sigma - \varepsilon$ for the elasto-plastic collapse of structural elements composing the transverse section is to be obtained from the following formula:

$$\sigma = \Phi \sigma_{YA}$$

σ_{YA}: Equivalent minimum yield stress (N/mm^2) of the considered element obtained by the following formula:

$$\sigma_{YA} = \frac{\sigma_{YP} A_p + \sigma_{YS} A_s}{A_p + A_s}$$

Φ : Edge function, equal to the following:

$\Phi = -1$ for $\varepsilon < -1$

$\Phi = \varepsilon$ for $-1 \le \varepsilon \le 1$

$\Phi = 1$ for $\varepsilon > 1$

ε: Relative strain, equal to the following:

$$\varepsilon = \frac{\varepsilon_E}{\varepsilon_Y}$$

ε_E: Element strain.

ε_Y: Strain at yield stress in the element, equal to the following:

$$\varepsilon_Y = \frac{\sigma_{YA}}{E}$$

3 Beam column buckling

The positive strain portion of the average stress – average strain curve $\sigma_{CR1} - \varepsilon$ based on beam column buckling of plate-stiffener combinations is described according to the following:

$$\sigma_{CR1} = \Phi \sigma_{C1} \frac{A_S + A_{pE}}{A_S + A_p}$$

Φ: Edge function, as defined in **-2.**

σ_{C1}: Critical stress (N/mm^2), equal to the following:

$$\sigma_{C1} = \frac{\sigma_{E1}}{\varepsilon} \quad \text{for} \quad \sigma_{E1} \le \frac{\sigma_{YB}}{2} \varepsilon$$

$$\sigma_{C1} = \sigma_{YB}\left(1 - \frac{\sigma_{YB}\varepsilon}{4\sigma_{E1}}\right) \quad \text{for} \quad \sigma_{E1} > \frac{\sigma_{YB}}{2}\varepsilon$$

σ_{YB}: Equivalent minimum yield stress (N/mm^2) of the considered element obtained by the following formula:

$$\sigma_{YB} = \frac{\sigma_{YP} A_{pE1} \ell_{pE} + \sigma_{YS} A_s \ell_{sE}}{A_{pE1} \ell_{pE} + A_s \ell_{sE}}$$

A_{pE1}: Effective area (cm^2), equal to the following:

$$A_{pE1} = 10 b_{E1} t$$

ℓ_{pE}: Distance (mm) measured from the neutral axis of the stiffener with attached plate of width b_{E1} to the bottom of the attached plate

ℓ_{sE}: Distance (mm) measured from the neutral axis of the stiffener with attached plate of width b_{E1} to the top of the stiffener

ε: Relative strain, as defined in **-2**.

σ_{E1}: Euler column buckling stress (N/mm^2), equal to the following:

$$\sigma_{E1} = \pi^2 E \frac{I_E}{A_E \ell^2} 10^{-4}$$

I_E: Moment of inertia of stiffeners (cm^4) with attached plating of width b_{E1}.

A_E: Area (cm^2) of stiffeners with attached plating of width b_E.

b_{E1}: Effective width corrected for relative strain (m) of the attached plating, equal to the following:

$$b_{E1} = \frac{s}{\beta_E} \quad \text{for} \quad \beta_E > 1.0$$

$$b_{E1} = s \quad \text{for} \quad \beta_E \le 1.0$$

β_E : Coefficient, given as follow:

$$\beta_E = 10^3 \frac{s}{t}\sqrt{\frac{\varepsilon \sigma_{YP}}{E}}$$

A_{pE}: Area (cm^2) of attached plating of width b_E, equal to the following:

$$A_{pE} = 10 b_E t$$

b_E: Effective width (m) of the attached plating, equal to the following:

$$b_E = \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2}\right)s \quad \text{for} \quad \beta_E > 1.25$$

$$b_E = s \quad \text{for} \quad \beta_E \le 1.25$$

4 Torsional buckling

The load-end shortening curve $\sigma_{CR2} - \varepsilon$ for the flexural-torsional buckling of stiffeners composing the hull girder transverse section is to be obtained according to the following formula:

$$\sigma_{CR2} = \Phi \frac{A_s \sigma_{C2} + A_p \sigma_{CP}}{A_s + A_p}$$

Φ : Edge function, as defined in **-2**.

σ_{C2} : Critical stress (N/mm^2), equal to the following:

$$\sigma_{C2} = \frac{\sigma_{E2}}{\varepsilon} \quad \text{for} \quad \sigma_{E2} \le \frac{\sigma_{YS}}{2}\varepsilon$$

$$\sigma_{C2} = \sigma_{YS}\left(1 - \frac{\sigma_{YS}\varepsilon}{4\sigma_{E2}}\right) \quad \text{for} \quad \sigma_{E2} > \frac{\sigma_{YS}}{2}\varepsilon$$

ε : Relative strain, as defined in **-2**.

σ_{E2} : Euler torsional buckling stress (N/mm^2), taken as σ_{ET} specified in **2.4.4-4 Annex C32.2.7 "GUIDANCE FOR BUCKLING STRENGTH ASSESSMENT"**.

σ_{CP} : Buckling stress of the attached plating (N/mm^2), equal to the following:

$$\sigma_{CP} = \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2}\right)\sigma_{YP} \quad \text{for} \quad \beta_E > 1.25$$

$$\sigma_{CP} = \sigma_{YP} \quad \text{for} \quad \beta_E \le 1.25$$

β_E : Coefficient, as defined in **-3**.

5 Web local buckling of stiffeners made of flanged profiles

The load-end shortening curve $\sigma_{CR3} - \varepsilon$ for the web local buckling of flanged stiffeners composing the hull girder transverse section is to be obtained from the following formula:

$$\sigma_{CR3} = \Phi \frac{10^3 b_E t \sigma_{YP} + (h_{we} t_w + b_f t_f)\sigma_{YS}}{10^3 st + h_w t_w + b_f t_f}$$

Φ : Edge function, as defined in **-2**.

b_E: Effective width (m) of the attached shell plating, as defined in **-3**.

h_{we}: Effective height (mm) of the web, equal to the following:

$$h_{we} = \left(\frac{2.25}{\beta_w} - \frac{1.25}{\beta_w^2}\right)h_w \quad \text{for} \quad \beta_w > 1.25$$

$$h_{we} = h_w \quad \text{for} \quad \beta_w \le 1.25$$

β_w : Coefficient, given as follow:

$$\beta_w = \frac{h_w}{t_w}\sqrt{\frac{\varepsilon \sigma_{YS}}{E}}$$

ε : Relative strain, as defined in **-2**.

6 Web local buckling of stiffeners made of flat bars

The load-end shortening curve $\sigma_{CR4} - \varepsilon$ for the web local buckling of flat bar stiffeners composing the transverse section is to be obtained from the following formula:

$$\sigma_{CR4} = \Phi \frac{A_p \sigma_{CP} + A_s \sigma_{C4}}{A_p + A_s}$$

Φ : Edge function, as defined in **-2**.

σ_{CP} : Buckling stress of the attached plating (N/mm^2), as defined in **-4**.

σ_{C4} : Critical stress (N/mm^2), equal to the following:

$$\sigma_{C4} = \frac{\sigma_{E4}}{\varepsilon} \quad \text{for} \quad \sigma_{E4} \le \frac{\sigma_{YS}}{2}\varepsilon$$

$$\sigma_{C4} = \sigma_{YS}\left(1 - \frac{\sigma_{YS}\,\varepsilon}{4\sigma_{E4}}\right) \quad \text{for} \quad \sigma_{E4} > \frac{\sigma_{YS}}{2}\varepsilon$$

σ_{E4} : Local Euler buckling stress (N/mm^2), equal to the following:

$$\sigma_{E4} = 160000\left(\frac{t_w}{h_w}\right)^2$$

ε : Relative strain, as defined in **-2**.

7 Plate buckling

The load-end shortening curve $\sigma_{CR5} - \varepsilon$ for the buckling of transversely stiffened panels composing transverse section is to be obtained from the following formula:

$$\sigma_{CR5} = \min\begin{cases} \sigma_{YP}\Phi \\ \Phi\sigma_{YP}\left[\frac{s}{\ell}\left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2}\right) + 0.1\left(1 - \frac{s}{\ell}\right)\left(1 + \frac{1}{\beta_E^2}\right)^2\right] \end{cases}$$

Φ : Edge function, as defined in **-2**.

β_E : Coefficient, as defined in **-3**.

s: Plate breadth (m), taken as the spacing between the stiffeners.

ℓ : Longer side of the plate (m).

2.3 Alternative Methods

2.3.1 General

1 Application of alternative methods is to be agreed by the Society prior to commencement. Documentation of the analysis methodology and detailed comparison of its results are to be submitted for review and approval. The use of such methods may require the partial safety factors to be recalibrated.

2 The bending moment-curvature relationship, M-χ, may be established by alternative methods. Such models are to consider all the relevant effects important to the non-linear response with due considerations of:

(1) Non-linear geometrical behaviour.

(2) Inelastic material behaviour.

(3) Geometrical imperfections and residual stresses (geometrical out-of-flatness of plate and stiffeners).

(4) Simultaneously acting loads:

- (a) Bi-axial compression.
- (b) Bi-axial tension.
- (c) Shear and lateral pressure.

(5) Boundary conditions.
(6) Interactions between buckling modes.
(7) Interactions between structural elements such as plates, stiffeners, girders, etc.
(8) Post-buckling capacity.
(9) Overstressed elements on the compression side of hull girder cross section possibly leading to local permanent sets/buckle damages in plating, stiffeners, etc. (double bottom effects or similar).

2.3.2 Non-linear Finite Element Analysis

1 Advanced non-linear finite element analyses models may be used for the assessment of the hull girder ultimate bending moment capacity. Such models are to consider the relevant effects important to the non-linear responses with due consideration of the items listed in **2.3.1-2**.

2 Particular attention is to be given to modelling the shape and size of geometrical imperfections. It is to be ensured that the shape and size of geometrical imperfections trigger the most critical failure modes.

Annex C32.2.8-2 has been added as follows.

Annex C32.2.8-2 "GUIDANCE FOR THE HULL GIRDER ULTIMATE STRENGTH ASSESSMENT CONSIDERING THE EFFECT OF THE LATERAL LOADS"

1.1 General

1.1.1 Definitions

Unless specified otherwise, the definitions of the symbols used in this Guidance are as specified in **Table 1**.

Table 1 Definition of the Symbols

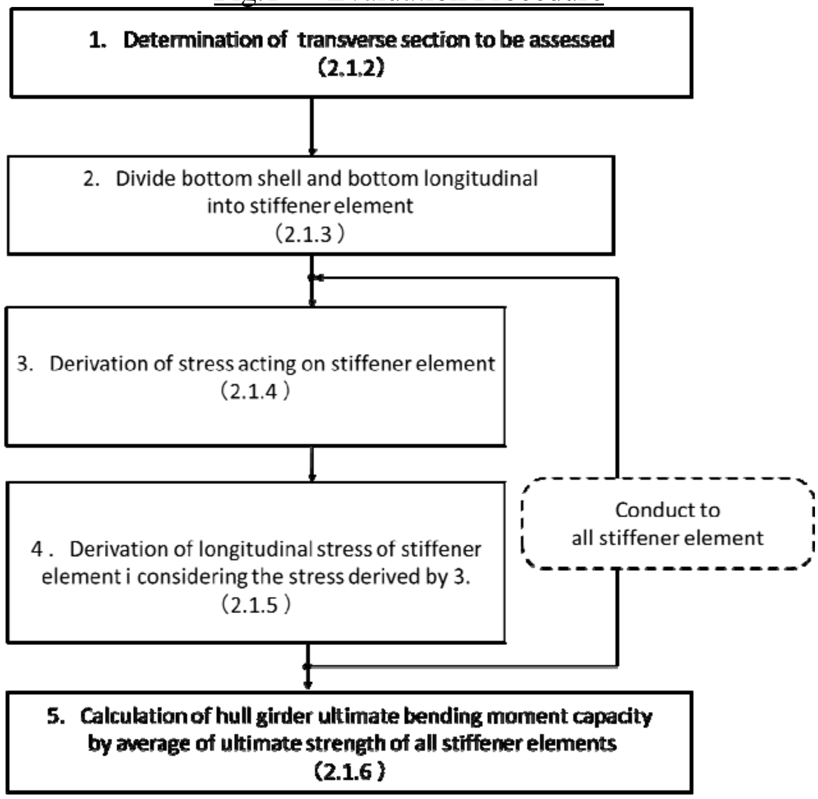
Symbol	Unit	Definition
Z_B	m^3	Section moduli at bottom
σ_{YS}	N/mm^2	Minimum yield stress of the material of the considered stiffener
σ_{YP}	N/mm^2	Minimum yield stress of the material of the considered plate
A_S	cm^2	Sectional area of stiffener, without attached plating
A_P	cm^2	Sectional area of attached plating
t	mm	Thickness of attached plating
b_f	mm	Face plate width of stiffener
t_f	mm	Face plate thickness of stiffener
h_w	mm	Web height of stiffener
t_w	mm	Web thickness of stiffener
ℓ	m	Length of longer side of attached plate
s	m	Breadth of attached plate
E	N/mm^2	Young's modulus of steel, taken as 2.06×10^5 (N/mm^2)
υ		Poisson's ratio, taken as 0.3

2.1 Evaluation Method of Hull Girder Ultimate Strength Considering the Effect of Lateral Loads

2.1.1 General

The procedure for evaluating hull girder ultimate strength in consideration of the effect of lateral loads is summarised in the flow chart in **Fig. 1**.

Fig.1　Evaluation Procedure



Note: Numbers in parentheses indicate section number

2.1.2 Determination of Transverse Section to be Assessed

"The transverse section located in the vicinity of the centre of the cargo hold at midship" in **32.2.8-2, Part C of the Rules** refers to the transverse section where the bottom shell generates maximum longitudinal stress as calculated by the provisions of **32.2.9, Part C of the Rules** under the condition specified in **Table 2**.

Table 2 Calculation condition

Loading condition	Wave load condition
One bay empty condition	*L-180-1*

2.1.3 Modelling of Stiffener Element

Modelling of bottom shell and bottom longitudinals is to be in accordance with the following **(1)** to **(3)**:

(1) Bottom shell and bottom longitudinals in the span, which includes the hull girder transverse section specified in **2.1.2** above, between two adjacent transverse webs are to be modelled. However, bottom shell and bottom longitudinals at bilge parts and under bench corners are not to be included in the modelling.

(2) The bottom shell and the bottom longitudinals being modelled are to be divided into the stiffener element *i* consisting of a longitudinal and an attached plate. The attached plate width is to be equal to the mean spacing of the stiffeners. (*See* **Fig. 2**)

(3) Where attached plating is made of steels having different thicknesses or yield stresses, an average thickness $\bar{t}$ (mm) or an average yield stress $\overline{\sigma_{YP}}$ (N/mm^2) obtained from the following

formulae are to be used for calculations. (*See* **Fig. 3**)

$$t = \frac{t_1 s_1' + t_2 s_2'}{s}$$

$$\sigma_{YP} = \frac{\sigma_{YP1} t_1 s_1' + \sigma_{YP2} t_2 s_2'}{ts}$$

t_1, t_2: Thickness of plate of attached plate (*mm*)

$\sigma_{YP1}, \sigma_{YP2}$: Minimum yield stress of plate of attached plate (N/mm^2)

s_1', s_2' : Breadth of plate of attached plate(*m*)

Fig. 2 Method of Dividing Stiffener Element

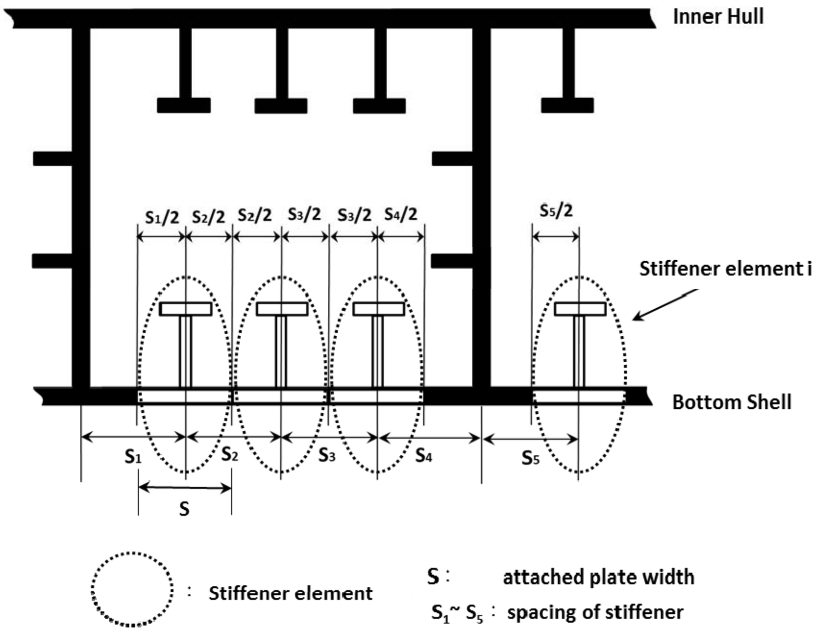
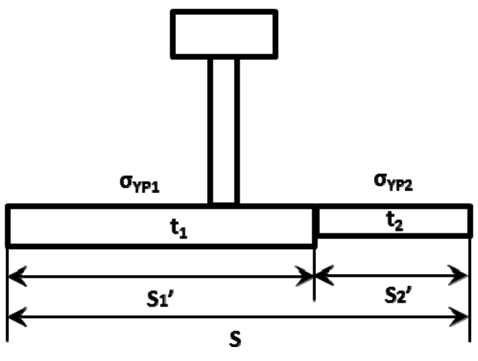


Fig. 3 Stiffener Element with Different thickness and Yield Strength



2.1.4 Derivation of Stress Acting on Stiffener Element

The longitudinal stress σ_{xi} (N/mm^2) and the transverse stress σ_{yi} (N/mm^2) which are generated at the bottom shell of the position of stiffener element *i* are to be calculated according to the provisions of **32.2.9, Part C of the Rules** under the condition specified in **Table 2**.

2.1.5 Calculation of Ultimate Strength of Stiffener Element

The ultimate strength of stiffener element *i*, $\sigma_{US\,i}$, (N/mm^2) is to be as follow, is not to be less than 0.

$\sigma_{US\,i} = \min(\sigma_{US1i}, \sigma_{US2i}, \sigma_{US3i}) - \sigma_{x0i}$ for bulb, angle and T profiles

$\sigma_{US\,i} = \min(\sigma_{US1i}, \sigma_{US2i}, \sigma_{US4i}) - \sigma_{x0i}$ for flat bars

σ_{x0i}: Longitudinal stress (N/mm^2) acting on stiffener element *i* due to lateral loads, to be taken as follows:

$\sigma_{x0i} = \sigma_{xi} - \sigma_{HG}$

σ_{xi}: Longitudinal stress (N/mm^2), as specified in **2.1.4** above

σ_{HG}: Hull girder bending stress (N/mm^2), to be taken as follows:

$$\sigma_{HG} = \frac{M_{S\max} + M_{W-Hog-Mid}}{Z_B} 10^{-3}$$

$M_{S\max}$: permissible maximum vertical still water bending moment in seagoing condition (kN-m) at the transverse section under consideration

$M_{W-Hog-Mid}$: As specified in **32.2.3-6 Part C of the Rules**

$\sigma_{US1i}, \sigma_{US2i}, \sigma_{US3i}, \sigma_{US4i}$: Ultimate strength of stiffener element *i* (N/mm^2) for each critical failure mode, to be taken as follow. All the symbols given in the following **(1)** through **(4)** pertain to stiffener element *i*.

(1) Ultimate strength of beam column buckling σ_{US1i} (N/mm^2), to be taken as follows:

$$\sigma_{US1i} = \sigma_{C1} \frac{A_S + A_{PE}}{A_S + A_P}$$

σ_{C1}: Critical stress (N/mm^2), equal to the following:

$$\sigma_{C1} = \sigma_{E1} \quad \text{for} \quad \sigma_{E1} \le \frac{\sigma_{YB}}{2}$$

$$\sigma_{C1} = \sigma_{YB}\left(1 - \frac{\sigma_{YB}}{4\sigma_{E1}}\right) \quad \text{for} \quad \sigma_{E1} > \frac{\sigma_{YB}}{2}$$

σ_{YB}: Equivalent minimum yield stress (N/mm^2), to be taken as follows:

$$\sigma_{YB} = \frac{\sigma_{YP} A_{PE1} \ell_{PE} + \sigma_{YS} A_S \ell_{SE}}{A_{PE1} \ell_{PE} + A_S \ell_{SE}}$$

ℓ_{PE}: Distance (mm) measured from the neutral axis of the stiffener with attached plate of width b_{E1} to the bottom of the attached plating.

ℓ_{SE}: Distance (mm) measured from the neutral axis of the stiffener with attached plating of width b_{E1} to the top of the stiffener.

A_{PE1}: Area (cm^2) of attached plating, equal to the following:

$$A_{PE1} = 10 b_{E1} t$$

b_{E1}: Corrected effective width (m) of the attached plating, equal to the following:

$$b_{E1} = \frac{s}{\beta_E} \quad \text{for} \quad \beta_E > 1.0$$

$$b_{E1} = s \quad \text{for} \quad \beta_E \le 1.0$$

β_E: Coefficient, given as follows:

$$\beta_E = \sqrt{\frac{k\pi^2}{12(1-\nu^2)}} \cdot \sqrt{\frac{\sigma_{YP}}{\sigma_E}}$$

k: Coefficient, given as follows:

$$k = \left(\frac{m_0 s}{\ell} + \frac{\ell}{m_0 s} \right)^2$$

m_0: Integer which satisfies the following formula, but is not to be less than 0.

$$\sqrt{m_0(m_0-1)} < \frac{\ell}{s} \le \sqrt{m_0(m_0+1)}$$

σ_E: Elastic buckling stress of attached plating (N/mm^2), equal to the following:

$$\sigma_E = \frac{Ek'\pi^2}{12(1-\nu^2)} \left(\frac{t}{10^3 s} \right)^2 - \left(\frac{\ell}{ms} \right)^2 \sigma_{yi}$$

m: Coefficient, given as follows:

$$m = m_0 \quad \text{for} \quad \sigma_{yi} \le \sigma_{ycm} \quad \text{or} \quad m_0 \le 2$$

$$m = m_0 - 1 \quad \text{for} \quad \sigma_{yi} > \sigma_{ycm}$$

$$\sigma_{ycm} = \frac{E\pi^2}{12(1-\nu^2)} \left(\frac{t}{10^3 s} \right)^2 \left(1 - m_0^{\,2} (m_0-1)^2 \left(\frac{s}{\ell} \right)^4 \right)$$

k': Coefficient, given as follows:

$$k' = \left(\frac{ms}{\ell} + \frac{\ell}{ms} \right)^2$$

σ_{yi}: Transverse stress (N/mm^2) specified in **2.1.4** above.

σ_{E1}: Euler column buckling stress (N/mm^2), equal to the following:

$$\sigma_{E1} = \pi^2 E \frac{I_E}{A_E \ell^2} 10^{-4}$$

I_E: Moment of inertia of stiffener (cm^4) with attached plating of width b_{E1}.

A_E: Area (cm^2) of stiffeners with attached plating width b_E.

b_E: Effective width (m) of attached plating, equal to the following:

$$b_E = \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2} \right) s \quad \text{for} \quad \beta_E > 1.25$$

$$b_E = s \quad \text{for} \quad \beta_E \le 1.25$$

A_{PE}: Area (cm^2) of attached plating width b_E, equal to the following:

$$A_{PE} = 10 b_E t$$

(2) Ultimate strength of torsional buckling σ_{US2i} (N/mm^2), to be taken as follows:

$$\sigma_{US2i} = \frac{A_S \sigma_{C2} + A_P \sigma_{CP}}{A_S + A_P}$$

σ_{C2}: Critical stress (N/mm^2), equal to the following:

$$\sigma_{C2} = \sigma_{E2} \quad \text{for} \quad \sigma_{E2} \le \frac{\sigma_{YS}}{2}$$

$$\sigma_{C2} = \sigma_{YS} \left(1 - \frac{\sigma_{YS}}{4 \sigma_{E2}} \right) \quad \text{for} \quad \sigma_{E2} > \frac{\sigma_{YS}}{2}$$

σ_{E2}: Euler torsional buckling stress (N/mm^2), taken as σ_{ET} specified in **2.4.4-4 Annex C32.2.7 "GUIDANCE FOR BUCKLING STRENGTH ASSESSMENT"**.

σ_{CP}: Buckling stress of the attached plating (N/mm^2), equal to the following:

$$\sigma_{CP} = \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2} \right) \sigma_{YP} \quad \text{for} \quad \beta_E > 1.25$$

$$\sigma_{CP} = \sigma_{YP} \quad \text{for} \quad \beta_E \le 1.25$$

β_E: As defined in **(1)** above.

(3) Ultimate strength of web local buckling of flanged stiffeners σ_{US3i} (N/mm^2), to be taken as follows:

$$\sigma_{US3i} = \frac{10^3 b_E t \sigma_{YP} + (h_{we} t_w + b_f t_f) \sigma_{YS}}{10^3 st + h_w t_w + b_f t_f}$$

b_E: As defined in **(2)** above.

h_{we}: Effective height of the web (mm), equal to the following:

$$h_{we} = \left(\frac{2.25}{\beta_w} - \frac{1.25}{\beta_w^2} \right) h_w \quad \text{for} \quad \beta_w > 1.25$$

$$h_{we} = h_w \quad \text{for} \quad \beta_w \le 1.25$$

β_w: Coefficient, given as follows:

$$\beta_w = \frac{h_w}{t_w}\sqrt{\frac{\sigma_{YS}}{E}}$$

(4) Ultimate strength of web local buckling of flat bar stiffeners σ_{US4i} (N/mm^2), to be taken as follows:

$$\sigma_{US4i} = \frac{A_P\sigma_{CP} + A_S\sigma_{C4}}{A_P + A_S}$$

σ_{CP}: As defined in **(2)** above.

σ_{C4}: Critical stress (N/mm^2), equal to the following:

$$\sigma_{C4} = \sigma_{E4} \quad \text{for} \quad \sigma_{E4} \le \frac{\sigma_{YS}}{2}$$

$$\sigma_{C4} = \sigma_{YS}\left(1 - \frac{\sigma_{YS}}{4\sigma_{E4}}\right) \quad \text{for} \quad \sigma_{E4} > \frac{\sigma_{YS}}{2}$$

σ_{E4}: Local Euler buckling stress (N/mm^2), equal to the following:

$$\sigma_{E4} = 160000\left(\frac{t_w}{h_w}\right)^2$$

2.1.6 Calculation of Hull Girder Ultimate Bending Moment Capacity

Hull girder ultimate bending moment capacity considering the effect of lateral loads M_{U_DB} ($kN\text{-}m$) is to be taken as follows:

$$M_{U\_DB} = \alpha_U \sigma_{US\_avg} Z_B 10^3$$

σ_{US_avg}: Average of ultimate strength (N/mm^2) of all stiffener elements, to be taken as follows:

$$\sigma_{US\_avg} = \frac{\sum_{i=1}(\sigma_{USi}A_i)}{\sum_{i=1} A_i}$$

σ_{USi}: As specified in **2.1.5** above.

A_i: Area (cm^2) of stiffener element i, to be taken as follows:

$$A_i = A_P + A_S$$

α_U: Correction factor, to be taken as follows:

$$\alpha_U = 1.25$$

Annex C34.1.2 has been amended as follows.

Annex C34.1.2 GUIDANCE FOR PREPARATION OF LOADING MANUAL

1.1 Composition of Loading Manual

(omitted)

1.2 Contents to be Included in the Introduction

1.2.1 Principal Dimensions
(omitted)

1.2.2 Precautions for Loading
(omitted)

1.2.3 Allowable Values for Longitudinal Still Water Bending Moment and Still Water Shearing Force

1 Allowable values of longitudinal still water bending moment and still water shearing force calculated in accordance with the requirements in **1.4** of the Annex are to be specified following the descriptive examples **1.2** and **1.3 of Appendix C2**. Furthermore, the sign convention of bending moment and shearing force is to be specified. (*See* in **15.2.1-1** and **15.3.1-1, Part C of the Rules** and **32.1.2, Part C of the Rules** for ships to which the requirements in **Chapter 32, Part C of the Rules** apply)

2 The stress levels of longitudinal strength of the ship are to be specified following the descriptive example **1.4 of Appendix C2**.

1.2.4 Allowable Values for Torsional Moment of Hull Due to Uneven Cargo Stowage

1 For ships to which the requirements in **Chapter 32, Part C** of the Rules apply, the values of torsional moment of hull due to uneven cargo stowage which is considered in the requirements in ~~C32.2.2~~**C32.3.1** are to be specified as the allowable value in the manual.

1.3 Standard Loading Conditions

(omitted)

1.4 Allowable Values for Longitudinal Strength

1.4.1 General

1 For ships to which the requirements in **Chapter 32, Part C** of the Rules do not apply, ~~T~~the allowable values for longitudinal still water bending moment and still water shearing force which are to be specified in the Loading Manual are to be determined with due consideration of the design condition of the ship. These values, however, are not to exceed the values obtained from the requirements in the following ~~**1.4.2**~~**(1)** to ~~**1.4.4**~~**(3)**, at positions of the transverse section of the hull where deemed necessary by the Society.

(1) Allowable Values for Vertical Still Water Bending Moment

The values obtained from the following formulae are to be taken as the allowable value for each positive and negative moment at the transverse section of the ship under consideration. However, these values are to satisfy the requirements in **15.4, Part C of the Rules**.

Value determined by longitudinal bending strength

For positive values: $\frac{fZ}{5.72C} - M_w(+)$ (kN-m)

For negative values: $-\frac{fZ}{5.72C} - M_w(-)$ (kN-m)

f : As specified in the following **(a)** or **(b)**:

(a) 1.0 for ships to which the requirements in **1.1.7-2(1), Part C** and **1.3.1-2(1), Part CS** of the Rules do not apply

However, for ships to which the requirements with f_B or f_D in **Part C of the Rules** or **Part C of the Guidance** apply, the value of f is to be taken as f_B or f_D.

(b) The value of f_{BH} or f_{DH} determined by the requirements in **1.2.1-2(1)** of **Annex C1.1.7-1 "GUIDANCE FOR HULL CONSTRUCTION CONTAINING HIGH TENSILE STEEL MEMBERS"** for ships to which the requirements in **1.1.7-2(1), Part C** or **1.3.1-2(1), Part CS** of the Rules is applied

Z : Section modulus (cm^3) of transverse section of the ship with respect to the ship's bottom or strength deck at the position under consideration

C : Coefficient specified in **C15.1.1(3), PartC of the Guidance**

However, where

$C_b' \geq 0.65$, $C = 1.0$.

C_b' : As specified in **15.2.1-1, Part C of the Rules**

$M_w(+)$ and $M_w(-)$: As specified in **15.2.1-1, Part C of the Rules**

(2) Allowable Values for Still Water Shearing Force

(a) The allowable values for still water shearing forces for ships without longitudinal bulkheads are to be obtained from the following formula:

For positive values: $\frac{t_s I}{0.455mK} - F_w(+)$ (kN)

For negative values: $-\frac{t_s I}{0.455mK} - F_w(-)$ (kN)

t_s : Plate thickness (mm) of side shell plating at positions under consideration

I, m, $F_w(+)$ and $F_w(-)$: As specified in **15.3.1-1, Part C of the Rules**

K : Coefficient corresponding to the kind of steel

e.g., 1.0 for mild steel, the values specified in **1.1.7-2(1) of the Rules** for high tensile steel

(b) For ships which have the plate thickness of side shell plating determined according to the requirements in **C15.3.1-1 of the Guidance**, the value of **(a)** above or the value obtained from the following formula is to be taken, whichever is smaller.

For positive values: $F\frac{\tau_p}{\tau} - F_w(+)$ (kN)

For negative values: $-F\frac{\tau_p}{\tau} - F_w(-)$ (kN)

F : Shearing force (*kN*) acting on the transverse section of the ship used in the direct calculation which is given by the formulae specified in **C15.3.1-1(1)**

$F_w(+)$ and $F_w(-)$: Wave induced longitudinal shearing force (*kN*) as specified in **15.3.1-1, Part C of the Rules**

τ_p : Allowable stress (*N/mm*^{2}) as specified in **C15.3.1-1(2)**

τ : The largest of the shearing stresses (*N/mm*^{2}) determined by direct calculation occurring in side shell plating, bilge hopper tanks and top side tanks

(c) For ships with one to four rows of longitudinal bulkheads, the allowable value for still water shearing force is to be as specified in the following requirements in **i)** and **ii)**:

i) The allowable value for still water shearing force is to be obtained from the following formula:

For positive values: $\frac{\sum tI}{0.455mK} - F_w(+)$ (*kN*)

For negative values: $-\frac{\sum tI}{0.455mK} - F_w(-)$ (*kN*)

I, m, $F_w(+)$ and $F_w(-)$: As specified in **15.3.1-1, Part C of the Rules**

$\sum t$:Sum of the plate thickness (*mm*) of each longitudinal bulkhead at positions under consideration

K : As specified in **(a)** above

ii) The allowable value for shearing force (F_L) acting on the longitudinal bulkheads on one side is to be obtained from the following formula:

For positive values: $\frac{tI}{0.910mK} - \alpha F_w(+)$ (*kN*)

For negative values: $-\frac{tI}{0.910mK} - \alpha F_w(-)$ (*kN*)

I, m, $F_w(+)$ and $F_w(-)$: As specified in **15.3.1-1, Part C of the Rules**

t : Plate thickness (*mm*) of the each longitudinal bulkhead at positions under consideration

α : Rate of distribution of shearing force in each longitudinal bulkhead as specified in **15.3.2, Part C of the Rules**

K : As specified in **(a)** above

(d) The allowable values for F_s determined from **(a)** to **(c)** above are to comply with the requirements in **15.4.1, Part C of the Rules**.

(3) Allowable Values for Longitudinal Still Water Bending Moment and Shearing Force in Harbour Condition

The allowable values for the longitudinal still water bending moment and shearing force in harbour water free from the effects of waves may be obtained by taking half the values of the wave induced longitudinal bending moment and shearing force as specified in **(1)** and **(2)** respectively.

2 For ships to which the requirements in **Chapter 32, Part C of the Rules** apply, the allowable values for the vertical still water bending moment and vertical still water shear force which are to be specified in the loading manual are to be the permissible vertical still water bending moment and vertical still water shear force specified in **32.2.3-4, Part C of the Rules**.

The allowable values for the vertical still water bending moment and vertical still water shear force in the harbour condition may be the values of the above allowable values for the vertical still water bending moment and vertical still water shear force plus half the value of the vertical wave induced bending moment and vertical wave induced shear force as specified in **32.2.9-6 and -7, Part C of the Rules**.

~~2~~3 References to the ship's loading computer and the operation manual are to be made, if provided with a computer according to the provisions of **34.1.1-2, Part C** of the Rules.

~~**1.4.2 Allowable Values for Longitudinal Still Water Bending Moment (M_S)**~~

~~**1** For ships to which the requirements in **Chapter 32, Part C** of the Rules apply, the smaller of the values obtained from the following **(1)** or **(2)** is to be taken as the allowable value for each positive and negative moment at the transverse section of the ship under consideration. However, these values are to satisfy the requirements in **C15.4.1**.~~

~~(1) Value determined by longitudinal bending strength~~

~~For positive values: $\frac{fZ}{5.72C} - M_w(+)$ (kN-m)~~

~~For negative values: $-\left(\frac{fZ}{5.72C} + M_w(-)\right)$ (kN-m)~~

~~f : As specified in the following **(a)** or **(b)**~~

~~(a) 1.0 for ships to which the requirements in **1.1.7-2(1), Part C** and **1.3.1-2(1), Part CS** of the Rules do not apply~~

~~However, for ships to which the requirements with f_B or f_D in **Part C** of the Rules or **Part C** of the Guidance apply, the value of f is to be taken as f_B or f_D.~~

~~(b) The value of f_{BH} or f_{DH} determined by the requirements in **1.2.1-2(1)** of **Annex C1.1.7-1, GUIDANCE FOR HULL CONSTRUCTION CONTAINING HIGH TENSILE STEEL MEMBERS** for ships to which the requirements in **1.1.7-2(1) of Part C** or **1.3.1-2(1) of Part CS** of the Rules is applied~~

~~Z : Section modulus (cm^3) of transverse section of the ship with respect to the ship's **bottom** or strength deck at the position under consideration~~

~~C : Coefficient specified in **C15.1.1(3)** of the Guidance~~

~~However, where~~

~~$C'_b \geq 0.65$, $C = 1.0$.~~

~~C'_b : As specified in **15.2.1-1, Part C** of the Rules~~

~~$M_w(+)$ and $M_w(-)$: As specified in **15.2.1-1, Part C** of the Rule~~s

~~(2) Value determined by torsional strength~~

~~Where torsional moment is generated in the hull due to uneven cargo stowage, the warping stress value used in applying the requirements in **C32.2.2** is to be deducted from the value in [ ] in the following formulae.~~

~~For positive values: $\left[\frac{1000}{5.72K} - \sqrt{(0.75\sigma_V(+))^2 + \sigma_H^2 + \sigma_\omega^2}\right]\frac{Z_V}{1000}$ (kN-m)~~

~~For negative values: $-\left[\frac{1000}{5.72K} + \sqrt{(0.75\sigma_V(-))^2 + \sigma_H^2 + \sigma_\omega^2}\right]\frac{Z_V}{1000}$ (kN-m)~~

~~$\sigma_V(+)$ and $\sigma_V(-)$: As specified in following formulae~~

$$\sigma_V(+)=1000\frac{M_w(+)}{Z_V}$$

$$\sigma_V(-)=1000\frac{M_w(-)}{Z_V}$$

$M_w(+)$ and $M_w(-)$: As specified in **15.2.1-1, Part C** of the Rules

σ_H , σ_ω and Z_V : As specified in **C32.**2

K : 1.0

However, where high tensile steels are used for bottom plates or strength deck plating, the values are specified in **1.1.7-2(1)**, **Part C** of the Rules.

2 Ships to which the requirements in **Chapter 32, Part C** of the Rules do not apply, the longitudinal still water bending moment at the positions of transverse section of the ship under consideration for each positive and negative moment is to be determined from **1.4.2-1(1)** above, and to satisfy the requirements in **C15.4.1**.

1.4.3 Allowable Values for Still Water Shearing Force (F_S)

1 The allowable values for still water shearing force for ships without longitudinal bulkheads are to be obtained from the following formula:

For positive values: $\frac{t_s I}{0.455mK}-F_w(+)$ (kN)

For negative values: $-\left[\frac{t_s I}{0.455mK}+F_w(-)\right]$ (kN)

t_s : Plate thickness (mm) of side shell plating at positions under consideration

I , m , $F_w(+)$ and $F_w(-)$: As specified in **15.3.1-1, Part C** of the Rules

K : As given in **1.4.2-1(2)** above

2 For ships which have the plate thickness of side shell plating determined according to the requirements in **C15.3.1-1** of the Guidance, the value of **(1)** above or the value obtained from the following formula, whichever is smaller is to be taken.

For positive values: $F\frac{\tau_p}{\tau}-F_w(+)$ (kN)

For negative values: $-\left[F\frac{\tau_p}{\tau}+F_w(-)\right]$ (kN)

F : Shearing force (kN) acting on the transverse section of the ship used in the direct calculation which is given by the formula specified in **C15.3.1-1(1)**

$F_w(+)$ and $F_w(-)$: Wave induced longitudinal shearing force (kN) as specified in **15.3.1-1, Part C** of the Rules

τ_p : Allowable stress (N/mm^2) as specified in **C15.3.1-1(2)**

τ : The greatest of the shearing stresses (N/mm^2) determined by direct calculation occurring in side shell plating, bilge hopper tanks and top side tanks

3 For ships with one or four rows of longitudinal bulkheads, the allowable value for still water shearing force is to be as specified in the following requirements in **(1)** and **(2)**.

(1) The allowable value for still water shearing force is to be obtained from the following formula:

For positive values: $\frac{\sum tI}{0.455mK}-F_w(+)$ (kN)

For negative values: $-\left[\frac{\sum tI}{0.455mK}+F_w(-)\right]$ (kN)

I, m, $F_w(+)$ and $F_w(-)$: As specified in **15.3.1-1, Part C** of the Rules

$\sum t$: Sum of the plate thickness (mm) of each longitudinal bulkhead at positions under consideration

K: As specified in **1.4.2-1(2)** above

(2) The allowable value for shearing force (F_L) acting on the longitudinal bulkheads on one side is to be obtained from the following formula:

For positive values: $\frac{tI}{0.910mK}-\alpha F_w(+)$ (kN)

For negative values: $-\left[\frac{tI}{0.910mK}+\alpha F_w(-)\right]$ (kN)

I, m, $F_w(+)$ and $F_w(-)$: As specified in **15.3.1-1, Part C** of the Rules

t: Plate thickness (mm) of the each longitudinal bulkhead at positions under consideration

α: Rate of distribution of shearing force in each longitudinal bulkhead as specified in **15.3.2, Part C** of the Rules

K: As specified in **1.4.2-1(2)** above

4 The allowable values for F_s determined from **1** to **3** above are to comply with the requirements in **C15.4.1**.

1.4.4 Allowable Values for Longitudinal Still Water Bending Moment and Shearing Force in Harbour Condition

The allowable values for the longitudinal still water bending moment and shearing force in harbour water free from the effects of waves may be obtained by taking half the values of the wave induced longitudinal bending moment and shearing force as specified in **1.4.2** and **1.4.3** respectively.

Appendix C1 REFERENCE DATA FOR DESIGN

Section 1.7 has been amended as follows.

1.7 Standard Value of Twisting Moment of Hull Due to Uneven Cargo Stowage in Container Carriers (~~C32.2.2~~C32.3 of the Guidance)

1.7.1

"The twisting moment generated in the hull due to uneven cargo stowage" to be considered in applying the requirements of ~~C32.2.2~~**C32.3 of the Guidance** is to be the following M_{TC} value, as a standard:

$$M_{TC} = 0.23LN_RW_C \quad (kN\text{-}m)$$

Where:

N_R :Maximum number of rows of containers loaded in a cargo hold

W_C :Mean weight per 20 *ft* container which is normally taken as 100 *kN*

The warping stress (N/mm^2) acting on the hull due to M_{TC} may be obtained from the following formula:

$$\sigma_{\omega C} = 0.000318 \frac{\omega l_C M_{TC}}{I_\omega + 0.04 l_C^2 J}$$

Where:

ω, l_C, I_ω and J : As specified in ~~C32.2.2~~**C32.3.1 of the Guidance**

EFFECTIVE DATE AND APPLICATION (Amendment 3-2)

1. The effective date of the amendments is 1 April 2016.

2. Notwithstanding the amendments to the Guidance, the current requirements may apply to ships for which the date of contract for construction is before the effective date.